The influence of the stand composition on the productivity of pine and spruce stands in different forest types on the territory of the Lisino Educational and Experimental Forestry Unit of the Leningrad Region

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Abstract. A study of the productivity of pine and spruce stands in various forest types growing on the territory of the Leningrad Region was carried out. Forest inventory materials were used to conduct a comparative analysis by forest type and stand composition. The analysis ANOVA was used to establish significant differences between spruce and pine stands. The largest growing stock in stands with a predominance of pine was recorded when a share of pine in the stand composition ranged from 70 to 100%. The largest growing stock of pine trees was recorded in the Oxalis acetosella - Vaccinium myrtillus and Vaccinium myrtillus - Polytrichoso-Sphagnosa forest types. In the stands with a predominance of spruce, the largest growing stock of this species was recorded in the stands with 70 – 90% of spruce. The largest growing stock of spruce was formed in Oxalis acetosella - Vaccinium myrtillus forest types. Our studies have shown that pine-dominated forest stands were more productive in a wider range of forest types than spruce stands. In general, this is due to the fact that the sample under consideration was within the optimum growing conditions for each species, and the stands formed within these boundaries were stable and productive.

1. Introduction
Pine stands are among the most economically valuable vegetation types of the northwest region of the boreal zone of Russia. Pine stands are found in all forest types. This is due to the fact that pine is a mesophyte with a broad range of tolerance to edaphic conditions, which affects its inventory characteristics and stand growth in genera [1-3]. Only pine can form acceptable stands in a variety of forest growing conditions while forming sufficiently stable stands; however, economic productivity of pine stands formed at the boundaries of the tolerance limit is often extremely low and cannot be considered economically effective [4, 5].

In the boreal zone, spruce stands are found in various forest types: Polytrichoso-Sphagnosa, Vaccinium myrtillus, Oxalis acetosella, Filipendulo-Herbosum; however the most productive from the point of view of economic activities and forest inventory indicators are the Oxalis acetosella and Vaccinium myrtillus forest types [6, 7]. Unlike pine, spruce is an obligatory mesophyte, which directly affects its distribution in various forest conditions. For spruce, the optimum boundaries do not vary greatly, since biological characteristics of spruce include a relatively high demand for soil moisture...
and soil nutrients; the latter can be satisfied on clay and loamy soils. Spruce forms stable stands only in the optimum conditions. However, it can grow under unfavourable conditions and form unproductive, in terms of the increment of forest inventory indicators, and economically unprofitable stands.

In this context, it is extremely important to correctly select species composition of plantations to achieve high productivity in order to conduct systematic and efficient forest management [5, 8]. If one of the species is growing under sub-optimum conditions in a mixed stand, then a number of measures should be taken to improve the growing conditions, which will further increase the stand productivity.

The aim of this work was to analyze forest inventory indicators of pure and mixed pine and spruce stands in various forest types to identify economically valuable combinations and the most productive stands.

2. Materials and Methods

2.1. Objects of research
Pine and spruce stands of natural origin growing on the territory of the Lisino Educational and Experimental Forestry Unit were selected as an object of the study [9, 10]. The territory of the Lisino forestry unit is located on the lacustrine-glacial, clay, swampy plains of the Ilmen-Volkhov lowland and is a flat, poorly drained plain with the maximum elevations of 52–68 m above sea level and depressions in the form of shallow valleys with numerous small rivers and streams, some of which dry up in summer. The largest river is Lustovka, with a catchment area of about 10 thousand hectares. The most widespread soil-forming rocks are moraine deposits formed by boulder loams with a thickness of over 2-3 m. The southeastern part is dominated by boulderless lacustrine-glacial loams and band clays. In some places, there are 1.0–1.5 m thick boulder sands. Peat bogs occupy a large area. In the past, more than 30% of the forestry unit was swampy. By now, a large part of the marshes and wetlands has been drained. Forests are mostly represented by mixed stands. A large part of the forest fund has not been affected by felling. These natural stands are essentially the only intact forest areas in Northwest Russia.

The Luga-Tosno landscape is a low, lacustrine-glacial plain composed of boulder loams, belt clays and, to a smaller extent, by water-glacial sands. Among the soils of automorphic positions, sod-podzolic soils formed on moraine loams and strip clays prevail. Peat and bog soils occupy a large part of the area. In this region, two types of landscapes have been identified, which differ in internal structure, ecological regimes, and forest composition and productivity [8, 9].

