Kragujevac J. Sci. (2025) 47 (1) UDC 581.92:552.47:551.435.11:502.13:(497.11)
doi: *Original scientific paper*

FLORISTIC DIVERSITY IN THE BRDJANI GORGE: ASSESSMENT OF ENDANGERMENT AND CONSERVATION MEASURES

Nenad M. Zlatić[1]*, Milan S. Stanković

University of Kragujevac, Faculty of Science, Department of Biology and Ecology, Radoja Domanovića No 12, 34000 Kragujevac, Republic of Serbia
*Corresponding author; E-mail: nenad.zlatic@pmf.kg.ac.rs

(Received November 20, 2024; Accepted January 29, 2025)

ABSTRACT. The aim of this study is to better understand the floristic composition of the Brdjani Gorge serpentinite habitat, focusing on diversity, conservation status and possible conservation strategies for specific plant groups. The results show that the gorge area is populated by 119 plant species distributed across 85 genera and 36 families. Among these species, there are autochthonous species specific to the habitat, such as *Asplenium adulterinum, Hemionitis marantae, Halacsya sendtneri* and *Silene paradoxa*. Upon reviewing the IUCN Red List shows that most species are classified as "Not evaluated," indicating that the conservation status of these species still needs to be studied in detail. However, human activities such as the construction of the municipal landfill pose a significant threat to the native plant species. Due to the important role of serpentinite habitats in the conservation of biodiversity, immediate action is needed to protect this valuable area in Serbia.

Keywords: ultramafic/serpentinite, edaphic endemism, serpentinophytes, conservation

INTRODUCTION

Plants that grow on special substrates such as serpentinite are attracting a great deal of attention due to their major contribution to global biodiversity (ALEXANDER *et al*., 2007). Serpentinite rocks make up less than 1% of the total continental crustal surface (KAZAKOU *et al*., 2008). Compared to other geological parent materials, they are less widespread in Europe and are mainly concentrated on the Balkan Peninsula (STEVANOVIĆ *et al*., 2003). The diverse climatic, orographic, hydrological and geological characteristics of the Balkan Peninsula have resulted in complex diversity of ecosystems. The significant occurrence of disjunct serpentine habitats also contributes significantly to the overall diversity of flora on the Balkan Peninsula. In Serbia, serpentinite occupies about 15% of the total area and contributes to some extent to the formation of mountain ranges (STEVANOVIĆ *et al*., 2003).

ORCID ID:
N. Zlatić - 0000-0002-7845-4825; M. Stanković - 0000-0001-9861-7700.

Serpentinite substrates are a well-known example of a harsh environment for plants (ZLATIĆ *et al*., 2017). Serpentinite (ultramafic) soil is a special substrate characterized by exceptional chemical and physical properties. The most important chemical properties include a disturbed mineral composition, a deficiency of important nutrients such as Ca, P, N, K, an altered ratio of Ca to Mg and an increased content of heavy metals such as Mn, Ni, Cr. Notable physical characteristics of this soil type include its shallow depth, skeletal structure and specific water and temperature conditions, which result in a limited and less productive vegetation (BRADY *et al*., 2005; ALEXANDER *et al*., 2007; ZLATIĆ and STANKOVIĆ, 2019).

Edaphic factors influence the development of various morpho-anatomical and ecophysiological traits in plants and lead to adaptive reactions. This leads to the emergence of different groups of species adapted to a wide range of edaphic conditions, as well as specialized groups adapted to specific substrate types, known as particular edaphic ecotypes. The complex adaptation mechanisms that plants have developed to their substrate determine the distribution of ecological groups, with some species being strictly restricted to certain substrates. However, some species groups exhibit a certain degree of tolerance to different edaphic conditions, leading to the differentiation of obligate and facultative ecological groups based on substrate type and associated edaphic ecotypes (ZLATIĆ and STANKOVIĆ, 2019). Obligate serpentinophytes are typically endemic species of serpentinite in the Balkan Peninsula. Their habitats are sites of differentiation and speciation in this part of Europe. Between facultative and obligate serpentinophytes there are certain differences in the structure and function of plant organs that enable them to cope with nutrient deficiencies and other types of environmental stress. The most important area in Europe for obligate serpentinophytes is the Balkans, where 123 taxa are represented. Facultative serpentinophytes exhibit the "serpentine syndrome," characterized by a complex of morpho-functional adaptations that differentiate plant populations present on serpentine soils from those of plants living on other substrates (STEVANOVIĆ *et al*., 2003).

The vegetation found on such soils is degraded, characterized by low growth and specific functional and structural adaptation characteristics, which leads to its classification in a separate ecological group called serpentinophytes. Numerous studies show that vegetation communities occurring on different serpentine soils share common characteristics regardless of their climatic zones. The formation of such specific flora is attributed to the characteristics of serpentine soils, which are characterized by unique physical and geochemical properties. Serpentine areas are characterized by low species richness and diversity, the presence of unique morphological features and the presence of paleo- and neoendemic species, making serpentine areas important in terms of global biodiversity (BRADY *et al*., 2005).

