

Floristic diversity of the rocky habitats of the Stara Planina Mountains in Serbia

Original Article

Abstract:

The flora of rock outcrops in the Stara Planina Mountains (Serbia) was analyzed to assess its diversity, as well as its biological and chorological spectra. A total of 125 vascular plant species, representing 75 genera and 35 families, were identified. The dominant families were Poaceae, Caryophyllaceae, and Asteraceae, while *Asplenium* and *Sedum* were the most species-rich genera. Hemicryptophytes (48.8%) and chamaephytes (31.2%) were the predominant life forms, well-adapted to harsh rocky environments. The dominance of taxa from the Eurasian Mountain (32%) and Eurasian (16%) area types reflects the montane-continental and temperate-continental climate characteristic of the study area. Furthermore, the presence of glacial relict species highlights the role of high-altitude rocky habitats as microclimatic refugia, offering long-term protection against adverse climatic changes. This study underscores the substantial floristic diversity and biogeographical significance of rocky habitats in this part of the Stara Planina Mts.

Key words:

chasmophytes, the Stara Planina Mts., biological spectrum, chorological spectrum, floristic diversity

Apstrakt:

Floristički diverzitet stenovitih staništa Stare planine u Srbiji

Flora stenovitih staništa Stare planine (Srbija) proučavana je sa ciljem utvrđivanja njenog diverziteta, biološkog i horološkog spektra. Ukupno je identifikovano 125 vrsta vaskularnih biljaka iz 35 familija i 75 rodova. Poaceae, Caryophyllaceae i Asteraceae su dominantne familije, a *Asplenium* i *Sedum* najzastupljeniji rodovi. Hemikriptofite (48,8%) i hamefite (31,2%) predstavljaju dominantne životne forme, prilagođene stenovitim staništima. Dominacija taksona koji pripadaju Evroazijsko planinskom (32%) i Evroazijskom (16%) areal tipu ukazuje na planinsko-kontinentalni i umereno-kontinentalni tip klime, koji su karakteristični za istraživano područje. Takođe, prisustvo glacijalnih reliktnih vrsta potvrđuje da stenovita staništa visokoplaninskih regiona imaju ulogu mikroklimatskih refugijuma, pružajući dugoročnu zaštitu od nepovoljnih klimatskih promena. Ovo istraživanje ukazuje na znatan floristički diverzitet i biogeografski značaj stenovitih staništa ovog dela Stare planine.

Ključne reči:

hazmofite, Stara Planina, biološki spektar, horološki spektar, floristički diverzitet

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Introduction

Due to their inaccessibility, rock outcrops are among the best-preserved terrestrial environments, providing refuge from grazing, competition, fire, anthropogenic pressures, and climatic changes (Larson et al., 2000). The floristic composition of vegetation on these outcrops is shaped by geological and geomorphological characteristics (e.g., bedrock composition, structural heterogeneity, eluvial processes, and erosion), topographic features (e.g., exposure and slope), and microclimatic conditions

(e.g., water availability, temperature, and insolation). In general, floristic diversity on rock outcrops tends to increase with higher humidity, greater rock stability, and an increased availability of space for seed germination (Larson et al., 2000).

Chasmophytes are highly specialized plants adapted to endure the harsh conditions of the rock fissures they inhabit. Many have evolved structural adaptations, such as bulbs, succulent leaves, aerial roots, vegetation mats (which facilitate the growth of other plants), and resurrection traits (Ribeiro et al., 2007). Chasmophytes share several functional



traits: they are predominantly long-lived perennials, typically woody at the base, with an extended flowering period, high seed germination rates, and various mechanisms for long-distance seed dispersal (Panitsa & Kontopanou, 2017).

The presence of vertical cliffs and rock outcrops leads to the fragmentation and isolation of open habitats, which support both endemic species and those at the edge of their distribution range (Juvan et al., 2011; Gwitira et al., 2013; Gentili et al., 2015; Zhao & Gong, 2015; Cutts et al., 2019; García et al., 2020). There is a strong link between chasmophyte ecology and endemism, as most endemic species are chasmophytes (Panitsa & Kontopanou, 2017). The occurrence of relict species within chasmophytic communities suggests that rock outcrops function as refugia from rapid climatic changes, allowing vegetation to persist as long as the rock remains intact (Larson et al., 2000). These habitats support plant populations with highly stable demographic dynamics and low extinction risks (Larson et al., 1999; Picó & Riba, 2002; García, 2003), as well as slow-growing, stable communities in a climax stage.

Although scattered records of species from the rocky habitats of the Stara Planina Mts. in Serbia exist in older literature (Pančić, 1884; Adamović,

1908-1911; Josifović, 1970-1977), these habitats have remained largely understudied until recently. While recent studies have examined rock outcrop vegetation - such as those by Randelović et al. (2000, 2021) in Serbia and Szokala (2023) in Bulgaria - no comprehensive research has specifically addressed the floristic diversity, life-form spectra, or biogeographical patterns of the rock outcrop flora in this mountain range. This study represents the first detailed investigation of the diversity, biological spectra, and chorological patterns of rock outcrop flora in the Serbian part of the Stara Planina Mts. By filling this knowledge gap, our research enhances the broader understanding of biodiversity patterns and species specialization within these unique ecosystems.