The first group includes glacial semi-wavy plains, 51–80 m above sea level, with tracts of end-moraine ridges, kams and lakes, composed of boulder loams, less often sandy loams, gravel and boulder sands, fed mostly by atmospheric precipitation. On these sites, pine and spruce stands grow on moist and fresh soils around bogs and boggy tracts of closed depressions with a convex oligotrophic ridge-hollow central part.

The second group include low-lying flat terraced lacustrine-glacial plains at ca 50 m above sea level. They are composed of strip clays, less often sands, and are fed by atmospheric precipitation and flowing waters. In these areas, coniferous stands with varying proportions of pine and spruce grow in boggy and riverine areas, in areas with flat and slightly convex bogs, and closed and drained depressions with mesotrophic swamp facies.

2.2. Study methods
The research data were obtained from the materials of a forest inventory materials, carried out by the Sevzaplesproekt branch of the Federal State Budgetary Institution "Roslesinforg" in 2005, and information of 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 age was made with at least 50% of pine and spruce in the stand composition. The samples were selected based on the analysis of inventory indicators of stands in various types of forest growing conditions. To identify statistically
significant differences between stands of different species composition and with different proportions of pine or spruce, a comparative analysis of the mean values and coefficients of variation of inventory indicators was used. To establish the differences between stands of different composition, analysis of variance was used, and an assessment was carried out according to the Fisher’s criterion [10]. Subsequently, a comparative analysis of the data was carried out.

3. Results and Discussion

Based on the analysis of the forest inventory data, statistical parameters of the sample were obtained: the average value of the stand structure was 50% Pine 20% Spruce 20% Alder 10% Birch; the average age was 108 years with the coefficient of variation of ± 36.9%; the average diameter was 24 cm, with the coefficient of variation of ± 30.5%; and the average growing stock was 216 m³ with the coefficient of variation of ± 25.5%. Based on the results of the statistical analysis, we concluded that the most productive was the 5 Pine 2 Spruce 2 Alder 1 Birch tree stand; the majority of stands was overmature; the diameter and growing stock variation was significant, but within the limits of the normal deviation. The degree of variability of the age structure was significant, since the coefficient of variation deviated from the standard value by ± 3.9%, which in turn affected the distribution, making the sample heterogeneous.

When spruce stands were considered, the average value of the stand structure was 60% Spruce 30% Birch 10% Alder; the average age was 61 year with the coefficient of variation of ± 63%; the average value of the diameter was 16 cm, with a coefficient of variation of ± 56%; and the average growing stock was 180 m³, with the coefficient of variation of ± 63%. On the basis of these indicators, we concluded that the most productive was the 60% Spruce 30% Birch 10% Alder stand, the majority of stands was maturing, the diameter and growing stock variation was significant and deviated from the normal value by 23% and 30%. The degree of variability of the age structure was significant, since the coefficient of variation deviated from the standard value by 33%, which in turn affected the distribution, making the sample heterogeneous.

All of the above indicators for forest stands with different proportions of pine and spruce depend on the type of forest growing conditions, which is a source of substantial variation in all statistical parameters.

After statistical analysis of the data, we carried out the analysis of variance of the growing stock depending on the share of pine and spruce in the stand composition and depending on the forest type. The results are presented in tables 1 and 2.

Based on the results of the analysis of variance, it can be concluded that there was a significant difference in productivity between stands with 90% of pine and stands with 80% and 60% of pine. The stand with 80% of pine was different from the stands with 70% and 60% of pine. There was also a significant difference in the growing stock between stands with 70% of pine and stands with 60% and 50% of pine. In other cases, the differences between stands with different proportions of pine were not statistically significant.

| Table 1. Statistical significance of differences in the growing stock depending on the stand composition. (0 - unreliable; 1 - reliable). | 100% pine | 90% pine | 80% pine | 70% pine | 60% pine | 50% pine |
|---|---|---|---|---|---|---|
| 90% pine | 0 | - | - | - | - | - |
| 80% pine | 0 | 1 | - | - | - | - |
| 70% pine | 0 | 0 | 1 | - | - | - |
| 60% pine | 0 | 1 | 1 | 1 | - | - |
| 50% pine | 0 | 0 | 1 | 1 | 1 | - |

