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SPECIES DIVERSITY AND STRUCTURE OF THE SAXICOLOUS FLORAL COMPLEX IN THE AKTOBE FLORISTIC DISTRICT

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SUMMARY

The study of the Aktobe floristic district is a relevant task for assessing anthropogenic factors' impacts on the flora of the steppe zone and developing measures to reduce the adverse effects of mining, metallurgical, and oil and gas facilities on the biodiversity of plant communities. The timely study evaluated the species composition and analyzed the saxicolous floral complex of the Aktobe floristic district, one of the most fascinating complexes based on florogenetics. The saxicolous complex flora comprised 219 species belonging to 119 genera and 39 families. However, the 10 leading families of the conglomerate manage 75.0% of the species composition of the saxicolous complex. Previous validations revealed that the saxicolous floral complex features have dominant families of Caryophyllaceae, Boraginaceae, and Chenopodiaceae and a more significant role for the Rosaceae and Scrophulariaceae. The saxicolous complex specificity has demonstrated the genera Potentilla and Centaurea as 2nd and 3rd position holders, respectively, and the presence of the genera *Orobanche*, *Lappul*a, *Atraphaxis*, and *Allium* as the leading genera; however, they are unregistered among the other floral complexes. The analysis of geographical habitat types has shown that the Black Sea/Kazakhstan, Volga/Kazakhstan, and Eastern ancient Mediterranean habitat types are predominantly characteristic of the saxicolous floral complex. Twelve endemic species have also received recognition, assembling 60% of the endemic flora. Based on the analysis of species habitat, its ecological and biological features, and paleobotanical material available in literature sources, researchers have identified two groups of miscellaneous plants (Neogene and Quaternary) with their ages and endemic plants. Data also indicated the formation of the chief autochthonous core of the flora in the Pleiocene-Holocene.

Keywords: Flora, floristic complex, life forms, habitat, disjunction, relic, endemic plant

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Key findings: The study and analysis of species composition in the saxicolous floral complex of the Aktobe Floristic District identified 12 endemic species, which generally comprised 60% of the endemic flora. Observations of the heterogeneity and heterochronism of the florogenesis processes also transpired based on the analysis of habitats, the phenomenon of disjunction, and the study of relics and endemic plants.

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INTRODUCTION

With the enhanced anthropogenic impact on natural ecosystems, biological diversity is considerably and rapidly declining worldwide, which may have significant direct human health impacts if ecosystem services no longer become satisfactory to meet social needs. Therefore, it is necessary to develop adequate measures to protect natural ecosystems based on identifying fundamental patterns that determine the ecological structure of regional biota, including plant communities. In this regard, studies of plant communities in various habitats based on varied approaches (taxonomic, geographical, biomorphological, ecological, and cenotic) are relevant (Demidova and Prilepsky, 2014; Sorokina and Kumacheva, 2021; Vakhlamova *et al.,* 2022).

Widely used approaches based on floristic zoning, comprising the allocation of subordinate regions that differ in their characterized floral composition, help portray the flora of various geographical zones. The said zoning can also solve several scientific and practical problems, namely, establishing patterns of spatial differentiation of plant communities and identifying plant species characteristic of certain territories. It also includes studying the impact of anthropogenic impacts on the composition of plant communities and recognizing the areas most in need of protection, as well as, studying the history of flora in different regions and predicting possible scenarios for developing plant communities in diverse circumstances (Bubyreva, 2004; Zanina *et al*., 2022).

The flora analysis requires a comprehensive study of its floristic complexes, including classifying their correct types, to make it complete. The research focuses on flora (and floral complexes in particular) at the Aktobe Floristic District (AFD), located in the territory of the northeastern part of West Kazakhstan. However, most of the sector of the Aktobe region (which is in the western part of Kazakhstan) has locations at the junction of Europe and Asia in the steppe zone (Aipeisova, 2012a, 2012b, 2012c, 2013, 2016, 2017, 2018; Utarbayeva and Aipeisova 2016; Aipeisova and Utarbayeva 2022). The steppes of the AFD are an example of intensive anthropogenic pressure on the ecosystem of an entire landscape zone since intensive development of mineral, oil, and gas fields persisted on its territory and adjacent areas (Izbastina *et al.,* 2018).

