Dynamics of the rank (social) structure of artificial spruce stands cultivated for high-quality wood

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Abstract. The paper discusses the results of 30 years of research on the dynamics of the rank (social) structure of a European spruce plantation. In 1985, in these stands trees of all size categories were pruned to a height of 7.0 m. As a result of the research, it was found that all forest stands retain their rank structures, which is confirmed by a strong correlation (with the coefficient of 0.9 and higher) between the tree diameters measured at the beginning and end of the study period. The rank law of growth in stands has been confirmed, since the diameter increment was directly proportional to the original tree size in all variants with pruning. The conclusion was made that pruning branches in all trees of the small size category and in trees of the middle category with the tree diameters below the average is inefficient.

1. Introduction
The need for the forestry intensification is becoming a pressing issue, primarily due to low profitability of forestry. A properly organized forestry is built on the concept of a reforestation cycle, and in a fully functional market economy standing timber is a commodity. Increasing the economic value of forest resources and gaining a long-term competitive advantage requires the creation of value-added products.

One of the priority areas for the development of forestry, as the basis of the forestry sector, is the qualitative productivity of plantations, which comprises quantitative and qualitative parameters of the entire stand and each individual tree, as well as improving the properties of the wood produced. This is the main criterion for the successful operation of various parts the forest industry complex (logging, woodworking, furniture, pulp and paper industries). Indicators such as presence of knots, wood density, fiber length and others affect the quality of the final product and its cost.

2. Methods and Materials
The most effective way to improve wood properties is pruning, which is not widespread in domestic silvicultural practice. With timely pruning carried out in conjunction with thinning in coniferous and deciduous plantations (as a rule, at the stage of clearing and thinning of stands), the content of high-quality knot-free wood increases. The yield of the best assortments of sawn timber and special assortments (including resonance wood) increases, and as a result of peeling, the yield of plywood and veneer also increases; the fire hazard class of forest stands decreases; the resistance of forest stands to
windblows, snow breaks, entomo- and phyto-pests increases; and the aesthetic appearance of stands and individual trees in landscape design improves [1]. In countries with developed forestry, pruning is almost a classic example of investment profitability [2].

Studies of the tree differentiation and rank structure of pine and spruce stands were carried out mainly under the influence of thinning [3]. It was found that 20 years of thinning in pine forests had a small influence on the rank hierarchy of trees. Thinning helps to accelerate the growth of individual remaining trees, which is generally proportional to their original size. The rank law of growth is also valid in this case and regulates the process of tree differentiation. In the work of L N Tovkach et al. [4], where the tree trunk growth, differentiation and shape in sparse pine plantations were studied. It is noted that the tree increment depends on the tree rank position before felling. At the age of silvicultural care, it is possible to assess the growth prospects of individual specimens of the main species by their biometric indicators and rank position in the canopy. When pruning with simultaneous intensive thinning (50%) a 50-year-old pine plantation, Burshel [5] notes the following. Pruning was carried out in 400 largest trees. After 10 years, these trees retained the highest increment and their rank position. Despite the intensive thinning, the previously stunted trees had stunted growth, and a gap in growth performance between them and the best trees widened significantly.

The process of growing high-quality wood in spruce stands, which consists in periodical pruning, requires long-term stationary research. Technologically optimal is the scheme when branches are removed from trees selected for further cultivation at the same height, for the convenience of subsequent cutting into assortments. Since trees of different growth classes (ranks) will fall into the selected category, it is natural that the same pruning height means a different degree of crown removal. Therefore, their reaction to this impact will be different. Hence, the general structure of the stand may look somewhat different.

The aim of the study was to assess the dynamics of the rank (social) structure in spruce plantations over a 30-year period after the removal of branches. The object of research was the artificial stands of European spruce planted in 1956; they were located in the Gatchinsky forestry unit, Taitsky district forestry unit, sq. 28, sub-unit 2, in which in 1985 the branches were pruned to a height of 7.0 m in trees of all size categories (figure 1).

