Wood density of pine and spruce stands according to trees diameter distribution after thinning

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Abstract. In this paper, we present the results of studies on the relationship between the stand composition, the distribution row by the diameter classes of the stand and the wood density. Objects of study were coniferous forest stands with different participation of pine and spruce passed by thinning. Wood cores sampling was carried out on this stands and basic density of wood according to trees diameter classes determinate by maximum moisture method. The influence of the distribution curve of the trunks by the diameter classes on the wood density of pine and spruce is presented. Different trees quantitative representation of these species reflects on wood density and varies with the share of main species participation in the stand.

1. Introduction
Growth of mixed coniferous forest stands with proper care and selection of wood species makes it possible to achieve higher productivity than growth of pure forest stands [1-3]. To form a mixed coniferous stand with high physical and mechanical properties of wood, namely its density, it is necessary to study the influence of the composition of the plantation and the quantitative representation of trees by the diameter classes on this indicator. Mixed coniferous stands of pine and spruce under the forestry impact give different reactions to the formation of the wood density, which is caused by the difference in the biological and ecological properties of the species [4-6].

Carrying out the forest care leads to a change in the structure of the stand at the level of the distribution row by the diameter classes of the plantation [7]. Making selection of trees with the help of cutting and leaving the most perspective from a forestry point of view, it is necessary to know how the formed composition of the plantation will affect not only the quantitative but also the qualitative characteristics of pine and spruce wood, that is, its density [8-10]. This problem requires close study, since the topic of research has practical importance for predicting the results of thinning in polydominant pine and spruce stands.

The aim of our study was to find out how trees diameter class distribution after thinning corresponds with the wood density variations in mixed forest stands with different spruce and pine participation.
2. Experimental part
The objects of the study were pure and mixed naturally formed stands in the polytrichum group of forest types with the prevalence of pine (*Pinus sylvestris*) and spruce (*Picea abies*), which were affected by forestry impact. Thinning on sample plots was 20-30% intensive, in a few cases fertilizers were applied. The experimental objects in mature (100-120 years old) stands were permanent trial plots with a long period of observations in the Leningrad region in the Gatchina forestry, Russia (59°20'N 30°15'E). The sample consisted of 22 trial plots with a different share of pine and spruce. Also 4 temporary trial plots with the same conditions were selected to find out how the time elapsed since thinning can take effect on wood density. They were immature spruce and pine stands (60-70 years old) from the same region in the Lisinsky Educational-Experimental Forestry (59°26'N 30°41'E). Size of sample plots was differ (0.4-0.5 ha), but each plot had at least 200 trees on it.

A continuous counting of trees was carried out according to the diameter classes on the plots; soil patches were taken on each sample area to determine the uniformity of soil conditions. So, soils and forest type were conditionally identical. 25-30 core samples were taken on each plot from model trees on 1.3m height. Numbers of core samples were different because quantitative representation of the diameter classes on plots was different. The basis density of the wood samples was determined by the maximum moisture method [11, 12]. Then it was recalculated to whole trunk medium basis density (in further text «wood density») with using conversion equations for the studying region [12]. We determined the wood density (\( \rho_{\text{basis}} \)) in the studied stands with the prevalence of pine and spruce, depending on the proportion of their participation by the dispersion analysis method [13]. Processing of quantitative data was carried out using the application package «Statistica 10» at a confidence level of 95%.

To determine the influence of the distribution row by the diameter classes of the stand on the wood density, we conducted a comparative analysis of these indices in the phytocenoses of pine and spruce. Groupings on the thinning intensity of the plantation were not carried out, because the studied stands had initially different quantitative representations of trees in terms of diameter classes (also thinning intensity was relatively the same). To enlarge the sample, a grouping was carried out according to the compositions: conditionally pure (with a 90-100% share in the composition), 70-80%, 50-60% of the prevailing species in the composition.

3. Result and discussion
As a result of the basic wood density study in pine stands with a different share of pine participation, affected by thinning, it can be noted that with a decrease in the share of pine to 80% in the composition of the plantation, the density of its wood can decrease (figure 1). Previous studies in this region have shown that high intensity thinning (30-40%) causes to more reduction of the wood density in pure and mixed coniferous stands [14-16]. Analysis of the wood density indices of pine and spruce on experimental objects touched by thinning cuttings shows that the densest wood is formed in stands with a composition of 50% pine and 40% spruce. This is due to the fact that in these stands (in addition to thinning cutting) the N\(_{120}/P_{60}\) (kg/ha) fertilizer was applied to the active substance. Consequently, the joint actions of these measures make it possible to form denser wood to both species.

For mature stands with spruce prevailing, the densest wood is formed after thinning in a conventionally pure stand with 90% spruce in the stand composition (figure 1). In mixed coniferous stands, the densest wood of spruce was formed in stands with a share of 70% spruce in the composition, which also can be noted for the wood of the pine part of this phytocenosis. It should be noted that in all cases with the participation of pine in the spruce prevailing stands, the density of pine wood is higher than that of spruce.

