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The proportion of heartwood in conifer (*Pinus sylvestris* L., *Picea abies* [L.] H. Karst.) trunks and its influence on trunk wood moisture

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ABSTRACT: As the tree age increases, the formation of heartwood takes place in the central part of the tree. Since there is a large difference in the moisture content between sapwood and heartwood in conifers, the proportion of heartwood expressed in percentage is one of the most important factors influencing the average moisture of trunk wood. The aim of the research was to find out the changes in parameters of heartwood proportion and the changes in average trunk wood moisture parameters, depending on the age of the tree. To evaluate and compare the heartwood proportion in pine and spruce trunk and its moisture, sample plots were established throughout the territory of Latvia in 2011. These sample plots were established in stands of different ages (37–143 years). The total number of sample plots was 61–29 for pines with 246 sample trees and 32 sample plots for spruces with 270 sample trees. With the increase in the tree age from 60 to 140 years, the heartwood proportion increases and the average moisture content of trunk wood decreases. With an increase of the heartwood proportion in pine from 18% to 39%, the average moisture of trunk wood decreases from 108% to 86%, but with an increase of the heartwood proportion in spruce from 30% to 49%, the average moisture content of trunk wood decreases from 107% to 81%.

Keywords: pine; spruce; heartwood; moisture content of wood

Initially sapwood functions as the transportation route for water and mineral nutrients between the roots and the crown. As the tree gets older, heartwood formation takes place in the inner annual rings (Wagenführ 1989; Tsoumis 1991). This transformation of sapwood includes the termination of physiological functions in parenchyma and epithelial cells and reduction of moisture content. The wood becomes resinous and saturated with phenol components, which makes heartwood darker (in pine) than sapwood.

One of the most frequently accepted theories gives evidence that the heartwood formation process can be explained by the aging and dying of parenchyma cells (Frey-Wyssling, Bosshard 1959; Bosshard 1965).

The research carried out by Priestley (1932) and Harris (1954) indicated that the formation of heartwood is initiated by the accumulation of air in the wood, since as a result of chemical changes, water leaves the inner part of the trunk. It has been stated in several studies that it is the chief factor that initiates the formation of heartwood (Harris 1954; Ohasi et al. 1991).

According to the "pipe-model theory" (Shinozaki et al. 1964), in order to transport water to the crown of a definite volume (needle biomass), a specific proportion of tissue (sapwood) is required.

Based on this theory Rudman (1966) and Bamber (1976) suggested that the formation of the tree heartwood could be a result of a correction in the sapwood zone for the definite mass of the crown (needles). The ratio is quite stable within one species, but it has been found that the ratio varies depending on growing conditions and on

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the location in the trunk (Whitehead 1978; Albrektson 1984).

The age when parenchyma cells die varies considerably within one species. This age is influenced by different factors, e.g. the ratio between the sapwood proportion and the size of the crown (Hillis 1987). Thus, it can be concluded that the proportion of heartwood expressed in percentage differs considerably both among individual trees and among stands.

Tamminen (1962) studied 20 forest stands in Sweden and found out that the proportion of heartwood expressed in percentage differed by 15% among the stands, but Björklund and Walfridsson (1993) included 29 forest stands of Sweden and determined approximately 25% differences among the stands.

The proportion of heartwood expressed in percentage is one of the most significant factors influencing the average moisture content of wood. It influences wood density, transportation, workability, drying process, biological durability, changes in combustion heat and other parameters.

Moisture of wood is one of the factors influencing the recalculation coefficients (mass and volume ratio) which are used in assessing the quantity of round timber. In conifers sapwood moisture differs considerably from that of heartwood (in pine) and heartwood with similar colour with sapwood (in spruce) moisture, i.e. sapwood is 3–4 times moister than heartwood (Trendelenburg 1939).

The proportion of heartwood expressed in percentage in pines and spruces differs considerably among individual trees and forest stands. These differences also influence the average moisture content.

The ratio of heartwood and sapwood influences also the mass of the tree trunk and log, since the heartwood of many coniferous species contains less water than sapwood.

The scaling of wood by weight has become a point of immediate concern of those who buy and sell green wood. Therefore, the aim of the research is to clarify the proportion of coniferous heartwood expressed in percentage and average moisture parameters of wood depending on the tree species and age.

As a result of the research, the knowledge of heartwood will increase, thus enhancing the understanding of the characteristics of pine and spruce wood in Latvia.

MATERIAL AND METHODS

To assess and compare the proportion of heartwood and its moisture content in pine (*Pinus sylvestris* L.) and spruce (*Picea abies* [L.] H. Karst.) trunk, sample plots were established in the stands of mixed age (37–143 years) throughout the territory of Latvia in 2011. The total number of sample plots was 61–29 for pines with 246 sample trees and 32 sample plots for spruces with 270 sample trees.

