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The effect of tree senescence on wood tissue characteristics in Scots pine (*Pinus sylvestris* L.)

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Abstract: *The effect of tree senescence on wood tissue characteristics in Scots pine (Pinus sylvestris L.).* It was investigated how the process of tree ageing affects characteristics of the wood tissue, defined on the basis of variation in the width of annual growth rings. Three stands were chosen for the study, aged between 155 and 166 years, from which a total of nine trees were selected for analysis of wood properties. It was found that Scots pine (*Pinus sylvestris* L.) growing in conditions typical of the region has a mean annual ring width of 1.94 mm. The rate of growth is fastest in the initial period, up to 50 years. However, no significant differences were found in the annual ring widths or in widths of early and late wood between the periods after the tree age exceeded 50 years. In the studied trees the width of early wood in the annual ring decreased after the age exceeded 100 years, which indicates a decline in crown vitality and in the hydraulic conductivity of the pine trunk after physiological and technical maturity has been reached.

Keywords: Scots pine, ageing process, diameter increment

INTRODUCTION

Ageing appears to be a universal principle for all living organisms, but is not a biologically inevitable process, since living systems are able to maintain immortality at the cellular level (Heininger 2002). According to Noodén (1988), senescence is a highly regulated process at the molecular, biochemical and physiological levels, leading to the death of a cell, tissue, organ or entire plant. It also represents the last ontogenetic stadium in the life of a plant. While senescence in this view is a complex of changes in the organism increasing the likelihood of its death, it does not fulfil the condition of being age-related. Another concept views senescence from a population biology standpoint, as a decrease in the age-specific value of survival and fertility which also decreases the performance of many physiological functions (Charlesworth 1980).

It would appear, nonetheless, that the qualitative and quantitative changes occurring in trees and tree stands can be presented as a function of age, expressed among other things in terms of the increments in wood volume, tree diameter and height. These parameters, which represent characteristics of any tree or stand, are dependent on the effect of external stimuli (Tomczak et al. 2009). Mäkinen (1998) and Miina (2000) have shown that changes in tree diameter increments are significantly influenced by external factors, although Wodzicki (2001) points out that the genotype has a significant impact on the formation of wood tissue. For these reasons the annual diameter increments of Scots pine are subject to a high degree of geographical and habitat-related variation (Paschalis 1980, Pazdrowski 1988a, Pazdrowski and Spława-Neyman 1999). On the cross-section of a tree trunk it can be observed that the width of the annual rings is not uniform. The rings close to the core are noticeably wider than those near the perimeter. This is an effect of the natural variation characteristic of conifer species (Borowski and Dziekoński 1974). On this basis, Raczkowski (1965) introduced to the Polish subject literature the concept of cyclic heterogeneity of wood. He stated that the heterogeneity results chiefly from the alternating zones of early and late wood, and the consequences that this system has for the wood's physical and mechanical properties. The early and late wood regions within the annual rings differ in terms of wood structure. Late wood, because of its structure, is heavier and stronger than early wood, and it is the proportional contribution of late wood that

determines the wood density, which in turn determines the wood's mechanical properties. For this reason, the greater the proportion of late wood, the better the technical quality of the wood (Bouriaud et al. 2004).

Analysis of the width of annual rings and the proportion of late wood is one of the methods of determining the quality of timber, and correlation of these features with the age of the tree makes it possible to establish how ageing processes affect the form of the wood tissue, as a result of which it is possible to estimate the technical quality of wood at different tree ages.

The aim of the study was to determine low processes of tree ageing affect the wood tissue characteristics in Scots pine.

METHODS

The experimental material was taken from mature pine stands aged between 155 and 166 years in three different areas (Fig. 1). On each site the heights and breast-height diameters of all trees were measured, and then using statistical characteristics each population was divided into three groups based on diameter and height. From each group one representative tree was selected. These trees were felled, and material was collected from them for laboratory analysis.

Measurement of the number of annual rings per centimetre, determination of the proportion of late wood and measurement of the mean annual ring width were carried out in accordance with the guidelines contained in the PN-55/D-04110 standard. The sample was prepared so that the annual rings on the cross-sections ran tangentially to one of the side edges. One cross-section was planed smooth so that the boundaries of the annual rings were clearly visible. The tests were carried out on samples with a humidity close to 12±3%.

The collected empirical data were analysed by statistical methods using the *STATISTICA 12* software package.

Figure 1. Study sites: 1) Warcino sect. 68i (N 16° 51′ 26″ E 54° 13′ 22″); 2) Bolewice sect. 250c (N16° 06′ 46″ E 52° 23′ 52″); 3) LZD Murowana Goślina sect. 65d (N 17° 06′ 40″ E 52° 33′ 17″).

