Ecological-coenotic structure of the pine forest flora at the southern margin of the geographical range of *Pinus sylvestris* L.

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Abstract. The ecological-coenotic structure of pine forest flora was compared at the southern margin of the geographical range of *Pinus sylvestris*. The Usmansky and Khrenovsky (Voronezh and Lipetsk regions), Krasnosamarsky and Buzuluksky (Samara and Orenburg regions) pine forests were investigated. The species diversity of vascular plants in the studied forests included also the alien and introduced species. The coenotic structure reflects the zonal location of the pine forests and their current state. The zonal coenoses are resistant for the penetration of alien species. The meadow component brings the most number of species into the plant diversity of the pine forests (23.3–25.2%). The pine forests, located in forest-steppe zone (Usmansky and Khrenovsky), are characterized by high species diversity of the forest and pine-forest component (20.4% and 20.2%), while in Buzuluksky and Krasnosamarsky pine forests, located in the steppe zone, it is significantly lower (19.6% and 15.7%, respectively). Meantime, the steppe component is more pronounced in the pine forests located in the steppe zone of the Trans-Volga Region (Buzuluksky, 21.9%, and Krasnosamarsky, 24.8%), while in forest-steppe pine forests Khrenovsky and Usmansky, it is quite lower, 16.4% and 15.5%, respectively. In the Usmansky pine forest, every third alien species of vascular plants is of cultural origin (escapee), in Khrenovsky and Buzuluksky, every fourth, and in Krasnosamarsky, every fifth species.

1. Introduction

Monitoring and conservation of the diversity of higher plants are based on ideas about the composition and structure of flora, which, in turn, depend on natural and anthropogenic factors. The ecological-coenotic structure reflects the features of the flora at the landscape level of organization, where the distribution of species is preconditioned by edaphic, micro- and mesoclimatic factors [1; 2]. Data on the environmental requirements and coenotic preferences of the species are traditionally used in comparative floristry [2—5].

The ecosystems that develop in extreme, or close to extreme, conditions are the most sensitive to the environmental changes. The forests at the southern margin of geographical range of *Pinus sylvestris* L. (further on, pine forests), located in sub-arid climate, are the examples of such ecosystems in the steppe and forest-steppe zones.
Figure 1. Schematic map of location of the studied pine forests (Crichfield, Little, Jr., [6], with modifications). Legend: 1 – main range of *Pinus sylvestris*; 2 – areas isolated from the main range of *Pinus sylvestris*; 3 – studied pine forests: 1 – Usmansky, 2 – Khrenovsky, 3 – Buzuluksky, 4 - Krasnosamarsky.

2. Materials and Methods

Floristic surveys were performed in the Usmansky and Khrenovsky pine forests located in the forest-steppe zone (Voronezh and Lipetsk regions), and Krasnosamarsky and Buzuluksky pine forests located in the steppe zone (Samara and Orenburg regions) (figure 1).

The floras of the studied pine forests were also analyzed using the available literary sources [7-11]. Each species was defined as belonging to the certain ecological-coenotic group, which was a group of plant species that had similar environmental and habitat requirements, i.e. a similar set of environmental factors inherent in a biotope of a particular type, characterized by a high degree of mutual conjugation and confined to habitats of a certain type [12].

Ecological-coenotic groups belonging to a certain ecosystem (forest, steppe, etc.) are combined in corresponding components:

1) Forests and pine forests (combines the groups of forest, woodland edge, swamp-forest, coastal-forest, meadow-forest, woodland edge of pine forest, psammophytic-pine forest, and psammophytic/petrophytous forest ecosystems);
2) Woodland edge (groups of woodland edge, swamp-woodland edge, and coastal woodland edge ecosystems);
3) Meadow (groups of meadow, swampy-meadow, woodland edge-meadow, coastal-meadow, weedy-meadow, and halophytic-meadow ecosystems);
4) Swampy (groups of swampy, meadow-swampy, and coastal-swampy ecosystems);
5) Coastal water (groups of coastal, water, and coastal-water ecosystems);
6) Steppe (groups of steppe, meadow-steppe, woodland edge-meadow-steppe, woodland edge-steppe, petrophytous-steppe, psammophytic-steppe, and desert-steppe ecosystems);
7) Multi-complex component consists of groups that include species that are characteristic of both the listed components and weed coenoses (groups of forest-weedy, coastal-forest-
Weedy, meadow-weedy, halophytic meadow-weedy, forest-meadow-weedy, meadow-steppe-weedy, steppe-weedy, and halophytic-weedy ecosystems). There are three more groups of the same name corresponding to the (8) halophytic, (9) weedy, and (10) cultivated components.

### 3. Results and Discussion

The taxonomic diversity of the studied pine forests varied from 674 species in the Krasnosamarsky pine forest up to 1076 species in the Usmansky pine forest; 794 and 850 species were found in the Buzuluksky and Khrenovsky pine forests, respectively (table).

| Pine forest     | Number of families | Number of genera | Number of species | Species          |
|-----------------|--------------------|------------------|-------------------|------------------|
|                 | indigenous  | alien  | introduced  | indigenous  | alien  | introduced  |
| Usmansky        | 123          | 512    | 848          | 216          | 8      |
| Khrenovsky      | 108          | 430    | 718          | 130          | 2      |
| Buzuluksky      | 101          | 282    | 675          | 112          | 4      |
| Krasnosamarsky  | 93           | 352    | 591          | 80           | 3      |

