Species Distribution Patterns in Subgenus Cuspidata (Genus Sphagnum L.) on the East European Plain and Eastern Fennoscandia

Sergei Yu. Popov

Abstract

The geographic range of 13 species from the subgenus Cuspidata in the East European Plain and Eastern Fennoscandia has been studied. Model maps for each species occurrence were constructed using geostatistics techniques (kriging method). Continuous coverages of 23 climatic factors were used in analysis also. We used dataset that proposed by authors of program WORLDCLIM. To learn how corresponding values of climatic factors and species occurrence correlation and cluster analysis were conducted. It was found that 7 of 13 species are widespread on the East European Plain and Eastern Fennoscandia, and 6 species have the restricted ranges. Values of occurrence of all species (except Sphagnum lenense) have a strong correlation with moisture factors (relative air humidity and sum of precipitation) in summer-autumn period. Such preferences allow them to grow successfully in Subarctic and Baltic regions, where high climatic humidity is observed. Restricted species are concentrated around the Baltic Sea and zones of the highest occurrence of widespread species are located at the same region. All species can be divided into four clusters according to its climatic preferences. Distribution of such species as S. obtusum seems to be strongly associated with two tongues of the Last Glacier, and this species seems to be a glacial relic.

Keywords: Sphagnum, Cuspidata, biogeography, BIOCLIM, distributional range, GIS, geostatistics, kriging method

1. Introduction

Sphagnum mosses are widely distributed plants in wet habitats. They are edificators in boggy forests and bogs in all plant zones. The ecology of species of the genus Sphagnum is now well studied, and environmental factors that play a leading role in the division of ecological space among Sphagnum species are well known [1–11]. Until now, however, the question about the division of geographical space by species remains open, especially due to the influence of climatic factors. There are two principal works on the biogeography of the genus Sphagnum [12, 13], which consider the geographical variability of species diversity of the genus in Western
Europe by methods of zonal statistics, that is, within the administrative boundaries of administrative states. In both cited works, the authors find the center of species diversity of the genus Sphagnum in the Scandinavian Peninsula. There does not seem to be any work that considers the distribution of species within its natural boundaries. Therefore, the present article is intended to fill this gap for the territory of the East European plain and Eastern Fennoscandia. As more than 50 species of Sphagnum grow in Europe [14], it is not possible to consider all of them in a single article due to lack of space. Therefore, in this chapter, we consider the distribution of species of the subgenus Cuspidata only, growing on the territory of the East European plain and Eastern Fennoscandia (EEPEF). In Europe (from the Atlantic to Urals), there are 17 species of the subgenus Cuspidata [14]. Only 14 species occur in the EEPEF. These are as follows: Sphagnum angustifolium, S. annulatum, S. balticum, S. cuspidatum, S. fallax, S. flexuosum, S. jensenii, S. lenense, S. lindbergii, S. majus, S. obtusum, S. pulchrum, S. riparium, and S. tenellum. Although some species are difficult to identify, these errors are easy to identify and correct by comparing bulk materials from different geographic locations. Moreover, a mathematical method for modeling maps, which is used in this work—the kriging method [15–20] serves as error protection. This method is widely used to build maps of temperature distribution in climatology, compiling digital elevation models in geodesy, etc. The advantages of this modeling method, compared to other ones currently used, are discussed in detail in previously published paper [21]. In bryology and biogeography, we use the kriging method for the first time. In short, the kriging method allows us to create model maps of the species distribution, which can reflect not only the boundaries of the species range as a whole, but also the species activity within the range. In addition, taking into account the weights of input points, values allow to cut off the noise while maintaining the overall trend of the distribution of the species. In the case of the study of mouses distribution, random incorrect definitions of species in some geographic points just appear as noise on a mathematical surface. All of the above is true for such species for which we have data set from the entire study area. Among the 14 species of the subgenus Cuspidata which is found in European Russia and adjacent countries, only one species does not satisfy this condition. This is Sphagnum annulatum. Since the valid description of this species was made relatively recently [22], and actually in Russian local floras, it “appears” around the late of 1990s, the definitions of this species cannot cover the entire study area (the database of local floras includes works, which were conducted since 1960s till 2017). In this connection, in the present work, 13 species of Sphagnum of the subgenus Cuspidata (from the list above), excluding S. annulatum, are analyzed.

The purpose of the present work is to simulate the ranges of species and study their distribution patterns, in connection with spatial changes of climatic factors in the EEPEF. In other words, it is completely within the competence of biogeography. The traditional task of biogeography is to identify the boundaries of the species ranges and find distribution patterns of the species due to geographic, biotic, and climatic factors. The ecological aspect of the species distribution analyzing in biogeography is most often associated with the concept of ecological niche in the understanding of Grinnell [23], that is, the attitude of a species to changes in environmental parameters. Unlike Hutchinson’s ecological niche [24], which is determined by the properties of a species in the hyperspace of environmental factors (i.e., the ecological preferences of the species, rather than the environment), Grinell’s niche is determined by environmental parameters. Changes of these parameters lead to changes of species environmental preferences. Therefore, studying the joint change of climatic factors and the numerical characteristics of the species in space, one can identify the climatic optimum and pessimum of the species.
2. Methods

To study the Sphagnum distribution on the EEPEF, 13 species were chosen, and the literature data with annotated lists of specific bryofloras from different regions (European part of the Russian Federation, the Baltic States, Ukraine, Belarus, and Moldova) were analyzed (Figure 1). Some dots have been chosen outside the study area (e.g., Romania, Poland, Kazakhstan, Caucasus, and eastern mountainside of Ural) to correct possible errors of extrapolation at the boundaries [17, 20]. Earlier,

Figure 1.
Study area, showing localities involved in analysis and vegetation zones: I—Tundra; II—Forest Tundra; III—Northern Taiga; IV—Middle Taiga; V—Southern Taiga; VI—Mixed forests; VII—Broadleaved forests; VIII—Forest Steppe; IX—Steppe; X—Semidesert; XI—Desert (boundaries of vegetation zones are given by [30, 31]. Study sites: 1–18—[32]; 19—[33]; 20–[34]; 21–23—[35]; 24–[36]; 26–[33]; 27–29—[35]; 30–[37]; 31–32—[38]; 33–[39]; 34–[40]; 35–[41]; 36–39—[42]; 40–[43]; 41–[44]; 42–43—[45]; 44–[46]; 45–[47]; 46–[42, 47]; 47–[48]; 48–51—[49]; 52–[50]; 53–[51]; 54–[52]; 55–57–[53]; 58–59—[54]; 60–64—[55]; 65–69—[27]; 70–72—[57]; 73–74—[58]; 75–77—[59]; 78–80—[60]; 81—[61]; 82—[62]; 83—[63]; 84–[64]; 85–[65]; 86–[66]; 87—[67]; 88—[68]; 89–92—[61]; 93–96—[69]; 97–[70]; 98–105—[71]; 106–108—[70]; 109–115—[57]; 116–[72]; 117–[73]; 118–[74]; 119–[75]; 120–[76]; 121–[77]; 122–[78]; 123–124—[79]; 125–[80]; 126–[81]; 127–[82]; 128–[83]; 129–130—[84]; 131–[85, 86]; 132–[87]; 133–[88]; 134–[89]; 135–[90]; 136–[91]; 137–138—[92]; 139–140—[93]; 141–[94]; 142–[95]; 143–[96]; 144–[97]; 145–[98]; 146–[99]; 147–[100]; 148–[101]; 159–162–[40]; 163–[102]; 164–166—[103, 104]; 165–[105]; 166–[106, 107]; 169–171—[107, 108]; 172–[109]; 173–[110]; 174–[94]; 175–[111]; 176–[112]; 177–[113]; 178–[114]; 179–[115]; 180–[116]; 181–182—[117]; 183–[118]; 184–188—[119]; 189–[77]; 190–[55].
the basic principles for creating model areas by geostatistics methods using the kriging method were printed, and the methodology for compiling model maps of species ranges was adapted to the goals of biogeography [20]. After literature data compilation, the occurrence of each species was estimated in ordinal six-point scale: 0—absent (abs), 1—very rare (1–2 records) (vr), 2—rare (3–7 records) (r), 3—sporadically (more than 7 records, but not everywhere) (sp), 4—frequent (usual species, but sometimes absent in suitable phytocoenosis) (fr), and 5—common
According to this scale, continuous coverages were constructed for each species using the kriging method \([17]\) with a resolution of 10 km in 1 pixel. In total, a sample of 190 points (local floras) was used to create continuous coverages (Figure 1).