![Figure 1. Spruce plantation with branches pruned to a height of 7.0 m.](image)
3. Results and Discussion

Analyzing the situation on a permanent sample plot (PSP) No. 157, with a density at the beginning of research similar to the control (2.6 thousand pieces / ha), the following can be noted (table 2). At the start of the project, trees from the same thickness class had a significant difference in the increment (from 2 cm to 23 cm). At the same time, the rank law of growth is confirmed, according to which trees retain their rank in a stand [3]. The correlation coefficient between tree diameter sizes at the beginning and end of the 30-year period was 0.977.

After the branches were removed, all trees from the sample plot, according to the reduction numbers, were divided by diameter into three size categories: small (M) up to 12 cm, medium (C) from 12 cm to 18 cm, and large (K) from 18 cm and thicker. After 30 years, according to the accepted size categories, small trees were up to 20 cm in diameter; medium, from 20 cm to 30 cm; and large, thicker than 30 cm, i.e. distribution by the size categories was similar to the control one.

From table 1, which presents the matrix of the transition of trees from one size category to others over 30 years of observations, it is clear that the structure of the experimental stand is somewhat different from the control one. In the experimental stand, medium trees predominate significantly, 76.3% versus 61.3%, and the number of small trees, on the contrary, is two times less: 8.6% versus 21.0%. Apparently, this is explained by the thinning operations carried out. Over a 30-year period of cultivation, the number of small trees has increased almost threefold, reaching 22.8%, due to a rather serious decrease in their status, by 20.9% in medium trees. The increase in the average diameter was 6.5 cm or 61.9%. The dynamics of the reduction numbers confirms the slowing down of the growth processes and further lagging behind of this tree category (table 2).

Medium trees, including those in the control, were the most mobile. A significant part (20.9%) went into the category of small, and 9.0%, into the category of large. Over the 30-year study period, the number of medium trees decreased by 15.9%, which is twice as much as in the control. This is explained, apparently, by repeated unauthorized fellings, when mainly small and medium trees were cut down. Analysis of reduction numbers (table 2) indicates the growth process stabilization in this part of the stand: for trees of all thickness levels, the reduction numbers at the beginning and end of the 30-year observation period are practically equal.

Table 1. Matrix of the transition of trees from one size category to others over a 30-year period (PSP 157).

| Size category | 2015, number of trees pcs./% | Cross section area, sm²/ % | Average diameter, cm |
|---------------|-----------------------------|----------------------------|----------------------|
|               | 1985 | 2015 | Increment in 30 year | 1985 | 2015 | Increment in 30 year | 1985 | 2015 | Increment in 30 year |
| small         | 16   | 4    | 20     | 80.0 | 20.0 | 100.0 | 8.6 | 1743.0 | 12071.0 | 10328.0 | 10.5 | 17.0 | 6.5 |
| medium        | 37   | 124  | 177    | 20.9 | 70.1 | 100.0 | 76.3 | 27666.0 | 65175.0 | 37509.0 | 14.1 | 24.4 | 10.3 |
| large         | 12   | 23   | 35     | 34.3 | 65.7 | 100.0 | 15.1 | 10408.0 | 33518.0 | 23110.0 | 19.5 | 33.1 | 13.6 |
| Total in 1985 | 53   | 140  | 232    | 22.8 | 60.4 | 100.0 | 100.0 | 39817.0 | 110764.0 | 70947.0 | 14.8 | 24.7 | 9.9 |
Table 2. Matrix of the transition of trees from one thickness category to others over a 30-year period in a 59-year-old spruce plantation in the variant with pruning (PSP 157).

