WOOD RESEARCH
57 (4): 2012
545-560

IDENTIFICATION OF JUVENILE AND MATURE WOOD ZONES IN STEMS OF EUROPEAN LARCH (*LARIX DECIDUA* MILL.) USING A K-MEANS ALGORITHM

Marcin Nawrot, Witold Pazdrowski, Marek Szymański, Agnieszka Jędraszak
Poznań University of Life Sciences, Department of Forest Utilisation
Poznań, Poland

Ryszard Walkowiak
Poznań University of Life Sciences, Department of Mathematical and Statistical Methods, Laboratory of Biometry
Poznań, Poland

Sławomir Borysiak
Poznań University of Technology, Institute of Chemical Technology and Engineering
Poznań, Poland

(Received May 2011)

ABSTRACT

The paper presents assumptions and results recorded thanks to the application of a novel method to identify juvenile and mature wood zones in stems of forest trees based on a k-means algorithm. The algorithm showed the boundary between analysed types of wood on the basis of input data based on macroscopic structure of wood, i.e. the width of the annual ring, the proportion of late wood in the annual ring and the length of the ray of the annual ring (the location of the annual ring on the ray). Analyses conducted using this method indicated that juvenile wood in 24 European larches covers from 9 to 22 annual rings located around the pith (on average 13). The applied method was verified by changing the degree of crystallinity of cellulose determined at breast height of 3 mean sample trees. Boundaries indicated by the algorithm coincided with high accuracy with places where the course of changes in values of the degree of crystallinity at successive annual rings started to be similar.

KEYWORDS: Juvenile wood, k-means algorithm, degree of crystallinity of cellulose, *Larix decidua*.

INTRODUCTION

The importance of problems related with juvenile wood results from the fact that it is found in stems of all trees as an element of structure connected with normal physiological processes of woody plants (Zobel and Sprague 1998, Passialis and Kiriazakos 2004).

In comparison to mature wood juvenile wood is characterised by several disadvantageous traits reducing its quality, thus limiting their potential processability (Pazdrowski 2004).

Both for forests and wood industry an indication of the boundary between juvenile and mature wood is essential for the optimization of timber utilisation, quality and value of final products and it is absolutely crucial from the point of view of a precise determination of the proportions of both types of wood in trunks and stems of forest trees. The capacity to objectively determine the proportions of juvenile and mature wood in timber makes it possible to manage it appropriately in terms of processing and obtain desirable quality of final products meeting consumer needs.

Scientists worldwide for years have distinguished juvenile and mature wood zones taking into consideration different macrostructural, microstructural and submicroscopic characteristics of wood, as well as its selected physical and mechanical properties. In the opinion of many authors (Abdel-Gadir and Krahmer 1993, Larson et al. 2001, Clark et al. 2006) a precise determination of the boundary between juvenile and mature wood requires an analysis of radial variation for several selected properties of the wood tissue.

The aim of this study was to present assumptions and results for a novel method to distinguish juvenile and mature wood zones in the form of a k-means algorithm in stems of 24 larches representing four age classes and the main stand according to the biological classification according to Kraft, which were grown in fresh broad-leaved forest. The study was also to verify the applied method using changes in values of the degree of crystallinity of cellulose at the breast height rays for three mean sample trees.

MATERIAL AND METHODS

Analyses were conducted on stands of age classes II, III, IV and V growing in the Gołąbki Forest Division (the Regional Directorate of State Forests in Toruń) and the Nowogard Forest Division (the Regional Directorate of State Forests in Szczecin), where larch was found as an admixture (in at least group mixture) under site conditions of fresh broad-leaved forest. In selected compartments mean sample plots of 0.5 ha were established, where breast height diameters of all trees of the investigated species were measured and they were listed within 2-cm diameter subclasses. Next heights were measured in proportion to the frequency of trees in the assumed diameter subclasses. On the basis of height and diameter characteristics of trees a total of 24 mean sample trees were selected according to Hartig's method (Grochowski 1973) and biological classification according to Kraft (1884). Only the first three classes were considered, i.e. the main stand. This classification based on the quality appraisal of the crown and height of a tree in relation to its immediate surroundings, describes relatively well the crown of a tree and its biological position in the community.

Tab. 1: Dimensions of mean sample trees grown in fresh broad-leaved forest in the Gołąbki and Nowogard Forest Divisions.

Gołąbki				Nowogard			
Age class	**Kraft's class**	**Breast height diameter (cm)**	**Height (m)**	**Age class**	**Kraft's class**	**Breast height diameter (cm)**	**Height (m)**
II	I	21	18.1	II	I	26	24.0
	II	19	16.9		II	21	21.8
	III	17	16.1		III	16	19.4
III	I	25	25.9	III	I	44	27.4
	II	30	25.2		II	35	25.8
	III	30	24.4		III	30	25.3
IV	I	25	27.2	IV	I	46	31.2
	II	33	26.4		II	37	29.6
	III	33	25.3		III	33	27.7
V	I	27	29.3	V	I	52	33.4
	II	39	28.6		II	43	31.2
	III	33	27.9		III	34	29.5

These trees were felled and next were debranched, following which stems were divided into 2-m sections, from which centres discs were cut in order to investigate selected wood macrostructure characteristics. Discs from a distance of 1 m from the lower butt end of the stem corresponds to a height of 1.3 m, the so-called breast height of a standing tree. Additionally a disc was collected from the kerf plane (0.0 m). On collected discs, based on the northern direction marked on site, the other cardinal geographical directions were marked using a linear ruler and in order to more effectively visualise elements of wood structure the discs were polished. Next, using an electronic increment meter coupled with a computer, widths of early and late wood zones for each annual ring were measured in the direction from the pith towards the circumference. Measurements were taken on four rays oriented according to the directions of the world. Measurements were accurate to 0.01 mm. Thanks to the application of the GrubeComm software it was possible to send measurement data to the MS Excel software, where they were further processed. After measurements were taken using an electronic increment meter the mean width of early and late wood, and the whole annual ring from measurements taken in the four cardinal geographical were calculated according to the formula:

$$d_{śr} = \frac{d_N + d_S + d_W + d_E}{4} \quad (mm) \tag{1}$$

where: d_N, d_S, d_W, d_E – widths of early or late wood in the north, south, west and east directions, respectively, expressed in mm.