Sample plots were established in stands where pine and spruce make up at least 60%. In the sample plot 7–10 sample trees were chosen according to the uniform placement principle in proportion with the distribution of the number of trees according to diameter classes. From these sample trees sample discs will be obtained.

During the logging operation 5 cm thick sample discs were obtained from each sample tree along the whole length of the trunk starting from the butt end after every round wood segment. The diameter of the last sample disc was 6–10 cm (Fig. 1).

The heartwood and sapwood annual rings were counted for the first sample disc at 0 meters. After that all the sample discs were divided into 4 parts and 1 segment (sample) from each sample was chosen for further treatment. The segments were cut out at an angle of approximately 30° clockwise. The segments were numbered with three numbers using a marker, e.g. 1-2-3 (1 – the number of sample tree, 2 – the sequence of sample disc in the longitudinal direction of the trunk, 3 – the number of segment).

As shown in Fig. 1, two segments (in this particular case the second and the fourth) were left undivided (for control), but for the first and third the bark was stripped and heartwood was separated from sapwood.

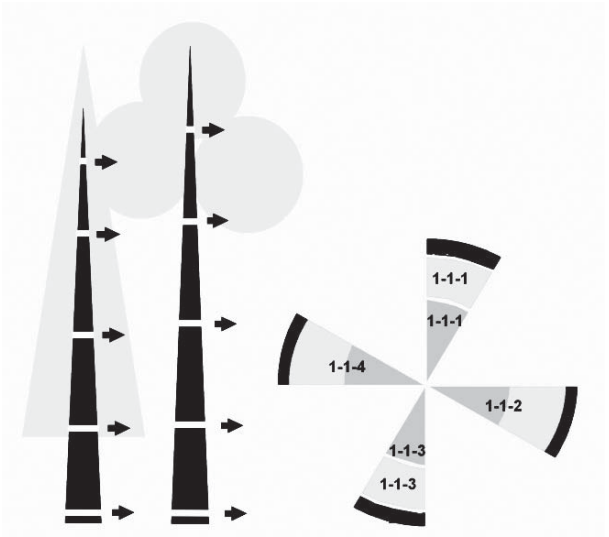

Fig 1. Choice of sample discs and preparation of segments from the sample disc

Right after cutting out, the mass of wood samples was determined in freshly cut condition. Afterwards the segment volume was determined using the immersion method (according to the amount of the water squeezed out in the measuring cylinder).

Then the samples were placed into the laboratory drying chamber and they were dried at a temperature of 103 ± 2°C until reaching non-changing mass. When the wood samples were dried, they were repeatedly weighed and their volume was determined.

The proportion of heartwood expressed in percentage in freshly cut condition is calculated according to the following formula:

$$HW = \frac{V_{HW}}{V_{HW+SW}} \times 100 \quad (1)$$

where:
HW – proportion of heartwood (%),
V_{HW} – volume of heartwood (cm^3),
V_{HW+SW} – total heartwood and sapwood volume (cm^3).

To characterize wood moisture, the absolute moisture indicator was used, which is the mass of water in wood expressed in percentage of dry wood mass (Eq. 2):

$$W_a = \frac{m_1 - m_2}{m_2} \times 100 \quad (2)$$

where:
W_a – absolute moisture content of wood (%),
m_1 – sample mass in wet condition (g),
m_2 – sample mass in dry condition (g).

To determine whether there is a statistical difference between the proportion of heartwood expressed in percentage and wood moisture content depending on the age, the average values of the indicators in diagrams are depicted together with ± 2 standard errors. The average value of two independent sample groups ± 2 standard errors characterizes (includes) a 95% credibility interval. If two independent sample groups with a 95% credibility interval overlap, then their difference will not be statistically significant. The analysis of the data was carried out using IBM SPSS Statistics and MS Excel software.

RESULTS

In order not to fragmentate the age, the average proportions of heartwood expressed in percentage were calculated starting from the age of 40 years, every 20 years. Regarding the average heartwood proportion indicators in pine at the ages of 40, 60, 80 and 100 years, it was observed that they differed significantly if viewed interrelated, but there was no significant difference among the ages of 100, 120 and 140 years.

Although a comparatively greater range in the proportion of heartwood expressed in percentage was observed in spruce at a certain age, when the average indicators of heartwood among definite ages were concerned, significant differences were observed. Mutually no significant differences in the proportion of heartwood expressed in percentage at the ages of 60, 80, 100 years were observed (Fig. 2).

As the tree grows older, the proportion of heartwood (wood with less moisture and insignificant range of moisture) increases, consequently the average moisture content of trunk wood decreases.