Materials and Methods

The sampling area was discontinuous, covering only localities with rock outcrops that support chasmophytic communities (Fig. 1), within the smaller western part of the Stara Planina Mts. in Serbia.

The study area is bounded by the Beli Timok, Trgoviški Timok, and Visočica rivers, as well as

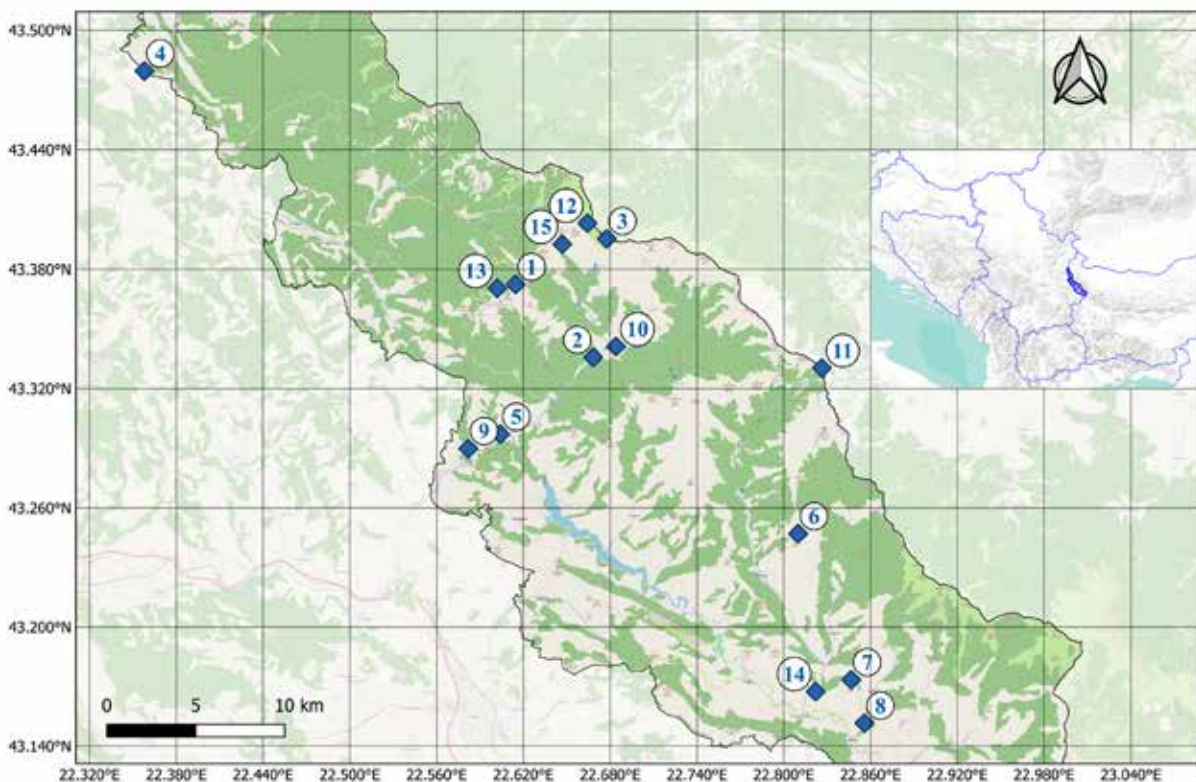


Fig. 1. Map of sampling localities (1 - Babin zub Peak; 2 - Crvene stene Peak; 3 - Midžor Peak; 4 - Pečka klisura Gorge; 5 - Gorge between the villages of Topli Do and Temska; 6 - Ponor Plateau; 7 - Rosomački vrh Peak; 8 - Rosomačka reka Gorge; 9 - Tumba Viewpoint; 10 - Kovani dol Gorge; 11 - Tri Čuke Peak; 12 - Tupanar Peak; 13 - Babin zub Viewpoint; 14 - Visočica River Gorge; and 15 - Žarkova čuka Peak)

the border with Bulgaria. Geologically, it is divided into northern pre-Permian formations and southern Permian to Cretaceous sediments (Lakušić & Četković, 2007). Soils on siliceous rock outcrops include silicate Lithosols, Regosols, and Rankers, while calcareous rocks support calcaric Leptosol. Terrain variation creates diverse microclimates: the foothills have a temperate-continental climate with semi-dry summers and mild winters, whereas higher altitudes experience a montane-continental climate with long, cold winters. January temperatures range from -5.3 °C to 3.7 °C, and July temperatures from 11.8 °C to 28.8 °C (Milovanović, 2010). Precipitation during the growing season varies between 300 and 360 mm, peaking in May and June (Lakušić & Četković, 2007). The vertical vegetation profile of the Stara Planina Mts. includes oak (300-1100 m a.s.l.), beech (1100-1500 m a.s.l.), Norway spruce (1500-1750 m a.s.l.), subalpine (1750-1900 m a.s.l.), and alpine (above 1900 m a.s.l.) altitudinal belts, with the timberline around 1550-1600 m a.s.l. (Randelović et al., 2019).