Next the width of annual rings was calculated, being a sum of the mean width of early and late wood:

$$d_{sł} = d_{dw} + d_{dp} \quad (mm) \tag{2}$$

Afterwards for each annual ring the relative proportion of late wood was calculated from the formula:

$$u_{dp} = \frac{d_{dp}}{d_{sł}} \times 100\ (\%) \tag{3}$$

where: $d_{sł}$ – width of annual ring (mm),
d_{dw} – width of early wood zone in the annual ring (mm),
d_{dp} – width of late wood zone in the annual ring (mm),
u_{dp} – proportion of late wood in the annual ring (%).

Determination of the boundary between juvenile and mature wood using cluster analysis in the form of k-means algorithm

Cluster analysis is one of the best known data mining methods. It is also frequently called segmentation or clustering of data, as it is an example of an analysis consisting in the search for and identification of clusters from data, i.e. groups of similar objects. It is an unoriented method, i.e. all relationships and regularities are found only on the basis of input data. Organisation of objects into clusters is based on searching for similar objects. In order to be able to compare observations with one another and to determine to what extent they are similar we have to introduce a measure of similarity of observations. In case of quantitative variables the Euclidean distance is applied most commonly. The Euclidean distance, as other similar measures of distance, has a certain drawback, since it may be strongly affected by one of the variables, which scope of values is the highest. If values of this variable are much bigger than values of other variables, then the difference or similarity between observations will to a high extent be determined by this one variable only (Harańczyk 2005).

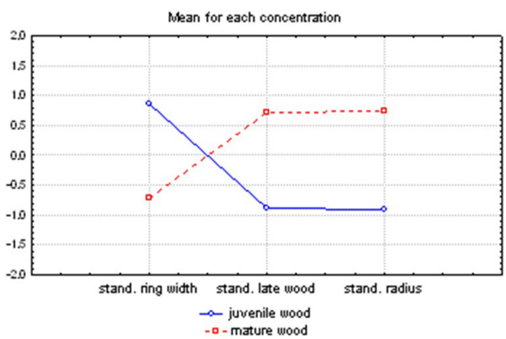


Fig. 1: Graphic presentation of fluctuations in mean values for distinguished clusters after standardisation.

In order to prevent such a situation standardisation was applied. The standardised variable is characterised by a mean amounting to 0 and variance and standard deviation amounting to 1 (Lissowski et al. 2008):

$$z = \frac{x - \mu}{\sigma} \tag{4}$$

where: z – standardized variable,
x - value of the variable to consider,
μ- arithmetic mean for the population,
σ- standard deviation for the population.

The k-means algorithm is a non-hierarchical method, yielding a disaggregation in which no cluster is a sub-cluster of another cluster (Hartigan 1975, Hartigan and Wong 1979). The algorithm transports objects to different clusters, aiming at the minimization of variation within clusters and maximization of variation between clusters. Assumptions of linearity and normality are not necessary in this analysis (Stanisz 2007).

Juvenile and mature wood zones were determined using input data in the form of standardised values of annual ring width, the percentage of late wood in the annual ring as well as the length of the annual ring ray (Fig. 1).

The first parameter k was established, i.e. the number of groups which we want to obtain. For the needs of this study the number of groups was determined as two, i.e. juvenile and mature wood. The algorithm worked until the moment of stabilisation, i.e. the moment when no other changes take place in the obtained groups. In the performed calculations the solution was found each time after the first iteration. Two annual rings differing most markedly in terms of analysed traits were selected as preliminary cluster centres. Next two clusters (groups) of annual rings were formed. The criterion for this partition was the distance of the annual ring from the centre of the cluster. For each of such formed clusters the new centre was calculated. Next distances of individual annual rings from new centres of the clusters were calculated and - if needed - annual rings were transferred to another cluster. Iterations were completed when no annual ring could be transferred to another group. At such adopted assumptions the algorithm identified numbers of observations (annual rings) belonging to the group of juvenile wood and those of mature wood, respectively. The clustering algorithm was not applied to discs coming from the upper sections of the stem if the number of annual rings at these sections was smaller or equal to the number of annual rings of juvenile wood calculated by the algorithm for the disc from the lower section. In such a case it was assumed that a given cross stem section is composed solely of juvenile wood. Such a method to determine the boundary between juvenile and mature wood was applied for each tree and each disc except for the situation described above. Additionally, a graph of changes in the proportion of late wood at the ray was also used.

After the number of rings assigned to each of the wood zones was obtained, their width was summed up in order to calculate:

- The width of the juvenile wood cylinder (mm),
- The width of the mature wood ring (mm).

The sum of the above widths constitutes the width of a given disc inside bark.