Therefore, the study of the AFD floristic complex is a relevant task for assessing the impact of anthropogenic factors on the flora of the steppe zone, developing measures to reduce the adverse influences of mining, metallurgical, and oil and gas facilities on the biodiversity of plant communities, and identifying the most threatened species and territories. Past studies assessed the systematic, bioecological, and geographical composition of the floristic complexes of the AFD, as well as, the analysis of endemic and relict plants and the habitats of various plant species (Aipeisova 2012a, 2012b, 2012c, 2013, 2016, 2017, 2018; Utarbayeva and Aipeisova, 2016; Aipeisova and Utarbayeva, 2022).

The AFD flora consisted of eight floristic complexes, i.e., steppe floristic complex (StFC), calciferous floristic complex (CFC), saxicolous floristic complex (SFC), psammophilic floristic complex (PFC), forest floristic complex (FFC), meadow floristic complex (MFC), halophilic floristic complex

(HFC), and aquatic and coastal-aquatic floristic complex (ACFC) (Aipeisova, 2016). The saxicolous floristic complex (SFCs) of various regions underwent dynamic scrutiny as their study was of great importance based on identifying a large variety of endemic plants, as well as, developing measures for their conservation (Grechushkina, 2011; Kovaleva, 2013; Ivanov and Kovaleva, 2014; Sadyrova and Baijigytov, 2019).

In addition, the petrophytes can be the basis for the development of bioremediation technologies for territories exposed to mining and metallurgical enterprises, as they often pioneer plant species that form a soil layer for further plant growth and therefore are of great interest for the reclamation and revegetation of mining waste dumps (Karimi *et al.,* 2018; Gastauer *et al.,* 2022). The presented study evaluated the species composition and analyzed the AFD's SFC, one of the most interesting complexes based on florogenetics.

MATERIALS AND METHODS

The object of the study was the diversity and structure analysis of the saxicolous floristic complex (SFC) of the Aktobe Floristic District (AFD). The AFD is in the territory of the northeastern part of West Kazakhstan, with most of the area of the Aktobe region lying between 51°30′ and 61°30′ E and 51°45′ and 47°30′ N, occupying an area of 160,000 km^2, in a site located at the junction of Europe and Asia in the steppe zone. The said research's implementation was according to long-term material collected by the site investigation methods, analysis of herbarium collections in Kazakhstan, and generalization of literature data.

In the pertinent study, the classical botanical, ecological, and geographical approaches' use further explored the SFC. A chorionomic approach also helped identify the types of flora habitats (Takhtajan, 2009). The habitats' types are indicative of the entire habitat they belong to, and most of it to phytochorions. The naming of plant species was according to the Takhtajan system (Takhtajan, 2009). The analysis of the ratio of life forms in the SFC ensued according to the Serebryakov classification (Aipeisova, 2017).

RESULTS

Overall, the saxicolous floristic complex (SFC) of the Aktobe Floristic District (AFD) comprised 39 families, 119 genera, and 219 species. The superfamily taxa ranged in importance as follows: *Rosidae*: 64 species and 30 genera (29.09%); *Lamiidae*: 41 species and 20 genera (18.7%); *Asteridae*: 36 species and 17 genera (16.4%); *Caryophyllidae*: 32 species and 18 genera (14.6%); *Dilleniidae*: 22 species and 18 genera (10.0%); *Liliidae*: 16 species and nine genera (7.3%); *Ranunculidae*: six species and four genera (2.7%); *Polypodiopsida*: two species and two genera (0.9%); and *Gnetopsida*: one species and one genus (0.4%). The 10 leading families of the SFC accounted for 75.0% of the species composition and variation (Table 1). The leading genera also demonstrated the specifics of the SFC (Table 2).

A comparison of the participation of genera allows for identifying the specifics of the SFC, which consists of the following: 1) the highest in the second position occupied by the genus *Potentilla* and the third position occupied by the genus *Centaurea*, where, in the regional spectrum of genera, the genus *Potentilla* only occupies the sixth position and the genus *Centaurea* the eighth; the absence of any polymorphic genus from the *Brassicaceae* and *Chenopodiaceae* families; and the presence of *Orobanche*, *Lappula, Atraphaxis, and Allium* in the leading genera, although they are not yet registered among the foremost families in other floral complexes (Aipeisova, 2013).