Forest stand classification and assessment were carried out according to the age structure and the total growing stock of the stand. The main criteria for the selection of the most productive stand were: forest type, age class, stand composition, and growing stock in specific forest growing conditions. The
following forest types were considered: *Vaccinium myrtillus*, *Filipendulo-Herbosum*, *Polytrichoso-Sphagnosum*, *Oxalis acetosella*, *Vaccinium vitis-idaea*, *Ledum palustre*. In the course of the analysis, it was revealed that *Vaccinium vitis-idaea*, *Polytrichoso-Sphagnosum* waterlogged and drained, *Filipendulo-Herbosum* types of forest did not have the number of stands required for the analysis, which does not allow using the data obtained to assess the above indicators.

Table 2. Significance of the growing stock differences depending on forest type (0 - unreliable; 1 - reliable).

| Forest type       | A  | B  | C  | D  | E  | F  | G  | J  | H  | I  | K  |
|-------------------|----|----|----|----|----|----|----|----|----|----|----|
| Significance of the growing stock differences by forest type |     |    |    |    |    |    |    |    |    |    |    |
| A*$^a$             | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| B*$^b$             | 1  |    |    |    |    |    |    |    |    |    |    |
| C*$^c$             | 1  | 0  |    |    |    |    |    |    |    |    |    |
| D*$^d$             | 0  | 0  | 1  |    |    |    |    |    |    |    |    |
| E*$^e$             | 0  | 0  | 0  | 0  |    |    |    |    |    |    |    |
| F*$^f$             | 0  | 0  | 0  | 0  | 0  |    |    |    |    |    |    |
| G*$^g$             | 1  | 0  | 1  | 0  | 0  | 0  |    |    |    |    |    |
| J*$^j$             | 1  | 0  | 0  | 0  | 0  | 0  | 0  |    |    |    |    |
| H*$^h$             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |    |    |    |
| I*$^i$             | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  |    |    |
| K*$^k$             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |    |

*a* - *Vaccinium myrtillus* well-drained,  
*b* - *Vaccinium myrtillus* waterlogged,  
*c* - *Vaccinium myrtillus* waterlogged and drained,  
*d* - *Caricoso-Sphagnosum*,  
*e* - *Caricoso-Sphagnosum* waterlogged and drained,  
*f* - *Sphagnum palustre*,  
*g* - *Oxalis acetosella*,  
*j* - *Polytrichos-Sphagnosum*,  
*h* - *Polytrichos-Sphagnosum* waterlogged and drained,  
*i* - *Ledum palustre*,  
*k* - *Ledum palustre* waterlogged and drained

Based on the ANOVA results, we concluded that pine stands of the *Vaccinium myrtillus* well-drained forest type significantly differed from pine stands in *Vaccinium myrtillus* waterlogged, *Vaccinium myrtillus* waterlogged and drained, *Oxalis acetosella*, *Polytrichos-Sphagnosum* types of forest growing conditions, which in theoretical aspect corresponds to the normalized indicators for these stands. The growing stock of pine stands of the *Vaccinium myrtillus* moist type differed significantly from the stands in the *Ledum palustre* and *Oxalis acetosella* types of forest. Drained *Sphagnum* pine forests significantly differed in their productivity from the long moss forest types.

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.

Based on the data obtained, we concluded that the most productive, in terms of the growing stock, were the *Vaccinium myrtillus* and *Oxalis acetosella* forest types. The stands with 70–80% of pine proved to be the most productive, but the average growing stock was larger in pure pine stands. In terms of the growing stock in m$^3$, the most productive pine stands, in descending order, were: *Oxalis acetosella*, *Vaccinium myrtillus* well-drained *Vaccinium myrtillus* waterlogged, *Polytrichos-Sphagnosum*, *Vaccinium myrtillus* waterlogged and drained, *Sphagnum*, *Caricoso-Sphagnosum*, *Ledum palustre* and *Caricoso-Sphagnosum* waterlogged and drained. When spruce stands were considered, the analysis of variance revealed a significant difference, in terms of the maximum productivity,
between stands with 50% of spruce and 70–80% of spruce (table 4). Significant differences were observed between stands with 60% spruce, pure spruce stands, and those with 70% of spruce. Significant differences were observed between pure spruce stands and those with a share of spruce of 70%. In all other cases, the differences in growing stock between spruce stands were not statistically reliable.