One such habitat is the Brdjani Gorge in the central part of Serbia, which is increasingly affected by anthropogenic factors such as urban landfills and the construction of a highway nearby. Due to the specific substrate type and the presence of endemic species, the mentioned locality was investigated in the framework of the composition of rudimentary and alternative serpentinophytes (VIĆENTIJEVIĆ-MARKOVIĆ, 2004), the study of the adaptive response of serpentinophytes to the physico-chemical conditions of the serpentine soil (VICIĆ, 2014) and the development of a phytocenological study of the vegetation dominated by species of the genus *Stipa* L. (KABAŠ *et al.,* 2013). The aim of this research is to obtain a better insight into the floristic composition of the Brdjani Gorge, its diversity, the endangered status of species and possible conservation measures for certain plant groups.

MATERIALS AND METHODS

Basic characteristics of the investigated locality

The research area is concentrated in a relatively small area with a high degree of geological complexity. The research area was selected as a representative section of the gorge,

as it includes the locality where most of the investigations were conducted. The examined area covers approximately 600.000 m^2. The presence of extensive serpentinite masses is remarkable in this area, and their geomorphology plays a decisive role in shaping the characteristics of the studied region. The study locality is located in the central part of Serbia, near Gornji Milanovac, at the geographical coordinates N 43°59'24.545"; E 20°25'14.454", with an altitude of 300 to 400 meters and southwest-facing slopes with an inclination of 45° (Figure 1). The area is surrounded by Mount Vujan and the Despotovica River flows through it. However, in the section of the Brdjani Gorge in the valley of the Despotovica River, the anthropogenic impact is considerable, mainly due to the presence of a municipal landfill, which weakens the primary influence of the parent material on soil formation.

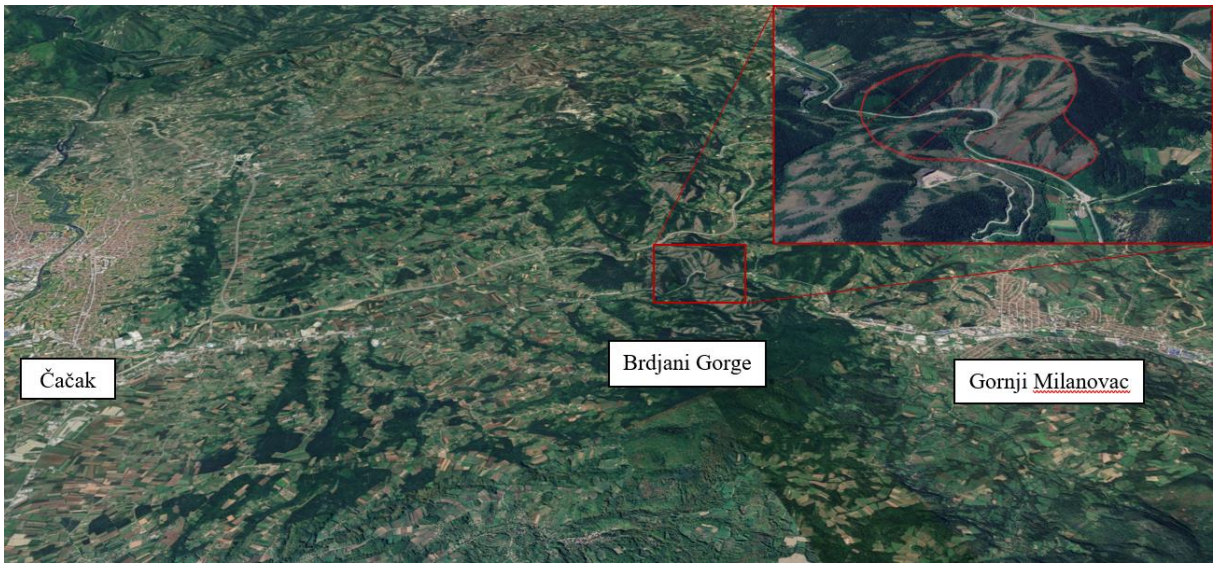

Figure 1. Geographical position of the researched locality in relation to nearby larger cities, including the research area

Climate characteristics of the locality

Climate characteristics of the researched locality were derived from data in the global climate database WorldClim version 2.1 (FICK and HIJMANS, 2017). This data could illustrate the climatic conditions in which specific flora develops on serpentinites.

Based on the global climate database, the Brdjani Gorge locality has an average annual temperature of 10.6°C. The range of mean monthly temperatures is 9.9°C. Isothermality is 32.7, and temperature seasonality is 749.2. The maximum temperature of the warmest month is 26.3°C, while the minimum temperature of the coldest month is -3.9 °C. The annual temperature range is 30.2°C. The mean temperature of the wettest quarter is 17.8°C, while the mean temperature of the driest quarter is 2.6°C. The mean temperature of the warmest quarter is 19.5°C, and that of the coldest quarter is 1.0°C. The annual precipitation is 793 mm, with the highest monthly precipitation being 89 mm and the lowest 50 mm. The precipitation seasonality is 19.7 mm. For the researched area, precipitation in the wettest quarter is 256 mm, and in the driest quarter is 158 mm. Precipitation in the warmest quarter is 229 mm, while in the coldest quarter is 172 mm.

