Mixed pine and spruce stands in the Luga-Volkhov and Valdai-Tikhvin landscape districts of the Leningrad Region

Danilov D.A.1,2, Yakovlev A.A.1,2, Bogdanova L. S.1, Boitsov A.K.1, Suvorov S.A.1

1Saint-Petersburg State ForestTechnical University named after S.M. Kirov, 5 Institutsky lane, Saint-Petersburg194021, Russian Federation
2Russian Potato Research Centre, Leningrad Scientific Research Institute of Agriculture BELOGORKA2Department of Agrochemistry and Ecology of Landscapes, 1 Institutskaya Street, Belogorka,Leningrad Region 188338,Russian Federation

E-mail: artem95692@gmail.com

Abstract. Pine- and spruce-dominatedmixed stands occupy a substantial part of the forested area. Depending on soil and hydrological conditions of different landscapes, stands of different forest types and tree stand composition dominate. Modern forestry is focused on growing monodominant stands, but it is worth noting that mixed stands have higher productivity and stability. This work is devoted to identifying the patterns of distribution of mixed stands by forest type in different geographic landscapes. For the study, two landscape districts of the Leningrad Region (Valdaysko-Tikhvinsky and Luzhsko-Volkhovsky) with landscape mosaics of different structure were selected. The dominant forest types and types of mixed forest stands were determined by summing the areas of each plant association. To carry out the calculations, data of the state forest inventory of the Leningrad Region were used. In the course of this study, it was found that blueberry forest type was the most common forest type in mixed stands. Most of the landscapes of the study region were dominated by spruce-deciduous stands, but in some landscapes with hilly relief, a predominance of spruce-pine stands was observed.

1. Introduction
Pine and spruce mixed stands occupy a large part of North-West Russia and up to a quarter of the forested area of the Leningrad Region. Mixed stands have higher values of inventory characteristics (average height, diameter, and growing stock per hectare) compared to monodominant stands [1, 2, 3]. The dominant tree species are determined by soil-hydrological conditions. To assess the impact of specific soil and hydrological conditions on the spatial distribution of mixed stands, geographical landscape is most suitableas a territorial unit. The heterogeneity of the distribution of mixed stands is associated with the fact that in each landscape type, specific conditions of growth are formed, which are optimal for stands of various types of mixing. Consequently, landscape heterogeneity of a region significantly increases its biodiversity [1,4, 5, 6, 7, 8, 9, 10,11].

Forest type is one of the most important silvicultural characteristics of a forest phytocenosis. By establishing the most common types of forest in the forest area and clarification of their spatial distribution, a forester can correctly choose the forms of forestry activities and carry them out in a timely manner, knowing the dependence of the activities carried out on the natural properties of the forest [12, 13].
In each group of landscape types, specific natural conditions are formed, which are characterized by certain forest types. In these forest types, the most common and most productive will be those mixed stands for which these conditions are optimal. This work is devoted to the establishment of such types of forests and stands for each group of landscape types of the Lozhsko-Volkhovsky and Valdaysko-Tikhvinsky landscape districts.

2. Problem Statement
The formation of forest types is largely influenced by such factors as soil fertility and water regime. Water regime, in turn, is influenced by the relief (the location of a site in a certain form of the macro-relief of a landscape) and parent rock of an area. Determining the optimal stand composition for each forest type in different geographic landscapes will significantly improve the efficiency of forestry.

3. Materials and methods
This study examines the part of the Leningrad Region located on the Russian Plain. The selected area is divided into two landscape districts: Luzhsko-Volkhovsky and Valdaysko-Tikhvinsky. The forested area of the Valdaysko-Tikhvinsky landscape district is 80%. The Luzhsko-Volkhovsky district has a lower forested area (60%), which is associated with a higher level of agricultural development [14].

To study the spatial distribution of pine and spruce mixed stands, the following information was used: a landscape map of the Leningrad Region and state inventory data. The analysis of the distribution of forest stands was carried out based on the summation of the area of each association.

The share of the dominant coniferous and co-dominant species in the stand composition was at least 40-50%, according to the forest inventory data. Forest types were determined according to Sukachev's edapho-cenotic scale [13].

In the studied landscape districts, the most common forest types are: Vacciniumvitis-idaea (V v-i), Oxalis acetosella (O.a), Vacciniummyrtillus well-drained (Vm.w.d), Vacciniummyrtillus waterlogged (Vm.wl.), Vacciniummyrtillus waterlogged and drained (VmS.d), Polytrichoso-Sphagnosa (P-S) and Polytrichoso-Sphagnosa waterlogged and drained (P-S. d). Since other forest types are represented by substantially smaller areas, the distribution of mixed forest stands given in this section will be considered only among the types listed above.