Verification of continuous coverages was carried out by cross-validation method in the SAGA GIS software. The index of quality of cross-validation in geostatistics is...
the coefficient of determination ($R^2$) [17]. The values of this indicator for continuous coverages of species under study are shown in Figure 2. Climatic optimum was determined for zones of frequent (fr) and common (com) occurrences.

Continuous coverages of climatic factors were used in analysis also. We used dataset that authors of WORLDCLIM program [25] propose. In total, 23 climatic variables were used. This is the following: annual mean of precipitation (amt), monthly temperature of April–October (tm04–tm10), annual precipitation (pr_a), monthly precipitation (pr04–pr10), and relative humidity (reh04–reh10) of April–October. We have chosen only months of growing season from dataset. Each coverage was composed in Azimuthal Equidistant Projection (Central Meridian 45°E, chief of the parallel 55°N). The coverages of climatic factors were combined with coverages of species occurrence to a single spatial database. This spatial database was converted into relative table, which contains 36 variables (23 climatic factors and 13 species occurrence) and 49,557 cases (number of pixels). This database was used for calculation of descriptive statistics and performing correlation and cluster analysis in software Statistica 10.0. Operation with creating and verification coverages was performed in SAGA software. The operations by intersection of the vector layers and calculating of areas were performed in software ArcGis 10.0. In more detail, all techniques were described in previous article [21].

3. Results

Model maps for 13 species are shown in Figure 2. The following species distribution patterns were found.

*Sphagnum angustifolium*. This species is widely distributed in the study area (Figure 2). The maximum score on the scale of occurrence is 5 (com). It grows in boggy forests and bogs. Its range is associated with the forest zone and tundra,
Species Distribution Patterns in Subgenus Cuspidata (Genus Sphagnum L.) on the East...
DOI: http://dx.doi.org/10.5772/intechopen.84648

where such habitats are widespread. To the south of the forest zone, *S. angustifolium* decreases its abundance and completely disappears in the steppe or even in forest steppe in some places. Its occurrence increases in the northern and middle taiga. It grows in all vegetative zones from tundra to steppe ([Figure 2](#) and [Table 1](#)). The zone of its greatest occurrence (com) occupies 35.9% of the total area of the EEPEF. The zone of total absence is 23.7% ([Table 1](#)). Thus, the range of this species covers 76.3% of the total area of the EEPEF, therefore *S. angustifolium* can be considered here as a common and widespread species.

The southern boundary of the range of *S. angustifolium* (the southern boundary of vr zone) passes in sublatitudinal direction and is approximately parallel to the boundaries of natural zones. The border of the zone of maximum occurrence (com) passes diagonally to the meridians. In terms of biogeography, this is the zone of its climatic optimum. In the best way, the border of the com zone correlates with the boundary of the maximum occurrence of wetlands [26] and with isotherm of July +17°C and with maximal average values of air humidity in July–September.

*Sphagnum fallax*. This species is distributed from tundra to forest steppe zone ([Figure 2](#)). The maximum score on the scale of occurrence is 5 (com). In the south of the steppe zone, this species is absent, with the exception of its tongue with lower occurrence along Dnieper river, where it occurs on rare bogs, located on the river terraces [27]. It has maximal abundance (com) in the forest zone and occurs with a small abundance (vr) in the forest tundra and forest steppe, but here it is rare ([Table 2](#) and [Figure 2](#)). The zone of maximal occurrence of the species takes about a half area of the EEPEF (44.7%) ([Table 2](#)). This species is absent in 13.9% of the area only, that is, its range covers 86.1% of the EEPEF area. Thus, *S. fallax* is the most common and widespread species.

As well as *S. angustifolium*, *S. fallax* has similar climatic preferences. The boundaries of all zones of *S. fallax* are generally parallel to the boundaries of natural zones ([Figure 2](#)). Unlike *S. angustifolium*, *S. fallax* comes further south—its range reaches the Black Sea along the Dnieper. However, in the steppe zone, it is an extremely rare species. In the north of the EEPEF, *S. fallax* does not completely disappear, but becomes much more rare, in contrast to *S. angustifolium*, which is a fairly frequent species in the tundra ([Figure 2](#) and [Table 2](#)). The boundaries of all zones best correspond to region with the

| Zones          | abs  | vr  | r    | sp  | fr  | com | Total |
|----------------|------|-----|------|-----|-----|-----|-------|
| Tundra         | 3.6  | 136.8 | 478  | 3.6 | 191.8 |
| Forest Tundra  | 0.0  | 1.9  | 85.6 | 14.6 | 102.1 |
| North Taiga    | 13.3 | 5.8  | 56.1 | 475.5| 550.7 |
| Middle Taiga   | 24.4 | 44.7 | 59.9 | 619.1| 748.0 |
| South Taiga    | 0.1  | 92.8 | 32.7 | 88.4 | 326.0 | 540.0 |
| Mixed Forest   | 0.6  | 81.5 | 113.1| 278.9| 340.2 | 814.3 |
| Broadleaves Forest | 44.3 | 72.1 | 235.4| 155.0| 10.3  | 517.2 |
| Forest Steppe  | 209.0| 253.0| 58.4 | 2.2  | 522.7 |
| Steppe         | 659.1| 49.5 |      |      | 708.6 |
| Semidesert     | 204.8| 0.0  |      |      | 204.8 |
| Desert         | 54.9 | 0.0  |      |      | 54.9  |
| **Total, km²** | 1172.1| 375.4| 509.5| 492.1| 626.9 | 1778.9| 4955.0 |
| **Total, %**   | 23.7 | 7.6  | 10.3 | 9.9  | 12.7  | 35.9 | 100   |

**Table 1.**
Areas (in 1000 km²) covered by *S. angustifolium* by zones of its occurrence.
Bryophytes

greatest average summer precipitation and air humidity, and the southern border of its range is generally well suited the isotherm of July of +21°C (southern boundary of the vr zone) and to +13°C in the north (southern boundary of the r zone) (Figure 2).

**Sphagnum flexuosum.** This species is distributed from tundra to the steppe zone (Figure 2). The maximum score on the scale of occurrence is 4 (fr). It reaches the highest occurrence (fr) to the west of the forest zone (Figure 2), but it occurs sporadically throughout almost the entire forest zone. Sporadic zone occupies most of the range of this species — 41.2% — and extends from the northern taiga to the forest steppe (Table 3). In general, *S. flexuosum* covers 80.7% of the total area, and therefore this species, as well as two previous species, can be considered as widespread species in this area.

The boundaries of almost all zones of occurrence of this species run almost parallel to the boundaries of natural zones (Figure 2). The boundary of the zone fr passes in the submeridional direction. This fact indicates that the optimum zone of *S. flexuosum* is limited by the factors of humidity and not by temperature. This zone is located in regions around the Baltic Sea, where relatively warm summers and the greatest amount of precipitation are observed [28]. In the south, the range of this species reaches to the northern steppes only and in the north — to the Arctic Ocean. True, in tundra, it is very rare. In the best way, the boundaries of all zones of occurrence (except for zone fr) correspond to the high average values of precipitation in July–September, and they have a weak correspondence with isotherms (Table 3).

**Sphagnum balticum.** The range of this species from north to south covers the area from the tundra zone to the zone of deciduous forests, and its occurrence does not exceed four on a six-point scale (Figure 2). In the southern Urals, it captures a small section of the forest steppe zone (Table 4). The maximum occurrence of *S. balticum* is observed in the tundra and in the north of the forest zone. Zone fr occupies about a quarter of the total area (25.6%) of the EEPEF (Table 4). The territory, where *S. balticum* is absent (abs), makes up 38.6% of the EEPEF, that is, the range of this species occupies 61.4% of total area. Therefore, *S. balticum* can also be called a relatively widespread species.

| Zones                    | abs  | vr   | r    | sp   | fr   | com  | Total |
|--------------------------|------|------|------|------|------|------|-------|
| Tundra                   | 1173 | 73.0 | 1.5  | 0.0  | 0.0  | 0.0  | 191.8 |
| Forest Tundra            | 2.4  | 76.8 | 22.1 | 0.8  | 0.0  | 0.0  | 102.1 |
| North Taiga              | 671  | 118.6| 126.4| 238.6| 550.7|
| Middle Taiga             | 2.5  | 745.5| 748.0|
| South Taiga              | 0.5  | 85.0 | 454.5|
| Mixed Forest             | 36.5 | 70.1 | 707.7| 814.3|
| Broadleaves Forest       | 10.5 | 20.4 | 58.6 | 151.4| 208.2| 68.2 | 517.2|
| Forest Steppe            | 30.9 | 220.5| 170.8| 89.1 | 11.3 | 522.7|
| Steppe                   | 390.6| 289.3| 28.4 | 0.2  | 708.6|
| Semidesert               | 202.5| 2.2  |      |      | 204.8|
| Desert                   | 54.9 |      |      |      | 54.9 |
| **Total, km²**           | 689.4| 652.2| 474.6| 420.0| 504.2| 2214.5| 4955.0|
| **Total, %**             | 13.9 | 13.2 | 9.6  | 8.5  | 10.2 | 44.7 | 100   |

