The influence of climatic and topographic parameters on the distribution of forest communities of the Ufa plateau

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Abstract. The purpose of this study was to analyse the influence of climatic and topographic parameters on the distribution of forest communities (on the alliance level) on the Ufa plateau. In order to characterize the features of the forest vegetation habitats of six alliances, topographic parameters were calculated using the digital elevation model SRTM-3, and bioclimatic variables Bioclim (CHELSA). Cluster analysis using climatic characteristics showed that the main factors in the differentiation of alliances are the amount of precipitation in January and in the winter quarter. The amount of precipitation determines the depth of soil freezing and the sufficiency of soil moisture in the initial period of the seasonal development of trees. These factors are the main ones in differentiating the habitats of the communities of the suballiance Tilio cordatae-Pinenion sylvestris from the habitats of the other forest communities. The amount of precipitation in the summer quarter is the next most important climatic parameter, differentiating the habitats of communities. Cluster analysis using topographic parameters showed that the main factors of differentiation of the habitats of the alliances are the profile and plan curvature, slope steepness and aspect. These factors determine the accumulation of soil, moisture and the temperature regime of soils.

1. Introduction

In the Bashkortostan Republic, as well as in the world as a whole, the composition, structure and functions of forests changes are significantly taking place due to the combined influence of natural and anthropogenic factors. These factors are climate change, fires, industrial pollution, massive outbreaks of insect pests, fungal and bacterial diseases, irrational forest management associated with a lack of modern knowledge and a low level of implementation of scientific discoveries [1, 2]. It is relevant to study biodiversity at all levels, as well as the interaction between levels of biodiversity and biotic and abiotic components of ecosystems. A large number of publications, both Russian and foreign [3-10], etc., are devoted to these problems. In the South Ural region, virtually no work has been carried out using the quantitative parameters of the relief and climate. The regions with a high diversity of forest vegetation in a relatively small area are of particular interest in such studies. The Ufa plateau (UP) can be attributed to such areas.

To analyze the composition, structure, factors of the formation and trends in the distribution of forest communities under the anthropogenic impact and climate change, it is necessary to analyze the relationships between climatic and topographic parameters with units of forest vegetation. The purpose of this study was to analyze the influence of climatic and topographic parameters on the distribution and spatial attribution of various types of forest communities (on the alliance level) on the UP.
2. Methods and Materials
The studies were carried out in the territory of the water protection forests of the Pavlovsk reservoir. This area of about 2300 km² is located between 55°13’ and 56°07’ N, and 56°16’ and 57°37’ E (figure 1). The territory is located on the UP and includes forest communities from the water's edge to the flat part on the plateau (distance up to 10-15 km from the reservoir).

In this study 217 geobotanical relevés of forest vegetation were used, performed by the staff of laboratory of Geobotany and plant resources UIB UFRC RAS on sample plots of 400 m² and classified according to the Braun-Blanquet method [11-13]. The main forest communities in the territory of the UP-water protection forests belong to 6 alliances and 8 associations of ecological-floristic classification [14, 15]:

- **Class CARPINO-FAGETEA** Jakucs ex Passarge 1968
  - Order CARPINETALIA BETULI P. Fukarek 1968
  - Alliance Aconito lycoctoni-Tilion cordatae Solomeshchet Grigoriev in Willner et al. 2016
    - Suballiance Tilio cordatae-Pinenion sylvestris Martynenko 2009 prov.
    - Ass. Euonymo verrucosae-Pinetum sylvestris Martynenko et al. 2007 (25 relevés)
  - Class ALNO GLUTINOSAE-POPULETEA ALBAE P. Fukareket Fabijanić 1968
    - Order ALNO-FRAXINETALIA EXCELSIORIS Passarge 1968
      - Alliance Alnion incanae Pawlowski, Sokolowskiet Wallisch 1928
        - Ass. Alnetum incanae Lüdi 1921 (6 relevés)
  - Class ASARO EUROPAEI-ABIETETEA SIBIRICA E Ermakov, Mucinaet Zhitlukhina in Willner et al. 2016
    - Order ABIETETALIA SIBIRICAE (Ermakov in Ermakov et al. 2000) Ermakov 2006
      - Alliance Aconito septentrionalis-Piceion obovatae Solomeshchet et al. ex Martynenko et al. 2008
        - Ass. Chrysosplenio alternifolii-Piceetum obovatae Martynenko et al. Zhitugov 2007 (30 relevés)
        - Ass. Frangulo alni-Piceetum obovatae Martynenko et Zhitugov 2007 (38 relevés)
      - Ass. Brachypodio sylvatici-Abietetum sibiricae Martynenko et Zhigunova 2007 (39 relevés)
  - Class BRACHYPODIO PINNATI-BETULETEA PENDULAE Ermakov, Koroljuket Latchinsky 1991
    - Order CHAMAECYTISO RUTHENICI-PINETALIA SYLVESTRIS Solomeshchet Ermakov in Ermakov et al. 2000
      - Alliance Caraganofruticis-Pinion sylvestris Solomeshchet et al. 2002
tics were calculated using the global digital elevation model SRTM 1arc_V3 with a spatial resolution of one arc second, available on the USGS website [16], and raster layers of 19 bioclimatic variables (Bioclim) with a resolution of 30 arc seconds, available on the website of global climate data CHELSA [17]. Raster layers of 15 topographic parameters were created: elevation above sea level, terrain ruggedness index [18], slope steepness, convergence / divergence index [19, 20], topographic wetness index [21], LS factor [22-24]; plan and profile curvature [25], as well as the proportion of flat and almost flat surfaces (up to 4 °), the proportion of gentle (4-10 °), slightly steep (10-20 °), moderately steep (20-30 °), steep and very steep (more than 30 °) slopes, according to slope classification for mountain areas [26]. The proportions of different steepness of insolated and non-insolated slopes were calculated separately. The calculations were carried out for each geo-referenced relevé of forest communities. Polygons with a size of 20x20 m were created, for which the characteristics were estimated using the Zonal Statistics plugin in QGIS. To identify the role of climatic and landscape characteristics of habitats in the spatial differentiation of forest communities on the UP, two hierarchical cluster analyzes were carried out in the STATGRAPHICS Centurion XV Version 15.1.02 (Nearest Neighbor (Single Linkage) method, distance metric: Squared Euclidean). The average values of climatic characteristics and topographic parameters were used for cluster analysis.

