Forest with broad-leaved species at the norther limit of distribution (Northwest of Russia)

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Abstract. Monodominant broad-leaved forests are more typical on the northern limit of their distribution as was shown in the Leningrad region. This feature distinguishes these northern communities from forests located in their optimum range of the Central part of Russia where forests have a polydominant composite on of their stands. At the norther limit, the vegetation growing on sod-carbonate loam soil is closer to the real zonal broad-leaved forests. The northern forests with broad-leaved species are sensitive to soil factors and temperature values was revealed by the nMDS ordination of 53 geobotanical plots. Despite the dominance of nemoral species in the forests in both the north and south of the Leningrad region, the diversity, constancy and abundance of species associated with boreal evergreen forests are higher in the northern part of the region. This is a consequence of the presence of a significant share of coniferous and small-leaved tree species in the stands and less nutritious and acidic soils also. A high proportion of edge-meadow grass species and adventive weeds are associated with recreation and park care activities.

1. Introduction

Forests with broad-leaved trees occupy small areas in Northwest of Russia. This type of forest has a northern limit of the distribution in the Leningrad region, because the northern limit of the range of broad-leaved trees, such as maple (Acer platanoides L.), linden (Tilia cordata Mill.), ash (Fraxinus excelsior L.), oak (Quercus robur L.) and elm (Ulmus glabra Huds.), passes through the area [1]. Broad-leaved forests do not belong to the zonal vegetation type in Northwest of Russia. So, they mainly occupy non-zonal positions such as floodplains, stream valleys and southern slopes. These sites are better provided with heat and protected from the northern winds. A higher proportion of broad-leaved trees in the forest stand have been provided by the Holocene Optimum when the climate of the territory was warmer and milder [2, 3]. The current dynamic status of these forests is defined as a relict diasporic sub-climax of the southern taiga [4].

Unfortunately, such forests do not often become objects of the study due to small and fragmentary area and the high anthropogenic transformation of the cover. However, the environmental significance of these forest communities is obvious. Usually they have a complex structural organization with a unique flora and fauna that different from zonal coniferous forests. Being at the limit of the distribution, they are more vulnerable to external influences compared to zonal vegetation. For this reason, they are often included to the lists of special protection objects and considered as key biotopes.
for biodiversity conservation not only in Russia, but in Europe also [5]. Currently, forests dominated by broad-leaved species such as linden (*Tilia cordata*) or maple (*Acer platanoides*) occupy very small areas (only 3-4%) on the territory of 30 European countries, but they are very widespread as undergrowth tree species [6-11].

There is very little relevant information about present state of the forests with broad-leaved species [12]. Some information about broad-leaved forests in the north of Europe can be found only in a few publications [13-15]. There is a lack of ecological and coenotic analysis of this northern type of forests to clarify their landscape position and environmental interpretation [16]. This fundamental knowledge of community structure is essential aspect for the effective management and conservation of forest biodiversity [17].

The aim of this investigation is to compare the floristic, coenotic and ecological composition of the vegetation cover of forests with broad-leaved species in different locations of the Leningrad region. The results of our research will be useful for further monitoring of forests located at the northern limit of distribution due to climate changes and anthropogenic press.

2. Methods and Materials

At the present time, forests with broad-leaved species are best preserved in natural reserves, large landscape parks or river valleys in the Leningrad region.

2.1. Field data collection

The data collection sites belong to two different subzones because the border of the middle and southern taiga passes through the Leningrad region. Forests with broad-leaved species were studied at six sites (figure 1).

![Figure 1. Location of field data collection sites in the Leningrad Region. I – the Nature Reserve “Nizhnesvirsky Natural Zapovednik”, II – Konevets island, III – the Nature Reserve “Sergievka Park”, IV – the Nature Reserve “Duderhof Heights”, V – the Gatchina Palace Park, VI – the Luga river basin.](image-url)

The latitudinal gradient is observed in the location of the data collection sites. So, the sites I and II are the northernmost and are located nearest the northern limit of the broad-leaved species’ ranges. The site VI is the southernmost and is located on the southern border of the taiga. The natural composition
of the forest stand is undeniable here. It is characterized by the participation of various combinations of broad-leaved tree species in the stands.

