Analysis of pine stands productivity in Boksitogorsky forestry unit of the Leningrad region

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Abstract. The article addressed the question of the development of stands with different proportions of pine in the stand composition on the territory of Boksitogorsk forestry unit of the Leningrad region. We used forest inventory data to carry out a comparative analysis of stands by forest type and stand composition. Analysis of variance was used to determine statistically significant differences in the growing stock depending on the stand composition and growing conditions. Based on the results of the study, we made a conclusion that on the territory of the forest fund in the part of the Boksitogorsk region considered, mixed stands with a share of pine of 50-80% and almost pure pine stands in blueberry types of forest growing conditions were the most promising. The stand composition did not make a significant effect on the productivity of stands with different proportions of pine. Apparently, this is due to the replacement of pine by other species and formation of growing stock similar to that of a pine forest. In the wetter forest types, stands with a lower productivity formed.

1. Introduction
Forest is a unity of plant communities related to each other and interacting with each other and with the environment. Mixed stands with pine and spruce represent the most productive communities of the middle taiga complex of forest stands [1-6]. These phytocenoses occupy 60% to 80% of the green moss series of forest types in various landscapes of the taiga zone [1, 2]. In the ecological-cenotic respect, these phytocenoses are transitional from simple pine forests to complex nemoral-boreal stands [2]. In pine stands, there is an unequal, but constant proportion of spruce, which in the upper canopy layer ranges from a tenth to half of the stand composition, and in the lower canopy layer, spruce always predominates. In some forest types, spruce has gained dominance in the first canopy layer, however, in comparison with pine, it has lower growth rates at the same age. In all forest types, the natural regeneration is mostly formed by spruce. These stands are the arena of competition between the two main forest-forming species of the boreal zone. On the territory of the middle subzone of the taiga zone, pine-and-spruce forests grow on low plains with two-member deposits. Under the canopy of forest stands, podzolic soils developed; they are often strongly podzolic. Mixed and complex pine stands are often highly productive. The most productive are pine-and-spruce stands, which are formed on thin sandy loam fresh podzols, and developing on sandy loam underlain by loam. These stands are characterized by the II-III productivity class, and the growing stock of mature stands in some cases exceeds 500 m³ per ha [1, 3, 6]. For the forest management to be successful, it is necessary to develop
specific standards that fully reflect characteristic features of the formation of mixed coniferous stands with a predominance of pine.

The aim of this study was to analyze pure and mixed pine stands in a narrow range of forest growing conditions in order to identify economically valuable combinations and the most productive stands under the conditions of the study area.

2. Methods and Materials

2.1. Objects of research
The Boksitogorsk Region is a municipality located in the south-eastern part of the Leningrad Region [7, 8]. The largest part of the region is located on the Tikhvin ridge, which is a hilly upland with a maximum height of 200-280 m. The relief of the forestry units is mainly flat. The soils in the western part of the region are soddy-podzolic and strongly podzolic, and in the considered eastern part of the region they are peaty and boggy, which directly affects the distribution of plant communities. The total area of the forest fund of the Boksitogorsk region is 283.7 thousand hectares, including 218.1 thousand hectares of forest lands; of those 207.01 thousand hectares are covered by forests. The plant communities are evenly distributed over the entire area of the region and comprise dark coniferous forests, spruce stands in the western part of the region, and pine stands in the eastern part of the region. Pine stands are among the most valuable from the point of view of economic activities in the southeastern part of the Leningrad Region [7]. Pine stands in the areas under consideration are found in various types of forest: Ledum palustre forest type, Polytrichoso-Sphagnosa forest type, Vaccinium vitis-idaea forest type, Sphagnosa forest type, Sphagnoso-Herbasum forest type, Vaccinium vitis-idaea and Oxalis acetosella forest type [2]. This is due to the fact that pine tolerate a broad range of edaphic conditions, due to the fact that this species is a xero-mesophyte and can grow within the optimum zone, as well as at its margins.

Pine forms fairly stable stands, even at the margins of pessimums; however, the economic productivity of pine stands formed near the tolerance limit is often extremely low and cannot be considered economically efficient due to small increments of inventory characteristics. In this context, it is extremely important to correctly select pine stands with high productivity with a systematic and effective forestry management in mind.

2.2. Study methods
The natural pine stands of the Boksitogorsk region were selected as the study object. The research data were obtained from forest inventory materials compiled by the branch of the Federal State Budgetary Institution Roslesinforg, Sevzaplesproekt in 2006, and information from the GLR-3 form of the state forest register as of 01.01.2018.

From the forest inventory database, by means of a special request, a sample of stands of different ages with at least 30% of pine units was taken. The sample was based on the analysis of such inventory indicators as the stem diameter, growing stock and species composition in various types of forest growing conditions.