In the landscape districts considered, the following groups of landscape types prevail:

- Hilly-moraine landscapes characterized by rugged terrain formed by hills and ridges with swampy depressions. In these landscapes, karst sinkholes and lakes are widespread;
- Plain-moraine landscapes characterized by flat undulated terrain and composed of moraine with different content of boulders. In some places, there are two-member sediments and eroded moraine covered with a thin (0.5 meter) layer of sand or sandy loam. These landscapes are characterized by high waterlogging (up to 60%).
- Lacustrine-glacial sandy landscapes characterized by hilly-flat terrain. A high level of waterlogging is due to the close proximity of an impermeable horizon of moraine or band clay. Closed hollows, which form complex chains of hills with closed slopes, are often filled with peat bogs and lakes.
- Lacustrine-glacial clay landscapes characterized by flat plain terrain. In these landscapes, up to 60% of the territory is subject to excessive hydration. High waterlogging of lacustrine-glacial clay landscapes is caused by a weak surface runoff and low water permeability of clay.
- Kama landscapes characterized by alternation of sandy hills (kams) with flat swampy lacustrine-glacial plains. There are relatively few bogs; they are mostly small in size and located in depressions and around lakes.
- An elevated plateau on carbonate rocks characterized by a slightly undulating terrain with scattered karst sinkholes and groups of moraine hills. The area is well-drained due to limestone fracturing. The level of waterlogging is low, and bogs are relatively small.
• A low-lying plain on carbonate rocks characterized by a flat-undulating terrain dissected by wide river valleys. This landscape is characterized by a low level of waterlogging (20%). A characteristic feature is a close proximity of Devonian limestones covered with carbonate loam [15,16].

4. Results and Discussion
On the territory of the Luga-Volkhovsky landscape district, the most widespread forest types are fresh blueberry and oxalis (figure 1). A wide distribution of oxalis forest types is associated with the predominance of landscapes with potentially rich forest growing conditions and a good drainage. These landscape types include: an elevated plateau on carbonate rocks, a low plain on carbonate rocks, plain moraine landscapes, and lacustrine-glacial clayey landscapes. On the territory of the Luga-Volkhovsky landscape district, the above groups of landscapes are characterized by the predominance of spruce stands. Among the mixed ones, spruce-deciduous stands dominate. Pine-dominated stands occupy the largest area in kame landscapes.

The high plateau on carbonate rocks (Izhora landscape) is characterized by the predominance of spruce-deciduous stands. Among spruce-deciduous stands, oxalis forest types are most common. Blueberry forest types occupy almost half the area. Pine-deciduous stands are poorly represented. Spruce-pine stands occupy the second place (in terms of area) among mixed stands. In these stands, oxalis and blueberry forest types occupy approximately the same area. Pine and spruce stands prevail in blueberry and long moss forest types. Lingonberry forest types are hardly ever found in this landscape. For a low-lying plain on carbonate rocks (Upper Luga landscape), the above-mentioned patterns are also present.

The group of plain-moraine landscapes (Samro-Plyussky, Luga-Oredezhsky, Vishersky, Pashsko-Syassky landscapes) is generally characterized by the prevalence of blueberry forest types. The area of oxalis-type forests is much smaller than on an elevated plateau on carbonate rocks. Also, in these landscapes, the area of forest stands with the participation of pine increases, while the dominance of spruce-deciduous stands persists. Among spruce-deciduous stands, in almost all cases, there is a predominance of blueberry forest types, and the area of oxalis forest types is much smaller. In pine-deciduous stands, blueberry forest types dominate, but the area of long moss types also increases. Among spruce-pine and pine-spruce stands, blueberry forest types also prevail. In pine-spruce stands, an increase in the area of lingonberry types is observed in comparison with other types of mixed stands.

In lacustrine-glacial clay landscapes (Tosno-Volkhovsky landscape), the most common types of forest are blueberry; this is associated with a deterioration in drainage. The largest area is occupied by spruce-deciduous stands. The second largest area is occupied by spruce and pine stands, and a slightly smaller area, by pine and spruce. The smallest area is occupied by pine-deciduous stands. In pine-deciduous stands, blueberry and long moss types have approximately the same area. Also, in this group of landscapes, the largest area of long moss forest types is observed, in comparison with other landscape groups of the Luga-Volkhovsky district.

The lacustrine-glacial sandy landscapes (Narva-Luga landscape) are also characterized by the predominance of blueberry forest types. In the landscapes of this group, the area of oxalis forest types is much smaller in comparison with those considered above. The distribution of mixed forest stands is similar to lacustrine-glacial sandy landscapes. In the Luga-Volkhovsky district, the approximately equal areas of blueberry and lingonberry types in pine-deciduous stands is a special feature of these landscapes.

