Formation of pine wood density depending on the parameters of annual ring and latitudinal zoning

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Abstract. The article presents the results of studies of changes in wood density depending on annual ring width and its characteristics. Density is a basic indicator for assessing operational and technical properties of wood. At the same time, density is characterized by certain variability within the same species, depending on annual ring characteristics, influenced by environmental factors, age of trees and position in the trunk. The purpose of this study is to establish the formation of density depending on annual ring width and late wood for Scots pine (Pinus sylvestris L.) wood in the central European part of Russia. Density research was made using the specimens with one annual ring by the method of buoyancy. Absolute values of the annual ring of early and late wood were measured in cores. It was found that wood density is only influenced by late wood width in the annual ring, being under strict genetic control. In the southern taiga zone correlation between density and late wood width is varying between 0.49-0.66 and it is less than in the forest-steppe zone. The correlation of density with annual ring width in the southern taiga zone is 0.5. It is less than in the forest-steppe zone (0.57-0.81).

1. Introduction

In practice, a variety of methods are used to determine the density of wood. The choice of the method for determination largely depends on the type of raw material and its effectiveness [1]. The density of wood is related to the macrostructural features of the annual ring. The ratio of annual ring width and late wood in it largely determines the value of wood density and can be used as an indicator of its quality [1].

The highest density of wood can be achieved at certain values of annual ring width, which depends on the region and growing conditions. The highest density of wood is achieved with an annual ring width of 1.0-1.2 mm for pine plantations growing in Northern Europe, and it is 1.4 mm for pine plantations from Central Europe. A decrease or increase in annual ring width under specific growing conditions leads to a decrease in the density of wood [2,3].

Annual ring width is a good diagnostic indicator for determining the density of wood in a growing tree. The possibility of accelerated cultivation of plantations and timber harvesting with certain quality indicators determines great practical significance of studying the dependence of density on the parameters of the annual ring.

The influence of climatic factors on the formation of wood density and structure variability of anatomical elements along the radius of the trunk in the plantations of northern and middle subzones of the taiga has been considered. The obtained results show an insignificant influence of climatic factors.
in this zone on the density and structure of wood [4]. A much greater influence on the formation of density is exerted by the presence of forest canopy at the early stages of tree development [5]. The role of climatic conditions on the formation of density in the stands with less favorable growing conditions is especially important. In more humid climatic conditions, the influence of climate on the formation of wood structure is not so significant [6,7].

The formation of the annual ring width, late wood width and density of pine wood in mixed plantations is greatly influenced by thinning. In similar plantations in the southern taiga zone with the influence of marine climate, the influence of thinning is insignificant [8]. The content of late wood in the annual ring has a much greater effect on the density than the width of the annual ring [9,10].

Currently, there is siloed information about the influence of climatic conditions and latitudinal zoning on annual ring characteristics which define density of Pine wood, growing in the central European part of the Russian Federation.

Therefore, the purpose of this study is to establish the formation of density depending on annual ring and late wood width, taking into account growing conditions and latitudinal zoning for Scots pine (Pinus sylvestris L.) wood in the central European part of Russia.

2. Methods and materials

Studies to determine the influence of latitudinal zoning and growing conditions within one geographic zone on the density and parameters of the annual ring were carried out on pine wood growing on the southern border of the forest-steppe zone in the Voronezh region and in the southern taiga zone in the Vologda region. In the Voronezh region, specimens of pine wood were harvested at Educational and Experimental Forestry (52ºN, 39º E). In the Vologda region, specimens were harvested at Ustyuzhanski special forestry enterprise (58º50’ N, 36º5’ E).

In the Voronezh region, two test plots were selected for the preparation of specimens: one with favorable growing conditions, which corresponds to the type of growing conditions - fresh subor (B2), the other with unfavorable ones, which corresponds to a site with the type of growing conditions A1 (dry pine forest).

