The influence of forest growing conditions and stand composition on the growing stock of pine and spruce stands of Shimsky forest unit of the Novgorod region

S A Suvorov, A V Safonov, M A Krestyanova and D A Danilov*

Institute of forests and natural resources, Saint-Petersburg State Forest Technical University named after S.M. Kirov, 5 Institutsky Lane, Saint-Petersburg 194021, Russian Federation

*Corresponding email: stown200@mail.ru

Abstract. Using as an example one district forestry unit of the Novgorod region, located in two contrasting landscapes, we studied the formation of stands with different proportions of pine and spruce in the stand composition. The aim of the study was to study 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 in terms of forest stand composition. To identify statistically significant differences between spruce and pine stands, a comparative analysis of the mean values and the coefficients of variation of forest inventory characteristics was used. The analysis of variance was used to find differences between stands of different composition. According to the results of the comparative analysis by forest type, the only significant difference in growing stock was between spruce stands of the herbaceous-meadow and fresh blueberry forest types. For the rest of the spruce forest types, no significant differences in growing stock were found. In terms of the growing stock, the most productive are forest stands with 60% of trees been spruce or pine, and pure pine stands in the green moss group of forest types in the given landscape conditions.

1. Introduction

Forests are the main asset of the boreal zone of Russia. Forests located on the watersheds of large rivers play an important hydrological and water protection role; at the same time, forests are the resource that serves as the basis for the development of the forest complex and plays an important role in the economy of the regions located in this zone. In the North-West Russia, mixed coniferous stands with a predominance of spruce and pine occupy from 25 to 30% of the forest lands [1]. Modal coniferous stands occupy up to two-thirds of the forest fund area of the green moss series of forest types in this region, with specific features of their growth being manifested on different types of soils [2, 3]. The development of these coniferous stands under the influence of environmental factors and forest management activities often has a multidirectional character. In terms of forest management, the current regulatory framework for maintenance is mainly aimed at growing single species coniferous plantations. However, the issue of greater productivity of pure or mixed coniferous plantations in the conditions of the green moss group of forest types is far from unambiguous and is often controversial [4]. How to sustain multipurpose forest enterprises in mixed coniferous stands, depending on the landscape features, is an open research question. New knowledge about the process of formation of pine and spruce stand inventory characteristics will make it possible to conduct sustainable, highly
profitable forest management now and in the future, while preserving the forest as a natural habitat for all living things.

2. Methods and Materials

2.1. Objects of research
The Novgorod Region is located in the forest zone of the Russian (East European) Plain, within the Priilmenskaya Lowland and the northern spurs of the Valdai Upland. The region stretches from west to east for 385 km, and from north to south, for 250 km. In the north it borders on the Leningrad region, in the west, on the Pskov region, in the south, on the Tver region, in the east, on the Vologda region; which strongly affects the distribution of forest formations [5, 6].

Shimsky district is located to the west of the Lake Ilmen, and a section of the western shore of the lake belongs to this administrative district. The main river of the region, Shelon, crosses the southern part of the region and forms the mouth. Shimskoye forestry unit is located within this administrative region and geographically belongs to the Ilmen-Luga landscape district. On the forest fund territory there are two types of landscapes: Prishelonsky, with a good drainage, covered by broad-leaved pine and pine forests on weakly podzolic and soddy-slightly podzolic soils; and West Ilmensky, with a weak drainage, covered by broad-leaved, spruce and pine forests on sod-podzolic gley and soddy-weak and medium-podzolic soils with a predominance of clay as a parent rock [5-7]. Coniferous forests occupy up to 50% of the district area; pine stands, 27%; and spruce stands, 23% [7, 8].