**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   |
|--------------------------------------------|--------------------------------------------------------------------------|--------|
|                                            | 50% pine | 60% pine | 70% pine | 80% pine | 90% pine | 100% pine |        |
| Oxalis acetosella                          | 396      | 364      | 378      | 427      | 416      | 380       | 394    |
| Vaccinium myrtillus well-drained           | 364      | 333      | 416      | 380      | 416      | 396       | 384    |
| Vaccinium myrtillus waterlogged            | 319      | 333      | 333      | 333      | 332      | 348       | 333    |
| Vaccinium myrtillus waterlogged and drained| 227      | 332      | 364      | 333      | 0        | 332       | 265    |
| Caricosa-Sphagnosum                        | 189      | 203      | 224      | 226      | 251      | 364       | 243    |
| Caricosa-Sphagnosum waterlogged and drained| 277      | -        | -        | -        | -        | 348       | 104    |
| Sphagnum palustre                          | 302      | 305      | 348      | 261      | 148      | 211       | 263    |
| Polytrichosos-Sphagnosa                    | 317      | 317      | 291      | 302      | 291      | 319       | 306    |
| Ledum palustre                             | 182      | 237      | 197      |          |          | 264       | 220    |
| Mean                                       | 286      | 269      | 283      | 283      | 232      | 329       | -      |

Forest stand classification and assessment were carried out according to the age structure and the total growing stock of the stand. The following forest types were considered: long moss, oxalis, sedge-sphagnum, near-the-stream, grass-meadowsweet, horsetail and blueberry. In the course of the analysis, it was revealed that the horsetail, near-the-stream and sedge-sphagnum forest types did not have the required number of stands for analysis, which did not allow using the data obtained to assess the above-mentioned indicators.

**Table 4.** Significance of differences in the growing stock depending on the share of spruce in the stand composition. (0 - unreliable; 1 - reliable).

| Significance of differences in the growing stock depending on the share of spruce in the stand composition | 50% spruce | 60% spruce | 70% spruce | 80% spruce | 90% spruce | 100% spruce |
|-------------------------------------------------------------------------------------------------------------|------------|------------|------------|------------|------------|-------------|
| 50% spruce                                                                                 |            | 0          |            |            |            |             |
| 60% spruce                                                                                 | 0          | -          |            |            |            |             |
| 70% spruce                                                                                 | 1          | 1          | -          |            |            |             |
| 80% spruce                                                                                 | 1          | 0          | 0          | -          |            |             |
| 90% spruce                                                                                 | 0          | 0          | 0          | 0          | -          |             |
| 100% spruce                                                                                | 0          | 1          | 1          | 0          | 0          | -           |

Based on the results of the analysis of significance of differences in spruce growing stock depending on the forest type, the following conclusion can be drawn: Polytrichosos-Sphagnosa type
differs from *Oxalis acetosella* and *Filipendulo-Herbossum* waterlogged and drained forest types (table 5). In a theoretical aspect, this shows the narrow boundaries of the spruce distribution, in this case the conditions are favorable, and therefore the stands will be fairly highly productive. The spruce forests of the *Polytrichoso-Sphagnosa* waterlogged and drained forest type were significantly different in the growing stock volume from the forest stands of the *Oxalis acetosella* type, which is typical, since in the *Polytrichoso-Sphagnosa* forest types, even if they are drained, spruce will not have high productivity. Spruce forests of the *Oxalis acetosella* type differed significantly in productivity from the fresh blueberry forest types, and the latter were significantly different from the *Filipendulo-Herbossum* spruce stands. For spruce stands *Filipendulo-Herbossum* waterlogged and drained, the forest type is favorable for growth, and at the same time has a full range of nutrients necessary for the development of highly productive forest stands; it often forms specific plant communities based on the grass layer and the accompanying species, which is often birch. Stands of the *Vaccinium myrtillus* waterlogged forest type were different from the spruce stands of the *Vaccinium myrtillus* well-drained type. This is due to the fact that the growing conditions considered for the most part have reliable distributions and are within the optimum growth zone of spruce.