In other locations (I-V), the presence of broad-leaved species is associated with human activity. These forests were formed from the seeds of trees once planted during the organization of parks and homesteads. But there has been no economic activity in these forests for the last 70 years or more. The exception is the site V. This is a landscape Palace Park, where cutting and grass planting are regularly carried out.

Sod-podzolic loam soils predominate in all locations excepting for site IV, where there is sod-carbonate soil with a humus horizon that is thick for the north (more than 30 cm). The basic method of the study was the inventory of vegetation in sample plots of 400 sq. m. The total number of plots was 53. In each sample plot we collected common data on species composition. In each community layer, species abundance was evaluated on the Brown-Blanquet scale [18]. In addition, the average height and the canopy density of the stand were measured.

2.2. Data Processing

Data processing is carried out in a free software environment for statistical analysis R. The ordination of sample plots is constructed using the nMDS method. The Bray-Curtis coefficient matrix was used because the data contains zero value. Indicator values of light, temperature, moisture, (soil) reaction, nutrient and continentality as well as belonging plant species to different geographic and coenotic groups were taken as the vectors of the ordination. The ordination has converged. The stress of the resulting ordination is 0.235 and it is on the border of acceptable values. The significance of the differences between the groups was checked. The groups of species in different communities differ significantly at the locations (PERMANOVA, p=0.001). Ellenberg’s scale was used to estimate abiotic factors by averaging the values for these factors across all the species present at the site [19]. Geographic ranges of the species as well as their coenotic preferences are indicated by N Tsvelev [20].

3. Results and Discussion

Broad-leaved tree species dominate in non-zonal forests in the south of the Leningrad region, where their share in the stand reaches up to 70-100% (sites IV - VI). In the comparison, the proportion of broad-leaved species is less (20-60%) in the northern sites of the region. They occupy mainly the second stand layer in the forests (sites I and II). The peculiarity of the studied forests in the northern locations is the monodominant composition of the stand. In general, it is not typical for broad-leaved forests but it is often observed at the limit of their distribution [13, 14]. This is due to the incomplete seed bank of broad-leaved species on the northern border of their ranges, and in some cases also to the artificial selection of species composition by the man. The table 1 shows some of the most significant characteristics of forests with broad-leaved species.