Pine forests are confined to sandy and partly sandy loam soils and peat bogs, and do not occupy a wide range of forest growing conditions; they are represented by ledum, lingonberry, long moss, oxalis, blueberry, sphagnum, sedge-sphagnum and herbaceous forest types. Most of the forest growing conditions are represented by lands with a high moisture coefficient (stagnant moisture) and a low content of mineral substances. Pine forms fairly stable stands under the least favourable environmental conditions, since it has large limits of tolerance to edaphic conditions, being a xero-mesophyte. Often, the economic productivity of pine plantations formed at the boundaries of the tolerance limit is extremely low and cannot be considered economically efficient due to low growth rates under unfavourable conditions. Spruce forests are confined to podzolic and soddy-podzolic soils on clay and loamy parent rocks and green moss edatopes; they have the greatest increases in inventory indicators and form stable stands in the optimal growing conditions. In this context, it is extremely important to correctly select the stand composition to achieve high productivity in order to conduct efficient forest management.

2.2. Study methods
The object of the study was pine stands of natural origin located in the Novgorod region. We used forest inventory materials and information from the GLR-3 form of the state forest register as of 01/01/2020.

The aim of this work 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.

From the forest inventory database, by means of a special request, a sample of stands of different age and composition was made with at least 50% of pine and 30% of spruce trees in the stand composition. The samples were based on the analysis of such inventory indicators as the stem diameter, growing stock and species composition 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 the 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 [9]. 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, namely: the average contribution of the main species (spruce) to the stand structure was 60%, and that of accompanying species, 40%; the average age was 19 years, and the coefficient of variation for the age structure was ± 47%; the average diameter was 5 cm with the coefficient of variation of ± 73%; and the average growing stock was 59 m³ with the coefficient of variation of ± 85%. Based on these results, we concluded that the stands with 60% of spruce trees and 40% of other accompanying species were the most productive, and that the sample was heterogeneous, which resulted in a high sample variance. This is due to the fact that the majority of forest stands were young (about 70%) and middle-aged (about 30%), therefore, the results of the statistical analysis were not representative.

Based on the data analysis, we obtained the following statistical parameters of the sample: the average contribution of the main species to the species composition of the stand was 60% or 100% of pine trees; the average age was 74 years with the coefficient of variation of ± 38%; the average diameter was 14 cm with the coefficient of variation of ± 44%; the average growing stock was 115 m³ with the coefficient of variation of ± 44%. Based on the above results, we concluded that: the most productive were the stands with 60% of pine and 40% of other species, or pure pine stands; the majority of stands were maturing (i.e. nearly mature, assuming the maturity age of 81 years), the deviation of diameter and growing stock from the mean were high and deviated from the normal distribution by 7% and 11%, respectively. The variability of the age structure was significant, since the coefficient of variation deviated from the standard value by ± 6%, which in turn affected the distribution, making the sample non-uniform. The difference between the calculated value of the average growing stock per hectare and the average for the study region (132 m³) was 13%, which did not much exceed the standard value. There was a direct relationship between these statistical parameters and the type of forest growing and edaphic conditions, which does not allow for a full assessment.

To get more accurate results, we carried out the analysis of variance for the growing stock depending on the share of pine and spruce in the stand composition [9]. We also carried out the analysis of variance for the growing stock depending on the forest type. The main purpose of the above analyzes was to get a better understanding of the primary data, and to determine the most productive forest growing conditions and stand composition.

Based on the results of the analysis of variance, we concluded that a significant difference in terms of productivity was observed between stands with 40% and 60% of spruce; and between 40% and 100% of spruce. The remaining compositions of spruce stands were not statistically significantly different from one another (table 1).

| 30% spruce | 40% spruce | 50% spruce | 60% spruce | 70% spruce | 80% spruce | 90% spruce | 100% spruce |
|------------|------------|------------|------------|------------|------------|------------|-------------|
| Statistical significance of differences in growing stock depending on the share of spruce in the stand composition |
| 30% spruce | -          | -          | -          | -          | -          | -          | -           |
| 40% spruce | 0          | -          | -          | -          | -          | -          | -           |
| 50% spruce | 0          | 0          | -          | -          | -          | -          | -           |
| 60% spruce | 0          | 1          | 0          | -          | -          | -          | -           |
| 70% spruce | 0          | 0          | 0          | 0          | -          | -          | -           |
| 80% spruce | 0          | 0          | 0          | 0          | 0          | -          | -           |
| 90% spruce | 0          | 0          | 0          | 0          | 0          | 0          | -           |
| 100% spruce| 0          | 1          | 0          | 0          | 0          | 0          | 0           |