The following statistical parameters of the sample were obtained: the average stand composition (80% pine, 20% spruce and 80% pine, 20% birch); the average age (91 years) and the coefficient of its variation (± 31%); the average diameter (18 cm) and the coefficient of its variation (± 35%); the average growing stock (146 m³) and the coefficient of its variation (± 44%). Based on these indicators, we came to a conclusion that these stands were the most productive, because the prevailing number of stands were mature, the variation of the average diameter and growing stock was significant and deviated from the normal distribution by 2% and 11%. The variability of the age structure was insignificant, since the coefficient of variation deviated from the standard value by ± 1.2%, which in turn affects the distribution, making the sample heterogeneous; however, we can assume that the error satisfies the normalized indicators. All of the above depends on the type of forest growing conditions, which increases variation when processing all statistical indicators.
After statistical analysis of the data, we carried out the analysis of variance of the growing stock depending on the share of pine in the stand composition and forest type, using Fisher's criterion as a test statistics [9]. Subsequently, a comparative analysis of the data was carried out.

3. Results and Discussion
Forest stands were classified and assessed according to the age structure and growing stock in specific forest growing conditions. The main criteria for selecting the most productive stands were: forest type, age class, and stand composition. Based on the results of the analysis of variance, we found no significant differences in the maximum productivity depending on the proportion of pine in the stand composition. To identify the differences in the growing stock depending on the forest growing conditions, the following forest types were considered: Vaccinium myrtillus, Sphagnum palustre, Caricoso-Sphagnosum Polytrichosos-Sphagnosa, Oxalis acetosella, Vaccinium vitis-idaea and Ledum palustre

In the course of the analysis, we established that the number of stands of the oxalis type was not sufficient for the analysis; this did not allow using the data obtained for assessing the above indicators. Forest stands with the proportion of pine no less than or equal to two units were also not included in the sample, since their number was not sufficient for the assessment of the above criteria.

Based on the results of the significance analysis of differences in growing stocks depending on forest type, the following conclusion was made: the Ledum palustre forest type was significantly different from pine forests of the Sphagnum palustre, Vaccinium myrtillus waterlogged and Vaccinium myrtillus types. The growing stock of the Vaccinium vitis-idaea pine forest was statistically significantly different from that of the Caricoso-Sphagnosum pine forest. The Caricoso-Sphagnosum pine forest was significantly different from forest stands of the Vaccinium myrtillus well-drained and Sphagnosos-Herbasum types. Pine stands of the Sphagnum palustre and Sphagnosos-Herbasum types differed significantly in terms of the growing stock from the moist and Vaccinium myrtillus types. The growing stock volumes of pine stands of the moist and fresh Vaccinium myrtillus types were statistically significantly different. The above is due to the fact that pine can tolerate a wide range of growing conditions, which allows the species to form productive stands in conditions of both pessimums and optima. Anything that is statistically significant according to the ANOVA results is the optimum in terms of the biological characteristics of the tree species studied [10]. The rest of the pine stands of the types considered were not statistically significantly different from one another (tables 1 and 2).

Table 1. Significance of the growing stock differences depending on forest type. (0 - unreliable; 1 - reliable).

| Forest type       | Vaccinium palustre | Vaccinium vitis-idaea | Polytrichosos-Sphagnosa | Caricoso-Sphagnosum | Sphagnum palustre | Sphagnosos-Herbasum | Vaccinium myrtillus waterlogged | Vaccinium myrtillus well-drained |
|------------------|-------------------|----------------------|------------------------|--------------------|------------------|---------------------|-----------------------------|--------------------------------|
| Ledum palustre   | -                 | -                    | -                      | -                  | -                | -                   | -                           | -                              |
| Vaccinium vitis-idaea | 0               | -                    | -                      | -                  | -                | -                   | -                           | -                              |
| Polytrichosos-Sphagnosa | 0               | 0                    | -                      | -                  | -                | -                   | -                           | -                              |
| Caricoso-Sphagnosum | 1               | 1                    | 0                      | -                  | -                | -                   | -                           | -                              |
| Sphagnum palustre | 1                 | 0                    | 0                      | -                  | -                | -                   | -                           | -                              |
| Sphagnosos-Herbasum | 0               | 0                    | 0                      | -                  | -                | -                   | -                           | -                              |
**Table 2.** Actual and theoretical values of the Fisher's criterion.