3. Results and Discussion

Figure 2A shows the results of cluster analysis of habitats by topographic parameters. Floodplain forests of the alliance *Alnion incanae* differ most strongly. These communities are found on the UP in the valleys of small rivers flowing into the Pavlovsk reservoir. They are located at the altitude from 162 to 180 meters above sea level. The calculated plan and profile curvature of their habitats indicate concave surfaces, which explains the accumulation of not only soil, but also moisture. Thus, the habitats of the communities of the alliance *Alnion incanae* are separated from the habitats of other alliances by their confinement to concave surfaces with the lowest altitude above sea level.

The rest of the alliances are divided into three groups. First and second groups include alliances *Caragano-Pinion* and *Brachypodio-Pinion* resp. The first alliance represents steppe-grass and shrub pine and larch forests. They are confined to the upper parts of the southern slopes and spurs of ridges at the altitude from 184 to 237 meters above sea level (figure 3). The alliance is characterized by relatively small variability of ecological characteristics. The slope steepness varies from 15 to 37 ° and averages 27 °. These areas are characterized by high values of the ruggedness index and LS factor, which indicates the susceptibility of soils to erosion. The habitats of the communities of the alliance *Caragano-Pinion* differ from the habitats of other alliances in their slope steepness and confinement to insolated slopes. The alliance *Brachypodio-Pinion* combines xerophytic and xeromesophytic herb-green moss pine and larch-pine forests occupying the lower and middle parts of the steep slopes of the banks of the Ufa river and other rivers flowing into the Pavlovsk reservoir. The aspect of the slopes is predominantly southeast and south. These communities are located at the altitude from 134 to 303 meters above sea level. The slope steepness varies from 10 to 37 ° and averages 20 °. The habitats of the communities of the alliance *Brachypodio-Pinion* were separated from the habitats of other alliances in the course of cluster analysis, above all, by the negative value of the convergence index, which indicates converging flows. In addition, these habitats are characterized by high values of the topographic wetness index.
Figure 2. Dendrograms of similarity / difference in habitats of communities of forest vegetation alliances in the territory of water protection forests of the Ufa plateau (A - according to topographic parameters, B - according to climatic characteristics), where TP – suball. *Tilio-Pinenion* (all. *Aconito-Tilion*); AP – all. *Aconito-Piceion*; Pe – all. *Piceion excelsae*; BP – all. *Brachypodio-Pinion*; CP – all. *Caragano-Pinion*; Aln – all. *Alnion incanae*.

Figure 3. Confinement of forest communities of the water-protective forests of the UP to habitats with different aspect.
The third group includes three alliances: Aconito-Tilion, Aconito-Piceion, and Piceionex celsae. The mesophytic communities of the alliances Aconito-Tilion and Aconito-Piceion of these are closest. The first alliance on the UP is represented by one suballiance Tilio-Pinenion, which includes xeromesophytic and mesophytic pine forests with the presence of broad-leaved species in the main tree layer and with a large participation of typical species of nemoral broad-leaved forests in the herbaceous layer. These communities are found at the altitudes from 134 to 274 meters above sea level. They occupy the upper parts of the slopes of various aspect and the flat ridge tops. The steepness of the slopes varies from 0 to 42 °, but the confinement to gentle slopes is more typical. The habitats of the communities of this alliance are characterized by a low ruggedness index, high convergence index and, accordingly, a high topographic wetness index.