However, it should be noted that sapwood and heartwood moisture content varies with different stages of age, especially in young stands. Wood moisture content in young (40 year-old) trees is higher than in older trees. Significant differences between sapwood and average moisture content of

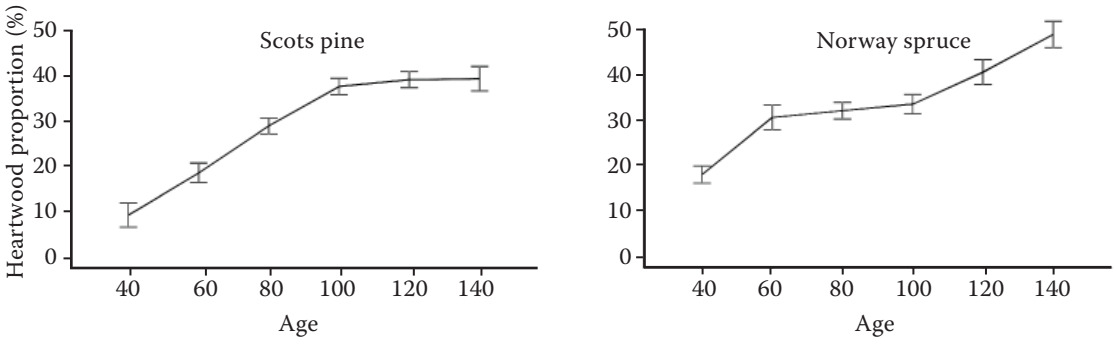

Fig. 2. Proportion of heartwood in pine and spruce depending on age (with ± 2 standard errors)

wood, as a result of an increase in the heartwood proportion, are observed at around the age of 60 in pine, but in spruce they are observed already at around 40 years of age (Fig. 3).

Significant changes in sapwood and average moisture content of wood in spruce are observed earlier, since the heartwood formation in spruce starts earlier, and its average annual ring increments e.g. at the age of 40 are also greater (in spruce – 0.40 annual rings, in pine – 0.30 annual rings).

In pine the greatest and statistically significant average decrease of wood moisture content is observed in the age period from 40 to 60 years. Within this range the average moisture content of wood decreases from 125% to 108%. These differences are caused by the decrease of moisture content in sapwood (from 132% to 123%) and heartwood (from 42% to 37%) and increase in the heartwood proportion from 9% to 18%. At the age of 60 the average moisture content gradually decreases from 108 % to 88 % when the tree reaches 100 years of age. This decrease in moisture content is mainly influenced by the increase of the heartwood proportion (from 18% to 37%), since the sapwood moisture content in the age period from 60 to 140 years is within the range of 125% to 122% and does not differ statistically significantly. In the age period from 100 to 140 years, the average moisture content of wood decreases from 88% to 86% and does not differ significantly, since the increase in the heartwood proportion is small in this age period (from 37% to 39%) and its annual increase in volume is similar to the outer annual ring increment of sapwood.

The greatest average decrease of wood moisture content in spruce is in the age period from 40 to 60 years (interrelated differ significantly). The main factors influencing these differences are a decrease in the moisture content of sapwood and heartwood and an increase in the proportion of heartwood. The average moisture content of wood at the age of 40 is 134%, but at the age of 60 it drops to 107%. These changes are due to the decrease in sapwood moisture content from 150% to 138% and decrease in heartwood moisture content from 54% to 45% and increase in the heartwood proportion from 18% to 30%. In the age period from 60 to 100 years the average moisture content of wood in spruce is stable and interrelated does not differ significantly (on average 107% –106%), since the increase of sapwood proportion is small (from 30% to 33%), because its annual volume increase is similar to the annual increment of sapwood outer rings. Also the moisture content of sapwood in the age period from 60 to 140 years is within the range of 139% to 130% and does not differ significantly. In the age period from 100 to140 years the average moisture content in spruce gradually decreases from 106% to 81%. This decrease in moisture is basically influenced by the increase in the proportion of heartwood from 33% to 49%, since its annual increase in volume is greater than the annual increment of the outer annual rings of sapwood.

DISCUSSION

In Latvia the average heartwood proportion for pine is within the range from 9% at the age of 40 years to 37–39% at the age of 100–140 years. In the case of spruce, the average proportion of heartwood expressed in percentage is within the range of 18% at the age of 40 years to 49% at the age of 140 years. Age is a significant factor which characterizes the relationships between sapwood and heartwood (Hillis 1987; Wagenführ 1989; Tsoumis 1991; Sellin 1996).