Test plot in fresh subor (B2) is a pine plantation which is 125 years old, 26 m high and with an average diameter of 44 cm. The type of forest is grassy subor with oak (SBT-2). Test plot under dry pine conditions (A1) is represented by the pine stands of 125 years old, 25 m high and with an average diameter of 36 cm. The type of forest is grass-mossy pine forest.

In the Vologda region (according to the growing conditions) blueberry-lingonberry pine forest is close to fresh subor, and lichen pine forest corresponds to dry forest (A1). A site with unfavorable growing conditions has a plantation which is 140 years old and 20 m high. Average diameter is 26 cm and type of growing conditions is lichen pine forest. A site with favorable growing conditions has a plantation which is 140 years old and 23 m high. Average diameter is 28 cm and type of growing conditions is blueberry-lingonberry pine forest.

Sixteen model trees were selected on each test plot, from which two cores were taken from the southeastern side of the trunk at breast height with an age drill. Wood cores were used to determine its density, annual ring width and late wood width using a microscope with 4× magnification (MBS-9, LLC ‘LZOS’, Russia).

Microspecimens, equal in width to one annual ring, were cut and numbered to determine the density of wood from the cores. Before determining the volume, the specimens were kept in Petri dishes in distilled water until they reached a moisture content of at least 100%.

Wood density was determined by measuring the buoyancy force of specimens immersed in a liquid [2]. A vessel with distilled water was placed on the weigh scales. There was a holder with a needle above the vessel. The holder was fixed on a tripod, which ensures the movement of the needle in the vertical plane. After immersing the tip of the needle in water, the vessel with water was weighed. Before pricking the specimen onto the needle, water droplets were removed from it and then immersed in water, after which it was re-weighed. The volume of the specimen is equal to the buoyancy force acting on it when immersed in water.
After weighing, the specimens were dried to an absolutely dry state, placed in a weighing bottle, cooled, and the basis density was determined by the formula (1):

$$\rho_\delta = \frac{m_o}{V_{\text{max}}} \rho_f$$

(1)

where $V_{\text{max}}$ – maximum volume of the specimen, which is the difference between the weight of a vessel with water and specimen immersed in it, and the weight of a vessel with water, but without specimen, g/cm$^3$; $m_o$ – weight of an absolutely dry specimen, g; $\rho_f$ – density of distilled water at test temperature, g/cm$^3$.

3. Results and discussion

The results of density research of pine wood depending on the annual ring width are presented in figures 1 and 2.

It has been experimentally established that annual ring width in the forest-steppe zone varies from 0.5-3.5 mm, regardless of the growing conditions. In the southern taiga zone, the annual ring width changes within 0.5-2.0 mm under favorable growing conditions, and 0.3-1.7 mm under unfavorable ones.

![Figure 1. Density of pine wood depending on the annual ring width in the forest-steppe zone: favorable conditions (a); unfavorable conditions (b).](image1)

![Figure 2. Density of pine wood depending on the annual ring width in the southern taiga zone: favorable conditions (a); unfavorable conditions (b).](image2)

The annual ring width has a great influence on the density of wood. In the forest-steppe zone, the density reaches the highest value, with the following annual ring width: 1.5-2.5 mm (in favorable conditions) and 1.5-2.3 mm (in unfavorable conditions). For the southern taiga, the values of the annual ring width, at which the largest density of wood is seen, is 0.8-1.6 mm in favorable conditions, and 0.9-1.5 mm in unfavorable conditions. From the data obtained, it follows that annual ring width, at
which the density of wood takes the largest values, is greater in the forest-steppe than in the southern taiga. Table 1 shows the analytical dependences of the density of pine wood on the annual ring width under different growing conditions.