Determination of the degree of crystallinity of cellulose

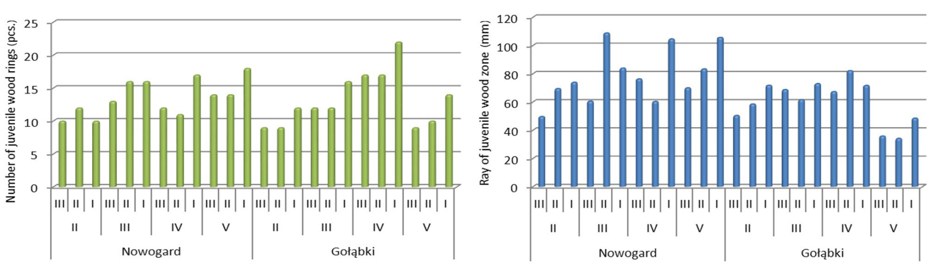
Crystallographic analyses were performed on the sample of three trees representing age class four and three biological classes within the main stand according to Kraft's classification, grown in the Nowogard Forest District. Samples for the determination of the degree of crystallinity of cellulose were cut from the northern rays of discs coming from a height of 1 m from the bottom butt end, in the form of plates of 35 × 35 × 3 mm (along the rays) x (tangentially) x (thickness) collected from seven locations on the northern ray of the stem, covering the following annual rings: 3, 7, 11, 16, 21, 28 and 58. Such a method of sample selection was used to determine the dynamics of changes in the degree of crystallinity with cambial age of annual rings and to verify the method of determination of juvenile and mature wood based on the k-means algorithm.

The supermolecular structure of wood samples was analysed by wide angle X-ray scattering (WAXS) using a lamp with a copper anode with a radiation length of 1.5418 A. The X-ray lamp was supplied with a current at an intensity of 25 mA and potential difference of 30 kV. Diffraction images were recorded within a diffraction angle range of 5 - 30° 2θ with a counting step of 0.04°/3 s.

Diffraction maxima corresponding to the crystalline structure and areas connected with the amorphous portion and the background line were separated by a method of Hindeleh and Johnson (1971) and using computer software developed by Rabiej (1991). The degree of crystallinity of samples was determined as a ratio of areas coming from the crystalline portion to the sum of areas coming from the crystalline and amorphous phases.

RESULTS

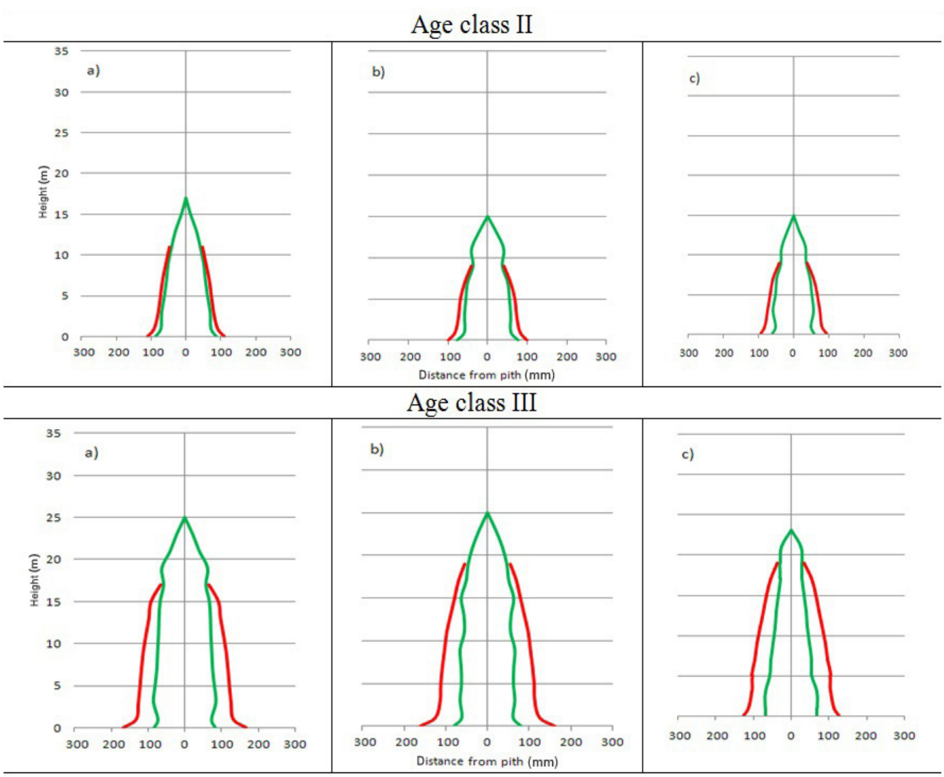
The number of annual rings of juvenile wood, determined using the k-means algorithm, ranged from 9 in codominant trees and dominant trees of age class II from the Gołąbki Forest District to 22 in the predominant tree representing age class IV grown in the same forest district (Fig. 2a). The mean number of annual rings for trees coming from the Nowogard Forest District was 13.6; in turn, a multiple modal value was found, which showed four values (10, 12, 14, 16), occurring twice. A similar situation in case of trees from Gołąbki, where at the mean number of juvenile wood annual rings (13.3) a multiple mode showing two values (9 and 12) occurring three times. The biggest number of annual rings in the juvenile zone was observed in dominant trees in age classes III, IV and V, coming from Nowogard and all age classes in case of larches from Gołąbki. An exception to the rule was the situation of a dominant tree from age class II grown in the Nowogard Forest District, which exceeded in terms of the number of annual rings of juvenile wood the predominant tree and codominant tree. A higher number of annual rings is not always connected with a longer ray of the juvenile wood, which is directly affected by the width of individual annual increments in diameter (Fig. 2a, b). We have such a trend in case of age class II (Nowogard) as well as age classes III and IV from Gołąbki. The ray of the juvenile wood zone ranged from 34 mm in a codominant tree of age class V coming from the Gołąbki Forest District to almost 106 mm in a dominant tree of age class III grown in the Nowogard Forest District. Bigger lengths of the ray in the juvenile zone were found in trees coming from Nowogard. Very small values of ray length in the analysed wood zone were recorded in trees representing age class V coming from the Gołąbki Forest District (Fig. 2b).



a) b)

Fig. 2: The number of annual rings of juvenile wood a) and the corresponding ray b) in the analysed age classes and social classes of tree position according to Kraft in fresh broad-leaved forest.