The review of the most polymorphic genus, *Astragalus,* established the specifics of the SFC. Of the 50 species of genus *Astragali* of the AFD, 16 species (32.0%) gained inclusion in the SFC. One must note that of the 16 species, nine were obligate petrophytes (56.2%). The genus *Astragali* of this floristic complex has its chief representation by the species section of the subgenus *Cercidothrix*. In this subgenus, the *Erioceras* section is richly distinguishable by three obligate petrophytes

Table 1. Leading families of the Saxicolous Floristic Complex (SFC).

Family No.	Leading families	Number of species	Total number of species of the Saxicolous Floristic Complex (%)
1	*Asteraceae*	36	16.4
2	*Fabaceae*	29	13.2
3	*Caryophyllaceae*	16	7.3
4-5	*Brassicaceae*	15	6.8
4-5	*Boraginaceae*	15	6.8
6	*Rosaceae*	14	6.4
7-8	*Scrophulariaceae*	10	4.5
7-8	*Poaceae*	10	4.5
9	*Chenopodiaceae*	8	3.6
10-11	*Polygonaceae*	6	2.7
10-11	*Apiaceae*	6	2.7

Table 2. The spectrum of the leading genera of the Saxicolous Floristic Complex (SFC).

Genus No.	Leading genera	Number of species	Total number of species of the Saxicolous Floristic Complex (%)
1	*Astragalus*	16	7.3
2	*Potentilla*	8	3.6
3	*Centaurea*	7	3.2
4-5	*Silene*	6	2.7
4-5	*Lappula*	6	2.7
6-7-8-9	*Artemisia*	5	2.3
6-7-8-9	*Veronica*	5	2.3
6-7-8-9	*Orobanche*	5	2.3
6-7-8-9	*Stipa*	5	2.3
10-11-12	*Dianthus*	4	1.8
10-11-12	*Atraphaxis*	4	1.8
10-11-12	*Allium*	4	1.8

species (*Astragalus arcuatus, Astragalus egiosegas,* and *Astragalus subarcuatus*).

Two species represent the *Xiphidium* and *Trachycercis* sections of said subgenus *Cercidothrix*, and the other three sections (*Cystodes, Paraxiphidium, Helmia*) are single-species. The second subgenus based on species number is *Astragalus*, represented by three single species: *Myobroma* (*Astragalus buchtormensis), Ankulotus (Astragalus stalinskyi*), and *Alopecias (Astragalus vulpinus)*. The third subgenus, *Phaca,* has a one-species representation (*Astragalus oxyglottis*) with a section of the same name.

The analysis of the life forms of the SFC showed the predominance of polycarpic herbaceous plants, with 121 species and 55.0% of the total number of species of the SFC (Figure 1). The following groups of polycarpic plants were short-rhizomatous (10.5%), long-rhizomatous (4.6%), and cespitose-rhizomatous (4.1%) (Figure 1). The second placer among the groups of life forms of the SFC is the monocarpic grasses, which account for 25.0% of the total number of species of the SFC, among which the annual long-growing plants predominate (17.3%).

The arboreous forms (19.1%) followed the group of monocarpic plants . This group also has two types of life forms dominating it, i.e., dwarf semi-shrubs (9.1%) (*Dianthus campestris*, *Silene suffrutescens, Camphorosma monspeliaca, Nanophyton erinaceum, Kochia prostrata, Alyssum lenense*, and *Alyssum tortuosum*) and erect deciduous shrubs (7.8%) (*Atraphaxis frutescens, Atraphaxis spinosa, Cotoneaster melanocarpus,* and *Spiraea crenata).* The smallest number of species represents graminiform ferns (0.9%). These were *Cystopteris fragilis* and *Asplenium*