**Table 5.** Significance of the growing stock differences depending on the forest type (0 - unreliable; 1 - reliable).

| Forest type                                      | A° | B° | C° | D° | E° | F° | G° | J° |
|-------------------------------------------------|----|----|----|----|----|----|----|----|
| **Significance of the growing stock differences**|----|----|----|----|----|----|----|----|
| depending on the forest type                     |----|----|----|----|----|----|----|----|
| A°                                              | -  | -  | -  | -  | -  | -  | -  | -  |
| B°                                              | 0  | -  | -  | -  | -  | -  | -  | -  |
| C°                                              | 1  | 1  | -  | -  | -  | -  | -  | -  |
| D°                                              | 0  | 0  | 0  | -  | -  | -  | -  | -  |
| E°                                              | 1  | 0  | 0  | 0  | -  | -  | -  | -  |
| F°                                              | 0  | 0  | 0  | 0  | 1  | 0  | -  | -  |
| G°                                              | 0  | 0  | 0  | 0  | 0  | 0  | 0  | -  |
| J°                                              | 0  | 0  | 1  | 0  | 1  | 1  | 1  | 0  |

*A - Polytrichoso-Sphagnosa,*
*B - Polytrichoso-Sphagnosa waterlogged and drained,*
*C - Oxalis acetosella,*
*D - Filipendulo-Herbossum Caricoso-Sphagnosum,*
*E - Filipendulo-Herbossum waterlogged and drained,*
*F - Vaccinium myrtillus well-drained, Sphagnum palustre,*
*G - Vaccinium myrtillus waterlogged,*
*J - Vaccinium myrtillus waterlogged and drained*

Based on the sample data, which were obtained according to the above criteria, it can be concluded that the most productive, in terms of the growing stock, were the oxalis and blueberry fresh forest types.

The distribution of the growing stocks of the spruce stands studied by forest type and the share of spruce in the stand composition, and the average values are shown in table 6.

**Table 6.** Growing stock distribution by forest type and stand composition.

| Forest type                                      | Growing stock (m³ per ha) with the share of spruce in the stand composition | Mean |
|-------------------------------------------------|--------------------------------------------------------------------------|------|
|                                                 | 50% spruce | 60% spruce | 70% spruce | 80% spruce | 90% spruce | 100% spruce |      |
| *Polytrichoso-Sphagnosa*                        | 361        | 316        | 261        | 179        | 286        | 128        | 255  |
| *Polytrichoso-Sphagnosa waterlogged and drained*| 261        | 205        | 0          | 0          | 0          | 40         | 127  |
| *Oxalis acetosella*                             | 453        | 453        | 529        | 429        | 499        | 298        | 444  |
The stands with 70% of spruce were the most productive, but the average indicators of high productivity were recorded in the stands with 90% of spruce in the stand composition. In terms of the growing stock in m³, the most productive stands, in descending order, were: Oxalis acetosella, Vaccinium myrtillus well-drained, Vaccinium myrtillus waterlogged, Polytrichos-Sphagnosa, Vaccinium myrtillus waterlogged and drained, Filipendulo-Herbsom, Filipendulo-Herbsom waterlogged and drained. The high productivity of pine stands was associated with both an older age and a wider range of forest types, where it forms stands with a larger growing stock than spruce under the same growing conditions.

4. Conclusion
As a result of the study, it can be concluded that in the topographic conditions of the Lisino Teaching and Experimental Forestry, the largest stock was formed in stands with a pine share from 70% to 100%.

The largest growing stocks of pine were recorded in the Oxalis acetosella - Vaccinium myrtillus and Vaccinium myrtillus - Polytrichos-Sphagnosa forest types.

When stands with a predominance of spruce were considered, the largest growing stock was observed in stands with 70–90% of spruce. The largest growing stock of spruce was formed in the Oxalis acetosella - Vaccinium myrtillus forest types.

The analysis showed that pine-dominated stands were more productive in a wider range of forest types than spruce stands. In general, this is due to the fact that the sample under consideration was within the optimum growing conditions for each species, and the stands formed within these boundaries were stable and productive.

By forming mixed plantations of pine and spruce, it is possible to optimize and increase the growing stock of coniferous species.

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