Kame landscapes (Mginsky, Luga landscapes) are distinguished by a wide distribution of forest stands with a predominance of pine. Pine and spruce stands have the largest area. Pine-deciduous stands followed by spruce-pine occupy the second largest area. Spruce-deciduous stands have the smallest area in kame landscapes. In this landscape group, the most common forest type is fresh blueberry. In the kame landscapes, oxalis forest types occupy the smallest area among all the landscape groups of the Luga-Volkhovsky district. A distinctive feature is the predominance of
lingonberry over oxalis forest types in pine-deciduous stands; and in pine-spruce stands, lingonberry and oxalis forest types have approximately the same area.

| Forest Type                                      | Percentage |
|--------------------------------------------------|------------|
| Spruce-broad-leaf stands                         |            |
| Pine-broad-leaf stands                           |            |
| Spruce-pine stands                               |            |
| Pine-spruce stands                               |            |

Figure 1. Distribution of mixed stands of the Luga-Volkhovsky landscape district by forest type, where V.v-i - Vaccinium vitis-idaea forest type, O.a - Oxalis acetosella forest type, V.m.w.d - Vaccinium myrtillus well-drained forest type, V.m.wl - Vaccinium myrtillus waterlogged forest type, V.mS.d - Vaccinium myrtillus waterlogged and drained forest type, P-S - Polytrichos-Sphagnosa forest type, P-S. d - Polytrichoso-Sphagnosa waterlogged and drained forest type.

The Valdai-Tikhvinsky landscape district, in contrast to the Luga-Volkhovsky district, does not have a diverse landscape. In this district, two landscape groups prevail: hilly-moraine and lacustrine-glacial sandy landscapes. In the Valdai-Tikhvinsky landscape district, the most widespread forest
types are: fresh blueberry, moist blueberry and long moss (figure 2). The predominance of these forest types is associated with insufficient drainage and high level of waterlogging of the Valdai-Tikhvinsky district.

In hilly-moraine landscapes (Svir-Oyat landscape), blueberry forest types prevail. The second place (in terms of area) is occupied by long moss types. The rest of the forest types have a small area. This landscape group is dominated by tree stands with a predominance of spruce. The largest area is occupied by spruce-pine stands, and the smallest, by pine-deciduous stands. In pine and spruce stands, lingonberry and oxalis forest types occupy approximately the same area.

Figure 2. Distribution of mixed stands of the Luga-Volkhovsky landscape district by forest type, where V v-i - Vaccinium vitis-idaea forest type, O.a - Oxalis acetosella forest type, Vm.w.d - Vaccinium myrtillus well-drained forest type, Vm.wl. - Vaccinium myrtillus waterlogged forest type, VmS.d - Vaccinium myrtillus waterlogged and drained forest type, P-S - Polytrichosos-Sphagnosa forest type, P-S. d - Polytrichosos-Sphagnosa waterlogged and drained forest type.

For lacustrine-glacial sandy landscapes (Nizhnesvirsky, Sudsko-Chagodsky, Tikhvin landscapes), the largest area is occupied by blueberry forest types. In these landscapes, in contrast to the hilly moraine, oxalis forest types prevail over long moss types. In this landscape group, the most
widespread stands are spruce-deciduous, and the smallest area is occupied by pine-deciduous stands. In pine and spruce stands, lingonberry forest types have a larger area than oxalis forest types. The Valdai-Tikhvinsky district differs from the lacustrine-glacial sandy landscapes by predominance of lingonberry types over oxalis types in pine-deciduous stands.

5. Conclusion
In the Luga-Volkhovsky and Valdai-Tikhvinsky landscape districts, the distributions of mixed pine and spruce stands by forest type are markedly different. Thus, on the territory of the Valdai-Tikhvinsky landscape district, lacustrine-glacial sandy landscapes dominate, in which blueberry forest types prevail. In lacustrine-glacial sandy landscapes, the largest area of mixed stands is occupied by spruce-deciduous stands. In the hilly-moraine landscape, spruce-pine stands dominate among mixed stands.

In the Luga-Volkhov landscape district, in addition to blueberry forest types, a significant area is occupied by oxalis types. This landscape district has a more diverse landscape in comparison with Valdai-Tikhvinsky. In general, in the Luga-Volkhovsky landscape district, the dominance of spruce-deciduous stands persists, but in the plain-moraine and kama landscapes, a predominance of pine-spruce stands is observed.

Knowledge of the distribution patterns of mixed forest stands by forest type in various landscape groups allows us to draw a conclusion about the most productive phytocenoses for certain landscapes. The use of a landscape approach in forestry management can significantly increase forest productivity and profitability of the industry, and preserve biodiversity of forest ecosystems.

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