Field research was conducted from June to September 2023, focusing on the flora of rock outcrops. Collected specimens were deposited at the Herbarium Moesiacum Niš (HMN). Plant material was identified using the dichotomous keys of Tutin et al. (1964-1980), Josifović (1970-1977), Sarić (1992), and Sarić & Diklić (1986). Nomenclature follows the

Euro+Med PlantBase (2006+), except for *Asplenium* × *alternifolium* Wulfen (Niketić & Tomović, 2018), while classification aligns with WFO. Plant life forms were determined following Mueller-Dombois & Ellenberg (1974), with adaptations for the flora of Serbia by Stevanović (1992a). Taxa were classified into six life forms: phanerophytes (P), chamaephytes (Ch), hemicryptophytes (H), geophytes (G), therophytes (T), and scandentophytes (S). Chorotypes were identified according to Meusel et al. (1965, 1978) and Meusel & Jäger (1992), as modified for Serbia by Stevanović (1992b). Taxa were categorized into the following area types: Arctic-Alpine (AA), Boreal (BOR), Central European (CE), Cosmopolitan (COSM), Eurasian (EA), Eurasian Mountain (EAM), Holarctic (HOL), Mediterranean-sub-Mediterranean (MED-SMED), and Pontic (PONT).

Results and discussion

A total of 125 vascular plant species, belonging to 35 families and 75 genera, were identified on the rock outcrops of the Stara Planina Mts. in Serbia (Tab. 1). Although rock outcrops host less than 10% of the total taxa reported for the vascular flora of the Stara Planina Mts. in Serbia (1,742 taxa) by Lakušić & Četković (2007), they display remarkable floristic diversity, especially considering the limited area

Table 1. List of recorded vascular plants on the rock outcrops of the Stara Planina Mts. (Serbia), including their life forms, area types, recorded localities, and bedrock types on which they were observed. Abbreviations for life forms: Phanerophytes (**P**), Chamaephytes (**Ch**), Hemicryptophytes (**H**), Geophytes (**G**), Therophytes (**T**), and Scandentophytes (**S**). Abbreviations for area types: Arctic-Alpine (**AA**), Boreal (**BOR**), Central European (**CE**), Cosmopolitan (**COSM**), Eurasian (**EA**), Eurasian Mountain (**EAM**), Holarctic (**HOL**), Mediterranean-sub-Mediterranean (**MED-SMED**), and Pontic (**PONT**). Locality numbers correspond to those in Fig. 1. In the bedrock type column, 'S' indicates siliceous rocks, 'L' indicates limestone, and 'S/L' indicates both. For species found on both types of bedrock, the predominant type is bolded; if both types are equally represented, neither is bolded

Taxa	Life form	Area type	Locality	Bedrock type
POLYPODIOPHYTA				
Fam: Aspleniaceae				
<i>Asplenium adiantum-nigrum</i> L.	Ch	COSM	9, 10	S
<i>Asplenium ceterach</i> L.	Ch	EA	4, 8	L
<i>Asplenium ruta-muraria</i> L.	Ch	HOL	1, 4, 5, 7, 8, 13, 14	S/L
<i>Asplenium septentrionale</i> (L.) Hoffm.	Ch	HOL	2, 9, 10, 13, 15	S
<i>Asplenium trichomanes</i> L.	Ch	COSM	1, 2, 5, 8, 9, 10, 12, 15	S/L
<i>Asplenium viride</i> Huds.	Ch	BOR	1, 3, 6, 12	S
<i>Asplenium</i> × <i>alternifolium</i> Wulfen	Ch	HOL	15	S
Fam: Cystopteridaceae				
<i>Cystopteris fragilis</i> (L.) Bernh.	Ch	COSM	1, 3, 5, 6, 8, 12, 14, 15	S/L