Table 2. Areas (in 1000 km²) covered by *S. fallax* by zones of its occurrence.
The boundaries of the range of *S. balticum* as a whole and the boundaries of zones of occurrence within the range are oblique with respect to the borders of natural zones and show a clear tendency toward concentration around the Baltic Sea (Figure 2). The boundary of the zone of maximal occurrence (fr) lies parallel and entirely within the zone of maximum distribution of the Valdai glaciation [29]. The boundary of the zone of sporadic occurrence (sp) generally coincides with the zone of maximal distribution of wetlands [26]. This is not surprising if we recall that *S. balticum* is predominantly a boggy (and not forest) species, especially in the north [9–11]. Thus, it can be assumed that the distribution of *S. balticum* in the northern parts of its range, where it occurs most often, in addition to climatic

| Zones        | abs  | vr   | r   | sp  | fr   | Total    |
|--------------|------|------|-----|-----|------|----------|
| Tundra       | 25.3 | 112.9| 41.6| 12.0|      | 191.8    |
| Forest Tundra| 8.9  | 18.5 | 66.5| 8.2 |      | 102.1    |
| North Taiga  | 12.1 | 61.7 | 320.8| 156.1|     | 550.7    |
| Middle Taiga |     |      | 78.9| 669.1|     | 748.0    |
| South Taiga  | 1.8  |      | 461.0| 772 |      | 540.0    |
| Mixed Forest | 0.4  | 6.5  | 435.0| 372.4|     | 814.3    |
| Broadleaves Forest | 35.6 | 27.4 | 119.1| 261.7| 73.3 | 517.2    |
| Forest Steppe| 92.9 | 270.9| 118.5| 38.5| 1.8  | 522.7    |
| Steppe       | 524.0| 174.7| 9.9 |    |      | 708.6    |
| Semidesert   | 204.8|      |     |     |      | 204.8    |
| Desert       | 54.9 |      |     |     |      | 54.9     |
| **Total, km²**| 958.5| 666.5| 763.8| 2041.5| 524.7| 4955.0   |
| **Total, %** | 19.3 | 13.5 | 15.4| 41.2| 10.6 | 100.0    |

Table 3. Areas (in 1000 km²) covered by *S. flexuosum* by zones of its occurrence.

| Zones        | abs  | vr   | r   | sp  | fr   | Total    |
|--------------|------|------|-----|-----|------|----------|
| Tundra       | 5.8  | 33.6 | 152.3|     |      | 191.8    |
| Forest Tundra| 23.3 | 78.8 | 102.1|     |      |          |
| North Taiga  | 21.3 | 28.9 | 147.6| 353.0|     | 550.7    |
| Middle Taiga | 124.2| 161.2| 198.5| 264.0|     | 748.0    |
| South Taiga  | 571  | 110.7| 74.9 | 219.9|      | 540.0    |
| Mixed Forest | 92.7 | 187.2| 139.4| 195.4| 199.6| 814.3    |
| Broadleaves Forest | 294.2| 194.3| 27.6 | 1.1  |      | 517.2    |
| Forest Steppe| 504.4| 18.3 | 522.7|     |      |          |
| Steppe       | 705.2| 3.4  | 708.6|     |      |          |
| Semidesert   | 204.8|      | 204.8|     |      |          |
| Desert       | 54.9 |      | 54.9 |     |      |          |
| **Total, km²**| 1913.2| 659.5| 437.7| 676.8| 1267.8| 4955.0   |
| **Total, %** | 38.6 | 13.3 | 8.8 | 13.7| 25.6 | 100.0    |

Table 4. Areas (in 1000 km²) covered by *S. balticum* by zones of its occurrence.
factors, is influenced by the historical conditions and landscape features of the territory. The influence of climatic factors, however, also occurs, since the southern border of the sp zone roughly corresponds to the isotherm of July +17°C. In the best way, the boundaries of the zones of occurrence correspond to the monthly precipitation and relative humidity of air in August–September.

*Sphagnum riparium*. It is rather widely distributed in the EEPEF (Figure 2); however, in most of the area, it occurs sporadically. The sp zone occupies about half of the investigated area (45.8%) (Table 5). The maximal occurrence zone reaches in Finland and Sweden (Figure 2), which is connected, in my opinion, with the greater prevalence of suitable habitats in these countries, such as aapa-bogs. In general, the *S. riparium* range covers 74.7% of the EEPEF, so this species can be considered widespread in this area.

In the west, the boundary of the sp zone more or less coincides with the isotherm of July +17°C. In the east—in the Ural Mountains—any correspondence to climatic factors is not detected. The decrease of the occurrence of *S. riparium* in Urals seems to be due to the lack of suitable habitats.

*Sphagnum majus* and *S. cuspidatum*. Both species, as well as *S. riparium*, are widely distributed throughout the EEPEF, but with a small abundance. The peak of their coenotic activity is observed in western regions, where they grow jointly or separately in the flooded hollows of oligotrophic or mesotrophic bogs. Apparently, their lower occurrence in the east is related to the difference in the composition of the bog complexes of the Western European and East European bogs. Although the ranges of both species are largely similar, *S. majus* is more northern than *S. cuspidatum*. Area of *S. majus* covers 66.8% and *S. cuspidatum*—59.7% (Tables 6 and 7) from total area. The boundaries of the zones of occurrence of both species are weakly related to the isolines of any climatic factors, except zone fr. This zone (for both species) lies within the region with the highest humidity and precipitation in August–September.

*Sphagnum jensenii*. The boundary of the range of this species has a fancy pattern. In general, it occupies 56.1% of the total area (Table 8). It is most prevalent in Fennoscandia and in Russian North (Figure 2). Throughout its range, *S. jensenii*

| Zones             | abs | vr | r  | sp | fr  | com | Total  |
|-------------------|-----|----|----|----|-----|-----|--------|
| Tundra            | 2.1 | 128.3 | 61.3 |   |     |     | 191.8  |
| Forest Tundra     | 13.3 | 88.8 |    |    |     |     | 102.1  |
| North Taiga       | 40.4 | 444.1 | 60.0 | 6.2 |     |     | 550.7  |
| Middle Taiga      | 49.4 | 592.6 | 41.5 | 64.5 |     |     | 748.0  |
| South Taiga       | 110.8 | 323.3 | 90.1 | 15.8 |     |     | 540.0  |
| Mixed Forest      | 6.5 | 128.5 | 672.7 | 6.7 |     |     | 814.3  |
| Broadleaves Forest| 34.6 | 205.9 | 190.9 | 85.7 |     |     | 517.2  |
| Forest Steppe     | 279.5 | 228.3 | 14.9 |     |     |     | 522.7  |
| Steppe            | 699.8 | 8.8 | 0.0 |     |     |     | 708.6  |
| Semidesert        | 204.8 | 0.0 |     |     |     |     | 204.8  |
| Desert            | 54.9 |     |     |     |     |     | 54.9   |
| Total, km²        | 1273.5 | 451.5 | 676.5 | 2268.6 | 198.3 | 86.6 | 4955.0 |
| Total, %          | 25.7 | 9.1 | 13.7 | 45.8 | 4.0 | 1.7 | 100    |

Table 5.
Areas (in 1000 km²) covered by *S. riparium* by zones of its occurrence.
practically does not change its environmental preferences—it grows everywhere in the wet hollows of oligotrophic bogs. However, on the territory of the Russian Plain, such bogs are not rare, but wet hollows are usually occupied mainly by *S. majus*. Therefore, it cannot be said that *S. jensenii* is extremely rare due to the lack of habitats in the central and eastern parts of the range. At the same time, it cannot be said that the boundaries of the zones of occurrence are associated with isolines of climatic factors. This type of range appears to be shrinking.