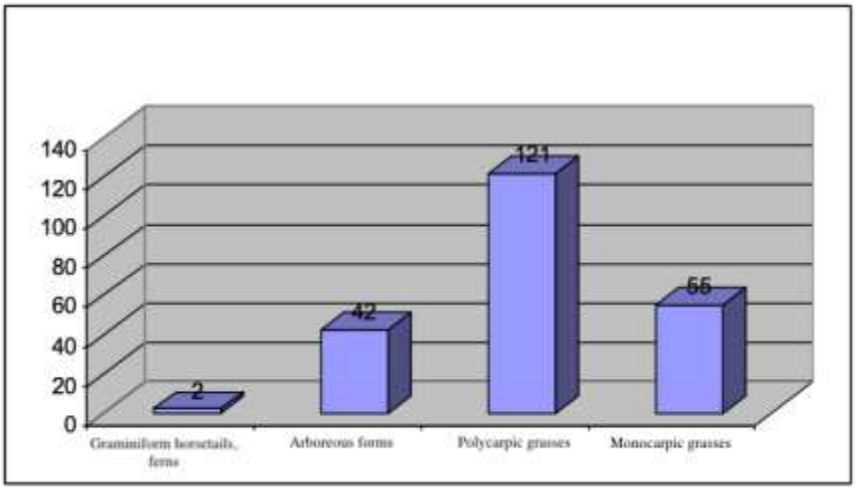

Figure 1. The ratio of life forms of the Saxicolous Floristic Complex (SFC) species.

septentrionale, which were obligate petrophytes of the flora.

The ratio of life forms of the SFC appears in Figure 1 which corresponds to the soil conditions of the complex. The number of exclusive species of the SFC comprises 63 species (28.8%) of the total number of species found in SFC (*Silene altaica, Ribes saxatile, Sedum mugodsharicum, Oxytropis mugodsharica, Cystopteris fragilis, Gypsophila patrinii, Rubus sachalinensis,* and *Astragalus mugodsharicus*). The analysis of geographical types shows that the Eastern Ancient Mediterranean, Black Sea/Kazakhstan, and the Trans-Volga/Kazakhstan habitat types were the most conventional ones in the SFC (Table 3).

The ratio of habitat group types showed that more than half of the SFC species were from the Eurasian steppe group (58.0%), followed by the Ancient Mediterranean group (27.8%), with the smallest group in percentage was the widespread group (14.1%). In general, these were species with habitats that do not go beyond the steppe zone and species with habitats within the steppe zone of Eurasia, forest-steppe zones of Europe and Siberia, together with widespread species, outweigh the share of the group of Ancient Mediterranean species and those connecting the steppe and desert zones (Aipeisova, 2012a). The 25 species of the SFC were of disjunctive habitat nature.

According to spatial disjunction, the disjunctive habitat species' distribution was as follows: four species *(Rubus sachalinensis, Potentilla argentea, Astragalus subarcuatus,* and *Hypericum scabrum*) were mega-disjunctive, 13 species *(Fumaria schleicheri, Eremogone koriniana, Eremogone saxatilis, Astragalus arkalycensis, Astragalus buchtormensis, Astragalus helmii, Lappula brachycentroides, Linaria altaica, Elytrigia prunifera,* and *Asplenium septentrionale*) were meso-disjunctive, and eight species (*Atraphaxis virgata, Hieracium procerum, Chelidonium majus, Stipa kirghisorum, Stipa orientalis*, etc.*)* were macro-disjunctive. Based on the available paleobotanical data, literature sources, and the species habitats, this study believes that the formation of mega-disjunctive habitats occurred in the Pliocene, macro-disjunctive at the end of the Pliocene and Pleistocene, and meso-disjunctive habitats at the end of the Pleistocene and in the Holocene (Aipeisova, 2012b).

The study of flora relics and endemic plants, along with the disjunction, further permits the research to draw phlorogenetic conclusions. Based on the analysis of the general habitat of the species, its ecological and biological features, and paleobotanical material available in literature sources, the two groups of relics in the flora identified in the Aktobe Floristic District (AFD) are Neogene and

Quaternary. The analysis further indicated that the composition of the SFC includes Pliocene desert-steppe relics *(Stipa capillata and Stipa pulcherrima)*, Pliocene desert-steppe relics *(Anabasis salsa* and *Nanophyton erinaceum),* Nemoral Pliocene relics (*Asplenium septentrionale* and *Rubus sachalinensis*), Pleistocene relics (*Rosa acicularis* and *Cystopteris fragilis*), Pleistocene-Holocene relics (*Orostachys spinosa, Sedum hybridum, Silene altaica, Thalictrum foetidum,* and *Linaria altaica*), and Holocene relics (*Scabiosa isetensis).* Jointly, the remnants, disjunctive habitat species, and endemic species can better demonstrate the heterogeneity and heterochronism of the AFD flora.

Table 3. Distribution of the Saxicolous Floristic Complex (SFC) plants by habitat types.