| Place and growing conditions | Regression equation | Bond index, $r$ |
|-----------------------------|---------------------|----------------|
| Forest-steppe              | $Y = 339 + 105.546x - 26.218x^2$ | 0.57 |
| favorable                   |                     |                |
| unfavorable                 | $Y = 296 + 176.74x - 48.497x^2$ | 0.81 |
| Southern taiga              | $Y = 234 + 256.47x - 102.06x^2$ | 0.50 |
| favorable                   |                     |                |
| unfavorable                 | $Y = 234 + 256.47x - 102.06x^2$ | 0.50 |

Analysis of the research results shows that the correlation between the density of pine wood and the annual ring width in the southern taiga zone is less than in the forest-steppe zone. The obtained data provide a less accurate forecast of density changes in the southern taiga zone than in the forest-steppe zone. Therefore, it is advisable to additionally take into account the parameters of the late zone width of the annual ring. The obtained data can also be used for a preliminary assessment of wood (timber) quality. The results of density changes depending on the late wood width are presented in figures 3 and 4.

Figure 3. Density of pine wood depending on the late wood width in the forest-steppe zone: favorable conditions (a); unfavorable conditions (b).

Figure 4. Density of pine wood depending on the width of the late wood in the southern taiga zone: favorable condition (a) s; unfavorable conditions (b).

Wood density reaches the highest values when the width of late wood is within 0.30-0.75 mm in the forest-steppe zone and with a width of 0.30-0.55 mm in the southern taiga zone. The lower limit for all the considered areas is the late wood width of about 0.30 mm. The upper limit of late wood width does
not exceed 0.9-1.0 mm in the forest-steppe zone and 0.55-0.60 mm in the southern taiga zone. A decrease in late wood width leads to a decrease in timber density. The minimum values of late wood width was 0.1 mm for all considered climatic zones. The maximum values of the late wood width, as well as of the annual ring width, at which the density of wood is highest can be seen in the forest-steppe zone.

Table 2 shows the empirical dependences of determining the density of pine wood on the width of the late wood in the annual ring under various climatic conditions.

The correlation of density with the late wood width is comparable in all growing conditions with the correlation of density with the annual ring width. In both geographical zones, its values are higher in unfavorable growing conditions. The correlation between the density and width of late wood is higher in the forest-steppe zone, than in the southern taiga zone.

**Table 2.** Density of pine wood (Y) depending on the width of the late wood in the annual ring (x) under different growing conditions.

| Place and growing conditions | Regression equation | Bond index, r |
|------------------------------|---------------------|---------------|
| Forest-steppe                |                     |               |
| favorable                    | \( Y = 342 + 281.72x - 206.895x^2 \) | 0.52          |
| unfavorable                  | \( Y = 324 + 390.823x - 313.99x^2 \) | 0.73          |
| Southern taiga               |                     |               |
| favorable                    | \( Y = 297 + 670.775x - 796.884x^2 \) | 0.49          |
| unfavorable                  | \( Y = 290 + 440.82x - 381.02x^2 \) | 0.66          |

4. Conclusions

The annual ring width at which wood density reaches its maximum value is higher in the forest-steppe zone than in the southern taiga zone. The minimum late wood width is the threshold for the considered environmental conditions. A decrease in its value entails a decrease in density and deterioration in the quality of wood. The correlation of density with the late wood width is comparable in its entire value with the correlation dependence of density with the annual ring width. The correlation of density with the annual ring width in the forest-steppe zone is higher than in the southern taiga zone. In both climatic zones, its value is higher under unfavorable growing conditions. In the forest-steppe, the correlation between the density and late wood width is higher than in the southern taiga zone.

The performed studies can be recommended for density determination according to the parameters of the annual ring during accelerated growth of forests and timber harvesting with certain quality indicators.

The studies carried out in different growing conditions and various latitudinal zoning show a greater genetic control over late wood compared to other parameters of the annual ring, which makes it possible to select specimens for growing wood with higher densities according to the above-mentioned indicator. The obtained data can be recommended when determining the density by the parameters of the annual ring during the accelerated growth of forests and timber harvesting quality indicators with certain.

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