RESULTS

The largest mean width of annual growth rings was recorded in the region nearest the core (age range 1–50 years); this value was 1.94 mm. For the range 51–100 years the mean value was 1.27 mm. The smallest width, 1.16 mm, was recorded for the rings furthest from the core, in the range 101–150 years. The standard deviations for these means were 1.08 mm, 0.56 mm and 0.56 mm respectively (Table 1).

There are statistically significant differences (at $p < 0.05$) between the computed mean annual growth widths in the range 1–50 years and in the other ranges (Fig. 2).

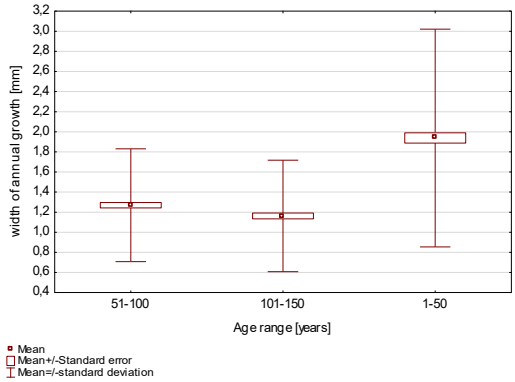

Figure 2. Mean width of annual growth in different periods.

Results of Tukey's HSD (honestly significant difference) test for mean width of early wood in the annual ring depending on tree age

	Age range		
	51–100	101–150	1–50
51–100		0.159397	**0.000022**
101–150	0.159397		**0.000022**
1–50	**0.000022**	**0.000022**	

** Differences statistically significant at p<0.05 are bolded*

Table 1. Statistical values for diameter increments of Scots pine (*Pinus sylvestris* L.) depending on age.

Age range [years]	Width of annual growth [mm]			Early wood [mm]			Late wood [mm]		
	Mean	N	Standard dev.	Mean	N	Standard dev.	Mean	N	Standard dev.
51–100	1.269	450	0.561	0.848	450	0.394	0.421	450	0.201
101–150	1.163	364	0.555	0.731	364	0.368	0.432	364	0.232
1–50	1.938	450	1.084	1.429	450	0.919	0.509	450	0.226
Total	**1.477**	**1264**	**0.859**	**1.100**	**1265**	**2.896**	**0.456**	**1264**	**0.223**

Because in conifer species each type of wood in the annual ring performs specific functions, a separate analysis was made of the width of the early wood in the ring, and similarly for the width of late wood.

In the case of early wood, the greatest width (1.43 mm) was recorded in the first period of growth, up to 50 years. In the next range (51–100 years) the value was 0.85 mm, and in the range 101–150 years it was 0.73 mm (Table 1, Fig. 3).

The mean width of late wood was also largest in the initial phase of growth, where it was equal to 0.51 mm. In the range 51–100 years the mean width of late wood in the annual ring was 0.43 mm, which is approximately 15% smaller, and in the range 101–150 years it was 0.42 mm, smaller than in the first zone by more than 17% (Table 1, Fig. 4).

As in the case of the mean total width of annual rings, the mean widths of early and late wood were greatest in the first period, up to age 50 years, the differences being statistically significant. No significant differences were found between periods II and III, although the zone of early wood in the studied pines is clearly narrowest in the range above 100 years. In this region the mean width of early wood was smaller by over 51% than in the first 50 years of growth, and smaller by 16% than in the 51–100-year range.

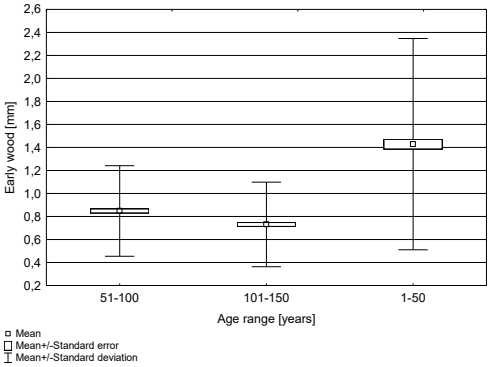

Figure 3. Mean width of early wood in the annual ring depending on the age of the tree.

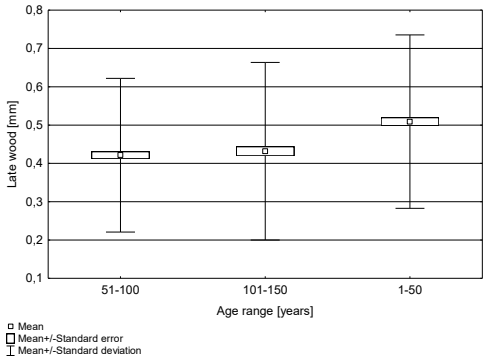

Figure 4. Mean width of late wood in the annual ring depending on the age of the tree.

