Biological diversity and spatial structure of the anthropogenic landscape flora

Yu V Kuleshova¹, T V Agapova and S S Meshkova
Krasnoyarsk State Agrarian University, 660130, 90, Mira ave., Krasnoyarsk, Russian Federation

¹E-mail: julia.kuleshova@yandex.ru

Abstract. The article considers the biodiversity and spatial structure of the urban flora as a complex phenomenon formed as a result of the interaction of natural and anthropogenic ecosystems. The data of the chorological analysis of the urban flora demonstrate the genesis of the species diversity and the relationship with other botanical and geographical areas, while being of great importance in predicting the ways of its formation. The purpose of this research was to study and analyze the spatial distribution of the flora species composition of Sosnovoborsk (south of Central Siberia, Krasnoyarsk Territory). The study of plant biodiversity was carried out using a special research method of urbanized territories - the model allocation method in combination with traditional route surveys. The types of areas and their elements were determined using the literature data of fundamental floristic and monographic summaries. In the course of the analysis, the types of areas identified by other authors studying the floras of various Siberian regions were taken as a basis. As a result of the study, 387 species of vascular plants were determined, distributed in 231 genera and 62 families. The chorological analysis showed the dominance of Eurasian and Euro-Siberian geographical elements, as well as the belonging of the flora of Sosnovoborsk to the subboreal type, formed on the basis of forest-steppe with a high activity of boreal species.

1. Introduction
At the moment, a significant part of the vegetation cover is under the influence of various anthropogenic factors. This impact is particularly represented in industrial and recreational areas. In its turn, the plant framework of urban ecosystems, adapting in a peculiar way, is transformed into new urbanized flora with new features of the species composition. Progressive urbanization is a powerful factor in the transformation of the environment, not always reflected in positive changes, which often leads to the degradation of vegetation cover, the threat of extinction of many rare species, and in general, to a significant reduction in natural resources. Therefore, the identification and analysis of the plant species diversity of different territories is still one of the priorities in modern research [1; 2].

Vegetation cover is an integral part and a significant environmental factor in the ecology of the city. The development of the industrial and recreational structure of megacities in the modern world leads to a reduction in biological diversity, since not all species are able to adapt and successfully exist in the changed environmental conditions under the influence of human activity. Of course, it is a reason of the species diversity depletion of urbanized territories. At the same time, the duration and scale of anthropogenic impact is of great importance in the process of changing the biodiversity of vegetation cover [3; 4]. Plant resources in the ecological structure of the city are a kind of filter of atmospheric air...
and at the same time represent an aesthetic value. The peculiarity of urban flora is determined not only by the preserved and adapted native plant species, but also by the inclusion of naturalized and successfully renewed introduced plants, invasive representatives.

One of the interesting representatives of the young urbanized environment, first studied in terms of the state and features of biodiversity of the vegetation cover as an indicator of a favorable ecological atmosphere, is Sosnovoborsk. The territory within the administrative boundaries of the town is differentiated into areas associated with different types of anthropogenic impact, including recreation areas, housing developments, industrial areas, wastelands, sanitary-protected areas, suburban areas, field lands removed from crop rotation. Native vegetation has been preserved in fragments on the territory of the town due to its natural ability to self-regulate and reproduce. Biodiversity and the spatial structure of flora in the urban environment are considered as a complex phenomenon that is formed as a result of the interaction of natural and anthropogenic ecosystems.

The inventory of the Sosnovoborsk’s flora shows a sufficiently rich and heterogeneous species composition of vascular plants, including 387 species, distributed in 231 genera and 62 families. The biodiversity of the vegetation cover of the town, due to the intact nature of its territories, has not only successfully adapted urbanophilic plants, but also rare, beautiful-flowering and red book species, preserved and concentrated mainly in isolated areas of the sanitary protection zone and the urban forest park. Among them there are representatives of the family Orchidaceae - Cypripedium calceolus L., Cypripedium guttatum Sw., Cypripedium macranthon Sw., Neottianthe cucullata (L.) Schlecht., Platanthera bifolia (L.) Rich, growing in groups or sparsely abundant rare representatives on the territory of the forest park. It should be noted that there is a very rare occurrence in a mixed pine forest and at the same time a fairly large abundance of the beautifully flowering red book representative Cypripedium guttatum Sw. In addition, for the first time for the flora of Central Siberia, a new species of Fabaceae - Securigera varia L. was found near the industrial territory and is probably an accidental species [5].