*Sphagnum obtusum.* The maximum score on the scale of occurrence for this species is 3 (sporadically). In other words, this species does not have an optimum in the study area. At the same time, the sp zone “goes” to EEPEF with two tongues—from

| Zones            | abs | vr  | r   | sp  | fr  | Total |
|------------------|-----|-----|-----|-----|-----|-------|
| Tundra           | 180.9 | 10.8 | 0.0 | 0.0 | 191.8 |
| Forest Tundra    | 49.6  | 52.1 | 0.4 | 0.0 | 102.1 |
| North Taiga      | 60.4  | 200.7 | 193.1 | 96.6 | 550.7 |
| Middle Taiga     | 62.3  | 107.4 | 98.9 | 332.3 | 147.1 | 748.0 |
| South Taiga      | 104.3 | 53.2 | 39.4 | 207.6 | 135.4 | 540.0 |
| Mixed Forest     | 31.0  | 73.1 | 401.0 | 304.5 | 4.7 | 814.3 |
| Broadleaves Forest | 93.4 | 174.1 | 227.5 | 22.2 | 517.2 |
| Forest Steppe    | 384.5 | 1278 | 10.4 | 522.7 |
| Steppe           | 708.6 |       |     | 708.6 |
| Semidesert       | 204.8 |       |     | 204.8 |
| Desert           | 54.9  |       |     | 54.9 |
| Total, km²       | 1643.7 | 826.5 | 1040.7 | 1060.1 | 383.9 | 4955.0 |
| Total, %         | 33.2  | 16.7 | 21.0 | 21.4 | 7.7 | 100.0 |

Table 6. Areas (in 1000 km²) covered by *S. majus* by zones of its occurrence.

| Zones            | abs | vr  | r   | sp  | fr  | Total |
|------------------|-----|-----|-----|-----|-----|-------|
| Tundra           | 191.8 |     |     |     |     | 191.8 |
| Forest Tundra    | 102.1 |     |     |     |     | 102.1 |
| North Taiga      | 405.8 | 144.3 | 0.7 |     |     | 550.7 |
| Middle Taiga     | 83.7  | 265.7 | 396.6 | 2.0 |     | 748.0 |
| South Taiga      | 26.1  | 68.1 | 307.7 | 99.5 | 38.6 | 748.0 |
| Mixed Forest     | 26.4  | 67.4 | 253.8 | 106.3 | 360.4 | 814.3 |
| Broadleaves Forest | 90.5 | 131.0 | 209.1 | 63.5 | 23.1 | 517.2 |
| Forest Steppe    | 184.2 | 310.0 | 25.4 | 3.2 |     | 522.7 |
| Steppe           | 627.0 | 81.6 |     |     |     | 708.6 |
| Semidesert       | 204.8 |     |     |     |     | 204.8 |
| Desert           | 54.9  |     |     |     |     | 54.9 |
| Total, km²       | 1997.0 | 1068.1 | 1193.3 | 274.5 | 422.2 | 4955.0 |
| Total, %         | 40.3  | 21.6 | 24.1 | 5.5 | 8.5 | 100.0 |

Table 7. Areas (in 1000 km²) covered by *S. cuspidatum* by zones of its occurrence.
Finland and Polar Urals. This is very similar to the tongues of the last glacier [29]. This is a suggestion that this species is a glacial relic. In general, the area of this species is 66.4% of the total area of the EEPEF (Table 9). This species does not change its ecology when geographic areas changing—everywhere it grows on quagmire along the shores of lakes or in hollows of transitional bogs and rich fens. Therefore, in our opinion, the range of this species can also be called shrinking.

_Sphagnum lindbergii_. This species is quite rare on the Russian Plain. Judging by the pattern of its range—it is rather Scandinavian. The area of its range is less than half of the total area (38.7%) (Table 10). Therefore, this species should be considered as a species with a restricted range for the EEPEF territory. The zone of

---

**Table 8.**
*Areas (in 1000 km²) covered by S. jensenii by zones of its abundance.*

| Zones      | abs | vr  | r   | sp | fr  | Total |
|------------|-----|-----|-----|----|-----|-------|
| Tundra     | 139.7 | 13.8 | 38.2 |    |     | 191.8 |
| Forest Tundra | 55.1 | 9.2  | 37.5 | 0.3 | 102.1 |
| North Taiga | 179.4 | 76.0 | 154.1 | 141.2 | 550.7 |
| Middle Taiga | 104.7 | 411.9 | 126.8 | 82.0 | 22.7 | 748.0 |
| South Taiga | 181.6 | 220.3 | 134.0 | 4.1 |     | 540.0 |
| Mixed Forest | 111.0 | 696.7 | 6.7  |     |     | 814.3 |
| Broadleaves Forest | 310.0 | 207.2 |     |     |     | 517.2 |
| Forest Steppe | 501.8 | 20.9 |     |     |     | 522.7 |
| Steppe     | 708.6 |     |     |     |     | 708.6 |
| Semidesert | 204.8 |     |     |     |     | 204.8 |
| Desert     | 54.9 |     |     |     |     | 54.9 |
| **Total, km²** | 2177.2 | 1931.2 | 366.5 | 315.8 | 164.3 | 4955.0 |
| **Total, %** | 43.9 | 39.0 | 7.4  | 6.4 | 3.3 | 100.0 |

**Table 9.**
*Areas (in 1000 km²) covered by S. obtusum by zones of its occurrence.*

| Zones      | abs | vr  | r   | sp | fr  | Total |
|------------|-----|-----|-----|----|-----|-------|
| Tundra     | 52.0 | 19.7 | 68.5 | 51.5 |    | 191.8 |
| Forest Tundra | 42.8 | 18.8 | 24.8 | 15.7 |    | 102.1 |
| North Taiga | 108.0 | 175.1 | 198.4 | 69.2 |    | 550.7 |
| Middle Taiga | 12.2 | 267.0 | 286.3 | 182.5 |    | 748.0 |
| South Taiga | 23.0 | 268.6 | 62.5 | 185.9 |    | 540.0 |
| Mixed Forest | 42.8 | 432.2 | 309.7 | 29.6 |    | 814.3 |
| Broadleaves Forest | 180.5 | 274.3 | 62.3 |     |    | 517.2 |
| Forest Steppe | 289.6 | 233.1 |     |     |    | 522.7 |
| Steppe     | 656.3 | 52.3 |     |     |    | 708.6 |
| Semidesert | 204.8 |     |     |     |     | 204.8 |
| Desert     | 54.9 |     |     |     |     | 54.9 |
| **Total, km²** | 1666.9 | 1741.1 | 1012.6 | 534.3 |    | 4955.0 |
| **Total, %** | 33.6 | 35.1 | 20.4 | 10.8 |    | 100.0 |
its maximal distribution occurs in subarctic regions, where an air humidity is high during the growing season (Table 11).

*Sphagnum pulchrum* and *S. tenellum*. These two species go to the EEPEF from Western Europe and Scandinavia. In the investigated area, they have a restricted range. Thus, the area occupied by *S. pulchrum* is only 26.3% and by *S. tenellum*—24.7% of the total EEPEF area (Tables 11 and 12).

*Sphagnum lenense*. This species is widespread in Siberia and goes to the EEPEF from the Polar Urals. Also, this is a species with a restricted range. The area of its range is only 5.1% of the total area (Table 13). In the tundra and forest tundra, it grows on the hummocks of raised bogs. Under the conditions of the Russian plain, in forest zone, such habitats are usually occupied by *Sphagnum fuscum*. The

| Zones             | abs | vr  | r   | sp  | fr  | com | Total  |
|-------------------|-----|-----|-----|-----|-----|-----|--------|
| Tundra            | 26.5| 99.7| 16.6| 49.1|     |     | 191.8  |
| Forest Tundra     | 0.4 | 278 | 36.1| 379 |     |     | 102.1  |
| North Taiga       | 0.3 | 63.8| 120.6|118.5|208.7|38.8 | 550.7  |
| Middle Taiga      | 371.1|190.7|48.4 |59.2 |63.1 |15.5 | 748.0  |
| South Taiga       | 293.7|104.7|61.6 |70.4 |9.6  |     | 540.0  |
| Mixed Forest      | 372.5|435.1|6.7  |     |     |     | 814.3  |
| Broadleaves Forest| 509.4|7.7  |     |     |     |     | 517.2  |
| Forest Steppe     | 522.7|     |     |     |     |     | 522.7  |
| Steppe            | 708.6|     |     |     |     |     | 708.6  |
| Semidesert        | 204.8|     |     |     |     |     | 204.8  |
| Desert            | 54.9 |     |     |     |     |     | 54.9   |
| Total, km²        | 3037.9|829.0|364.8|300.7|368.3|54.3 |4955.0 |
| Total, %          | 61.3 |16.7 |7.4  |6.1  |7.4  |1.1  |100.0  |