Fam. Dryopteridaceae				
<i>Dryopteris expansa</i> (C.Presl) Fraser-Jenk. & Jermy	Ch	BOR	1, 11	S
<i>Dryopteris filix-mas</i> (L.) Schott	Ch	HOL	1	S
Fam. Ophioglossaceae				
<i>Botrychium lunaria</i> (L.) Sw.	G	BOR	3	S
Fam. Polypodiaceae				
<i>Polypodium vulgare</i> L.	Ch	HOL	1, 5	S
Fam. Woodsiaceae				
<i>Woodsia alpina</i> (Bolton) Gray	Ch	AA	15	S
PINOPHYTA				
Fam. Cupressaceae				
<i>Juniperus communis</i> subsp. <i>nana</i> Syme	P	BOR	1	S
ANGIOSPERMS				
Fam. Amaryllidaceae				
<i>Allium carinatum</i> L.	G	MED-SMED	3	S
<i>Allium carinatum</i> subsp. <i>pulchellum</i> (G.Don) Bonnier & Layens	G	MED-SMED	15	S
<i>Allium flavum</i> L.	G	MED-SMED	2, 5, 7	S/L
<i>Allium schoenoprasum</i> L. subsp. <i>schoenoprasum</i>	G	HOL	15	S
Fam. Apiaceae				
<i>Angelica sylvestris</i> L.	H	BOR	1	S
<i>Seseli libanotis</i> (L.) W.D.J.Koch	H	EA	1	S
Fam. Araliaceae				
<i>Hedera helix</i> L.	S	CE	8	L
Fam. Asparagaceae				
<i>Muscari comosum</i> (L.) Mill.	G	EA	9	S
<i>Ornithogalum kochii</i> Parl.	G	MED-SMED	3, 13, 15	S
Fam. Asteraceae				
<i>Anthemis cretica</i> subsp. <i>carpatica</i> (Willd.) Grierson	Ch	EAM	1, 13	S
<i>Aster alpinus</i> L.	H	AA	1	S
<i>Centaurea stoebe</i> subsp. <i>australis</i> (A.Kern.) Greuter	H	PONT	9	S
<i>Centaurea stoebe</i> subsp. <i>serbica</i> (Prodan) Ochsmann	H	PONT	15	S
<i>Cicerbita muralis</i> (L.) Wallr.	H	EA	8	L
<i>Hieracium bifidum</i> Hornem.	H	BOR	1	S
<i>Leontodon crispus</i> Vill.	H	MED-SMED	2	S
<i>Leucanthemum graminifolium</i> (L.) Lam.	H	EAM	12	S

<i>Pilosella alpicola</i> (Hoppe) F.W.Schultz & Sch. Bip.	H	CE	9	S
<i>Pilosella hoppeana</i> (Schult.) F.W.Schultz & Sch. Bip.	H	EAM	1	S
<i>Senecio rupestris</i> Waldst. & Kit.	H	EAM	13	S
<i>Solidago virgaurea</i> L.	H/G	HOL	9	S
Fam. Brassicaceae				
<i>Arabis alpina</i> subsp. <i>caucasica</i> (Willd.) Briq.	H	EAM	7	L
<i>Arabis sagittata</i> (Bertol.) DC.	H	EA	5	S
<i>Aurinia saxatilis</i> subsp. <i>orientalis</i> (Ard.) T.R.Dudley	Ch	MED-SMED	5	L
<i>Draba doerfleri</i> Wettst.	H	EAM	1	S
<i>Draba lasiocarpa</i> Rochel	H	EAM	4	L
<i>Rorippa lippizensis</i> (Wulfen) Rchb.	H	EAM	15	S
Fam. Campanulaceae				
<i>Campanula rapunculoides</i> L.	H	EA	14	L
<i>Campanula rotundifolia</i> L.	H	HOL	1	S
<i>Campanula sparsa</i> Friv.	T	CE	9	S
<i>Campanula wanneri</i> Rochel	H	EAM	1, 3, 5, 12, 13, 15	S
Fam. Caryophyllaceae				
<i>Arenaria serpyllifolia</i> L.	T	EA	4	L
<i>Cerastium alpinum</i> L.	Ch	AA	3, 12	S
<i>Cerastium banaticum</i> (Rochel) Heuff.	Ch	MED-SMED	15	S
<i>Dianthus moesiacus</i> Vis. & Pančić	H	EAM	15	S
<i>Dianthus petraeus</i> Waldst. & Kit. subsp. <i>petraeus</i>	Ch	EAM	7	L
<i>Heliosperma pusillum</i> (Waldst. & Kit.) Rchb. subsp. <i>pusillum</i>	Ch	EAM	1, 3, 12	S
<i>Minuartia verna</i> (L.) Hiern	Ch	EA	7, 12	S/L
<i>Petrorhagia prolifera</i> (L.) P.W.Ball & Heywood	T	MED-SMED	2	S
<i>Petrorhagia saxifraga</i> (L.) Link	Ch	MED-SMED	4, 5	L
<i>Scleranthus perennis</i> L.	Ch	EAM	13	S
<i>Silene flavescens</i> Waldst. & Kit.	Ch	EAM	4, 5, 14	L
<i>Silene lichenfeldiana</i> Baumg.	Ch	EAM	1, 9, 11, 13	S
<i>Silene viscaria</i> (L.) Jess.	H	EA	5, 9	S
Fam. Crassulaceae				
<i>Jovibarba heuffelii</i> (Schott) Á.Löve & D.Löve	Ch	EAM	1, 15	S
<i>Sedum album</i> L.	Ch	EAM	2, 5, 7, 8, 10, 15	S/L
<i>Sedum alpestre</i> Vill.	Ch	EAM	3, 12	S
<i>Sedum annuum</i> L.	T	AA	1, 2, 9, 12, 13, 15	S
<i>Sedum cepaea</i> L.	T	MED-SMED	9	S