The field research was conducted during the vegetation period of 2023 as part of a one-year project titled "Monitoring and Assessment of the Serpentinite Floristic Diversity with the Focus on the Endemic Species and *Paraceterach marantae* (L.) R. M. Tryon (Pteridaceae)" funded by Rufford Foundation (https://www.rufford.org/). The study was concentrated on a limited section of the Brdjani Gorge, characterized by the presence of distinct and ecologically significant plant species. This targeted approach allowed for detailed

investigation of the most representative and biologically unique areas within the constraints of the project's duration. It involved photography, collection, and inventorying of plant species, with their identification using various literature (JOSIFOVIĆ, 1970-1977; SARIĆ and DIKLIĆ 1986; SARIĆ, 1992; (ANONYMOUS, 2024a). The taxonomic overview of species is standardized according to the World Flora Online (WFO) database (ANONYMOUS, 2024a). The analysis of life forms within the total flora of Brdjani Gorge was conducted according to the RAUNKIAER (1934). The floristic elements are determined and categorized into defined area types and area groups, which were modified for the territory of Serbia according to STEVANOVIĆ (1992) and BRKOVIĆ (2015). All data were consolidated into a special electronic database application, and accurate geographical coordinates for each phytocoenological record were determined using GPS devices.

RESULTS AND DISCUSSION

In the floristic composition of Brdjani Gorge, a total of 119 plant species classified into 85 genera and 36 families were recorded. Based on the floristic composition, a Table showing the systematic affiliation of the identified species was constructed (Table 1).

Table 1. Floristic composition of Brdjani Gorge

No.	Family	Species	Life form	Area type	Status according to IUCN
1.	Aspleniaceae	*Asplenium adiantum-nigrum* L.	G*	COS**	LC***
2.		*Asplenium adulterinum* Milde^{+}	H	CE	VU
3.		*Asplenium ruta-muraria* L.	Ch	HOL	LC
4.	Amaryllidaceae	*Allium flavum* L.	G	MWA	LC
5.		*Allium moschatum* L.	G	MWA	LC
6.	Anacardiaceae	*Cotinus coggygria* Scop.	P	MWA	LC
7.	Apiaceae	*Seseli rigidum* Waldst. & Kit.	H	SCEm	NE
8.	Asparagaceae	*Muscari botryoides* (L.) Miller	G	EWA	NE
9.		*Ornithogalum orthophyllum* Ten.	G	MWA	NE
10.		*Ornithogalum umbellatum* L.	G	MWA	NE
11.	Asteraceae	*Artemisia alba* Turra	Ch	SEm	LC
12.		*Centaurea stoebe* L.	H	EWA	NE
13.		*Doronicum columnae* Ten.	G	SCEm	NE
14.		*Leontodon crispus* Vill.	H	MWA	NE
15.		*Leontodon hispidus* L.	H	EWA	NE
16.		*Picris hieracioides* L.	H	EA	NE
17.		*Pilosella piloselloides* (Vill.) Soják	H	MWA	NE
18.		*Sonchus asper* (L.) Hill	H	HOL	NE
19.		*Tragopogon dubius* Scop.	T	EWA	NE
20.		*Taraxacum officinale* Web.	H	COS	LC
21	Boraginaceae	*Halacsya sendtneri* (Boiss.) Dörfler^{++}	G	SEm	NE
22.		*Buglossoides arvensis* (L.) I.M.Johnst.	T	EA	NE
23.		*Onosma heterophylla* GriCEb.	Ch	MSM	NE

Table 1.continued

No.	Family	Species	Life form	Area type	Status according to IUCN
24.	Brassicaceae	*Aethionema saxatile* (L.) R. Br.	Ch	MSM	NE
25.		*Odontarrhena chalcidica* (Janka) Španiel, Al-Shehbaz, D.A.German & Marhold[++]	Ch	MWA	NE
26.		*Brassica rapa* L.	T	ADV	DD
27.		*Erysimum diffusum* Ehrh.	H	EA	NE
28.		*Erysimum linariifolium* Tausch	Ch	SEm	NE
29.		*Neslia paniculata* (L.) Desv.	T	EA	NE
30.		*Thlaspi kovatsii* Heuffel	H	SCEm	NE
31.	Campanulaceae	*Campanula rapunculus* L.	H	EWA	NE
32.	Caprifoliaceae	*Scabiosa columbaria* L.	H	EWA	NE
33.		*Cephalaria transsylvanica* (L.) Schrad.	T	PON	NE
34.	Caryophyllaceae	*Cerastium brachypetalum* Pers.	T	EWA	NE
35.		*Cerastium glutinosum* Fries	T	EWA	NE
36.		*Gypsophila muralis* L.	Ch	MSM	NE
37.		*Herniaria hirsuta* L.	H	EA	NE
38.		*Herniaria incana* Lam.	H	MWA	NE
39.		*Minuartia verna* (L.) Hiern.	Ch	EA	DD
40.		*Petrorhagia saxifraga* (L.) Link	H	EWA	NE
41.		*Scleranthus perennis* L.	T	SCEm	NE
42.		*Silene bupleuroides* L.	Ch	EA	NE
43.		*Silene paradoxa* L.	H	MSM	NE
44.	Crassulaceae	*Sedum acre* L.	H	EWA	LC
45.		*Sedum album* L.	H	EWA	NE
46.		*Sedum rupestre* L.	Ch	CE	NE
47.	Cyperaceae	*Carex caryophyllea* Latourr.	H	EA	NE
48.		*Carex humilis* LeysCEr	H	EA	NE
49.		*Carex pallescens* L.	H	HOL	NE
50.		*Carex paniculata* L.	H	CE	LC
51.		*Carex vulpina* L.	H	EA	LC
52.	Euphorbiaceae	*Euphorbia cyparissias* L.	H	EWA	NE
53.	Fabaceae	*Astragalus onobrychis* L.	Ch	EWA	LC
54.		*Cytisus nigricans* L.	Ch	MWA	LC
55.		*Cytisus procumbens* (Waldst. & Kit. ex Willd.) Spreng.	Ch	PON	LC
56.		*Genista pilosa* L.	Ch	EWA	NE
57.		*Genista tinctoria* L.	Ch	EWA	NE
58.		*Medicago falcata* L.	H	COS	DD
59.		*Medicago prostrata* Jacq.	H	SEm	LC
60.		*Robinia pseudacacia* L.	P	ADV	NE
61.		*Coronilla varia* L.	H	EWA	LC
62.		*Vicia villosa* Roth	H	MWA	NE
63.	Fagaceae	*Quercus cerris* L.	P	MSM	LC
64.		*Quercus petraea* (Mattuschka) Liebl.	P	EWA	LC
65.		*Quercus pubescens* Willd.	P	MWA	LC