**Table 10.**
Areas (in 1000 km²) covered by *S. lindbergii* by zones of its occurrence.

| Zones             | abs   | vr  | r   | sp   | fr   | com  | Total  |
|-------------------|-------|-----|-----|------|------|------|--------|
| Tundra            | 191.8 |     |     |      |      |      | 191.8  |
| Forest Tundra     | 102.1 |     |     |      |      |      | 102.1  |
| North Taiga       | 412.7 |51.7 |46.0 |35.5  |4.8   |      | 550.7  |
| Middle Taiga      | 532.4 |46.3 |41.2 |50.8  |77.3  |      | 748.0  |
| South Taiga       | 300.9 |42.0 |52.4 |66.8  |778   |      | 540.0  |
| Mixed Forest      | 232.7 |170.8|228.8|182.1 |     |      | 814.3  |
| Broadleaves Forest| 386.2 |124.3|6.6  |      |      |      | 517.2  |
| Forest Steppe     | 522.5 |0.2  |     |      |      |      | 522.7  |
| Steppe            | 708.6 |     |     |      |      |      | 708.6  |
| Semidesert        | 204.8 |     |     |      |      |      | 204.8  |
| Desert            | 54.9  |     |     |      |      |      | 54.9   |
| Total, km²        | 3649.5|435.4|374.9|335.2|160.0 |      |4955.0  |
| Total, %          | 73.7  |8.8  |7.6  |6.8  |3.2   |1 |100.0  |

**Table 11.**
Areas (in 1000 km²) covered by *S. pulchrum* by zones of its abundance.
southern boundary of the sp zone approximately corresponds to the isotherm of annual mean temperature of −4°C and an annual precipitation amount of 500 mm.

4. Discussion

If we consider the model maps of species, constructed according to the value of occurrence, as their geographical range in the territory of the EEPEF, then the areas of occurrence identified on it indicate areas where mosses have optimal and pessimal conditions. Results show that almost all species have an optimal area in the regions around the Baltic Sea or in the subarctic, where the wettest conditions are observed in the EEPEF. If we express the values of the moisture factors necessary for
the successful distribution of species, in absolute values, they look as follows: annual precipitation is not less than 550 mm and relative humidity is not less than 60–70%.

A total of 7 species of 13 are widespread in the study area. These are *S. angustifolium*, *S. fallax*, *S. flexuosum*, *S. balticum*, *S. riparium*, *S. majus*, and *S. cuspidatum*. All of them play an important phytocenotic role in wetlands. Restricted species have western distribution. And only *S. lenense* comes to the north of the European part of Russia from the east. Some of the restricted species, such as *S. obtusum* and *S. tenellum*, do not have an optimum in the EEPEF. This suggests that they come here only at the edge of the range, and the center of their distribution is outside the EEPEF. Abovementioned seven species are characterized by the largest phytocenotic significance in wetland communities. If we compare their ranges (Figure 2), it is clear that they overlap significantly, but, nevertheless, each species is characterized by its own characteristics. The *S. flexuosum* area pattern is the most different from the others. This species is practically absent in the tundra and reduces its abundance to the north and south of the forest zone. At the same time, it cannot be called the most “southern” of all seven species, since the range of *S. fallax*, for example, goes even further south than *S. flexuosum* (Figure 2). At the same time, *S. fallax* is able to grow in the tundra, that is, far north than *S. flexuosum*. Although *S. flexuosum* grows throughout the entire EEPEF forest zone, it is obvious that its western regions are under heavy rainfall conditions. The range of *S. angustifolium* in the southern part is similar to the pattern of the ranges of *S. fallax* and *S. flexuosum*. In the north, *S. angustifolium* comes much farther into the tundra and can be found there quite often, unlike the last two (Figure 2). The most northern species, perhaps, can be called *S. balticum*. On the southern limit of its range, it is limited to the southern boundary of the forest zone, and in the north, it is widely represented in taiga and in tundra. The orientation of the boundaries of its range is parallel to the boundary of the last glaciation and the zone of maximal spread of wetlands (and not the boundaries of natural zones). Such orientation of boundaries indicates that its distribution in the EEPEF is caused not only by climate parameters but also by the landscape structures that formed on the plain as they recede the glacier. This equally applies to *S. riparium*.

As correlation analysis shows (Table 14), the occurrence in the local floras of all species of the subgenus Cuspidata, except for *S. lenense*, *S. pulchrum*, and *S. tenellum*, has a high positive relationship with the rainfall of August (pr09), September (pr08), and October (pr10) (Table 2). According to WorldClim data [25], the maximum humidity in the EEPEF is observed in the west of forest zone and tundra zone during the summer-autumn season and sharply decreases in values starting from the south of the forest steppe zone, which is associated with an increase in monthly and average annual temperatures. Therefore, in the south, species of the subgenus Cuspidata quickly reduce their abundance, completely disappearing in the south of the steppe zone, or even further north (Figure 2). This is associated with high negative correlation coefficients between the values of occurrence and monthly temperatures (tm) of the vegetation period (Table 14). In the north, in the tundra, the occurrence of many species decreases, but not as sharply as at the southern limit of distribution. Apparently, despite the cold summer, they still find enough moisture here to grow successfully.

The cluster analysis conducted for 13 species of the subgenus Cuspidata by the values of 23 climatic factors shows that the studied species are divided into four clusters according to their climatic preferences (Figure 3). First cluster: *S. lenense*; second cluster: *S. tenellum*, *S. pulchrum*, and *S. lindbergii*; third cluster: *S. jensenii*, *S. obtusum*, *S. majus*, *S. cuspidatum*, and *S. balticum*; and fourth cluster: *S. fallax*, *S. flexuosum*, *S. angustifolium*, and *S. riparium*. It is interesting to note that within these groups, there is a similarity in environmental preferences also. So the species...
| Factor | ang | fal | flex | balt | cusp | jens | lenens |
|--------|-----|-----|------|------|------|-------|--------|
| **amt** | −0.65 | −0.47 | −0.28 | −0.62 | 0.08 | −0.66 | −0.50 |
| pr04 | 0.05 | 0.30 | 0.41 | −0.08 | **0.54** | −0.08 | −0.20 |
| pr05 | 0.11 | 0.39 | 0.43 | −0.06 | 0.52 | −0.07 | −0.21 |
| pr06 | 0.15 | 0.43 | 0.50 | 0.00 | **0.61** | 0.02 | −0.19 |
| pr07 | 0.40 | 0.65 | 0.69 | 0.22 | 0.71 | 0.23 | −0.17 |
| pr08 | 0.79 | 0.81 | 0.72 | 0.72 | 0.62 | 0.70 | −0.08 |
| pr09 | 0.80 | 0.80 | 0.74 | 0.71 | 0.50 | 0.69 | 0.01 |
| pr10 | 0.77 | 0.78 | 0.67 | 0.59 | 0.47 | 0.58 | −0.10 |
| pr_a | 0.47 | 0.69 | 0.73 | 0.33 | 0.72 | 0.30 | −0.20 |
| reh04 | 0.75 | 0.48 | 0.39 | 0.84 | 0.19 | 0.79 | 0.25 |
| reh05 | 0.57 | 0.32 | 0.30 | 0.72 | 0.17 | 0.65 | 0.24 |
| reh06 | 0.54 | 0.43 | 0.45 | 0.65 | 0.44 | 0.56 | 0.15 |
| reh07 | 0.71 | 0.61 | 0.59 | 0.77 | 0.54 | 0.69 | 0.05 |
| reh08 | 0.83 | 0.61 | 0.50 | 0.90 | 0.30 | 0.84 | 0.17 |
| reh09 | 0.85 | 0.64 | 0.49 | 0.90 | 0.28 | 0.86 | 0.16 |
| reh10 | 0.83 | 0.66 | 0.50 | 0.80 | 0.22 | 0.78 | 0.19 |
| tm04 | −0.75 | −0.54 | −0.36 | −0.75 | −0.02 | −0.77 | −0.41 |
| tm05 | −0.79 | −0.58 | −0.42 | −0.81 | −0.09 | −0.82 | −0.51 |
| tm06 | −0.81 | −0.59 | −0.43 | −0.85 | −0.13 | −0.83 | −0.51 |
| tm07 | −0.82 | −0.59 | −0.45 | −0.89 | −0.19 | −0.86 | −0.51 |
| tm08 | −0.79 | −0.59 | −0.42 | −0.82 | −0.10 | −0.82 | −0.50 |
| tm09 | −0.76 | −0.57 | −0.38 | −0.75 | −0.05 | −0.78 | −0.40 |
| tm10 | −0.59 | −0.44 | −0.25 | −0.54 | 0.11 | −0.59 | −0.20 |