The types of areas of the identified representatives of this urbanized environment, as well as their elements, were determined using the literature data of fundamental floral summaries and modern monographs. In the course of the analysis, the types of areas identified by other authors in the study of floras of various Siberian regions were taken as a basis [6]. The data of the chorological analysis of the urban flora characterize the genesis of the species diversity and the relationship with other botanical and geographical areas, while being of great importance in predicting the ways of its formation.

2. Problem statement
The increase in the urban population and the escalation of anthropogenic impact on the environment is a powerful factor in the transformation of vegetation cover, producing the emergence of a qualitatively new plant biodiversity, which is an integral part of the ecological structure of the city. Urban flora has its own characteristics of the species diversity formation, accompanied by the reduction of certain representatives and the emergence of new ones under the influence of human economic activity. The identification and analysis of the distribution of species composing the native urban flora demonstrate the role of allochthonous processes in its formation, the peculiarities of the genesis of species diversity and relations with other botanical and geographical areas, which is of great importance in predicting and managing changes in vegetation cover.

3. Research questions
The research of the biodiversity of the vegetation cover of Sosnovoborsk is interesting because of the "youth" of its urbanized environment and the study of the "behavior" of species in these changed, but still forming conditions. The town is located in the Krasnoyarsk Territory to the north-east of the regional center in the south of Middle Siberia and was founded in 1971, characterized by a developing social infrastructure. The name of the town, assigned to it in 1973, is associated with the surrounding pine and pine-birch forests. The characteristic features of the urban area are the intensive construction of residential areas and the allocation of the "green zone" as a recreational territory consisting of areas of native flora and introduced plant communities. These include the forest park, Esaulovka river bank, a
sanitary protection zone consisting of herbaceous native vegetation and introduced tree stands. The total area of the "green zone" within the administrative boundaries of the town is about 50 hectares. However, this "green" territory includes the share of agroecenoses occupied by garden plots and agricultural lands that have lost their functional significance, as well as lawn and house territories.

In this regard, the object of the study was the vegetation cover within the administrative boundaries of the city; the subject was the species diversity and geographical distribution of the highest flora representatives of Sosnovoborsk.

Geographically, Sosnovoborsk is located almost in the center of the Asian part of Russia (56° 08' n. l. and 93° 08' e. l.) at the junction of the western edge of the Middle Siberian Plateau, the south-eastern Yenisei strip of the Western Siberian Plain and the Altai-Sayan Mountains from the south. According to the zoning of the Krasnoyarsk Territory, the location of the urban territory is connected with belonging to a complex intermountain country consisting of a series of isolated depressions of the Kansk-Achinsk lowland. The physical and geographical zoning of the Krasnoyarsk Territory shows the eastern border of Western Siberia, which runs along the right bank of the Yenisei River along the edge of the third terrace in the north after the mouth of the Angara River and in the southern part of the Krasnoyarsk Territory passes to the left bank. Therefore, the location of the town is a border between such physical and geographical countries as Western Siberia, Middle Siberia and the Altai-Sayan mountain country. According to the data of the natural zoning of the Krasnoyarsk Region, the studied territory belongs to the Middle Siberian country, located in the zone of subtaiga and island forest-steppe near its southern border. Floristically, Sosnovoborsk is located in the Krasnoyarsk-Kansk province, a subzone of the northern forest-steppe, in the Yeniseisk district of the Krasnoyarsk Region [7].

4. Purpose of the study
The purpose of this research was to study and analyze the spatial distribution of the flora species composition of Sosnovoborsk - a satellite town of Krasnoyarsk (south of Central Siberia, Krasnoyarsk Territory). The main tasks included floristic and geobotanical studies, inventory of species diversity, cameral processing, determination of the systematic position of higher plants and the main arealogue groups with detailed geographical elements.