Habitat type	Number of species	Total number of types in the Saxicolous Floristic Complex (%)
Pluriregional	1	0.45
Holarctic	11	5.0
Holarctic/Ancient Mediterranean	1	0.45
Palearctic	11	5.0
Arctic/Asian/North American	1	0.45
Ancient Mediterranean	2	0.9
European/Ancient Mediterranean	16	7.3
Eastern Ancient Mediterranean	20	9.1
European/Eastern Ancient Mediterranean	9	4.1
Iranian/Turanian	9	4.1
Turanian	5	2.3
Asian	1	0.45
European	1	0.45
European/Siberian	2	0.9
Eastern European/Asian	1	0.45
European/Black Sea/Kazakhstan	1	0.45
European/Central Asian/Black Sea/Kazakhstan	2	0.9
European/Central Asian/Trans-Volga/Kazakhstan	4	1.8
European/Trans-Volga/Kazakhstan/Mountain Central Asian	1	0.45
European/Trans-Volga/Kazakhstan/Turanian	1	0.45
European/Trans-Volga/Kazakhstan/Siberian	3	1.4
European/Trans-Volga/Kazakhstan	1	0.45
Eastern European/West Kazakhstan	4	1.8
Black Sea/Kazakhstan	22	10.0
Black Sea/Kazakhstan/Turanian	9	4.1
Caucasus/Trans-Volga/Kazakhstan/Turanian	4	1.8
Caucasus/Trans-Volga/Kazakhstan/Iranian/Turanian	1	0.45
Trans-Volga/Kazakhstan	21	9.5
Trans-Volga/Kazakhstan/Mongolian/Siberian	5	2.3
Trans-Volga/Kazakhstan/Siberian	5	2.3
Trans-Volga/Kazakhstan/Turanian/Mongolian	3	1.4
Trans-Volga/Kazakhstan/Turanian	14	6.4
West Kazakhstan	1	0.45
West Kazakhstan/Turanian	1	0.45
Mugalzhar	5	2.3
Mugalzhar/Aral	1	0.45
Ural	2	0.9
Emba/Mugalzhar/Aral	1	0.45
South Ural/Central Kazakhstan	1	0.45
Black Sea/Kazakhstan/Mountain Central Asian	4	1.8
Trans-Volga/Kazakhstan/Mountain Central Asian	6	2.7
West Kazakhstan/Turanian/Mountain Central Asian	2	0.9
Mugalzhar/Altai	1	0.45
Ural/Mountain Central Asian	2	0.9

Endemism is an essential indicator reflecting the idea of the originality of the flora, allowing researchers to draw florogenetic conclusions. The SFC includes 12 endemic species (60% of the total number of endemic flora species: five endemic and seven subendemic ones), which is 60% of the total number of endemic species of Kazakhstan flora. The investigation identified the following endemic plants as part of the saxicolous floristic complex:

Megacarpaea mugodzharica Golosk. et Vass: A narrow-locality species whose distribution is limited to the rocky slopes of the central part of the Mugodzhar ridge. The species is closest to the widespread *Megacarpaea megalocarpa* (Fish. ex DC.) B.Fedtsch. This species was probably based on a narrow-locality Mugalzhar population of *Megacarpaea megalocarpa*. *Megacarpaea mugodzharica* is a Holocene autochthonous neoendemic by origin (Aipeisova, 2012c).

Sedum mugodsharicum Boriss: A narrow-locality species described from the Berchogur tract. By origin, it is a Holocene autochthonous neoendemic plant like the previous species.

Vincetoxicum mugodsharicum Pobed: A narrow-locality species found only in Mugodzhar ridge. It is an autochthonous Holocene neoendemic by origin.

Arthrophytum pulvinatum Litv: Probably a mesochronoendemic species with Pliocene/Pleistocene age.

Jurinea mugodcharica Iljin, a semi-shrub: A steno-endemic species with a very limited habitat in the Mugodzhar district (near the city of Boktybai). It is a Holocene neoendemic by origin.

Subendemic species *Astragalus mugodsharicus* Bunge: A confinite West Kazakhstan subendemic. The possible formation of *Astragalus mugodsharicus* occurred based on the Mugalzhar population of *Astragalus zingeri.* A quaternary Holocene neoendemic.

Astragalus subarcuatus M. Pop: A duplicate Mugalzhar/Aral/Kashgar subendemic plant. It is probably a Paleoendemic, dating back to the Miocene/Pliocene.