The presented figures (Figs. 3, 4) show the distribution of juvenile and mature wood at the longitudinal sections of larch stems. The occurrence of juvenile wood is marked in green, while the range of mature wood is marked in red. The outer line changing from the buttress from the red colour to green in the top sections of trees constitutes a boundary between wood and the phloem. Juvenile wood constitutes the inner part of the stem and it is found along the entire length of the stem from the buttress to the tree top. Mature wood surrounds on the outside juvenile wood, assuming at the cross stem section the form of a ring. Mature wood begins to form starting from the lowest sections of the stem, being the most distant from the physiologically active assimilating and transpiring organ, being a source of phytohormones and with tree growth and development it moves towards the upper sections of the stem, although the top parts of trees are composed solely from the juvenile wood tissue (Figs. 3, 4). Due to stem tapering, the juvenile wood zone assumes a conical shape, although in several cases it is similar to a pointed cylinder. In the initial development phases juvenile wood predominates in the total tree volume. With age of trees the proportion of mature wood increases, since over a longer part of the stem length the deposited increment has characteristics of mature wood tissue, whereas the increment of wood with juvenile characteristics occurs only in the tree top section. Thus timber harvested from older stands will be characterised by a higher proportion of mature wood exhibiting better physical and mechanical properties, in this way determining its final use.



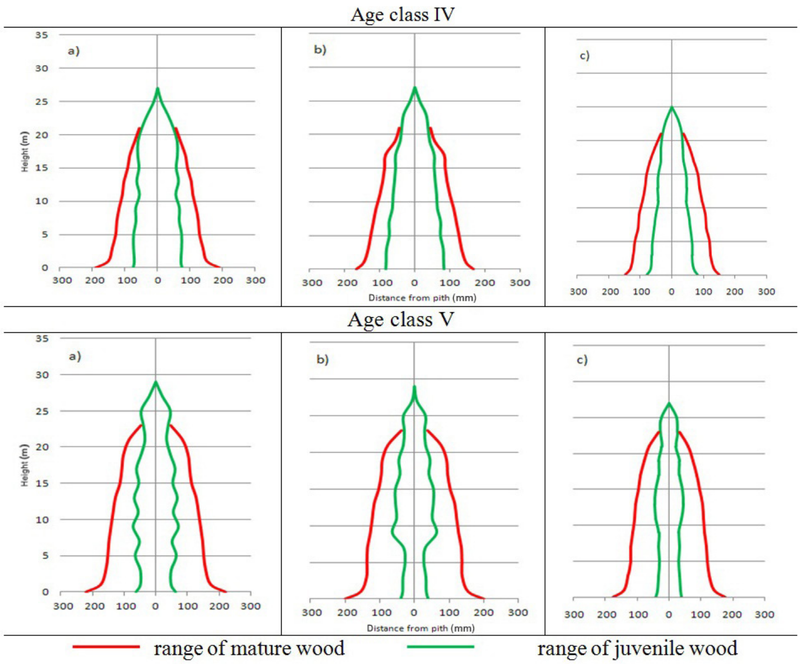
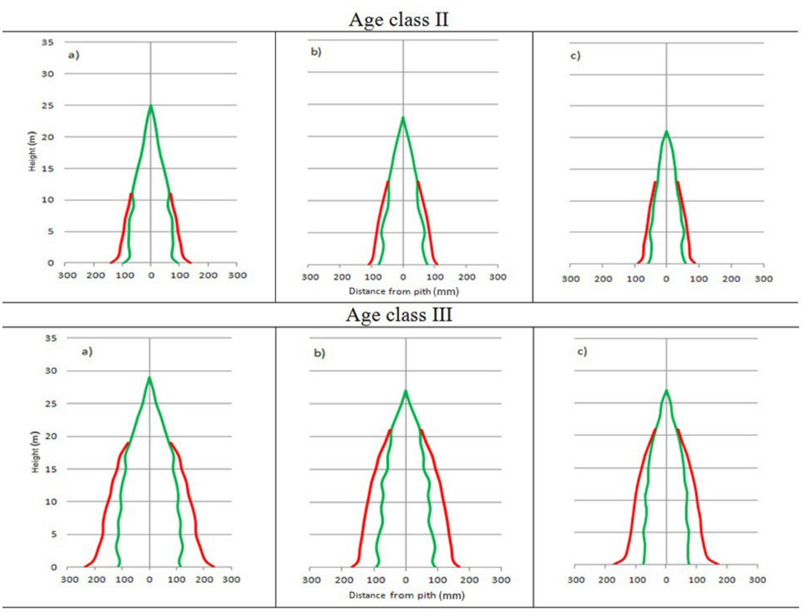


Fig. 3: Distribution of juvenile and mature wood in stems of larches representing age classes II, III, IV and V coming from the Gołąbki Forest District grown in fresh broad-leaved forest and occupying social class a) I, b) II, c) III in the forest community.