Table 1. The main geobotanical features of the forests with broad-leaved species in the Leningrad region.
|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 4 | Pt-4, T-2, A-2 | 180/0.6 | 31/10 | 22 | 70  |
| 5 | Pt-4, A-2, Pa-2 | 90/0.6  | 29/14 | 18 | 70  |
| II | Ai-4, A-3, B-2 | 90/0.7  | 19/9  | 24 | 90  |
| 7 | A-3, Ps-2, B-2 | 80/0.7  | 15/-  | 14 | 90  |
| 8 | F-5          | 90/0.5  | 19/8  | 21 | 80  |
| 9 | Pa-4, A-3, B-2| 80/0.5  | 15/-  | 19 | 90  |
| 10| B-5, A-2     | 70/0.6  | 21/12 | 15 | 85  |
| III| A-4, Ai-3    | 75/0.7  | 22/-  | 13 | 80  |
| 12| A-5, 20uc    | 70/0.7  | 21/-  | 12 | 70  |
| 13| A-3, F-2, Ai-2| 75/0.7  | 22/-  | 7  | 60  |
| 14| A-5          | 75/0.8  | 20/-  | 1  | 70  |
| 15| A-5, Ag-2    | 75/0.7  | 24/-  | 10 | 10  |
| 16| T-5, Pa-2    | 70/0.8  | 21/-  | 19 | 40  |
| 17| T-5          | 70/0.7  | 22/-  | 12 | 40  |
| 18| T-5, Q-2     | 75/0.5  | 23/-  | 21 | 85  |
| 19| T-4, Pa-3    | 70/0.7  | 21/-  | 22 | 40  |
| 20| T-5, Ag-2    | 85/0.6  | 25/-  | 4  | 10  |
| 21| T-4, A-3, Q-2| 75/0.6  | 25/-  | 7  | 5   |
| 22| Ag-4, T-3, A-2| 120/0.5 | 26/-  | 8  | 30  |
| IV | A-4, Q-2     | 90/0.9  | 25/-  | 19 | 70  |
| 24| A-5          | 70/0.8  | 19/12 | 17 | 65  |
| 25| A-3, Q-2, Pt-2| 90/0.9  | 22/14 | 13 | 75  |
| 26| A-4, Pt-2, U-2| 50/0.8  | 16/8  | 14 | 70  |
| 27| A-4, Q-2, T-2| 70/0.9  | 18/10 | 15 | 65  |
| 28| A-5, F-2     | 50/0.8  | 15/8  | 12 | 55  |
| 29| A-5, U-2     | 50/0.8  | 15/7  | 11 | 60  |
| V  | T-5          | 90/0.8  | 21/-  | 4  | 60  |
| 31| A-4, B-4     | 70/0.8  | 22/-  | 16 | 95  |
| 32| Q-5          | 95/0.7  | 15/-  | 23 | 75  |
| 33| F-5, Q-2, T-2| 70/0.6  | 18/-  | 11 | 40  |
| 34| T-4, A-3     | 75/0.8  | 18/-  | 7  | 38  |
| 35| A-3, Q-3, T-3| 90/0.6  | 20/-  | 9  | 75  |
123 species were recorded in the grass-shrub layer of all studied sites. Such species as Aegopodium podagraria L., Anthriscus sylvestris (L.) Hoffm., Athyrium filix-femina, Quercus robur, Ulmus glabra, Pa-Picea abies, B - Betula pendula, P - Populus tremula, Alnus glutinosa, Tilia cordata, have high constancy (70-85%) in all communities. The most part of these species are nemoral. They account for 75-81% of the species in communities of the southern sites and about 62-65% - in the northern ones. Only nemoral species achieve a high value of projective cover in southern sites (IV-VI). For example, the average projective cover of Aegopodium podagraria is up to 50% and Mercurialis perennis L. – 35%.
Boreal species show the opposite trend. Some species of boreal evergreen forest have high constancy (up to 50%) and abundance in communities of the northern sites (I-II). For example, the average projective cover of *Equisetum sylvaticum* is 50%, *Millium effusum* L. – 35%, *Rubus saxatilis* L. – 15%, and *Vaccinium myrtillus* L. – 15%.

The projective cover of green mosses (i.e. *Hylocomium splendens* (Hedw.) B.S.G., *Pleurozium schreberi* (Brid.) Mitt., *Dicranum polysetum* Sw., *D. scoparium* Hedw., *Brachythecium salebrosum* (Web. et Mohr) B. S. G., *Plagiomnium cuspidatum* (Hedw.) T.J. Kop., *Ann.*., *Tetraphis pellucida* Hedw., etc.) is only 2-5% in all plots. The highest values of the moss projective cover (up to 15%) were recorded in communities with spruce dominance in the first layer of the stand in the northern sites of the region (I-II).

### 3.1. Environmental factors

The ordination shows the division of plots into groups and helps to identify the general trend towards the main environmental factors leading in the ecological differentiation of the forests with broad-leaved species. Soil conditions have a primary influence on the differentiation of forests with broad-leaved species as shown by the PCA ordination of 53 geobotanical plots from the Leningrad region (figure 2).

![Figure 2](image_url)

**Figure 2.** The PCA ordination of 53 geobotanical plots. The vectors reflect the factors of the Ellenberg scale: Nutr – Nutrient value, Reac – (Soil) Reaction value, Temp – Temperature value, Light – Light value, Moist – Moisture value, Cont – Continentality value. I-VI – Site number, see figure 1.