<i>Sedum dasyphyllum</i> L.	Ch	MED-SMED	8, 10	S/L
<i>Sedum hispanicum</i> L.	H/T	MED-SMED	2, 4	S/L
<i>Sedum ochroleucum</i> Chaix	Ch	MED-SMED	7	L
<i>Sempervivum marmoreum</i> Griseb	Ch	EAM	3, 4, 15	S/L
Fam. Cyperaceae				
<i>Carex kitaibeliana</i> Bech.	H	EAM	15	S
<i>Carex sempervirens</i> Vill.	H	EAM	3, 12	S
Fam. Ericaceae				
<i>Vaccinium myrtillus</i> L.	Ch	BOR	1	S
Fam. Gentianaceae				
<i>Gentiana asclepiadea</i> L.	H	EAM	1	S
Fam. Geraniaceae				
<i>Geranium lucidum</i> L.	T	EA	5	S
<i>Geranium macrorrhizum</i> L.	G	EA	1	S
<i>Geranium purpureum</i> Vill.	T	MED-SMED	8, 14	L
<i>Geranium rotundifolium</i> L.	T	EA	4	L
Fam. Hypericaceae				
<i>Hypericum maculatum</i> Crantz	H	EAM	1, 12	S
Fam. Juncaceae				
<i>Juncus trifidus</i> L.	H	AA	3, 11, 12	S
<i>Luzula luzuloides</i> (Lam.) Dandy & Wilmott	H	CE	1	S
<i>Luzula spicata</i> (L.) DC.	H	AA	3	S
Fam. Lamiaceae				
<i>Clinopodium alpinum</i> (L.) Kuntze	Ch	EA	2, 4, 15	S/L
<i>Lamium garganicum</i> L.	H	MED-SMED	1, 13	S
<i>Satureja kitaibelii</i> Wierzb. ex Heuff.	Ch	MED-SMED	4	L
<i>Stachys recta</i> L.	H	EA	2	S
<i>Thymus praecox</i> subsp. <i>jankae</i> (Čelak.) Jalas	Ch	MED-SMED	1, 3, 13, 15	S
<i>Thymus praecox</i> subsp. <i>polytrichus</i> (A.Kern. ex Borbás) Jalas	Ch	EAM	1, 15	S
Fam. Orobanchaceae				
<i>Euphrasia pectinata</i> Ten.	T	EA	15	S
Fam. Oxalidaceae				
<i>Oxalis acetosella</i> L.	G	EA	1	S
Fam. Plantaginaceae				
<i>Plantago holosteum</i> Scop.	H	MED-SMED	15	S
<i>Veronica barrelieri</i> Roem. & Schult.	H	EAM	15	S

Fam. Poaceae				
<i>Agrostis capillaris</i> L.	H	HOL	1	S
<i>Anisantha sterilis</i> (L.) Nevski	T	HOL	2	S
<i>Avenella flexuosa</i> (L.) Drejer	H	HOL	9, 11	S
<i>Bellardiochloa variegata</i> (Lam.) Kerguélen	H	EAM	11, 12	S
<i>Festuca dalmatica</i> (Hack.) K.Richt.	H	PONT	1, 11, 12, 13	S
<i>Festuca ovina</i> subsp. <i>supina</i> (Schur) Oborny	H	EA	1, 3, 11, 12	S
<i>Festuca panciciana</i> (Hack.) K.Richt	H	EAM	1, 7, 11, 13, 15	S/L
<i>Festuca picturata</i> Pils	H	CE	12	S
<i>Festuca rubra</i> L. s.l.	H	HOL	12	S
<i>Melica transsilvanica</i> Schur	H	EA	2, 4	S/L
<i>Poa alpina</i> L.	H	AA	3, 15	S
<i>Poa badensis</i> Haenke ex Willd.	H	EAM	7, 15	S/L
<i>Poa laxa</i> Haenke	H	EAM	1	S
<i>Poa nemoralis</i> L.	H	HOL	1, 2, 5, 9, 10, 13	S
<i>Sesleria coerulans</i> Friv.	H	EAM	1, 3, 12	S
<i>Sesleria filifolia</i> Hoppe	H	EAM	7	L
Fam. Polygonaceae				
<i>Rumex acetosella</i> L.	H	HOL	9	S
Fam. Primulaceae				
<i>Primula minima</i> L.	H	EAM	3, 12	S
Fam. Ranunculaceae				
<i>Clematis vitalba</i> L.	S	CE	10	S
<i>Ranunculus montanus</i> Willd.	H	EAM	1	S
<i>Thalictrum aquilegifolium</i> L.	H	CE	1	S
Fam. Rosaceae				
<i>Drymocallis rupestris</i> (L.) Soják	H	CE	15	S
<i>Rubus geniculatus</i> Kaltenb.	P	CE	9	S
Fam. Rubiaceae				
<i>Asperula purpurea</i> (L.) Ehrend.	Ch	EAM	4	L
<i>Galium album</i> Mill.	H	CE	5	L
<i>Galium anisophyllum</i> Vill.	H	EAM	4	L
<i>Galium lucidum</i> All.	H	MED-SMED	7	L
<i>Galium odoratum</i> (L.) Scop.	H	EA	1	S
Fam. Saxifragaceae				
<i>Saxifraga bryoides</i> L.	Ch	EAM	3	S
<i>Saxifraga moschata</i> Wulfen	Ch	EAM	3, 12	S
<i>Saxifraga paniculata</i> Mill.	Ch	AA	1, 3, 7, 12, 15	S/L
<i>Saxifraga pedemontana</i> subsp. <i>cymosa</i> Engl.	Ch	EAM	1, 3	S
<i>Saxifraga rotundifolia</i> L.	H	EAM	1, 5, 12	S
<i>Saxifraga tridactylites</i> L.	T	EA	3, 8, 10, 12	S/L