| Forest type                                      | $F_i$ | $F_t$ |
|--------------------------------------------------|-------|-------|
| *Ledum palustre* - *Caricoso-Sphagnosum*         | 2.6812| 1.2907|
| *Ledum palustre* - *Sphagnum palustre*           | 1.638 | 1.2911|
| *Ledum palustre* - *Vaccinium myrtillus* waterlogged | 1.3711| 1.3129|
| *Ledum palustre* - *Vaccinium myrtillus* well-drained | 1.3118| 1.3113|
| *Vaccinium vitis-idaea* - *Caricoso-Sphagnosum*  | 2.0477| 1.3891|
| *Caricoso-Sphagnosum* - *Vaccinium myrtillus* waterlogged | 1.5403| 1.21545|
| *Sphagnum palustre* - *Vaccinium myrtillus* waterlogged | 1.6895| 1.2159|
| *Sphagnum palustre* - *Vaccinium myrtillus* well-drained | 1.2966| 1.2129|
| *Sphagnoso-Herbosum* - *Vaccinium myrtillus* waterlogged | 1.5879| 1.311|
| *Sphagnoso-Herbosum* - *Vaccinium myrtillus* well-drained | 1.3655| 1.3094|
| *Vaccinium myrtillus* waterlogged – *Vaccinium myrtillus* well-drained | 1.3668| 1.2406|

For the analysis, the most productive stands were selected from various forest types and each stand composition. The results of the distribution of the growing stocks of the stands studied by the forest type and share of pine in the stand composition are given in table 3.

**Table 3.** Growing stock distribution by forest type and stand composition.

| Forest type                                      | Growing stock (m³ per ha) with the share of pine in the stand composition | Mean |
|--------------------------------------------------|------------------------------------------------------------------------------|------|
|                                                  | 30% pine | 40% pine | 50% pine | 60% pine | 70% pine | 80% pine | 90% pine | 100% pine | Mean |
| *Ledum palustre*                                 | 215       | 264       | 211       | 251       | 251       | 238       |
| *Vaccinium vitis-idaea*                          | 189       | 204       | 251       | 271       | 332       | 291       | 264       | 257       |
| *Polytrichosos-Sphagnosa*                        | 215       | 264       | 302       | 264       | 286       | 286       | 266       | 264       | 263       |
| *Caricoso-Sphagnosum*                            | 197       | 134       | 169       | 211       | 241       | 237       | 237       | 237       | 208       |
| *Sphagnum palustre*                              | 59        | 197       | 115       | 148       | 211       | 148       | 197       | 154       |
| *Sphagnoso-Herbosum*                             | 211       | 224       | 237       | 224       | 203       | 91        | 211       | 200       |
| *Vaccinium myrtillus* waterlogged                | 277       | 264       | 356       | 277       | 264       | 237       | 286       | 286       | 281       |
| *Vaccinium myrtillus* well-drained               | 291       | 251       | 277       | 277       | 261       | 291       | 264       | 203       | 264       |
| Mean                                             | 205       | 225       | 247       | 231       | 245       | 251       | 224       | 239       |

Based on the sample data, which was obtained according to the above criteria, it can be seen that the most productive from the point of view of the growing stock were the stands of the moist blueberry type. In terms of the share of pine in the stand composition, forest stands with 50% and 80% units of
pine proved to be the most productive. However, growing stock averages were also high in pure pine forests and stands with 70% of pine.

In terms of the quantitative indicators of the growing stock (in m³), the most productive stands, in descending order, were: *Vaccinium myrtillus*, *Polytrichososphygnum*, *Vaccinium vitis-idaea*, *Ledum palustre*, *Caricoso-Sphagnosum*, *Sphagnum palustre*.

In the study area, the *Vaccinium myrtillus*-type pine forests occupied the largest areas (up to 40%), where intensive forestry activities have been carried out. The analysis of the structure of mature forest stands with different proportions of pine, which are mostly represented by fresh and moist blueberry forest types, showed that, depending on the stand composition, the average heights and diameters of pine change significantly.

In stands with different proportions of pine, a variation in the average height can be observed. There is a tendency toward a stepwise decrease and increase in the average height in stands with different proportions of pine. The maximum height of pine (22 m) was observed in stands with 60-70% of pine in the stand composition as well as in a pure pine stand. The average height of the pine canopy layer varied from 19 to 22 meters. In the stands with the participation of pine, the average diameters varied with the stand composition. The largest average diameter (28 cm) was observed in stands with 80% and 100% of pine. The analysis of the quantitative characteristics of stands with a predominance of pine in the stand composition revealed that the maximum growing stock (277-356 m³) of the coniferous species accumulated in the stands with 50% of pine. A slightly smaller growing stock was observed in a relatively pure pine plantation (with 90% of pine), 264-286 m³. The same volumes were recorded in the stands with 70% of pine, 261-264 m³.

4. Conclusion
Based on the results of the study we came to a conclusion that on the territory of the forest fund in the part of the Boksitogorsk Region considered the most promising were mixed pine stands of the moist *Vaccinium myrtillus* type with the stand composition close to pure pine stands. The stand composition did not have a significant effect on the productivity of stands with different proportions of pine. Apparently, this is due to the replacement of pine by other species and formation of growing stock similar to that of a pine forest. In the wetter forest types, stands with lower productivity are formed, since edaphic conditions in the part of the area considered are characterized by a high degree of waterlogging and a low nutrient content.

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