Table 1.continued

No.	Family	Species	Life form	Area type	Status according to IUCN
66.	Hypericaceae	*Hypericum barbatum* Jacq. $^{++}$	H	SCEm	NE
67.	Iridaceae	*Crocus vernus* (L.) Hill	G	SCEm	NE
68.	Lamiaceae	*Acinos alpinus* Moench	Ch	SEm	LC
69.		*Ajuga genevensis* L.	H	EWA	NE
70.		*Ajuga pyramidalis* L.	H	EWA	NE
71.		*Stachys recta* L.	H	SEm	NE
72.		*Teucrium montanum* L. $^{++}$	Ch	SCEm	LC
73.		*Thymus longicaulis* C. Presl	Ch	MSM	NE
74.		*Thymus pannonicus* All.	Ch	MSM	NE
75.		*Thymus serpyllum L.* $^{++}$	Ch	EWA	LC
76.	Oleaceae	*Fraxinus ornus* L.	P	MWA	LC
77.		*Ligustrum vulgare* L.	P	EWA	NE
78.	Orobanchaceae	*Orobanche alba* Stephan ex Willd.	T	MWA	NE
79.		*Orobanche purpurea* Jacq.	T	MWA	NE
80.	Papaveraceae	*Chelidonium majus* L.	H	EA	LC
81.		*Fumaria officinalis* L.	T	EA	LC
82.		*Papaver rhoeas* L.	T	EWA	LC
83.	Pteridaceae	*Hemionitis marantae* (L.) Christenh $^{+}$	G	HOL	NT
84.	Pinaceae	*Pinus nigra* Arnold	P	SEm	LC
85.	Plantaginaceae	*Plantago lanceolata* L.	H	COS	LC
86.		*Linaria genistifolia* (L.) Miller	H	MWA	NE
87.		*Veronica austriaca* subsp. *jacquinii* (Baumg.) Watzl	H	MWA	NE
88.	Plumbaginaceae	*Goniolimon tataricum* (L.) Boiss.	H	PON	NE
89.	Poaceae	*Bromus erectus* Hudson	H	EWA	LC
90.		*Bromus riparius* Rehmann	H	EWA	NE
91.		*Chrysopogon gryllus* (L.) Trin.	H	EA	NE
92.		*Festuca heterophylla* Lam.	H	CE	LC
93.		*Festuca pratensis* Hudson	H	EA	NE
94.		*Festuca rupicola* Heuffel	H	EWA	NE
95.		*Festuca valesiaca* Schleicher ex Gaudin	H	EA	NE
96.		*Koeleria pyramidata* (Lam.) Beauv.	H	CE	NE
97.		*Melica ciliata* L.	H	MWA	NE
98.		*Melica nutans* L.	H	EA	NE
99.		*Milium vernale* M.Bieb.	H	HOL	NE
100.		*Poa bulbosa* L.	H	EA	NE
101.		*Sesleria serbica* (Adamović) Ujhelyi^{++}	H	SEm	NE
102.		*Stipa pennata* L.	H	PON	NE
103.	Polygalaceae	*Polygala supina* Schreber	Ch	EA	NE
104.	Polygonaceae	*Reynoutria japonica* Houtt.	G	ADV	NE
105.		*Rumex acetosella* L.	H	HOL	LC
106.	Ranunculaceae	*Helleborus odorus* Waldst. & Kit.	G	MWA	NE
107.		*Ranunculus millefoliatus* Vahl	G	MSM	NE

Table 1.continued

No.	Family	Species	Life form	Area type	Status according to IUCN
108.	Rosaceae	*Potentilla alba* L.	H	EWA	NE
109.		*Potentilla heptaphylla* L.	H	EWA	NE
110.		*Potentilla incana* P. Gaertner, B. Meyer & Scherb.	H	MWA	NE
111.		*Potentilla tommasiniana* F. W. Schultz	H	EWA	NE
112.		*Sanguisorba minor* Scop.	H	EA	NE
113.	Rubiaceae	*Galium lucidum* All.	Ch	MSM	NE
114.		*Galium mollugo* L.	H	EA	LC
115.	Rutaceae	*Dictamnus albus* L.	Ch	EWA	LC
116.	Sapindaceae	*Acer tataricum* L.	P	EA	LC
117.	Scrophulariaceae	*Verbascum thapsus* L.	H	EWA	LC
118.	Violaceae	*Viola arvensis* Murray	T	EA	LC
119.		*Viola tricolor* L.	H	MSM	LC

*Life-form categories: Phanerophyte (P); Chamaephyte (Ch); Hemicryptophyte (H); Geophyte (G) and Therophyte (T).