| Factor | lindb | maj | obtus | pulch | rip | tenell |
|--------|-------|-----|-------|-------|-----|--------|
| **amt** | −0.57 | −0.49 | −0.51 | 0.02 | −0.59 | 0.03 |
| pr04 | −0.21 | 0.12 | 0.19 | 0.27 | 0.02 | 0.15 |
| pr05 | −0.22 | 0.15 | 0.14 | 0.19 | 0.12 | 0.09 |
| pr06 | −0.16 | 0.23 | 0.19 | 0.28 | 0.18 | 0.18 |
| pr07 | 0.02 | 0.43 | 0.40 | 0.41 | 0.45 | 0.26 |
| pr08 | 0.53 | 0.79 | 0.76 | 0.66 | 0.74 | 0.50 |
| pr09 | 0.53 | 0.70 | 0.79 | 0.43 | 0.76 | 0.34 |
| pr10 | 0.37 | 0.62 | 0.65 | 0.28 | 0.72 | 0.16 |
| pr_a | 0.13 | 0.48 | 0.52 | 0.48 | 0.47 | 0.35 |
| reh04 | 0.75 | 0.69 | 0.69 | 0.44 | 0.69 | 0.34 |
| reh05 | 0.63 | 0.55 | 0.53 | 0.42 | 0.52 | 0.37 |
| reh06 | 0.48 | 0.56 | 0.49 | 0.51 | 0.51 | 0.38 |
| reh07 | 0.56 | 0.70 | 0.60 | 0.58 | 0.67 | 0.44 |
| reh08 | 0.75 | 0.75 | 0.72 | 0.44 | 0.77 | 0.34 |
| reh09 | 0.76 | 0.78 | 0.75 | 0.43 | 0.81 | 0.32 |
| reh10 | 0.66 | 0.72 | 0.73 | 0.26 | 0.75 | 0.17 |
| tm04 | −0.68 | −0.61 | −0.62 | −0.13 | −0.69 | −0.10 |
belonging to the 4th cluster grow mainly in the carpets of mesotrophic or oligotrophic bogs and boggy forests; the species belonging to the third cluster are most often found in heavily flooded hollows of bogs and fens; the species belonging to the second cluster grow in less flooded hollows of bogs. The *S. lenense* stands apart, which is found in the studied territory on hummocks in the boggy tundra. It seems to us that the similarity in the species relation to the conditions of watering of the habitat and climate is not accidental. The fact is that the amount of precipitation determines the hydrological regime in peat, and the humidity of the air affects the safety of the growing point during the dry season in the middle of summer.

### 5. Conclusion

Comparing the distribution ranges of 13 species of the subgenus Cuspidata in the EEPEF shows that there are as well as widespread and restricted species. The widespread species are as follows: *S. angustifolium*, *S. fallax*, *S. flexuosum*, *S. balticum*, *S. riparium*, *S. majus*, and *S. cuspidatum*. The restricted ones are *S. pulchrum*,

---

| tm05 | −0.72 | −0.65 | −0.67 | −0.21 | −0.73 | −0.17 |
| tm06 | −0.74 | −0.69 | −0.69 | −0.27 | −0.75 | −0.22 |
| tm07 | −0.79 | −0.73 | −0.70 | −0.40 | −0.77 | −0.32 |
| tm08 | −0.72 | −0.66 | −0.66 | −0.23 | −0.74 | −0.18 |
| tm09 | −0.67 | −0.62 | −0.61 | −0.14 | −0.71 | −0.10 |
| tm10 | −0.50 | −0.42 | −0.46 | 0.10 | −0.54 | 0.09 |

Values of $r > 0.5$ in absolute value are highlighted in bold. All values are statistically significant at $p < 0.05$.

**Note:** Climatic factors: *amt*—annual amount of precipitation; *pr01*–*pr12*—monthly amount of precipitation in January–December; *pr. a*—annual precipitation average; *reh4*–*reh10*—relative humidity in April–October; and *tm04*–*tm10*—monthly temperature average in April–October.

**Table 14.**

The Spearmen correlation coefficient between the values of climatic factors and species abundance.
S. obtusum, S. jensenii, S. tenellum, S. lindbergii, and S. lenense. Widespread species are common in wetland communities through entire area of the EEPEF in forest zone and tundra (except S. cuspidatum, which is absent in tundra). Restricted species (except S. lenense) have western trend in its ranges. Maximum activity (optimum) of these species depends on moisture factors (humidity and precipitations), and southern boundaries are limited by temperature. The only S. lenense is eastern (Siberian) species. It mainly occurs in tundras and one can see a middle dependence of its distribution on the temperature factors (Table 14).

Author details

Sergei Yu. Popov
Lomonosov Moscow State University, Moscow, Russia

*Address all correspondence to: sergei.popov.2015@yandex.ru

IntechOpen

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
References

[1] Clymo RS. Experiment on breakdown of Sphagnum in two bogs. Journal of Ecology. 1965;53:747-757

[2] Vitt DH, Crum H, Snider JA. The vertical zonation of Sphagnum species in hummock-hollow complexes in Northern Michigan. Michigan Botanist. 1975;14:190-200

[3] Clymo RS, Hayward PM. The ecology of Sphagnum. In: Smith AJE, editor. Bryophyte Ecology. London: Chapman & Hall; 1982. pp. 229-289

[4] Rochefort L, Vitt DH, Bayley SE. Growth, production, and decomposition dynamics of Sphagnum under natural and experimentally acidified conditions. Ecology. 1990;71(5):1986-2000

[5] Vitt DH, Wai-Lin C. The relationships of vegetation to surface water chemistry and peat chemistry in fens of Alberta, Canada. Vegetatio. 1990;89:87-106

[6] Vitt DH. Peatlands: Ecosystems dominated by bryophytes. In: Shaw AJ, Goffinet B, editors. Bryophyte Biology. Cambridge: University Press; 2000. pp. 312-343

[7] Rydin H, Gunnarsson U, Sundberg S. The role of Sphagnum in peatland development and persistence. In: Boreal Peatland Ecosystems, Ecological Studies. Vol. 188. Berlin: Spinger-Verlag; 2006. pp. 49-65

[8] Smolyanitzkiy LY. Some regularities of the formation of Sphagnum moss cushions. Botanicheskii Zhurnal. 1977;52(9):1269-1272

[9] Maksimov AI. Ecology of several peat mosses in Karelia and their role in plant communities. In: Ekologo-biologicheskie osobennosti i produktivnost' rastenii bolot. Petrozavodsk. 1982. pp. 187-195

[10] Popov SY, Fedosov VE. Coenotic distribution and ecological preferences of Sphagna in Northern Taiga, European Russia (Pinega State Reserve, Arkhangelsk Province). Trudy KarNC. 2017;9:3-29. DOI: 10.17076/ec0610

[11] Smagin VA, Noskova MG, Antipin VK, Boichuk MA. Diversity and phytosociological role of mosses in mires of southwestern Arkhangelsk Region and adjacent territories. Trudy KarNC. 2017;1:75-96. DOI: 10.17076/bg382

[12] Séneca A, Söderström L. Species richness and distribution ranges of European Sphagnum. Folia Cryptog. Estonica. 2008;44:125-130

[13] Geffert JL, Frahm J-P, Barthlott W, Mutke J. Global moss diversity: Spatial and taxonomic patterns of species richness. Journal of Bryology. 2013;35(1):1-11

[14] Hill MO, Bell N, Bruggeman-Nannenga MA, Brugués M, Cano MJ, Enroth J, et al. An annotated checklist of the mosses of Europe and Macaronesia. Journal of Bryology. 2006;28:198-267

[15] Isaaks EH, Srivastava RM. An Introduction to Applied Geostatistics. Vol. 561. New York: Oxford University Press; 1989

[16] Cressie NAC. The origins of kriging. Mathematical Geology. 1990;22:239-252

[17] Dem’yanov VV, Savel’eva EA. Geostatistics: Theory and Practice. Vol. 327. Moscow: Nauka; 2010

[18] Lur’e IK. Geoinformatical Mapping. The Methods of Geoinformatics and Digital Processing of Satellite Images. Vol. 424. Moscow: KDU; 2010
[19] Savel'ev AA, Mukharamova SS, Pilyugin AG, Chizhikova NA. Geostatistical data analysis in ecology and nature management (using the R package). Vol. 120. Kazan: Kazanskii Universitet; 2012

[20] Popov SY. Modeling the species distribution range based on the geostatistical techniques (on example of Sphagnum mosses). Trudy KarNC. 2017;6:70-83. DOI: 10.17076/bg558

[21] Popov SY. Distribution pattern of seven Polytrichum species in the East European Plain and Eastern Fennoscandia. Botanica Pacifica. 2018;7(1):25-40. DOI: 10.17581/bp.2018.07108