From the research, analysing the trees of different ages (37–143 years), the obtained average heartwood proportion in pine is 27%, but in spruce it is 32%. According to the results reported by Bruun (1965), depending on the geographical location of the place in the north-south direction the pro-

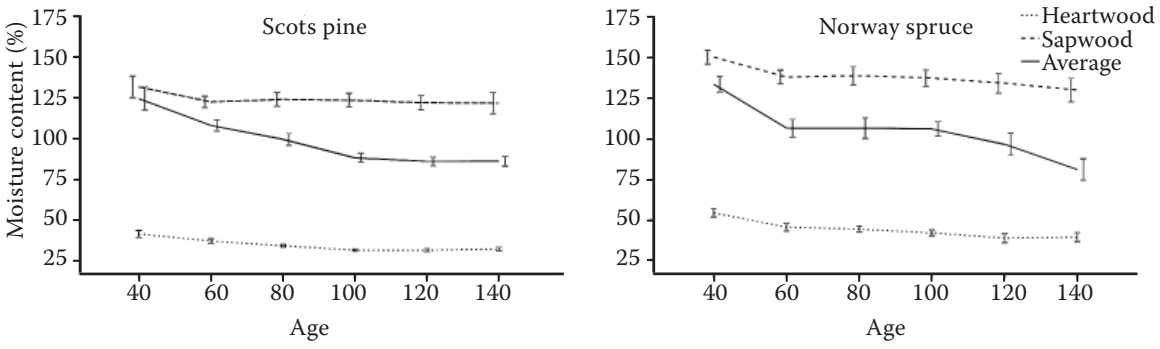

Fig. 3. Average moisture of wood in pine and spruce depending on age (with ± 2 standard errors)

portion of heartwood in pine decreases from 41% (Kemi–Rovaniemi) to 18–21% (Kouvola, Rauma), but in spruce it decreases from 52% (Kemi–Rovaniemi) to 26–29% (Kouvola, Rauma).

The average heartwood formation age in spruces in Latvia is lower than in pines (spruce – 30 years, pine – 35 years), therefore the formation of heartwood starts earlier, and in young stands as well as in medium-age stands spruce has a greater proportion of heartwood. Also Hartig (1892) and Bertog (1895) found out that the heartwood formation in spruce starts earlier than in pine. The Björklund (1999) study also indicated, although this result was obtained by extrapolation, that the heartwood formation in pine should start at a cambial age of about 15 years.

During the process of heartwood formation, each year a definite number of new heartwood annual rings are formed. According to the research carried out by several authors, it could be concluded that in pine when it reaches 50 years of age, heartwood increases by 0.53 (Björklund 1999) to 0.58 (Gjerdrum 2003) annual rings per year, at around the age of 90–100 it increases by 0.70 (Gjerdrum 2003) to 0.74 (Björklund 1999) annual rings per year and at the age of 150 by 0.76 (Gjerdrum 2003) to 0.95 (Björklund 1999) annual rings per year. The results obtained in Latvia are shown in Table 1.

Uusvaara (1974) conducted research on the pines grown in plantations with an age interval from 20 to 80 years and stated that depending on the age of the trees, the proportion of heartwood changed by 37%. In Björklund and Walfridsson (1993) research the age of pine was reported to be within the range of 42 to 192 years and it was stated that depending on the age, the proportion of heartwood changed by 40%.

With the tree age increasing, and with an increase in the heartwood proportion, the average moisture content of trunk wood decreases. These differences are caused by an increase in the heartwood proportion in percentage and a decrease of moisture content in sapwood and in heartwood. As the tree grows older and increases in diameter, the changes in pine wood moisture content were observed also in Latvia. According to Millers and Magaznieks (2012) calculations, the pine of an age from 37 to 70 years – 108%, of an age over 70 years – 90%.

Table 1. Annual ring formation of heartwood per year in Latvia

Age	Scots pine	Norway spruce
60	0.40	0.50
100	0.63	0.61
140	0.85	0.75

CONCLUSIONS

Age is an essential factor to explain the heartwood proportion changes in pines and spruces. The greatest decrease of average moisture content of trunk wood in pine and spruce is in the age period from 40 to 60 years. These differences are caused by an increase of the heartwood proportion and a decrease of sapwood and heartwood moisture content. With an increase in the tree age from 60 to 140 years, the average moisture content of wood is basically influenced by the ratio of heartwood proportion increase and the increase of the annual increment of outer annual rings of sapwood. If the increase of heartwood proportion is similar to the increase of outer annual rings of sapwood, the average moisture content does not change. Knowing the age of pine and spruce, heartwood proportion, sapwood and heartwood moisture content, it is possible to forecast the approximate average moisture content of trunk wood. Moisture content is the principal factor that may cause the weight of a specific quantity of wood to vary.

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