**Area type: Adventive (ADV); Central European (CE); Cosmopolite (COS); Eurasian (EA); European-Western Asian (EWA); Holarctic (HOL); Mediterranean sub-Mediterranean (MSM); Mediterranean-West Asian (MWA); Pontic (PON); South-Central European – mountain (SCEm); South European – mountain (SEm).

***Categories of species endangerment according to IUCN: VU (vulnerable – taxa with a high risk of extinction due to a population decline of 30% to 50% over the past 10 years); NT (near threatened – taxa not included in protection programs but are close to being considered sensitive); LC (least concern – taxa not considered dependent on protection or near threatened); DD (data deficient – taxa not categorized due to insufficient data on population status, abundance, and range); NE (not evaluated – taxa not yet subjected to assessment criteria for their conservation status).

[+]Strictly protected plant species in accordance with the Regulation on the Declaration and Protection of Strictly Protected and Protected Wild Species of Plants, Animals, and Fungi (ANONYMOUS, 2010).

[++]Protected plant species in accordance with the Regulation on the Control of Use and Trade of Wild Flora and Fauna+

Most species belong to the Poaceae family (14 species), followed by the Asteraceae, Caryophyllaceae and Fabaceae families with 10 species each. Families with a moderate number of species include Lamiaceae (8 species), Brassicaceae (7 species), Cyperaceae and Rosaceae (5 species each). Families with only one species include Pteridaceae, Anacardiaceae, Campanulaceae and others.

All taxa recorded at the studied locality occur in relatively small numbers and form stands in smaller areas. The dominant role in the floristic composition is played by species from the Poaceae family, including xerophilous grass-like species, which indicate the strong influence of climatic and edaphic factors that create conditions for the development of steppe vegetation (MARKOVIĆ, 2007). At the bottom of the Brdjani Gorge, there is mesophilous vegetation on the banks of the Despotovica River, as well as communities of ruderal plant species in areas where anthropogenic impact is most pronounced (near the main road).

According to STEVANOVIĆ *et al*., (1995), the characteristic cenobionts of the serpentine community in Brdjani Gorge are: *Stipa novakii, Chrysopogon gryllus, Halacsya sendtneri, Potentilla tommasiniana, Silene paradoxa, Genista depressa* subsp. *friwaldskyi, Allium moschatum, A. flavum, Bromus riparius, Medicago prostrata, Sedum album, Galium album, Arthemisia lobelii, Aethionema saxatile, Hemionitis marantae, Silene bupleuroides, Melica ciliata*, while MARKOVIĆ, (2007) mentions the following species: *Stipa pennata, Potentilla incana, Medicago falcata, Chrysopogon gryllus, Melica ciliata, Festuca vallesiaca, Koeleria*

pyramidata, Bromus riparius, Silene bupleuroides, Odontarrhena chalcidica, Hemionitis marantae, Euphorbia spinosa subsp. *glabriflora, Halacsya sendtneri.*

Within the ecological spectrum of flora in Brdjani Gorge, hemicryptophytes dominate with 61 taxa, followed by chamaephytes with 23 taxa, and then therophytes and geophytes with 13 taxa each. The least represented life form is phanerophytes, with only 9 species. The biological spectrum of flora in a specific area is an indicator of the complex interdependence between plant life forms and the ecological, primarily climatic and edaphic characteristics of that region. MARKOVIĆ (2007), who studied steppe vegetation in Brdjani Gorge, states that steppe vegetation is characterized by the life forms of hemicryptophytes and chamaephytes, which is consistent with our results.

Based on the chorological analysis of the flora in the Brdjani Gorge, 5 groups of areas with other subgroups were identified. The diversity of habitats in the study area is the result of the specific geological substrate that has enabled the survival of a certain number of taxa belonging to different floristic elements. The area spectrum of the flora in the Brdjani Gorge is dominated by the Euro-Asian area type with 87 taxa, which is due to the presence of a larger number of mountain massifs in this area. A considerable part of the flora in the study area also belongs to the Mediterranean-Sub-Mediterranean area type with 10 taxa, which indicates the openness of the area to influences from the Mediterranean-Sub-Mediterranean climate. The Holarctic range type is represented by 6 species, followed by the Central European range type with 5 species. Cosmopolitan and Pontic species are also represented in the Brdjani Gorge with 4 taxa each. The area type of adventitious plants is the least represented, comprising 3 taxa. The occurrence of adventitious plants on roadsides is a consequence of the influence of anthropogenic factors in the study area. The taxonomic affiliation of a given taxon to a specific floristic element consists in the precise determination of the distribution of each plant species using the abbreviated names of the floristic elements in which they occur.

On serpentine habitats, the stability of the structure is the result of ecological balance between abiotic and biotic factors over a long period. In degraded phytocoenoses, this balance is disrupted by the extreme influence of a single ecological factor, in this case, the soil formed on a serpentine geological substrate. This specific substrate has led to the emergence of endemic plant species that are strictly limited to unique habitat types with distinct geological and pedological characteristics. These species have developed special adaptations that allow them to survive and thrive under conditions unfavorable to most other organisms. Edaphic endemism has significant ecological and conservation importance, as it contributes to biodiversity and ecosystem stability. At the studied locality, the species *Asplenium adulterinum, Hemionitis marantae*, and *Halacsya sendtneri*, which belong to Tertiary relicts, were identified (VASIĆ and DIKLIĆ, 2001). In addition to relict species, the endemic species *Odontarrhena chalcidica* (syn. *Alyssum markgrafii*) and *Silene paradoxa* were also identified (VASIĆ and DIKLIĆ, 2001).