Table 1. Statistical significance of differences in growing stock depending on the stand composition (0 - unreliable; 1 - reliable).
Based on the results of the significance analysis of differences in growing stock depending on the forest type, we concluded that a spruce stand of the herbaceous-meadow type was significantly different from the *Vaccinium vitis-idaea* forest type in terms of the growing stock. For the rest of the spruce forest types, no significant differences in growing stock were found. This was due to the fact that spruce had clear limits of tolerance to edaphic and hydrological conditions. In turn, the oxalis type of forest is a standard one, since it has average normalized growing stock indicators. This allows spruce to form productive and stable stands. However, the herbaceous meadow type of forest is more humid, but does not strongly deviate from the norm, which is within the tolerance range of the species studied.

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 (table 2). The following forest types were considered *Polytrichoso-Sphagnosa*, *Oxalis acetosella*, *Vaccinium myrtillus waterlogged*, *Vaccinium vitis-idae, Herbosum* and near a stream. The division and assessment of forest stands were carried out according to the age structure and total growing stock of a stand. In the course of the study, it was revealed that there were not enough spruce stands in near a stream and *Polytrichoso-Sphagnosa* forest types to carry out the analysis. Therefore, the data obtained were not suitable for the productivity analysis, since a small sample size for specific edatopes was not representative and made the results unreliable. For the analysis, the most productive stands were selected from various forest types for each stand composition. The results of the distribution of the growing stock of the stands studied depending on the forest type, the share of spruce in the stand composition and their averages are given in table 3. Based on the sample data, which was obtained according to the above criteria, we concluded that the most productive, in terms of the growing stock, was the oxalis forest type with 60% of spruce trees in the stand composition. However, stands with the share of spruce of 30% and 40% were also productive.

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

| Forest type                  | Polytrichoso-Sphagnosa | Oxalis acetosella | Fontinalum Herbosum | Vaccinium myrtillus waterlogged | Vaccinium vitis-idaea |
|------------------------------|-------------------------|-------------------|---------------------|--------------------------------|-----------------------|
| *Polytrichoso-Sphagnosa*     |                         |                   |                     |                                |                       |
| *Oxalis acetosella*          | 0                       | 0                 |                     |                                |                       |
| *Fontinalum Herbosum*        | 0                       | 0                 | 0                   |                                |                       |
| *Vaccinium myrtillus waterlogged* | 0                     | 0                 | 0                   | 0                              |                       |
| *Vaccinium vitis-idaea*      | 0                       | 0                 | 0                   | 0                              | 0                     |

In terms of the quantitative indicators of the growing stock (m$^3$), the most productive stands with a predominance of spruce, in descending order, are: fresh oxalis and blueberry, i.e. the green moss group of the forest types, as well as *Filipendulo-Herbosum* and moist *Vaccinium myrtillus* types.

The rest of the forest growing conditions were not so promising, since the predominant number of forest stands were located on lands with stagnant moisture, and on raised or transitional bogs; this is an adverse factor for the development of spruce stands, since spruce is very sensitive to soil moisture and nutrient content.
Table 3. Growing stock distribution by the forest type and stand composition.