Fam. Caprifoliaceae				
<i>Valeriana tripteris</i> L.	H	EAM	1	S
Fam. Violaceae				
<i>Viola arvensis</i> Murray	T	EA	2	S

they occupy. Moreover, several species documented in this study, such as *Poa laxa* Haenke (Niketić et al., 2023), *Festuca picturata* Pils., *Rubus geniculatus* Kaltenb., and *Draba doerfleri* Wettst., are new records for the region, suggesting that the floristic diversity of the Stara Planina Mts. is greater than previously recognized. However, it is important to note that the local endemic chasmophyte *Campanula calycialata* V. Randjel. & Zlatković was not observed during the study, as expected, since it is considered extinct (Randelović et al., 2019).

The phylum Polypodiophyta comprises six families, six genera, and 13 species, accounting for 10.4% of the total taxa recorded in the study area. The phylum Pinophyta consists of a single family, represented by one species (0.8%). Angiosperms are the most diverse, encompassing 28 families, 68 genera, and 111 species, constituting 88.8% of the total taxa identified.

The dominant vascular plant families are Poaceae Barnhart, Caryophyllaceae Juss., and Asteraceae Giseke, represented by 16, 13, and 12 species, respectively (Fig. 2), accounting for 12.8%, 10.4%, and 9.6% of the total species recorded. *Asplenium* L. and *Sedum* L. are the dominant genera, each contributing 5.6% of the total species, followed by *Saxifraga* L. at 4.8% (Fig. 2). Certain genera, such as *Asplenium* among ferns and *Sedum* among herbaceous vascular plants, exhibit notable consistency in their global distribution on rock outcrops (Larson et al., 2000). Desiccation-tolerant

plants, particularly poikilohydric species such as *Asplenium ruta-muraria* L., *A. ceterach* L. (Sádlo & Chytrý, 2009), and succulent xerophytes from the genera *Sempervivum* L. and *Sedum* (Oettli, 1905; Lüth, 1993), are prevalent in these habitats. Photographs of selected fern and succulent species found on rock outcrops in the Stara Planina Mts. are presented in Figs. 3 and 4, respectively. The species with the highest frequency within the study area are *Campanula wanneri* Rochel, *Heliosperma pusillum* (Waldst. & Kit.) Rchb. subsp. *pusillum*, and *Cystopteris fragilis* (L.) Bernh.

The most dominant life forms on the rock outcrops are hemicryptophytes (48.8%) and chamaephytes (31.2%) (Fig. 5A), which possess functional traits that enable them to endure the harsh conditions of these habitats (Tomaselli et al., 2018). These plants have strong root systems that anchor them to the rock, allowing them to penetrate cracks in search of water and minerals (Bacchetta et al., 2007). Hemicryptophytes' traits offer protection against harsh climatic conditions at higher altitudes, while enhancing survival at lower and mid-elevations, where the growing season is longer (Carlsson et al., 1999; Körner, 2003). Furthermore, hemicryptophytes are dominant in the flora of Serbia (Diklić, 1984). In extreme cliff environments, the lignified underground and partially above-ground parts of chamaephytes help them withstand wind impacts and recover from harsh environmental conditions (Georghiou & Delipetrou, 2010). Chamaephytes, more tolerant