STEVANOVIĆ *et al*. (2003) identified *Halacsya sendtneri, Sesleria serbica, Sedum album*, and *Odontarrhena chalcidica* as endemic to serpentine habitats in the Balkan Peninsula. These species, being exclusively adapted to serpentine soils, further emphasize the ecological specificity of the substrate. This classification emphasizes the adaptations of plant species to serpentine environments, underscoring their ecological importance and the unique biodiversity present in the studied area. The mentioned species are specific to the serpentine substrate and represent obligate species, whereas facultative endemics, characterized by broader distributions and greater adaptability to various substrates and habitat conditions, are rarer among endemics. By comparing floristic data with other relevant studies on serpentine floras across the Balkan Peninsula, significant similarities have been observed in the presence of endemic species such as *Odontarrhena chalcidica, Sedum album*, and *Halacsya sendtneri*, as reported by STEVANOVIĆ *et al*. (2003) and studies conducted in Bulgaria and Greece (PAVLOVA *et al*., 2004). However, differences in floristic composition can be attributed to

climatic conditions and the specific characteristics of serpentine substrates in various regions. This comparison enhances our understanding of the distribution and ecology of species associated with serpentine habitats in the Balkans.

The examined serpentinite habitat in Brdjani Gorge has a significant number of plant species that are listed on both international and national lists of strictly protected or protected plants. The IUCN threat status of all examined species is summarized in Table 1. Among the recorded species, the most prevalent threat category is "Not Evaluated," with 77 species. Following this, the "Least Concern" category includes 36 species. There are also three species classified as "Data Deficient," one species categorized as "Near Threatened," and one species identified as "Vulnerable." This distribution emphasizes the need for further research to accurately assess the conservation status of many plants in the area. The predominance of species in the "Not Evaluated" category suggests that the current knowledge of the biodiversity in Brdjani Gorge is incomplete, potentially overlooking species that may require conservation efforts. The presence of species in the "Least Concern" category indicates that a portion of the flora is currently stable, yet ongoing monitoring is crucial to ensure their continued well-being. The "Data Deficient" category underscores the necessity for more comprehensive data to determine the risk level for these species accurately. Finally, the identification of species as "Near Threatened" and "Vulnerable" requires immediate conservation actions to prevent further decline and potential extinction (ANONYMOUS, 2024b).

From the perspective of flora protection, species that are legally protected at the national level, according to (ANONYMOUS, 2010), are also significant in the researched area of Brdjani Gorge. Some of plant species in Brdjani Gorge are listed on the Annex 1 of the Regulation on the Declaration and Protection of Strictly Protected and Protected Wild Species of Plants, Animals, and Fungi (ANONYMOUS, 2010) and includes *Asplenium adulterinum* and *Hemionitis marantae*. Additionally, the species *Asplenium adulterinum* is included in the Habitats Directive, which permits limited harvesting and collection as defined by a specific regulation (STOJANOVIĆ *et al*., 2015). Other species listed in Annex 1 of the Regulation on the Declaration and Protection of Strictly Protected and Protected Wild Species of Plants, Animals, and Fungi of the Republic of Serbia are as follows: *Hypericum barbatum, Teucrium montanum* and *Thymus serpyllum*.

Among the invasive plant species recorded is *Robinia pseudoacacia* and *Reynoutria japonica* which is classified as a highly invasive species in the List of invasive alien species threatening the biodiversity in Europe (ANONYMOUS, 2012). In the studied area, it is most prevalent in ruderal habitats at the foot of Brdjani Gorge. Anthropogenic factors that could contribute to the spread of *Robinia pseudoacacia*, *Reynoutria japonica* and other invasive species in the broader area of the investigated habitat include primarily traffic, as well as the thinning of shrubland in this and surrounding areas. The dynamics of vegetation cover and succession on ultramafic terrains are slowed down due to all these problems (PROCTOR, 1992). Additionally, the degrading zoo-anthropogenic factor, in synergy with pronounced erosion factors, further complicates the already difficult conditions for the establishment and survival of vegetation on serpentinite soils (TATIĆ and VELJOVIĆ, 1992). These findings underscore the need for targeted management strategies to control invasive species and mitigate anthropogenic impacts, ensuring the protection and stability of native plant communities in Brdjani Gorge.

Based on the specific characteristics of the flora of Brdjani Gorge, it is essential to implement targeted conservation measures to the ecological requirements and vulnerability of the present species. Strictly protected species require stringent conservation actions, including a ban on collection and habitat degradation, as well as the introduction of strict penalties for non-compliance. Furthermore, critical habitats for the preservation of these species should be mapped and marked with educational and warning signs. For species subject to regulated collection, it is crucial to establish sustainable management practices, including setting

maximum allowable quotas, implementing seasonal restrictions, and conducting continuous population monitoring to prevent overexploitation. Introducing controlled use regimes can achieve a balance between biodiversity conservation and the sustainable use of natural resources.