[22] Flatberg KI. Taxonomy of Sphagnum annulatum and related species. Annales Botanici Fennici. 1988;25(4):303-350

[23] Grinnel J. The niche-relationships of the California Thrasher. Foundation of Ecology. Chicago: The Univ. of Chicago Press; 1991. 118-125 p

[24] Hutchinson GE. The nicheAnabstractly inhabited hyper-volume. In: The Ecological Theater and the Evolutionar Play. New Haven: Yale Univ. Press; 1965. pp. 26-78

[25] BIOCLIM project [Internet]. 2009. Available from: http://www.andra.fr/bioclim [Accessed: 2019-01-14]

[26] Mazing V, Svirezhev YM, Loffler H, Patten BC. Wetlands in the biosphere. Wetlands and Shallow Continental Water Bodies. 1990;1:313-344

[27] Boiko MF. Bryobionta of the Steppe Zone of Ukraine. Vol. 264. Kherson: Ailant; 2009

[28] Alisov BP. The climat of the USSR. Moscow: Izdatelstvo MGU; 1956. 126 p

[29] Kvasov DD. Late Quaternary History of Large Lakes and Inland Seas of Eastern Europe. Leningrad: Nauka; 1974. 278 p

[30] Ahti T, Hämet-Ahti L, Jalas J. Vegetation zones and their sections in northwestern Europe. Annales Botanici Fennici. 1968;5:169-211

[31] Kurnaev SF. Forest Growth Zoning of the USSR. Moscow: Nauka; 1973. 203 p

[32] Söderström L, editor. Preliminary Distribution Maps of Bryophytes in Northwestern Europe. Musci J-Z. Vol. 3. Trondheim: Mossornas Vänner; 1998. 72 p

[33] Belkina OA, Likhachev AY. Mosses of Kandalaksha State Nature Reserve (White Sea). Apatity: Kola Science Centre; 1997. 46 p

[34] Likhachev AY, Belkina OA. Mosses of Lavna-Tundra Mountains (Murmansk Province, Russia). Arctoa. 1999;8:5-16. DOI: 10.15298/arctoa.08.02

[35] Shlyakov RN, Konstantinova NA. Check-list of Mosses of Murmansk Province. Vol. 227. Apatity: Kol’skiy filial AN SSSR; 1982

[36] Drugova TP, Belkina OA, Likhachev AY. Mosses of surroundings of Alakurtii settlement and Kutsa nature reserve (Murmansk Province, Northwest Russia). Arctoa. 2017;26(1):72-80. DOI: 10.15298/arctoa.26.07

[37] Bogdanova NE. Bryophytes of Velikiy Island (White Sea). In: Floristic researches in the Nature Reserves of the USSR. Moscow; 1981. 112 p

[38] Abramov II, Volkova LA. Handbook of Mosses of Karelia. Moscow: KMK; 1998. 390 p

[39] Boichuk MA. On the moss flora jf the Kostomuksha State Reserve and the vicinities of Kostomuksha town
Species Distribution Patterns in Subgenus Cuspidata (Genus Sphagnum L.) on the East...  
DOI: http://dx.doi.org/10.5772/intechopen.84648

[Karelia]. Novosti sistematiki nizshih rastenii. 2001;35:217-229

[40] Churakova EY. Mosses of the Taiga zone of the Arkhangelsk Province (Northern European Russia). Arctoa. 2002;11:351-392. DOI: 10.15298/arctoa.11.24

[41] Boichuk MA. Mosses of Protected Areas of Karelia [thesis]. Petrozavodsk: Institute of Biology; 2002

[42] Kurbatova LV. Mosses of the Leningrad Province [thesis]. S.-Peterburg: Komarov Botanical Institute; 2002

[43] Andreeva EN, Filip’eva EO. Bryophyta of the Remda Reservation (Pskov Region). Novosti sistematiki nizshih rastenii. 2005;38:307-327

[44] Vellak K, Ingerpuu N, Leis M, Ehrlich L. Annotated checklist of Estonian bryophytes. Folia Cryptogamica Estonica. 2015;52:109-127

[45] Abolin AA. Mosses of Latvian SSR. Riga: Zinatne; 1968. 329 p

[46] Dolnik C, Napreenko MG. The bryophytes of the Southern Curonian Spit (Baltic Sea coast). Arctoa. 2007;16:35-46. DOI: 10.15298/arctoa.16.05

[47] Strazdiņa L, Madžule L, Brümelis G. A contribution to the bryoflora of Moricsala island Nature Reserve, Latvia. Folia Cryptogamica Estonica. 2011;48:107-117

[48] Stebel A. Preliminary studies on the bryoflora of Narwianski National Park (NE Poland). The Journal of Silezian Museum in Opava. 2012;61:265-271

[49] Rykovsky GF, Maslovsky OM. The Flora of Belarus. Bryophytes. 1. Andraeopsida–Bryopsida. Minsk: Belaruska Nauka; 2009. 437 p

[50] Dite D, Hajek M, Hajkova P. Formal definition of Slovakian mire plant associations and their application in regional research. Biologa. 2007;62(4):400-408

[51] Papp B, Erzberger P, Odor P, Zs H, Szoveyi P, Szurdoki E, et al. Updated checklist and red list of Hungarian Bryophytes. Studia Botanica Hungarica. 2010;41:31-59

[52] Erzberger P, Hohn M, Pocks T. Contribution to the bryoflora of Călimani Mountains in the Eastern Carpathians, Romania. Acta Biologica Plantarum Agriensis. 2012;2:73-95

[53] Zerov DK, LYa P. The Bryophytes of Ukrainian Carpathians. Kiev: Naukova Dumka; 1975. 230 p

[54] Lazarenko AS. Handbook of Mosses of Ukraine. Kiev: AN Ukrainy; 1955. 467 p

[55] Gapon SV. Check-list of bryoflora of Ukrainian Leftbank Forest-Steppe. Poltava: Poltavsky Derzhavny Institut; 1997. 37 p

[56] Simonov GP. Handbook of mosses of Moldavian SSR. Kishinev: Shtiinza; 1978. 168 p

[57] Popova NN. Bryoflora of the Central Russian Uppland. I. Arctoa. 2002;11:101-168. DOI: 10.15298/arctoa.11.12

[58] Sereda VA, Ignatov MS. Bryoflora of Northern Azov area (Rostov-On-Don Province, European Russia). Arctoa. 2008;17:185-190. DOI: 10.15298/arctoa.17.15

[59] LYa P. The bryoflora of Crimea. Kiev: Fitosociocentr; 2005. 170 p

[60] Ignatova EA, Ignatov MS, Seregin AP, Akatova TV, Konstantinova NA. Bryophyte flora of the projected Utrish Reserve (North–West Caucasus,
[61] GYa D. Mosses of the Southern Kalmykia (European Part of Russia). Novosti sistematiki nizshih rastenii. 2011;45:292-300

[62] Akatova TV, Ignatova EA. On the moss flora of Lagonaki Highland (Adygea Rebublic, Western Caucasus). Arctoa. 2015;24:148-155. DOI: 10.15298/arctoa.24.15

[63] Akatova TV. Moss flora of the Caucasian Nature Reserve (Western Caucasus, Russia). Arctoa. 2002;11:179-204. DOI: 10.15298/arctoa.11.15

[64] GYa D. The mosses (Bryophyta) of Abkhazia. Novosti sistematiki nizshih rastenii. 2015;49:295-313

[65] Ignatova EA, Ignatov MS, Konstantinova NA, Zolotov VI, Onipchenko VG. Moss flora of Teberda Reserve. Moscow: Nauka; 2008. 86 p

[66] Kharzinov Z, Portenier N, Ignatova E, Shagapsoev S, Ignatov M. Rare species and preliminary list of mosses of the Kabardino-Balkaria (Caucasus). Arctoa. 2004;13:33-40. DOI: 10.15298/arctoa.13.05

[67] Abakarova AS, Fedosov VE, Doroshina GY. Mosses of Tsudakhlar (Dagestan, Caucasus). Arctoa. 2015;24:536-540. DOI: 10.15298/arctoa.24.45

[68] Ignatov MS, Fedosov VE, Ignatova EA. Moss flora of Gunib Area in Dagestan, Eastern Caucasus. Arctoa. 2010;19:87-96. DOI: 10.15298/arctoa.19.07

[69] Suragina SA, Ignatova EA, Ignatov MS. Contribution to the moss flora of Astrakhan Province (South European Russia). Arctoa. 2002;10:169-174. DOI: 10.15298/arctoa.11.13

[70] Suragina SA. Mosses of the Volgograd Province (South-Eastern European Russia). Arctoa. 2001;10:45-70. DOI: 10.15298/arctoa.10.06