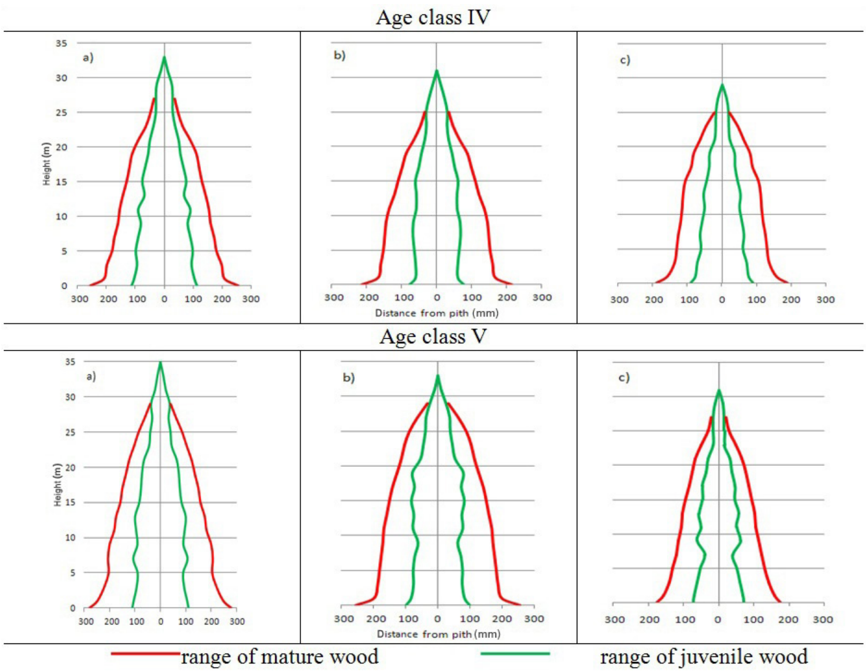


Fig. 4: Distribution of juvenile and mature wood in stems of larches representing age classes II, III, IV and V coming from the Nowogard Forest District grown in fresh broad-leaved forest and occupying social class a) I, b) II, c) III in the forest community.

Based on the conducted X-ray analyses the values of the degree of crystallinity of cellulose were found to increase with the cambial age of annual rings. The biggest differences in values of the degree of crystallinity of cellulose were recorded between the first four samples, while its values in the successive samples of analysed trees were very similar (Fig. 5).

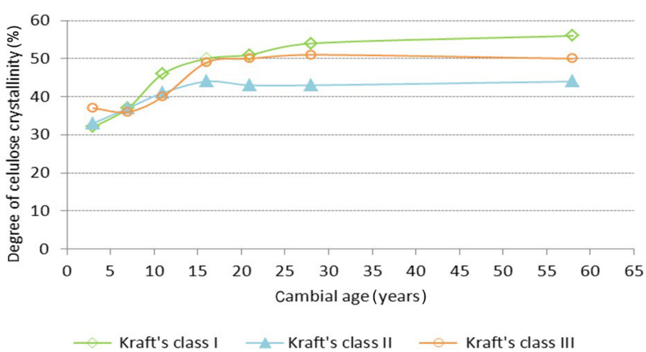


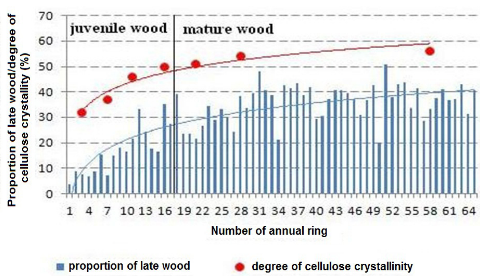
Fig. 5: Fluctuations in the degree of crystallinity of cellulose in relation to the cambial age of annual rings in larches representing the main stand according to Kraft's classification.

Among the analysed social classes of tree position according to Kraft the highest values of crystallinity of cellulose were found for wood of the predominant tree, while the lowest for the dominant tree. Intermediate values were found for wood of the codominant tree (Fig. 5).

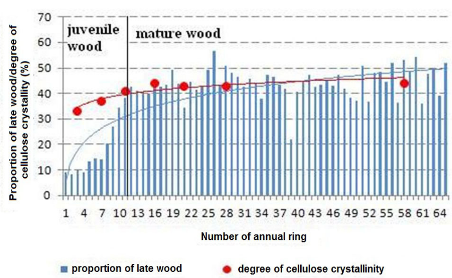
It was next decided to verify the relations between the degrees of crystallinity calculated for specific annual rings in reference to the percentages of late wood at the ray of the breast height section. Trend lines for changes in the degree of crystallinity of cellulose and the proportion of late wood are very similar, indicating a comparable trend for changes in all trees of the main stand (Figs. 6a, b, c). The most evident interdependence was observed in the tree classified to Kraft's class I, where the trend lines in relation to one another run almost parallel (Fig. 6a).

Figs. 6a, b and c present a plotted boundary between juvenile wood and mature wood, which was indicated by the k-means algorithm based on the following input data: the proportion of late wood, the width of the annual ring and the distance of the annual ring from the pith (the location of the annual ring on the ray). Juvenile wood determined in this way was characterised by lower values of the degree of crystallinity of cellulose in relation to mature wood in all trees of the main stand according to Kraft's classification of social tree position in the stand (Figs. 6a, b, c). On the basis of the presented figures it may be stated that boundaries produced by the algorithm, separating the juvenile and mature wood zones seem justified by the fluctuations of changes in values of the degree of crystallinity of cellulose at the breast height ray in the mean sample tree. The boundary identified by the algorithm appears roughly in the place, where the degree of crystallinity of cellulose after evident changes in values begins to stabilise (Figs. 6a, b, c).

a) predominant tree (Kraft's class I)



b) dominant tree (Kraft's class II)



c) codominant tree (Kraft's class III)

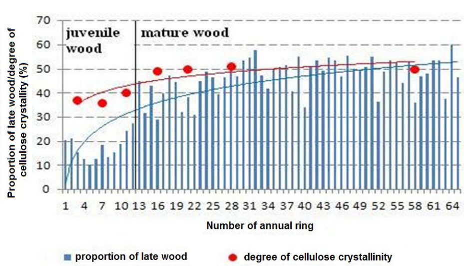


Fig. 6: Relation between the degree of crystallinity of cellulose and the proportion of late wood in annual rings of a predominant a), dominant b) and codominant c) larch presented in the form of logarithmic trend lines.