The conservation proposal also includes integrating Brdjani Gorge into a broader network of protected areas, given the presence of endemic and endangered species. Key microhabitats, particularly those with serpentine substrates should be prioritized in conservation planning. Further research is essential to determine the population dynamics of protected species, assess the impacts of climate change, and understand pressures caused by anthropogenic factors such as waste disposal and unsustainable resource exploitation. Such research would enable the development of adaptive strategies for biodiversity conservation.

The implementation of conservation measures requires the involvement of a diverse range of stakeholders. Experts and researchers in ecology, botany, and nature conservation play a crucial role in assessing the current state of biodiversity and proposing optimal strategies for its protection. Local authorities and relevant institutions are essential for establishing a robust legal framework and ensuring the enforcement of prescribed measures. Non-governmental organizations and local communities contribute significantly by raising awareness about the importance of nature conservation and encouraging sustainable resource management practices. Additionally, the Ministry of Environmental Protection and inspection services are key to monitoring the proper implementation of legal provisions. Developing a comprehensive conservation plan for Brdjani Gorge, with a focus on safeguarding species and their habitats, is a vital step toward ensuring the long-term preservation of this area as a valuable biodiversity hotspot (ANONYMOUS, 1995).

CONCLUSION

The serpentinite habitat of the Brdjani Gorge has a diverse and unique flora, shaped by specific orographic and edaphic factors. These factors, including the unique geological composition of the serpentinite substrate, influence soil chemistry and nutrient availability, creating conditions that support a distinctive range of plant species. Among these are endemic *Halacsya sendtneri* and relict *Hemionitis marantae*, which are crucial to the region's biodiversity and underscore the ecological significance of this environment. Additionally, the presence of obligate species, such as *Odontarrhena chalcidica* (syn. *Alyssum markgrafii*), *Stachys recta*, *Asplenium adulterinum*, *Halacsya sendtneri*, and facultative species like *Seseli rigidum*, *Teucrium montanum*, and *Thymus serpyllum*, further emphasizes the ecological distinctiveness of this habitat. However, anthropogenic activities, including the establishment of the municipal landfill in Gornji Milanovac and the proximity of transportation infrastructure, represent a significant threat to these autochthonous plant species. The high percentage of rare plant species indicates the isolation of this flora, which emphasizes the need for its protection. The coexistence of endemic species and specific steppe communities underlines the ecological value of this area. Given the rarity of such ecosystems and the importance of biodiversity conservation, urgent action is needed to protect this valuable area in Serbia. In developed countries, the proximity of natural values and landfills is considered unacceptable, which adds to the urgency of addressing this issue in the Brdjani Gorge.

Acknowledgments

This research was supported by the Rufford Foundation (https://www.rufford.org/) and is an outcome of the project "Monitoring and Assessment of the Serpentinite Floristic Diversity with the Focus on the Endemic Species and *Paraceterach marantae* (L.) R. M. Tryon (Pteridaceae)".

References:

[1] ALEXANDER, E.B., COLEMAN, R.G., KEELER-WOLF, T., HARRISON, S.P. (eds) (2007): Serpentine geoecology of western North America: Geology, solis, and vegetation. *Oxford University Press*. New York, USA.

[2] ANONYMOUS (1995): NATIONAL RESEARCH COUNCIL (US) COMMITTEE ON SCIENTIFIC ISSUES IN THE ENDANGERED SPECIES ACT. Science and the endangered species act. *Washington (DC): National Academies Press.* USA. doi: 10.17226/4978

[3] ANONYMOUS (2010): Regulation on the declaration and protection of strictly protected and protected wild species of plants, animals, and fungi (Official Gazette RS No. 5/2010, 47/2011, 32/2016 and 98/2016). [in Serbian] Accessed 20 January 2024

[4] ANONYMOUS (2012): European and Mediterranean Plant Protection Organisation (EPPO): (http://www.eppo.int/INVASIVE_PLANTS/ias_plants.htm) Accessed 18 January 2024

[5] ANONYMOUS (2024a): WORLD FLORA ONLINE (WFO): http://www.worldfloraonline.org Accessed 25 June 2024

[6] ANONYMOUS (2024b): INTERNATIONAL UNION FOR CONSERVATION OF NATURE (IUCN). https://www.iucnredlist.org/ Accessed 02 September 2024.

[7] BRADY, U.K., KRUCKEBERG, R.A., BRADSHAW, J.H.D. (2005): Evolutionary ecology of plant adaptation to serpentine soils. *Annual Review of Ecology Evolution and Systematics* **36**: 243–266. doi: 10.1146/annurev.ecolsys.35.021103.105730

[8] BRKOVIĆ, D. (2015): Vascular flora of the hilly-mountainous region of Northwestern Serbia and Šumadija – Ecological and phytogeographical study. *PhD Thesis*, Faculty of Biology, Belgrade. [in Serbian]

[9] FICK, S.E., HIJMANS, R.J. (2017): WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology* **37** (12): 4302–4315. doi: 10.1002/joc.5086

[10] https://www.rufford.org/projects/nenad-zlati%C4%87/monitoring-and-assessment-serpentinite-floristic-diversity-focus-endemic-species-and-paraceterach-marantae-l-r-m-tryon-pteridaceae/ Accessed 02 September 2024.