[71] Spirina UN, Zolotov VI. Mosses of the Orenburg State Nature Reserve (South-Eastern European Russia). Arctoa. 2004;13:51-56. DOI: 10.15298/arctoa.13.07

[72] Teleganova VV. Mosses of Kaluga (Middle European Russia) and their reproductive features. Arctoa. 2008;17:169-184. DOI: 10.15298/arctoa.17.14

[73] Popova NN, Teleganova VV, Boychuk MA. Bryoflora of the memorial and nature museum-reserve “Kulikovo pole” (Tula Province, Middle European Russia). Arctoa. 2015;24(2):567-573. DOI: 10.15298/arctoa.24.49

[74] Serebryakova NN. Ecological and biological features of mosses and their use in environmental monitoring [thesis]. Saratov: State Research Institute of Industrial Ecology; 2009

[75] Doroshina-Ukrainskaya GYa. Bryophytes. In: Works of the State Nature Reserve «Privolzhskaya forest-steppe». Penza; 1999. p. 43-46

[76] Popov SY. Flora of peat mosses of Zhiguli State Reserve. In: Biodiversity of Protected Areas: Estimate, Conservation, Monitoring. Moscow-Samara: Zhiguli State Reserve; 2000. pp. 194-196

[77] Zolotov VI, Baisheva EZ. Moss flora of «Shulgan-Tash» Nature Reserve (Republic Bashkortostan, Russia). Arctoa. 2003;12:121-132. DOI: 10.15298/arctoa.12.13

[78] Baisheva EZ, Ignatova EA, Kalinauskaite N, Potemkin AD. On the Bryophyte flora of Iremel National Park (Southern Urals). Arctoa.
[23] Rubtsova AV. Bryoflora of Udmurt Republic. In: Actual Problems of Bryology. St.-Petersburg: NC RAN; 2005. pp. 171-177

[88] Bezgodov AG. On the bryoflora of the Kungur city environs (Perm Province). Arctoa. 2002;11:53-62. DOI: 10.15298/arctoa.11.07

[89] Djachenko AP, Ignatova EA, Marina IV. Mosses of the Visimskij State Reserve (Middle Ural Mountains). Arctoa. 1996;6:1-6. DOI: 10.15298/arctoa.06.01

[90] Ignatova EA, Ignatov MS, Bezgodov AG. Moss flora of the Basegi State Reserve (Perm Province, Middle Ural Mountains). Arctoa. 1995;4:23-34. DOI: 10.15298/arctoa.04.04

[91] Zheleznova GV. On the moss flora of Kirov Province. Arctoa. 2014;23:212-218. DOI: 10.15298/arctoa.23.18

[92] Fedosov VE, Popov SY. Bryophyte flora of Kostromskaya Taiga Station (European Russia, Kostroma Province). Arctoa. 2004;13:183-195. DOI: 10.15298/arctoa.13.14

[93] Volkova LA, Zhukova AL, Potemkin AD, Nemceva ND. Bryophytes of Darvin State Reserve. In: Flora and vegetation of the Tver Province, Tver’. Tverskoi Gosudarstvennyi Universitet; 1994. pp. 13-24

[94] Notov AA, Spirina UN, Ignatova EA, Ignatov MS. Mosses of the Tver’ Province (Middle Part of European Russia). Arctoa. 2002;11:297-332. DOI: 10.15298/arctoa.11.21

[95] Ignatov MS, Ignatova EA, Kuraeva EN, Minaeva TY, Potemkin AD. Bryophyte flora of Zentral’no-Lesnoj Biosphere Nature Reserve (European Russia, Tver Province). Arctoa. 1998;7:45-58. DOI: 10.15298/arctoa.07.07
[96] Karmazina EV. Ecologo-coenotic characteristics of bryophytes of the national Park «Russian North» [thesis]. Moscow: Lomonosov Moscow State University; 2013

[97] Filippov DA, Boichuk MA. The mosses of Shichengsky Reserve (Vologda Province). Vestnik severnogo (Arkticheskogo) federal’nogo universiteta. Vol. 2. Seria: Estestvennye nauki; 2015. pp. 80-89

[98] Djachenko AP, Djachenko EA. Mosses of the reserve «Denezhkin Kamen’». In: Bryology: Tradition and Modernity. S.-Peterburg: ATTASHE; 2010. pp. 59-64

[99] Ignatova EA, Ignatov MS, Bezgodov AG. Mosses of the Vishera State Reserve (Perm Province, Northern Ural Mountains). Arctoa. 1996;6:7-19. DOI: 10.15298/arctoa.06.02

[100] Zheleznova GV, Shubina TP. Bryoflora of the Pechora-Ilych Biosphere Reserve. In: Flora and vegetation of the Pechora-Ilych Biosphere Reserve. Ekaterinburg: UrO RAN; 1997. pp. 175-210

[101] Zheleznova GV. The moss flora of the European North-East. S.-Peterburg: Nauka; 1994. 149 p

[102] Boichuk MA, Antipin VK, Baklin VA, Lapshin PN. Contribution to the bryoflora of Vodlozero National Park. Novosti sistematiki nizshih rastenii. 2002;36:213-224

[103] Ignatov MS, Ignatova EA, Popov SY, Churakova EY, Braslavskaya TY, Kucherov IB. Mosses. In: Ecosystem Components and Biodiversity of Karst Areas of Russian European North-East. Arkhangelsk: GPZ «Pinezhsky»; 2008. pp. 177-197

[104] Popov SY, Buryanina NN. Ecological features of Sphagnum mosses in the Northern taiga. In: Long-term dynamics of ecosystem components of the natural complex of the Pinezhsky nature reserve and adjacent areas. Arkhangelsk: GPZ «Pinezhsky»; 2012. pp. 51-63

[105] Zheleznova GV, Shubina TP. Mosses of the Belaya River Basin (Northern Timan, Nenets Autonomous District). Arctoa. 2015;24:204-209. DOI: 10.15298/arctoa.24.20

[106] Czernyadjeva IV. The moss flora of the region of Sob Station (Polar Ural). Arctoa. 1994;3:133-138. DOI: 10.15298/arctoa.03.08

[107] Czernyadjeva IV. Moss flora of Yamal Peninsula (West Siberian Arctic). Arctoa. 2001;10:121-150. DOI: 10.15298/arctoa.10.13

[108] Afonina OM, Czernyadjeva IV. Mosses of the Russian Arctic: Check-list and bibliography. Arctoa. 1995;5:99-142. DOI: 10.15298/arctoa.05.07

[109] Natcheva R, Ganeva A. Check-list of the bryophytes of Bulgaria. II. Musci. Cryptogamica Bryologica. 2005;26:149-172

[110] Ignatov MS, Ignatova EA. Moss flora of Middle European Russia. Moscow: KMK Scientific Press Ltd; 2003. 608 p

[111] Maksimov AI, Kuznetsov OL, Maksimova TA. Moss flora of the planned national park Tulos (Republic of Karelia). Novosti sistematiki nizshih rastenii. 2009;36:362-376

[112] Bolyukh VA. A comparison of moss flora of Central Podolia (Ukraine) and adjacent regions. Arctoa. 1995;4:45-54. DOI: 10.15298/arctoa.04.06

[113] Shestakova AA. Ecologo-coenotical and floristical features of organization of bryobiota on the Nizhniy Novgorod Province [thesis]. Nizhniy Novgorod: Lobachevsky State University; 2005
[114] Czernyadjeva IV, Mežaka A, Grishutkin OG, Potemkin AD. Bryophyta of Mordosky Reserve. In: Flora and Fauna of State Reserves. Moscow: Nauka; 2017. p. 29

[115] Silaeva TB, Chugunov GG, Kirjukhin IV, Ageeva AM, Vargot EV, Grishutkina GA, et al. Flora of National Park Smolny. Mosses and vasculars. In: Flora and fauna of National Parks. Moscow: Nauka; 2011. p. 128

[116] Volkova LA, Kuzmina EO, Boch MS, Luknickaya AF, Chaplygina OY, Belyakova RN, et al. Mosses, algae and lichens of Nizhnesvirsky State Reserve. In: Flora and Fauna of State Reserves. Moscow: Nauka; 1996. p. 34

[117] Jandovka LF, Mamonova NS. Most frequent mosses in the Tambov region. TSU Bulletin. 2009;14(1):166-167

[118] Baisheva EZ. Sphagna in the Republik of Bashkortostan (The Southern Ural). In: Materials of the VI International Symposium “Biology of Sphagnum Mosses”; Tomsk. 2016. pp. 11-13