The Component 1 (PC1) determines 40.1% of the variation in our PCA model. This is a combination of acidity and nutrient availability of the soil as showed by using of ecological scales proposed by H. Ellenberg. In the south of the region, the forest communities with broad-leaved species grow on more nutritious and less acidic soils than in the northern sites.

Another key factor is the temperature value, which is revealed by Component 2. It provides 21% of the total variation. This is not surprising, because this factor has a well-defined gradient in the Leningrad region. So, the sum of active temperatures above 10°C varies from 1600-1750 in the northern sites, to 1980-2080 in the southern sites [21]. The better heat allows for the existence and dominance of real nemoral species in the forest communities of the southern sites in comparison with the northern ones. Humidity has the least influence on the ecological differentiation of the forests with broad-leaved species.

The nMDS ordination of the plots was carried out both taking into account the species composition of the stand (figure 3a) and without it (figure 3b).
3.2. Geographical range features
The vectors in figure 2 reflect the participation of species associated with different zonal vegetation types, such as boreal evergreen forests, temperate needle evergreen forests, temperate deciduous forests in the communities with broad-leaved species. Some species were plurizonal. The communities of the northern sites (I-II) have a high proportion of arctoboreal species or species associated with boreal evergreen forests in the grass-dwarf shrub layer (i.e. *Agrostis tenius* Sibth., *Melampyrum pratense* L., *M. sylvaticum* L., *Orthilia secunda* (L.), *Vaccinium vitis-idaea* L.) and a significant share of *Picea abies* (L.) Karst. and *Populus tremula* L. in the stand. Some plots from the southern site (VI: 41, 44) close to them by these traits because they also have a significant share of *Populus tremula* in the stand and some boreal evergreen forest species in the herb layer (i.e. *Filipendula ulmaria* (L.) Maxim.). In General, the presence of species associated with temperate deciduous forests (i.e. *Alliaria petiolata* (Bieb.) Cavara et Grande, *Impatiens parviflora* DC., *Rumex obtusifolius* L.) is observed in the communities of the southern sites. The forests of the Gatchina Palace Park (V) differ from others by the presence of plurizonal species (i.e. *Plantago major* L., *P. lanceolata* L.).

3.3. Coenotic features
The ordination vectors indicating the species associated with different type of plant communities (i.e. forest, meadow, swamp and others) are shown in figure 3. Broad-leaved tree species clearly predominate in the forest stands of the communities in site IV with fertile-sod-carbonate soil. The cover of this vegetation consists of broad-leaved forest herbs such as *Asarum europaeum* L. and *Lathraea...
squamaria L. These features bring these forests closer to the zonal type of broad-leaved forests located much more to the south of the Leningrad region [22]. The similarity of these communities to zonal broad-leaved forests is confirmed by the results of previous studies [22, 23].

A special feature of the forests in the Gatchina Palace Park is the abundance of edge-meadow species (i.e. Poa annua L., Festuca rubra L., Dactylis glomerata L., Trifolium hybridum L.) and a high proportion of the adventive species (Lotium perenne L.). This is a consequence of recreation and regular service activities such as lawn mowing and grass planting.

4. Conclusion

Our study revealed that monodominant broad-leaved forests are more typical near the northern limit of their distribution in the Leningrad region. The analysis of the geographical elements of the flora showed that temperate Central European nemoral species predominate in the forests with broad-leaved trees in both the north and south of the region. The differences are evident in the participation of species associated with boreal evergreen forests, whose diversity, constancy and abundance are higher in the north of the region than in the south.

The vegetation growing on nutritious sod-carbonate loam soils mostly correspond with the real zonal broad-leaved forests by the main features of their structure. The park forests with participation of broad-leaved species differ from others by a significant share of edge-meadow and adventive species. This is the result of regular activity on lawn mowing and grass planting in these sites.

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