DISCUSSION

Between juvenile and mature wood there are several described differences in terms of anatomical, chemical and submicroscopic structure, as well as physical and mechanical properties, which evidently increase the non-homogeneity of the wood tissue. Literature describing methods to distinguish juvenile and mature wood zones is extensive. On the basis of changes in macrostructural characteristics the boundary between juvenile and mature wood was distinguished by Jakubowski (2000), Pazdrowski (2004), Alteyrac et al. (2006), Nawrot et al. (2007) and Tomczak et al. (2008). Helińska-Raczkowska and Fabisiak (1999), Bhat et al. (2001), Yang and Hazenberg (1994), Fabisiak (2005), Yeh et al. (2006) and others distinguished a demarcation line between juvenile and mature wood in stems of common ash based on analyses of microstructural characteristics, mainly on changes in length of basic anatomical elements of wood. On the basis of the submicroscopic structure the most commonly used characteristic of wood structure used to determine the boundary between juvenile and mature wood is the angle of cellulose fibrils in relation to the longitudinal axis of cells (Sahlberg et al. 1997, Bhat et al. 2001, Deresse et al. 2003, Kojima and Yamamoto 2004, Fabisiak and Moliński 2007), while the degree of crystallinity of cellulose was applied less frequently (Marton et al. 1972, Kocoń 1991, Andersson et al. 2004).

In this study a novel method was applied in the determination of the boundary between juvenile and mature wood, which was based on the k-means algorithm, indicating the boundary on the basis of input data based on selected macrostructural characteristics of wood. Using advanced mathematic models (mainly regression equations) based on several selected characteristics (properties) of wood tissue the range of the juvenile wood zone was determined by Abdel-Gadir and Krahmer (1993), Tassisa and Burkhardt (1998), Fabris (1999), Zhu et al. (2000), Csoka et al. (2005) and Mansfield et al. (2007).

An obvious advantage of the applied algorithm seems to be its objectivity in the division of the cross stem section in the juvenile and mature zones. At the same time it was attempted to verify the accuracy of the applied method, X-ray analyses were performed on a sample of 3 trees in order to determine the degree of crystallinity of cellulose. The application of several methods simultaneously enhances the objectivity of evaluation and makes it possible to gain insight into relations between macroscopic characteristics and the supermolecular structure of wood tissue.

The number of annual rings determined for juvenile wood at breast height, depending on the age of trees, forest site type and the occupied social class of tree position in the stand, ranged from 9 and 22 annual rings. On average the number of annual rings of juvenile wood included 13 annual rings around the pith. A similar mean number of annual rings of juvenile wood (11) was determined based on the analyses of basic density in their study by Tasissa and Burkhart (1998) in stems of taeda pine (*Pinus taeda*). Investigations conducted by Yang and Hazenberg (1994) based on the tracheid length in black spruce (*Picea mariana* (Mill.) B.S.P) indicated a boundary between juvenile and mature wood between the 11th and 21st annual increment in diameter, i.e. within a very similar range as in case of European larch. Juvenile wood on the basis of tracheid length was also distinguished by Fabisiak (2005). The author established the boundary age in 35-year old dominant larch trees at 20 years, in medium trees at 15 years, while in intermediate trees at 12 years, respectively. In this study differences were also found in the number of annual rings of juvenile wood between specimens occupying different positions in the stand canopy, where as a rule predominant trees, and less frequently dominant trees were characterised by their highest number. A markedly higher number of annual rings of juvenile wood was found by Mansfield et al. (2007). The boundary between juvenile and mature wood, distinguished in stems of shore pine (*Pinus contorta*) based on analyses of basic wood density, was on average established at the 31st annual ring (±17). In the opinion of many authors (Bendtsen 1978, Loo et al. 1985, Abdel-Gadir and Krahmer 1993, Zobel and Sprague 1998) the boundary between juvenile and mature wood assumes different values depending on tree species and investigated wood properties. For example, Alteyrac et al. (2006) in stems of back spruce (*Picea mariana*) found the zone separating two types of wood to be at the 25th annual ring based on the density of annual rings, at the 20th annual ring in case of the area of annual rings and between the 10th and 25th annual ring following measurements of the cellulose microfibril angles.

Properties of wood tissue result from its structure at all structural levels and this dependence was observed in the form of an evident relationship between changes in the proportion of late wood in annual rings and values of the degree of crystallinity of cellulose. For this reason elements of macroscopic wood structure (the width of the annual ring, the proportion of late wood in the annual ring), included in the analyses as input data, show marked relationships with submicroscopic wood characteristics and seem to be good parameters describing broadly understood wood structure, used to differentiate juvenile and mature wood zones.