The alliance Aconito-Piceion includes dark-coniferous and mixed broad-leaved-dark coniferous hemiboreal forests with the participation of nemoral species, occupying the upper parts of slopes predominantly of west and northwest aspect and flat ridge tops (figure 3). The communities are found at the altitudes from 149 to 329 meters above sea level. In comparison with the suballiance Tilio-Pinenion, this alliance is characterized, by higher variation of ecological conditions, which explains its high syntaxonomic diversity on the UP. Low ruggedness index values indicate confinement to flat areas. The topographic wetness index is high, but lower than in the areas occupied by the communities of the suballiance Tilio-Pinenion.

The alliance Piceion ex celsae combines mesophytic and hygromesophytic dark coniferous green moss forests dominated by spruce in the tree layer. Communities of this alliance occupy the lower and middle parts of steep slopes of the Ufa river valley and its tributaries of mostly northwest aspect. Green moss spruce forests are found at an altitude of 143 to 210 meters above sea level. The steepness of the slopes varies from 9 to 43 ° and averages 27 °. The areas occupied by the communities of this alliance are characterized by a high LS factor, which indicates their susceptibility to erosion. The main factor in the differentiation of the communities of the alliance Piceion ex celsae is their confinement to non-insolated humid slopes. Thus, the communities of the mixed broad-grass forests of the suballiance Tilio-Pinenion and the broad-leaved-dark coniferous forests of the alliance Aconito-Piceion are the closest in relation to the relief elements. The exposition steep south and north aspect of steep slopes determines the distribution and accumulation of moisture and can greatly affect the temperature regime of the soil under the conditions of rugged relief. Thus, the main differentiation factors of habitats of alliances on the UP are the profile and plan curvature, and steepness and aspect of slopes, which determine the accumulation of moisture and the steepness and aspect of slopes and also soil temperature regime.

Figure 2B shows the results of cluster analysis of habitats by climatic characteristics. The first cluster separates the suballiance Tilio-Pinenion from other alliances through more precipitation in the driest month (January), in the driest quarter (January-March) and in the coldest quarter (December-February) of the year. The greater amount of winter precipitation determines the depth of soil freezing and the sufficiency of soil moisture in the initial period of the seasonal development of broad-leaved trees. Second cluster separates communities of the alliance Alnion incanae from all others. The main factors are the greater amount of summer and annual precipitation.

The other two clusters include, respectively, the pairs of the alliances Caragano-Pinion – Brachypodio-Pinion and Aconito-Piceion – Piceion ex celsae. These two clusters differ in the amount of precipitation in the wettest month (July), and in the amount of precipitation in summer and winter. The alliances Caragano-Pinion and Brachypodio-Pinion are close in temperature and precipitation. The reasons for the differences in vegetation are related to the topography, namely, the position on the slope and the topographic features that contribute to the accumulation of precipitation in the habitats of the communities of the alliance Brachypodio-Pinion. Thus, the topography plays a greater role in their difference than the climate.

Similar patterns are observed in the pair of alliances Aconito-Piceion and Piceion ex celsae. Despite the fact that their main climatic differences are associated with the amount of precipitation, which is higher in the habitats of the communities of the alliance Aconito-Piceion, moisture
accumulates in the lower parts of the slope to which *Piceion excelsae* are confined. This is reflected in the profile curvature.

4. Conclusions

According to the results of the cluster analysis using topographic parameters, it was established that the main factors of differentiation of the habitats of the alliances of forest vegetation were the profile and plan curvature, steepness and aspect of slopes. These factors determine the accumulation of soil, moisture and the temperature regime of soils of various relief elements. Cluster analysis using climatic characteristics showed that the main factors in the differentiation of alliances are the amount of precipitation in January and in the winter quarter. The amount of precipitation determines the depth of soil freezing and the sufficiency of soil moisture in the initial period of the seasonal development of trees. These factors are the main ones in differentiating the habitats of the communities of mixed coniferous-broadleaf forests from the habitats of the forest communities of other alliances. The amount of precipitation in the summer quarter is the next most important climatic parameter, differentiating the habitats of communities of different alliances. The differences in the mean monthly and mean annual air temperatures in the habitats of communities of different alliances on the Ufa plateau are insignificant. Thus, the climate determines the distribution of the communities of the suballiance *Tilico cordatae-Pinenion sylvestris* due to the greater amount of precipitation of the winter quarter, which ensures less soil freezing. The distribution of communities of the other five alliances is determined mainly by the topographic features.

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