5. Research methods
As the main method of research of the vegetation cover biodiversity, the method of model allocations was chosen, the advantage of which is the high information content of the material and the objectivity of the allocated boundaries. At the same time, this method combines geobotanical, floristic and ecotopological methods of research of plant biodiversity. The method was developed by the Russian scientist N.G. Ilminskikh, who believed that from the entire general combination, including all subscape urban elements and partial floras, it is possible to distinguish the most representative contours (model allocations) that characterize the general combination of floras as a whole [8]. The selection of model allocations was carried out in accordance with certain methodological requirements, including the equal size of the plots, the typical use of the urban area, environmental and visual isolation. For several years, a seasonal repetition of research was carried out in the planned areas in order to minimize random facts. Inside the model plots, a complete description of all isolated and different microecotopes (mound, slope, ravine, separate lawn, part of the park, etc.) was made. The size of the contour of the model allocation, taken conventionally as a square, was 250x250 meters. In addition, the traditional route method of field research was used.

The types of areas and their elements were determined using the literature data of fundamental floristic summaries, plant determinants and the latest monographs [9; 10]. In the course of the analysis, the types of areas identified by other authors studying various regions of Siberia were taken as a basis. In addition, the stock collections of the Herbarium of L.M. Cherepnin of the Krasnoyarsk State Pedagogical University, the Herbarium of the Siberian Federal University, the Krasnoyarsk Regional Museum of Local Lore, the Herbarium of P.N. Krylov of the Tomsk State University, the Herbarium of the Central Siberian Botanical Garden SB RAS, the Herbarium of the Dresden Technical University
were analyzed.

The analysis of the spatial (geographical) distribution of the species composing the urban flora is an important indicator of the unique features of the genesis and connections with the floras of other botanical and geographical regions. Plant areas, clearly reflecting their current distribution, at the same time indicate the history of the species composition formation of the vegetation cover in a gradually changing physical and geographical environment [11]. As a result of the research of the floral diversity of Sosnovoborsk, 387 species of vascular plants were identified, distributed in 231 genera and 62 families. In the process of arealological analysis, the entire set of plant species of this territory was distributed into 5 main groups and 7 geo-elements.

The cosmopolitan group includes 29 species widely distributed around the globe, which are mainly ruderal plants with a wide ecological amplitude (*Amarantus retroflexus*, *Urtica dioica*, *Potentilla anserina*, etc.).

The Holarctic includes 60 species distributed in Eurasia and extratropical North America (*Geum aleppicum*, *Equisetum pratense*, *Poa pratensis*, etc.).

Eurasian is the most numerous and heterogeneous group, consisting of 229 species distributed within the Eurasian continent. The group has the following geo-elements: the Eurasian geo-element from 85 meadow, meadow-steppe, coastal and weed-ruderal plant species distributed in the territories of the Holarctic Kingdom and the Old World (*Arctium tomentosum*, *Vicia cracca*, *Trifolium pratense*, etc.), the Euro-Siberian Far Eastern geo-element from 51 species of forest, meadow, wetland plants distributed in Europe, Siberia and the Russian Far East (*Salix viminalis*, *S. dasyclados*, etc.), the Euro-Siberian geo-element of 93 boreal species distributed in Europe and Siberia (*Galium verum*, *Poligala hibrida*, *Erodium cicutarium*, etc.), including various types of areas: Euro-East Siberian, Euro-Middle Siberian, Euro-West Siberian, Euro-Baikal, East European-Siberian, North European-Ural-Siberian. The Euro-Siberian geo-element is formed by forest, meadow, meadow edge, meadow steppe, wetland plant groups and ruderal species.

The Asian North American group consists of 5 species found within North America and North Asia (*Beckmannia syzigachne*, *Pulsatilla patens*, etc.).