The obtained results of dispersion analysis showed that with a decrease in the share of pine in the composition of the stand, there is an increase in the reliability of differences in the indices of the density of its wood. Probably, this is due to the fact that in the pine stands there is an insignificant variability in the wood density according to the diameter classes of the stand. For spruce stands, the
statistical analysis data showed that in stands with different shares of spruce, in most cases, there are no significant differences in the wood density of spruce. Significant differences in the wood density of spruce are observed only in the case of stands with 90% of spruce in the composition of the plantation. Thus, thinning lead to the formation of a fairly uniform in terms of the wood density of spruce, regardless of the proportion of its participation in the composition.

Figure 1. Wood density of pine and spruce.

Mixed spruce-pine stands by their nature are formed from the forest elements originally of different ages in their structure. Accordingly, therefore, the formation of the wood density in the extreme stages of the distribution row is most different for spruce, and to a lesser extent in pine from the main part of the most represented tree trunks on the plantation. In general, it should be noted that, regardless of the proportion of pine in the composition of the stand, the distribution row of its trees by the diameter classes actually has a close to normal distribution (figure 2). However, the density of pine wood varies according to the diameter classes, depending on the proportion of its participation in the stand. In conditionally pure plantations of pine, for the most represented diameter classes of it, it is possible to observe a pronounced dependence of the change in the density of its wood with the representation of trees of various diameter classes. With the decrease in the proportion of pine in the composition of the stand, this variability increases.

Changes in the wood density of pine, which does not coincide with a row of normal distribution by the diameter classes of the stand, are associated with different age of smaller diameter classes. Smaller diameter classes trees most often 10-15 years younger than the main part of the stand. For larger diameter classes, which in most cases are older by 10 years in relation to the main part of pine dendrocenosis, a similar dependence is observed.
For spruce-prevailing stands the following dependence is traced: with a decrease of spruce in the stand composition, a more ordered change in the wood density is observed by the diameter classes (figure 3). In spruce stands without forestry influence, the densest wood of spruce usually is formed in smaller diameter classes of the plantation [12]. The studied spruce stands by their nature consist of several age generations, but, as the analysis showed, the ages of the extreme diameter classes trees (smallest and largest) differ from the main part of this forest element for 10-20 or more years. This fact has a great influence on the formation of spruce wood density, both in smaller diameter classes and in the largest diameter classes of the diameter distribution row. The diameter distribution row has a bell shape (close to normal distribution) in conditionally pure spruce stands as in pure pine stands. For example to the pine forest stands which were not affected by cutting, this distribution also is typical for stands with less participation of pine in the composition. For the spruce element of the forest, with a decrease of it representation in the stand composition, a slope appears to the left in the distribution row by the diameter classes. In the stand with a share of 50-60% spruce, the distribution curve of the trunks according to the diameter classes has a close to exponential shape (figure 3).
Figure 3. Prevailing thickness class distribution and the density of wood in spruce-dominating stands.

The conducted studies on experimental objects in the ripening plantations (60-70 years old) showed that the wood density of spruce, as in cases with its prevalence, and with the domination of pine, exceeded the wood density of pine (figure 4). In the ripening coniferous stands, the statistically significant differences in the wood density of pine and spruce in stands with different shares of their participation in the composition is not observed.

Figure 4. Wood density of pine and spruce on the ripening objects.

As a result of earlier cutting operations in the ripening stands with a 40-50% share of the pine, the left displacement in the distribution row by the diameter classes is observed (figure 5). The curve for the distribution of the wood density by the diameter classes of pine has a normal shape for the main diameter classes of the trees (16-36 cm). For the largest diameter class trees in the stands with 40-50% pine participation, the density has the highest value (420 kg/m³), apparently due to the higher age of this diameter class trees.

On the ripening experimental objects with spruce domination, with its participation in the composition of the plantation of 70%, the curve of the distribution row has a form close to normal
As a result of forest management, a decrease in the proportion of spruce to 40% in the stand, the left slope of the curve of the distribution row by diameter classes in the stand is observed. The wood density of spruce in such plantations tends to increase from diameter classes of the stand to larger ones.

![Figure 5](image)

**Figure 5.** Thickness class distribution and the density of wood on the ripening experimental objects.

4. **Conclusion**

Experimental sample consisted of stands belong to polytrichum forest group with the same conditions, so, according to the conducted research it is possible to make significant conclusions. Thinning in the pine and spruce stands causes to the stand structure changing at the level of quantitative representation of trees on the stand. Thinning causes to the variety of wood density by diameter classes in the mature age. In some cases wood density variation is regardless to the proportion of the prevailing coniferous tree species. Pine stands with 80-100% pine participation are formed relatively homogeneous wood after thinning, analogical tendention showed by spruce in 50-70% spruce participation stands.

The variability of wood density according to the diameter classes has for both pine and spruce sharp changes in the smallest and largest diameter classes of the stand. Some authors have similar data [9]. In our opinion this fact is related to their age differences from the main part of the stand. For the pine element of the forest, there is an increase in the wood density from smaller to larger diameter classes after thinning. In the spruce part of the stand, the wood density is changed with the quantitative representation of the diameter classes.

Opposite to mature stands, in ripening coniferous stands, a more uniform wood density of pine and spruce is formed (by each element of forest). This correlates with other studies on this topic [7, 12]. So the influence of pine and spruce participation on the medium basis wood density formation at ripening stand age does not play so great role as at the age of mature stands.
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