Results of Tukey's HSD test for the mean width of early wood in the annual ring depending on the age of the tree

	Age range		
	51–100	101–150	1–50
51–100		0.801773	**0.000022**
101–150	0.801773		**0.000027**
1–50	**0.000022**	**0.000027**	

Results of Tukey's HSD test for the mean width of late wood in the annual ring depending on the age of the Tree

	Age range		
	51–100	101–150	1–50
51–100		0.031976	**0.000022**
101–150	0.031976		**0.000022**
1–50	**0.000022**	**0.000022**	

** differences statistically significant at p<0.05 are bolded*

CONCLUDING REMARKS AND DISCUSSION

Many authors consider that ageing is favoured by natural selection and that it is genetically programmed (Rose 1991, Finch and Ruvkun 2001). This leads to the fundamental question in ageing theory – whether or not the process is programmed. Much research has shown that the process is associated with a decline in vitality, and the physiological processes taking place in an ageing organism proceed in a different manner than in the phase before Based maturity is reached or even the phase of maturity (Noodén 1988, Brutovská et al. 2013) on the quantitative relations in the growing wood tissue of old pines, it can be assumed that the rate of growth falls slightly after the culmination point, or what is generally considered as technical maturity, is reached. The differences between the increments in the second period (51–100 years) and in the third (101–150 years) amounted to just 9%.

The width of annual growth rings, and its variation in a radial direction, in the studied pines are in agreement with generally accepted results obtained for conifer species, as investigated, among others, by Pazdrowski (1998b). With increasing distance from the core (that is, with increasing age) the width of the rings decreases. The decrease in widths is initially very rapid, becoming less marked in later periods.

The largest values of annual ring width at breast height are recorded in the age range 10–20 years, and it is also observed that the rate of diameter increment slows over that period. According to Jackowski (1972) there is a decreasing relationship between the wood quality and the mean annual ring width between the ages of 10 and 20 years.

The mean annual ring widths measured at breast height in the present study were 1.94 mm in the age range 1–50 years, 1.27 mm in the range 51–100 years, and 1.16 mm in the range 101–150 years. Statistically significant differences were found between the mean widths in the ranges 51–100 and 101–150 years on the one hand, and 1–50 years on the other. The mean annual ring width for all studied trees was 1.48 mm. Similar results were obtained by Staniszewski (1997), who for a tree stand aged over 80 years, in a wet coniferous forest,

reported an average ring width of 1.40 mm. Rola et al. (2014) obtained similar results for pines aged between 88 and 91 years, for which the average widths of annual rings on the northern and southern sides were respectively 1.43 mm and 1.40 mm. Wanin (1953) investigated the average annual ring widths for a 100-year-old stand in the Moscow region, obtaining a similar result of 1.30 mm, although he obtained higher values for pines in the Central European part of the former USSR, where the average ring width was 1.60 mm. These differences result from the fact that the ring width depends on the effect of many varied external factors and on geographical location, as well as on the quality of the habitat.

It is notable that in the studied pines, the region of early wood, responsible for the transport of water and mineral salts, was at its narrowest after the age of the trees exceeded 100 years. This may indicate that the hydraulic conductivity of the wood tissue and the vitality of the tree crowns decrease with age. Similar conclusions were reached by Jelonek (2012) in considerations of Pipe Model Theory. In studying the relationship between the conducting surface area of the trunk, namely early wood in the sapwood region, and the crown size and needle mass, that author found that ageing processes were significantly faster in the case of trees growing on land formerly used for agricultural purposes.

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Streszczenie: *Wpływ procesów starzenia się drzew na cechy tkanki drzewnej u sosny zwyczajnej (Pinus sylvestris L.)*. W pracy podjęto próbę określenia wpływu procesów starzenia się drzew na cechy tkanki drzewnej określone na podstawie zmienności szerokości rocznych przyrostów grubości. Do badań wytypowano trzy drzewostany w wieku od 155 do 166 lat, z których wybrano dziewięć drzew do analiz właściwości drewna. Uzyskane wyniki dowiodły, iż sosna zwyczajna (*Pinus sylvestris* L.) wzrastająca w typowych dla danego region warunkach cechuje się średnią szerokością słoja rocznego wynoszącą 1,94 mm. Największa dynamika wzrostu występuje w pierwszy z okresie tj. do 50 lat. Nie stwierdzono natomiast istotnych różnic w szerokości słoja rocznego oraz szerokości drewna wczesnego i późnego po przekroczeniu przez drzewa 50 roku życia. U badanych drzew wystąpiło zmniejszenie się szerokości drewna wczesnego w słoju rocznym po przekroczeniu 100 lat, co wskazuje na obniżanie się witalności koron oraz konduktywności hydraulicznej pnia sosny po osiągnięciu dojrzałości fizjologicznej i technicznej.

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