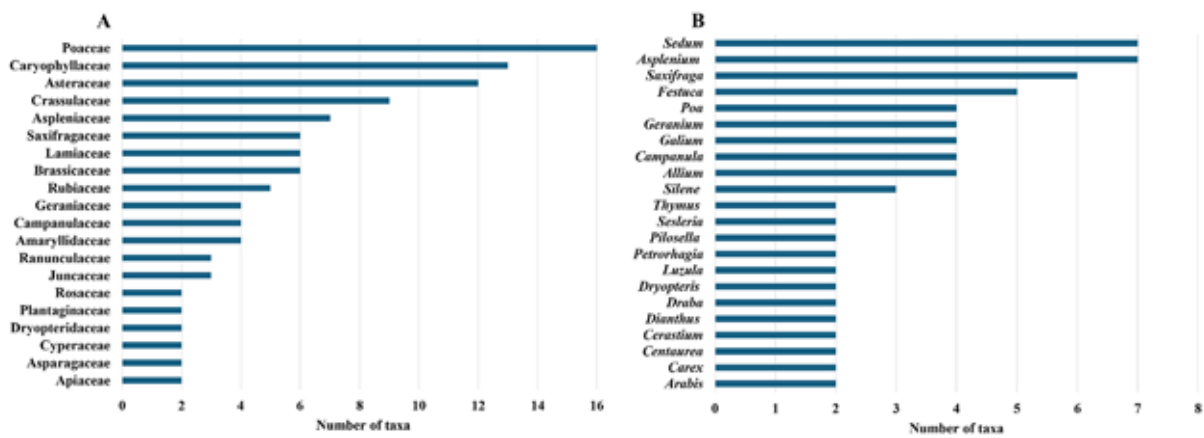


Fig. 2. A - Species and subspecies richness at the family level (families represented by one or two species are excluded); B - Species and subspecies richness at the generic level (genera represented by a single species are excluded)

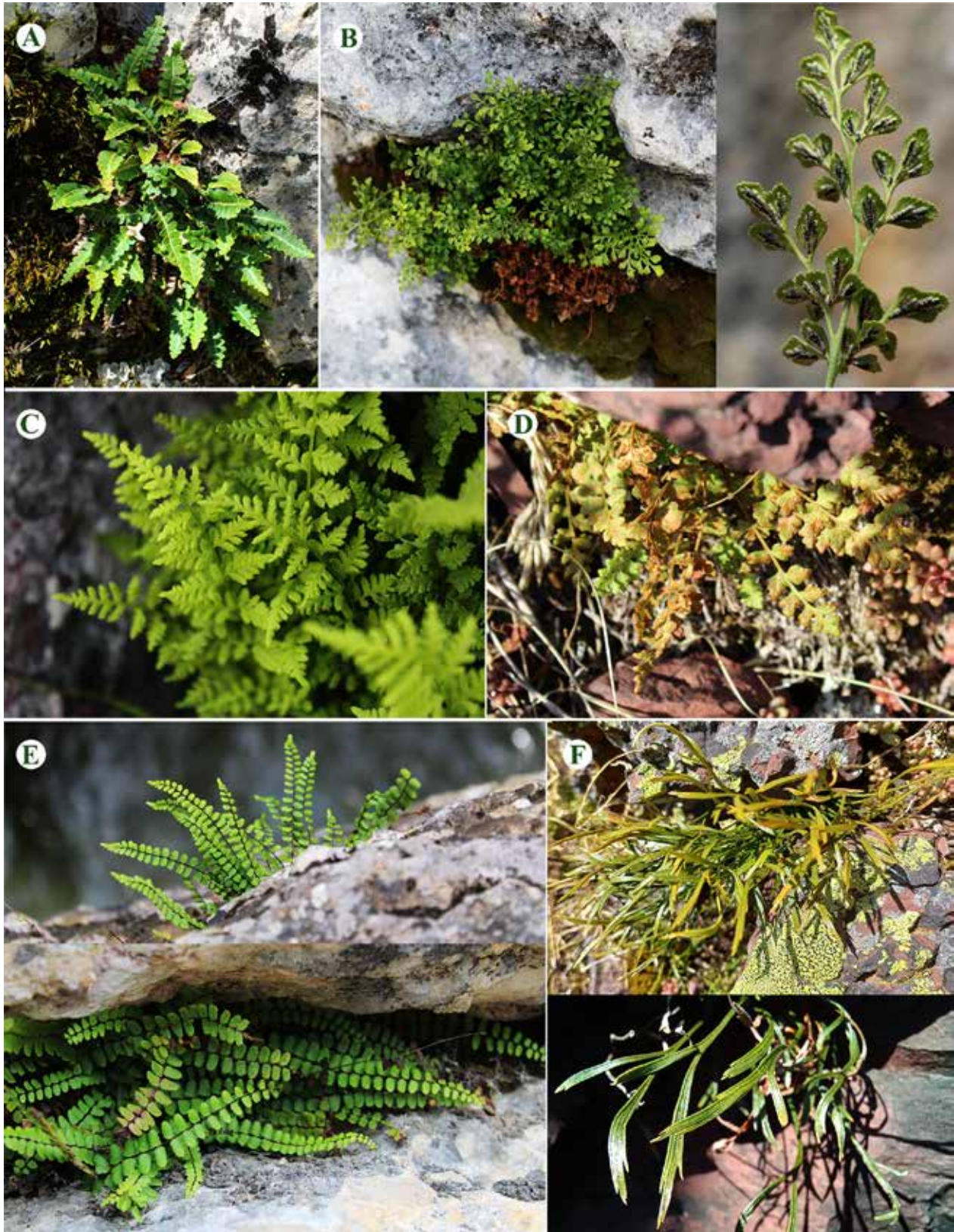


Fig. 3. Representative fern species inhabiting rock outcrops on the Stara Planina Mts. (Serbia) (**A** - *Asplenium ceterach*, **B** - *A. ruta-muraria*, **C** - *Cystopteris fragilis*, **D** - *Woodsia alpina*, **E** - *Asplenium trichomanes*, and **F** - *A. septentrionale*. Photos by Jovana Stojanović