This study does not completely solve the discussed problem, either scientifically or practically. Thus it seems advisable to conduct further, more advanced studies on methods to distinguish both wood zones based to a bigger extent on the submicroscopic wood tissue. Investigations should also be conducted on relationships between e.g. the occupied social class of tree position in the forest community, intensity of tending interventions, growth conditions or biometric characteristics of trees and the formation of the boundary between analysed wood types, since as it was stressed by Punches (2004) understanding of growth and development processes of trees makes it possible for foresters to modify living conditions for trees in such a way so as to predict consequences of forest management resulting in the quality of final wood products.

CONCLUSIONS

The novel method to distinguish juvenile and mature wood zones in tree stems based on the k-means algorithm based on macrostructural characteristics of wood tissue as input data seems to be methodologically justified and free from subjectivism, so characteristic of other methods.

The applied method was verified through changes in values of the degree of crystallinity of cellulose determined on tree mean sample trees. The boundary indicated by the algorithm coincided with high accuracy with places where the course of changes in values of the degree of crystallinity in successive annual rings, after previous distinct changes in these values, started to be similar.

Juvenile wood in European larches grown in fresh broad-leaved forest covered the range from 9 to 22 annual rings surrounding the pith, at the arithmetic mean of 13 annual rings and a mode of 12 repeated 5 times. The axial distribution of juvenile wood is conical in shape, frequently similar to a pointed cylinder.

Work conducted in the search for an advanced, reliable and objective method to distinguish juvenile and mature wood zones in stems of forest trees should be continued and it seems justified to base them to a bigger extent on characteristics of submicroscopic wood structure.

ACKNOWLEDGMENT

This scientific study was financed from funds for science in the years 2008-2010 as a research project.

REFERENCES

1. Abdel-Gadir, A.Y., Krahmer, R.L., 1993: Estimating the age of demarcation of juvenile and mature wood in Douglas fir. Wood and Fiber Science 25(3): 242-249.
2 Alteyrac, J., Cloutier, A., Zhang, S.Y., 2006: Characterization of juvenile wood to mature wood transition age in black spruce (*Picea mariana* (Mill.) B.S.P) at different stand densities and sampling heights. Wood Sci. Technol. 40(2): 124-138.
3. Andersson, S., Wikberg, H., Pesonen, E., Maunu, S.L., Serimaa, R., 2004: Studies of crystallinity of Scots pine and Norway spruce cellulose. Trees 18(3): 346–353.
4. Bendtsen, B.A., 1978: Properties of wood from improved and intensively managed trees. Forest Products Journal 28(10): 61-72.
5. Bhat, K.M., Priya, P.B., Rugmini, P., 2001: Characterization of juvenile wood in teak. Wood Science and Technology 34(6): 517-532.
6. Clark, A.III., Daniels, R.F., Jordan, L., 2006: Juvenile/mature wood transition in loblolly pine as defined by annual ring specific gravity, proportion of latewood, and microfibril angle. Wood and Fiber Science 38(2): 292-299.
7. Csoka, L., Zhu, J., Takata, K., 2005: Application of the Fourier analysis to determine the demarcation between juvenile and mature wood. J. Wood Sci. 51(3): 309-311.
8. Deresse, T., Shepard, R.K., Shaler, S.M., 2003: Microfibril angle variation in red pine (*Pinus resinosa* Ait.) and its relation to the strength and stiffness of early juvenile wood. Forest Prod. J. 53 (7/8): 34-40.
9. Fabisiak, E., 2005: Variation in basic anatomical elements and wood density in selected tree species. (Zmienność podstawowych elementów anatomicznych i gęstości drewna wybranych gatunków drzew). Roczniki Akademii Rolniczej w Poznaniu, Rozprawy Naukowe, book 369: 1-176 (in Polish).
10. Fabisiak, E., Moliński, W., 2007: Variation in the microfibryl angle in the tangential walls of the larch wood tracheids (*Larix decidua* Mill.) from plantation culture. Folia Forestalia Polonica Seria B (38): 41-53.
11. Fabris, S., 1999: Influence of cambial ageing, initial sparing, stem taper and growth rate on wood quality of three coastal conifers. Ph.D. thesis, Faculty of Graduate Studies, Department of Forestry, University of British Columbia, Vancouver, B.C..
12. Grochowski, J., 1973: Dendrometry. (Dendrometria). Warszawa, PWRiL (in Polish).
13. Harańczyk, G., 2005: Cluster analysis based on segementation of cancers. (Analiza skupień na przykładzie segmentacji nowotworów). StatSoft Polska. Pp 77-92 (in Polish). http://www.StatSoft.pl.
14. Hartigan, J.A., 1975: Clustering algorithms. New York: John Wiley & Sons, Inc., 365 pp.
15. Hartigan, J.A., Wong, M.A., 1979: A K-means clustering algorithm. Applied Statistics 28(1): 100-108.
16. Helińska-Raczkowska, L., Fabisiak, E., 1999: Radial variation of earlywood vessel lumen diameter as an indicator of the juvenile growth period in ash (*Fraxinus excelsior* L.) Holz als Roh- und Werkstoff 57(4): 283-286.