The Asian group consists of 64 species distributed in Western and Eastern Siberia, the Far East, Eastern, Central and Central Asia (*Hordeum brevisubulatum*, *Potentilla acaulis*, etc.) and includes the following geo-elements: East Asian of 20 species distributed in Siberia and extratropical East Asia - North Eastern China, Manchuria, Eastern Mongolia, Japan, Korea, southern Russian Far East (*Sedum aizoon*, *Artemisia integrifolia*, etc.), Central Asian - of 10 species entering the territory of Southern Siberia (*Populus laurifolia*, *Potentilla sericea*, etc.), Middle Asian - of 9 species associated with the territories of the West Asian subregion of the Iran-Turan region (*Sedum hybridum*, *Carum buriaticum*, etc.), Siberian - of 21 species found throughout Siberia. The Siberian geo-element includes several types of areas: Native Siberian, West Siberian, East Siberian, South Siberian, and Mongolian South Siberian.

6. Findings
The spectrum of the ratio of the main geo-elements shows that the majority of species - 92.5 % of the flora of Sosnovoborsk belongs to the areas of Euro-Asian and North American territories, and only 7.5 % of the flora, being cosmopolitan, has an even wider distribution.

If we compare the data obtained with the zonal flora of the Krasnoyarsk forest-steppe, the number of pluri-regional species in the flora of Sosnovoborsk is twice as high, which emphasizes the uniqueness and originality of the urban flora. At the same time, the basis of the flora of Sosnovoborsk is almost equally composed of Boreal sub-kingdom species - 43.7 % and wide-area species - 45%, slightly exceeding the boreal species. But compared to the background zonal indicators of the Krasnoyarsk forest-steppe, these urban indicators are slightly lower.

It should also be noted that the spatial structure of the Sosnovoborsk flora is dominated by wide-area species, showing that the studied species composition belongs to the flora of the cold and temperate cold zones, as well as the presence of migration processes in the formation of urban flora.

Eurasian species (22 %) and Holarctic species (15.5 %) are particularly distinguished, emphasizing
the historical links with the northern hemisphere floras. Boreal species are distributed as much as possible in the Euro-Siberian (24 %), a smaller but significant share belongs to the Euro-Siberian Far Eastern (13.2 %) and Siberian types of areas.

The revealed diversity of geo-elements in the Asian group is due to the complexity of the physical and geographical location of Sosnovoborsk, located at the junction of the West Siberian, Middle Siberian and Altai-Sayan floral provinces. The predominance of Siberian species in the Asian group (6.5 %) emphasizes and confirms the zonal features. The insignificant participation of the flora of South Siberian and Mongolian South Siberian species (2.8 %) indicates a low level of originality of the town’s flora and a low role of autochthonous processes. Feature of the geographical location of Sosnovoborsk is also confirmed by the presence of differential species in the flora that are located near the borders of their distribution. So, near the northern border of the area are Artemisia glauca, Juncus vvedenskyi, Elytrigia geniculata, Carduus thoermeri, Salix cinerea, Campanula sibirica grow on the north-eastern and eastern borders of the distribution. Only one species from the East Asian group, Carex lanceolata, reaches the western border of its area. Thus, the areological analysis of the flora of Sosnovoborsk indicates the predominance of the western element over the eastern one.

7. Conclusion
The distribution of species in the main chorological groups indicates the heterogeneous nature of the flora of Sosnovoborsk, due to the complex ecotonic position of the study area. The predominant share of wide-area species over South Siberian ones indicates allochthonous processes in the formation of urban flora. The revealed diversity of relations with the flora of other botanical and geographical areas is explained by the peculiarity of the town’s position on the border of the floral zoning areas of different ranks: the West Siberian, Middle Siberian and Altai-Sayan provinces; Circum-boreal and Iran-Turan regions; Boreal and Ancient Mediterranean sub-kingdoms; at the boundary of two long-range sectors of Northern Asia and Eurasia: continental West Siberian-Near-Asian and sharply continental East Siberian-Central-Asian [12; 13]. Thus, the chorological analysis showed the dominance of the Euro-Asian and Euro-Siberian geographical elements in the spatial structure of the flora, as well as the belonging of the vegetation cover of Sosnovoborsk to the subboreal type (40.8 %), formed on the basis of forest steppe and highly active boreal plant species.

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