| Forest type               | Growing stock (m$^3$/ha) with the share of spruce in the stand composition | Mean     |
|---------------------------|------------------------------------------------------------------------------|----------|
|                           | 30% spruce         | 40% spruce         | 50% spruce         | 60% spruce         | 70% spruce         | 80% spruce         | 100% spruce         |          |
| Oxalis acetosella         | 170                | 170                | 170                | 250                | 170                | 80                 | 90                 | 157.1     |
| Filipendulo-Herbosum      | 170                | 170                | 170                | 93                 | 80                 | 40                 | 80                 | 114.7     |
| Vaccinium myrtillus       | 120                | 120                | 110                |                    |                    |                    |                    | 97.5       |
| waterlogged               |                    |                    |                    |                    |                    |                    |                    |            |
| Vaccinium myrtillus       | 170                | 170                | 150                | 140                | 100                | 40                 | 60                 | 118.6     |
| Mean                      | 157.5              | 157.5              | 150.0              | 161.0              | 116.7              | 53.3               | 67.5               |            |

When forest stands with a predominance of pine in the stand composition were considered, we found statistically significant differences in terms of the maximum productivity between stands that contained 60% and 50%, 100% and 60%, and 90% and 100% of pine trees. For the remaining stands with the participation of pine the results were not statistically significant (table 4).

Table 4. Statistical significance of differences in growing stock depending on the stand composition (0 - unreliable; 1 - reliable).

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

Based on the results of the significance analysis of differences in the growing stock of pine stands depending on the forest type, we made the following conclusion: the ledum type of forest was significantly different from the long moss forest type (table 5). The pine stand of the long moss forest type differed significantly from the stand of the sphagnum type in terms of the growing stock. Pine stands of the sedge-sphagnum forest type differed from stands of the sphagnum and blueberry forest types. The above is due to the fact that pine has a broad tolerance limit within the optima and zones of unfavourable conditions, which allows it to form productive stands, depending on edaphic and forest growing conditions. Everything that is significant according to the results of statistical analysis and the analysis of variance is the optimum or close to the optimum in terms of the biological characteristics of the tree species studied.
Table 5. Significance of the growing stock differences depending on the forest type (0 - unreliable; 1 - reliable).

| Forest type | Ledum palustre | Polytrichoso-Sphagnosa | Caricoso-Sphagnosum | Sphagnum palustre | Vaccinium myrtillus waterlogged | Vaccinium vitis-idaea |
|-------------|----------------|------------------------|---------------------|------------------|-------------------------------|----------------------|
| Significance of the growing stock differences depending on the forest type |
| Ledum palustre | - | - | - | - | - | - |
| Polytrichoso-Sphagnosa | 1 | - | - | - | - | - |
| Caricoso-Sphagnosum | 0 | 0 | - | - | - | - |
| Sphagnum palustre | 0 | 1 | 1 | - | - | - |
| Vaccinium myrtillus waterlogged | 0 | 0 | 0 | 1 | - | - |
| Vaccinium myrtillus | 0 | 0 | 1 | 1 | 0 | - |

The division and assessment of forest stands were carried out according to the age structure and the total growing stock of each stand. The main criteria for the selection of the most productive stands were: forest type, age class, stand composition, and growing stock in specific forest growing conditions. The following forest types were considered: *Ledum palustre*, *Vaccinium vitis-idaea*, *Polytrichoso-Sphagnosa, Oxalis acetosella*, *Vaccinium myrtillus, Sphagno-So-Herbo* and *Herbo* . In the course of the analysis, it was revealed that the herbaceous forest types did not have the required number of stands for the analysis; this does not allow using the data obtained for productivity assessment, since a small amount of data will not be representative and provide an unreliable result.

The results of the distribution of the growing stocks of the stands studied depending on the forest type and the share of pine in the stand composition are given in table 6.