17. Hindeleh, A.M., Johnson, D.J., 1974: Crystallinity and crystallite size measurement in cellulose fibres: 2. Viscose rayon. Polymer 15(11): 697-705.
18. Jakubowski, M., 2000: The effect of site, social class of tree position and age of trees on fluctuations in proportions of juvenile wood as well as sapwood and heartwood in stems of Scots pine (*Pinus sylvestris* L.). (Wpływ siedliska, pozycji biosocjalnej i wieku drzew na kształtowanie się udziału drewna młodocianego oraz bielastego i twardzielowego w strzałach sosen zwyczajnych (*Pinus sylvestris* L.)). Manuscript of doctoral dissertation. Department of Forest Utilisation, Poznań, 81 pp (in Polish).
19. Kocoń, J., 1991: Structure and ultrastructure of juvenile and mature wood of silver fir. (Struktura i ultrastruktura drewna młodocianego i dojrzałego jodły pospolitej). Folia Forestalia Polonica, series A, book 31: 139-148 (in Polish).
20. Kojima, Y., Yamamoto, H., 2004: Effect of microfibril angle to the longitudinal tensile creep behavior of wood. J. Wood Sci. 50(4): 301-306.
21. Kraft, G., 1884: Beiträge zur Lehre von den Durchforstungen, Schlagstellungen und Lichtungshieben. Klindworth's Verlag, Hannover, 147 pp.
22. Larson, P., Kretschmann, D., Clark, A., Isebrands, J., 2001: Formation and properties of juvenile wood in Southern pines: A synopsis. Gen. Tech. Rep. FPL-GTR-129. Madison, Wisconsin, USA. USDA Forest Service, Forest Products Laboratory, 42 pp.
23. Lissowski, G., Haman, J., Jasiński, M., 2008: Foundations of statistics for sociologists. (Podstawy statystyki dla socjologów). Wydawnictwo Naukowe Scholar (in Polish).
24. Loo, J.A., Tauer, C.G., McNew, R.W., 1985: Genetic variation in the time of transition from juvenile to mature wood in loblolly pine (*Pinus taeda* L.). Silvae Genetica 34(1): 14-19.
25. Mansfield, S.D., Parish, R., Goudie, J.W., Kang, K.Y., Ott, P., 2007: The effects of crown ratio on the transition from juvenile to mature wood production in lodgepole pine in western Canada. Can. J. For. Res. 37(8): 1450-1459.
26. Marton, R., Rushton, P., Sacco, J.S., Sumiya, K., 1972: Dimension and ultrastructure in growing fibers. Tappi 55(10): 1499-1504.
27. Nawrot, M., Pazdrowski, W., Szymański, M., Kupczyk, G., Lubieński, K., 2007: Volume and share of juvenile, maturing and mature wood in stems of Norway spruce (*Picea abies* (L.) Karst)) grown in mixed mountain forest sites. Acta Sci. Pol., Silv. Colendar. Rat. Ind. Lignar 6(3): 67-76.
28. Passialis, C., Kiriazakos, A., 2004: Juvenile and mature wood properties of naturally-grown fir trees. Holz als Roh- und Werkstoff 62(6): 476-478.
29. Pazdrowski, W., 2004: The proportion and some selected physical and mechanical properties of juvenile, maturing and adult wood of Black pine and Scots pine. Electronic Journal of Polish Agricultural Universities, Forestry 7(1): 1-8.
30. Punches, J., 2004: Tree growth, forest management, and their implications for wood quality. A Pacific Northwest Extension publication 576: 1-8.
31. Rabiej, S., 1991: A comparison of two X-ray diffraction procedures for crystallinity determination. Eur. Polym. 27(9): 947-954.
32. Sahlberg, U., Salmen, L., Oscarsson, A., 1997: The fibrillar orientation in the S2-layer of wood fibres as determined by X-ray diffraction analysis. Wood Science and Technology 31(2): 77-86.
33. Stanisz, A., 2007: Accessible course of statistics using STATISTICA PL with the example of medicine. Vol 3. Multivariate analysis. (Przystępny kurs statystyki z zastosowaniem STATISTICA PL na przykładach z medycyny. Tom 3. Analizy wielowymiarowe). Publisher: StatSoft, 500 pp (in Polish).

34. Tasissa, G., Burkhart, H.E., 1998: Juvenile-mature wood demarcation in loblolly pine trees. Wood and Fiber Science 30(2): 119-127.
35. Tomczak, A., Pazdrowski, W., Jelonek, T., Szaban, J., Jakubowski, M., 2008: Variability in selected macrostructural characteristics of juvenile wood in stems of Scots pine (*Pinus sylvestris* L.). Annals of Warsaw University of Life Sciences – SGGW, Forestry and Wood Technology 66: 146-150.
36. Yang, K.C., Hazenberg, G., 1994: Impact of spacing on tracheid length, relative density, and growth rate of juvenile wood and mature wood in *Picea mariana*. Can. J. Forest Res. 24(5): 996-1007.
37. Yeh, T.F., Braun, J.L., Goldfarb, B., Chang, H.M., Kadla, J.F., 2006: Morphological and chemical variations between juvenile wood, mature wood, and compression wood of loblolly pine (*Pinus taeda* L.). Holzforschung 60(1): 1-8.
38. Zhu, J., Nakano, T., Hirakawa, Y., 2000: Effects of radial growth rate on selected indices for juvenile and mature wood of the Japanese larch. J. Wood Sci. 46(6): 417-422.
39. Zobel, B.J., Sprague, J.R., 1998: Juvenile wood in forest trees. Springer Series in Wood Science, Springer-Verlag, New York, 300 pp.

Marcin Nawrot, Witold Pazdrowski, Marek Szymański, Agnieszka Jędraszak
Poznań University of Life Sciences
Department of Forest Utilisation
Ul. Wojska Polskiego 71
60-625 Poznań
Poland
Phone: +48 61 848 77 54
Corresponding author: agnieszka.jedraszak@up.poznan.pl

Ryszard Walkowiak
Poznań University of Life Sciences
Department of Mathematical and Statistical Methods
Laboratory of Biometry
Ul. Wojska Polskiego 28
60-627 Poznań
Poland

Sławomir Borysiak
Poznań University of Technology
Institute of Chemical Technology and Engineering
Ul. Wojska Polskiego 28
60-627 Poznań
Poland