| Thickness grades in 2015, cm | Th | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 |
|-----------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|                             |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 8                           |    | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 9                           |    |    | 2  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 10                          |    |    |    | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 11                          |    |    |    |    | 1  | 3  | 2  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 12                          |    |    |    |    |    | 1  | 3  | 2  | 5  | 4  | 5  | 3  | 1  | 2  | 1  | 2  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 13                          |    |    |    |    |    |    | 2  | 2  | 3  | 4  | 3  | 2  | 2  | 3  | 7  | -  | 2  | 4  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 14                          |    |    |    |    |    |    |    | 1  | 2  | 2  | -  | -  | 3  | 1  | 3  | 6  | 4  | 6  | 2  | 1  | 2  | 3  | -  | -  | -  | -  | -  | 1  | -  | -  | -  | -  | -  | -  | -  | 46  | 23.8 | 9.8 | 189.0 | 0.95 | 0.96 |
| 15                          |    |    |    |    |    |    |    |    | 1  | 3  | 1  | 4  | -  | 4  | 5  | 4  | 3  | 2  | 3  | -  | 2  | 2  | 1  | -  | -  | -  | -  | 1  | -  | -  | -  | -  | -  | -  | 37  | 24.0 | 9.0 | 156.0 | 1.01 | 0.97 |
| 16                          |    |    |    |    |    |    |    |    |    | 1  | -  | 1  | 3  | -  | 1  | 2  | 1  | 2  | 1  | 1  | 1  | 1  | 2  | -  | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | 18  | 26.3 | 10.3 | 170.2 | 1.08 | 1.06 |
| 17                          |    |    |    |    |    |    |    |    |    |    | 1  | 1  | 1  | 2  | 2  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 18                          |    |    |    |    |    |    |    |    |    |    |    | 1  | -  | 3  | 2  | 2  | -  | 1  | 3  | -  | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 19                          |    |    |    |    |    |    |    |    |    |    |    |    | 1  | -  | 1  | 1  | -  | 1  | 1  | -  | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 20                          |    |    |    |    |    |    |    |    |    |    |    |    |    | 1  | -  | 2  | -  | 2  | -  | 1  | -  | 1  | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 21                          |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 1  | -  | -  | -  | -  | -  | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 22                          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 25                          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| Total in 2015               |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 232 | 24.7 | 9.9 | 178.5 | 1.00 | 1.00 |

where, Th - Thickness grades in 1985, cm Tot - Total in 1985, Avr - Average diameter in 2015, Dia inc - Diameter increment, cm, Cro - Cross section area increment, %, Dia red - Diameter reduction numbers, Aft pru - After pruning, Aft 30 - After 30 years
Large trees have significantly reduced their status, by 34.3%, which is 3.7 times higher than in the control. This is rather unusual for this category of trees. This phenomenon can be explained by the fact that several breakouts of root fungus were recorded on this experimental plot when taking core samples of wood. Outwardly, the trees looked healthy, but on the cores, damage to the heartwood was already noticeable. At the beginning of the research, in the experimental variant the average increment in large trees was 1.2 cm lower than in the control; after 30 years this difference increased to 2.0 cm. The average increment was 13.6 cm or 69.7% of the initial value, and in the control, 14.4 cm or 69.6%. The average increment of the stand as a whole was 9.9 cm or 66.9%, which is 1.0 cm lower than the control value.

4. Conclusion

All the stands in which branches were removed, regardless of age, density, and pruning intensity, retain their social (rank) structures, which is confirmed by a strong correlation (with the coefficient of 0.9 and higher) between the tree diameter sizes at the beginning and end of the study period. This indicates a functional relationship between these tree parameters. The diameter increments in all the variants with pruning and thinning are directly proportional to the initial tree size, which confirms the rank law of growth in the stands. Since the prevailing number of small trees retained their status, in this tree category pruning is impractical, since the trees are likely to fall out, and also due to the fact that no accumulation of valuable knot-free wood will occur by the age of felling. The same applies to trees from the medium size category, primarily those with a diameter below the average. Therefore, trees with a diameter above the average, in the amount of 600-800 pcs/ha, evenly distributed over the area, without thick branches, curvatures and other trunk defects are subject to pruning.

Pruning should be considered a necessary element in combination with regular silvicultural maintenance (clearing and thinning) and repeated fertilization in a comprehensive forest management system. This technology of intensive forest growing can increase the quantitative and qualitative parameters of the entire stand and each individual tree, as well as improve wood properties, which increases profitability of forestry production.

References

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