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

| Forest type | Growing stock (m$^3$ per ha) with the share of pine in the stand composition | Mean |
|-------------|--------------------------------------------------------------------------------|------|
|              | 50% Pine | 60% Pine | 70% Pine | 80% Pine | 90% Pine | 100% Pine |          |
| Ledum palustre | 109 | 169 | 150 | 200 | 200 | 250 | 179.7 |
| Polytrichoso-Sphagnosa | 240 | 270 | 220 | 250 | 220 | 271 | 245.2 |
| Caricoso-Sphagnosum | 180 | 210 | 190 | 220 | 200 | 190 | 198.3 |
| Sphagnum palustre | 110 | 160 | 150 | 180 | 200 | 210 | 168.3 |
| Vaccinium myrtillus | 270 | 240 | 260 | 210 | 210 | 263 | 242.2 |
| Vaccinium myrtillus waterlogged | 251 | 301 | 240 | 270 | 250 | 260 | 262.0 |
| Mean | 193.3 | 225.0 | 201.7 | 221.7 | 213.3 | 240.7 |      |

The analysis of pine stands showed that pure pine stands and those with 60% of pine in the stand composition were the most productive. The most productive from the point of view of the growing
stock were the green moss types of forest growing conditions and pine forests of the long moss type.

According to the growing stock (m$^3$), the most productive stands, in descending order, are: \textit{Vaccinium vitis-idaea}, \textit{Polytrichoso-Sphagnosa}, \textit{Vaccinium myrtillus} waterlogged, \textit{Caricoso-Sphagnosum}, \textit{Ledum palustre} and \textit{Sphagnum}.

4. Conclusion

Based on the above, we concluded that on the territory of the Novgorod region, in similar landscape conditions the most promising were mixed pine stands with a share of pine in the stand composition of 60%, or pure pine stands growing in the \textit{Vaccinium myrtillus} or \textit{Polytrichoso-Sphagnosa} forest types.

In Shimskoye forestry unit, the most promising are mixed spruce and pine stands with a share of spruce in the stand composition of 60%, or spruce stands with a share of spruce in the stand composition of 30-40% of the green moss group of the forest types. Other forest conditions are not so promising, since the predominant number of forest stands are located on waterlogged lands, and on raised or transitional bogs, which, although they are within the limits of tolerance corresponding to the biological characteristics of the tree species studied, will not ensure adequate productivity without irrigation and drainage.

References

[1] Danilov D A, Beliaeva N V, Martynov A N and Zaytsev D A 2017 The impact of share participation of pine and spruce on inventory indices of mixed forest stands \textit{Forest Engineering Journal} \textbf{1}(25) pp 49-58
[2] Zaytsev D A Danilov D A and Navalihin S V 2019 Wood density of pine and spruce stands according to trees diameter distribution after thinning \textit{IOP Conf. Ser.: Earth Environ. Sci.} \textbf{226} 012065
[3] Pretzsch H and Schutze G 2016 Effect of tree species mixing on the size structure, density, and yield of forest stands \textit{European Journal of Forest Research}, \textbf{135} (1) pp 1–22
[4] Fedorchuk V N, Neshatayev V Yu and Kuznetsova M L 2005 \textit{Forest ecosystems of the Northwestern regions of Russia: Typology, dynamics, forest management features factors} [in Russian – Lesnye ekosistemy severo-zapadnyh rajonov Rossii: Tipologiya, dinamika, hozyajstvennye osobennosti] St-Petersburg p 382
[5] Andreev Y N et al 2002. \textit{Geography and geology of Novgorod region} [Geografiya i geologiya Novgorodskoi oblasti] Veliky Novgorod. p 307
[6] Barysheva A A 2008 \textit{Local climates and landscapes of the Novgorod region} [Mestnie klimati i landshafti Novgorodskoi oblasti] (Veliky Novgorod: Novgorod Regional Center for Education Development) p 166
[7] Novgorod Region Forest Plan 2019 p 309 Available at: http://\texttt{http://leskom.nov.ru/images/uploads/lesnov/Lesplan.pdf} - 15. 10. 2020
[8] Forestry regulations of the Shimsky Forest Management District of the Novgorod region 2019, 2020 Veliky Novgorod p 336
[9] Gregoire T G and Lappi J 2014 Statistical Methodology in Forestry Biometrics \textit{Wiley StatsRef: Statistics Reference Online} vol 2