Ecological-coenotic structure of the florals of the studied pine forests is presented on figure 2. In the Usmansky pine forest, the largest number of species belongs to the meadow component, followed by forest and boreal components with a significant dominance of indigenous species. Such a pattern is typical for the regional floras of the Central Black Soil (Chernozem) Region [1; 8; 9], where alien species account for about 3% of the total number of species. Alien species’ presence in coenotic groups differs from that of indigenous species [13; 14]. The species belonging to the steppe component are also numerous. Despite the dominance of indigenous species, the share of alien species here reaches 10.8%. The weedy component comprises more than 50% of all alien species registered in the flora of the Usmansky pine forest and 4.7% of indigenous species (apophytes). Woodland edge and swamp components are represented mostly by indigenous species (excluding *Typha laxmannii* Lepech., the only alien species of the coastal-swamp group in the floras of all the studied pine forests). These data are consistent with the studies by Y.K. Vinogradova et al. [13], which state the lowest number of alien species in the swamp ecosystems comparing to other types of ecosystems. *Crataegus sanguinea* Pall. is the only woodland edge component of alien flora in the Usmansky and Khrenovsky pine forests. On the contrary, the cultivated component of the flora is represented exclusively by alien and introduced species. The coastal-water multi-complex components include both indigenous and alien species.

The flora of Khrenovsky pine forest includes numerous meadow, forest and pine forest components (figure 2B). Indigenous species prevail here, the share of alien species is 2.8% in the meadow and 1.7% in the forest and pine-forest ecological-coenotic components. Steppe component also plays significant role in flora of the Khrenovsky pine forest. Indigenous species form the flora basis, alien species comprise 7.2% of the species diversity. Weedy component is presented mostly by alien species, 39.3% of the registered species are apophytes. Woodland edge and swamp components are presented by indigenous species (excluding *Crataegus sanguinea* and *Typha laxmannii*). The cultivated component combines introduced and alien species, with a significant predominance of the latter. There are few species in the coastal-water coenotic component, most of them are indigenous. The halophytic and multi-complex ecological-coenotic components are characterized by the lowest species diversity, represented by both indigenous and alien species.
Figure 2. Ecological-coenotic structure of the floras of the studied pine forests with reference to indigenous, alien, and introduced plant species. The pine forests: (a) Usmansky; (b) Khrenovsky; (c) Buzuluksky; (d) Krasnosamarsky.

The species of the meadow and steppe components are the absolute dominants in the coenotic structure of the flora of the Buzuluksky pine forest, represented by a significant share of indigenous species (figure 2C). The number of alien species is not high, comprising 2.2% in the meadow component and 9.2% in the steppe component. Forest and pine-forest components are among the top three in the eco-coenotic structure of the Buzuluksky pine forest, most of species are indigenous, and only 4.5%, alien. The weedy component are represented mostly by alien species; apophytes comprise 32.3%. The woodland-edge component is represented by alien species, the swamp component, mostly by indigenous species (excluding Typha laxmannii). The cultivated component is significant in terms of the number of alien and introduced species. This is due to the active introduction of trees and shrubs in the forest and the uncontrolled spread of some cultivated plants. The coastal-water component combines both indigenous and alien species. The multi-complex component is represented by the smallest number of species.

The coenotic structure of the Krasnosamarsky pine forest was earlier analyzed by N M Matveev [15], our data fit these results well. The meadow and steppe coenotic components dominate in the pine forest flora, represented mostly by indigenous species (figure 2D). The forest and pine-forest components are among the top three by the number of species of coenotic components. The
indigenous species dominate. The alien species bring the most to the weedy-coenotic component (73.0%). The woodland-edge and halophytic components are represented in the Krasnosamarsky pine forest by indigenous species only. One alien species (Typha laxmannii and Lappula squarrosa (Retz.) Dumort.) was found in the swamp and multi-complex component, respectively. Cultivated component is represented by alien and introduced species only.

4. Conclusion
The meadow component is represented by the largest number of predominantly indigenous species in all the studied pine forests, from 23.3% in the Usmanky pine forest to 25.2% in the Buzuluksky pine forest. The Usmansky and Khrenovsky pine forests, located in forest-steppe zone on the Oka-Don Lowland, are rich in forest and pine-forest components (20.4% and 20.2%, respectively) due to favorable conditions. Pine forests located in the steppe zone are characterized by lower number of this component, 19.6% in the Buzuluksky pine forest and 15.7% in the Krasnosamarsky pine forest. Meantime, the steppe component is the most essential in the pine forests located in the steppe zone of the Trans-Volga Region, 21.9% in the Buzuluksky pine forest and 24.8% in the Krasnosamarsky pine forest, in the forest-steppe Khrenovsky and Usmansky pine forests, as low as 16.4% and 15.5%, respectively.

The main number of alien species is observed in weedy (73%, the Krasnosamarsky pine forest) and cultivated (up to 93.3% in the Khrenovsky pine forest) components. Every third alien species of vascular plants registered in the Usmansky pine forest flora is an escapee, every fourth species, in the Khrenovsky and Buzuluksky pine forests, and every fifth, in the Krasnosamarsky pine forest. The share of alien species in the forest and pine-forest ecological-coenotic component is much lower, about 3%, except that in the Buzuluksky pine forest (6.3%). This is probably due to the fact that this forest area experiences a stronger influence of the steppe climate comparing to other studied pine forests, so it is less resistant to the penetration of alien species into the forest and pine-forest communities. On the contrary, the share of alien species in the steppe component in the forest-steppe forests increases by 2.5–3.0 times as compared to the forest and pine-forest components. Meantime, in the Buzuluksky pine forest, the share of alien species decreases in this component, which is probably due to the resistance of zonal communities to the penetration of alien species.

The woodland-edge and swamp ecological-coenotic components in the florlas of the studied pine forests are represented mostly by low number of indigenous species, evidencing on a high stability of the woodland-edge and swamp communities to the penetration of alien species.

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