[11] JOSIFOVIĆ, M. (ed) (1970–1977): Flora of the Socialist Republic of Serbia 1-9. *Serbian Academy of Sciences and Arts*. Belgrade. [in Serbian]

[12] KABAŠ, E., ALEGRO, A., KUZMANOVIĆ, N., JAKOVLJEVIĆ, K., VUKOJIČIĆ, S., LAKUŠIĆ, D. (2013): *Stipetum novakii* ass. *nova* – A new association of serpentine rocky grassland vegetation (*Halacsyetalia sendtneri*) in Serbia. *Acta Botanica Croatica* **72**: 169–184. doi: 10.2478/v10184-012-0016-6

[13] KAZAKOU, E., DIMITRAKOPOULOS, P.G., BAKER, A.J.M., REEVES, R.D., TROUMBIS, A.Y. (2008): Hypotheses, mechanisms and trade-offs of tolerance and adaptation to serpentine soils: from species to ecosystem level. *Biological Reviews* **83** (4): 495–508. doi: 10.1111/j.1469-185X.2008.00051.x

[14] MARKOVIĆ, A. (2007): Steppe phytocenoses in Šumadija. *Faculty of Science*, University of Kragujevac, Kragujevac, Serbia. [in Serbian]

[15] PAVLOVA, D., DIMITROV, D., KOŽUHAROVA, E. (2004): Flora of the serpentine complexes in Eastern Rhodopes (Bulgaria). *In*: Beron, P., Popov, A (eds) *Biodiversity of*

Bulgaria 2. Biodiversity of Eastern Rhodopes (Bulgaria and Greece). Pensoft Publishers, Sofia, BG. 111–121 pp.

[16] PROCTOR, J. (1992): Chemical and ecological studies on the vegetation of ultramafic sites in Britain. *In*: Roberts, B.A., Proctor, J (eds) *The ecology of areas with serpentiniyed rocks: A world view*. Kluwer Academic Publishers, Dodrecht, NL. 135–168 pp.

[17] RAUNKIAER, C. (1934): The life forms of the plant and statistical geography. *Clarendon Press*. Oxford, UK.

[18] SARIĆ, M.R. (ed) (1992): Flora of Serbia No. 1. *Serbian Academy of Sciences and Arts*. Belgrade, Serbia. [in Serbian]

[19] SARIĆ, M.R., DIKLIĆ, N. (eds) (1986): Flora of the Socialist Republic of Serbia No. 10. *Serbian Academy of Sciences and Arts*. Belgrade, Serbia. [in Serbian]

[20] STEVANOVIĆ, B., GLIŠIĆ, O., ŠINŽAR, J. (1995): Ecology, distribution and protection of endemorelict serpentinophyte *Halascya sendtneri* (Boiss) Dorfl. *7th European Ecological Congress*. Budapest, Hungary.

[21] STEVANOVIĆ, V. (1992): Floristic division of the territory of Serbia with an overview of higher horizons and corresponding floristic elements. *In*: Sarić, M.R. (ed) *Flora of the Socialist Republic of Serbia No. 1*. Serbian Academy of Sciences and Arts, Belgrade. 47-56 pp. [in Serbian]

[22] STEVANOVIĆ, V., TAN, K., IATROU, G. (2003): Distribution of the endemic Balkan flora on serpentine I. – obligate serpentine endemics. *Plant Systematics and Evolution* **242**: 149–170. doi: 10.1007/s00606-003-0044-8

[23] STOJANOVIĆ, V., RILAK, S., JELIĆ, I., PERIĆ, R., SABOVLJEVIĆ, M., LAZAREVIĆ, P. (2015): Biljke od međunarodnog značaja u flori Srbije. *Zavod za zaštitu prirode Srbije*, Beograd. [in Serbian]

[24] TATIĆ, B., VELJOVIĆ, V. (1992): Distribution of serpentinized massives on the Balkan Peninsula and their ecology. *In*: Roberts, B.A., Proctor, J. (eds) *The ecology of areas with serpentinized rocks*. Kluwer Publishing, Dordrecht, NL. 199–215 pp.

[25] VASIĆ, O., DIKLIĆ, N. (2001): The flora and vegetation on serpentinites in Serbia – a review. *Bocconea* **13**: 151–164.

[26] VIĆENTIJEVIĆ-MARKOVIĆ, G. (2004): The serpentinophytae of the Brdjani Gorge. *Acta Agriculturae Serbica* **9**: 65–72.

[27] VICIĆ, D. (2014): Adaptive response of *Halacsya sendtneri* (Boiss.) Dörfl., *Cheilanthes marantae* (L.) Domin., and *Seseli rigidum* Waldst. et Kit. to the physicochemical conditions of serpentine soil. *PhD thesis*, Faculty of Biology, University of Belgrade. [in Serbian]

[28] ZLATIĆ, N.M., STANKOVIĆ M.S. (2019): Effects of calcareous and serpentinite parent material on the mineral characteristics of soils and plant material of *Teucrium montanum* L. (Lamiaceae). *Environmental Monitoring and Assessment* **191**: 564. doi: 10.1007/s10661-019-7750-3

[29] ZLATIĆ, N.M., STANKOVIĆ M.S., SIMIĆ Z.S. (2017): Secondary metabolites and metal content dynamics in *Teucrium montanum* L. and *Teucrium chamaedrys* L. from habitats with serpentine and calcareous substrate. *Environmental Monitoring and Assessment* **189**: 110. doi: 10.1007/s10661-017-5831-8