Lappula brachycentroides M. Pop: An extensive Mugalzhar/Central Kazakhstan subendemic species (with disjunctive habitat). Its age is probably Pleistocene/Holocene.

Tanacetum saxicola (Krasch.) Tzvel: A confinite subendemic species with an Emba/Mugalzhar habitat. The species is found in the Mugodzhar district and the middle course of the Emba River. A Pleistocene/Holocene neosubendemic species.

Dianthus uralensis Korsh: A confinite Ural Holocene subendemic. A Pleistocene/Holocene neosubendemic.

Elytrigia prunifera Nevski: A confinite Ural Holocene subendemic.

Artemisia lessingiana Bess: A confinite West Kazakhstan subendemic. A Pleistocene-Holocene neoendemic.

The recorded data revealed the formation of the chief autochthonous core of the flora of the AFD in the Pliocene/Holocene period. The ratio of groups of disjunctive habitat species, relicts, and endemic plants in the AFD's SFC confirms the heterogeneity and heterochronism of the flora. The study's opinion is consistent with the geographical location of the studied habitats and the history of their development.

DISCUSSION

The features of the Saxicolous Floristic Complex (SFC) of the Aktobe Floristic District (AFD) were of the highest position of the *Caryophyllaceae, Boraginaceae, and Chenopodiaceae* and the more significant role of the *Rosaceae* and *Scrophulariaceae* families than in the CFC and PFC of the AFD (Aipeisova, 2016). In general, the leading families were consistent with the recorded data on the flora of the northern temperate zone, differing only in their ranking. It has validation from the rocky flora of the Ural river valleys, in which the head part of the spectrum comprised representation of families, such as, *Fabaceae*, *Asteraceae*, and *Poaceae* (Knyazev, 2018), and the flora of the Southern Rocky Mountains of Central Colorado (Fowler *et al*., 2014), where the most abundant families were *Asteraceae* (104 species), *Poaceae* (58 species),

Cyperaceae (57 species), and *Brassicaceae* (42 species).

Pyak (2003) reported the formidable development of underground plant organs as a morphological adaptation of petrophytes. The presented study showed that the polycarpic grass type and the dominant group were taproot graminiform plants (58 species, 26.4%), characteristic of soils with a dense substrate that does not contribute to vegetative reproduction. One of the most vital indicators of the systematic structure of the flora was the generic coefficient, which in the AFD flora was 1.8. However, it was close to this indicator of the saxicolous floristic flora of the Russian Altai, where it equals 1.7 (Pyak, 2003).

In the flora of rock expositions and crevices in the Mazandaran Mountains of Northern Iran, the generic coefficient was equal to 1.4 (Naqinezhad and Esmailpoor, 2017). For the Russian Caucasus, this indicator was 3.3 (Kovaleva, 2013; Ivanov and Kovaleva, 2018; Magomedova, 2022). It was interrelated with the geographical location and different histories of petrophyte community formation, as well as, with soil and climatic conditions. Its confirmation came from studies of flora of marble expositions and nearby matrices in the mountains of Central Argentina.

The rock expositions of those mountains differed in floral composition and the ratio of life forms, as well as, in diagnostic types depending on the substrate rocks (Cantero *et al.,* 2021). The structure and various aspects of the flora and vegetation of rock expositions resulted in the research of Nowak *et al.* (2014) and Pigott and Sage (1997). It has also been noticeable that plants of the dominant genera can best benefit the reclamation of waste dumps and soil purification from heavy metals (Prasad and Freitas, 1999; Karimi *et al.,* 2018; Raklami *et al*., 2022).

CONCLUSIONS

The species composition and analysis of the Saxicolous Floristic Complex (SFC) of the Aktobe Floristic District (AFD) revealed that 12 endemic species were identifiable, accounting for 60% of the overall endemic flora. Based on the analysis of the general habitat of the species, its ecological and biological features, and paleobotanical material available in literature sources, two groups of relics emerged, i.e., Neogene and Quaternary, with the estimated age of the heirlooms, as well as, endemic plants, established. The data indicating the formation of the chief autochthonous core of the flora was in the Pleiocene/Holocene. The heterogeneity and heterochronism of the florogenesis processes were also observable based on the analysis of habitats, the phenomenon of disjunction, and the study of relics and endemic plants. The study is limited to 12 identified endemic species; thus, further research should focus on other endemic flora species.

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