Fig. 4. Representative succulent species inhabiting rock outcrops on the Stara Planina Mts. (Serbia) (**A** - *Sedum dasyphyllum*, **B** - *S. hispanicum*, **C** - *Jovibarba heuffelii*, **D** - *Sedum alpestre*, and **E** - *S. album*). Photos by Jovana Stojanović

of mountainous conditions than other life forms (Lazarina et al., 2019), can complete their life cycle despite a short growing season, particularly at high altitudes (Vogiatzakis et al., 2003). Although the number of microhabitats suitable for colonization is limited (Davis, 1951), therophytes are relatively well-represented (9.6%), which may indicate an increase in disturbances and habitat degradation (Randelović et al., 2007). Disturbances such as rockfalls and erosion expose bare soil, creating open habitats that therophytes can quickly exploit. Their short life cycle allows for rapid reproduction, enabling them to establish before slower-growing species take root, thereby reducing competition. Geophytes, though limited by the space available for underground storage organs (Davis, 1951), are still present (7.2%), particularly in larger crevices or on ledges with greater soil accumulation. The diversity of life forms on rock outcrops can be attributed to the wide variety of microhabitats found in close proximity (Oettli, 1905).

Mountain area type are represented in Fig. 6. The Eurasian area type ranks second (16%), including species like *Asplenium ceterach*, which are commonly found in rocky habitats. The predominance of taxa from these two area types suggests that the sampling localities exhibit montane-continental and temperate-continental characteristics, in line with the region's climate (Lakušić & Četković, 2007). The third most represented area type is Mediterranean-sub-Mediterranean (15.2%), which includes species found exclusively on carbonate rocks within the study area, such as *Aurinia saxatilis* subsp. *orientalis* (Ard.) T.R.Dudley, *Sedum ochroleucum* Chaix, and *Satureja kitaibelii* Wierzb. ex Heuff. Taxa belonging to this area type are typically associated with calcareous rocks and their presence in the study area can be attributed to the influence of the changed Mediterranean climate from the Aegean region, transmitted through river valleys and deep gorges, particularly the Vardar Valley and the Južna Morava River. This climate influence extends into the

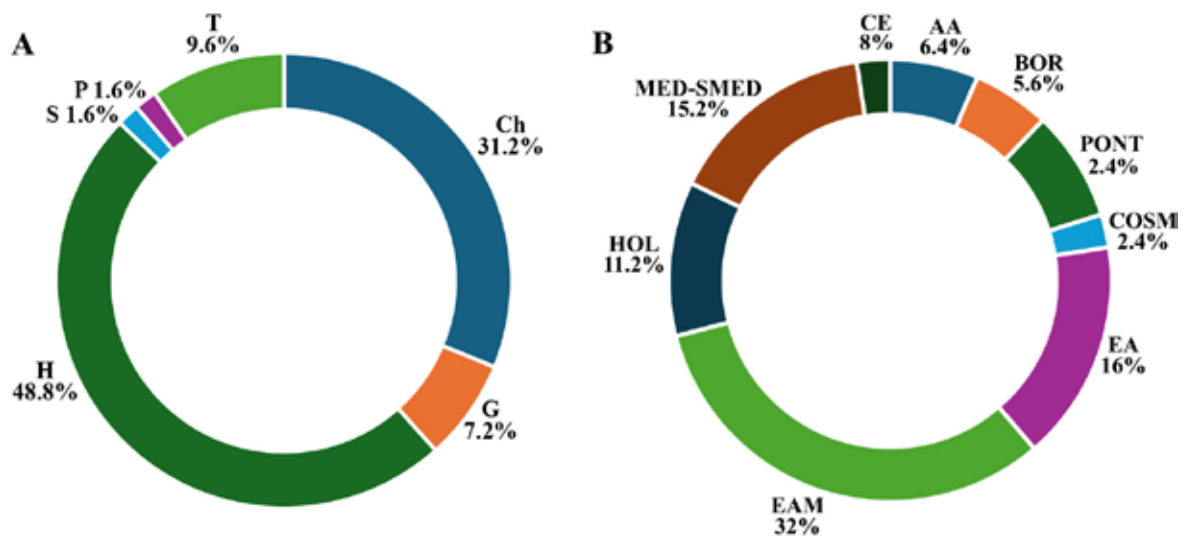


Fig. 5. A - Biological spectrum of the flora in the rocky habitats of the Stara Planina Mts. in Serbia (**P** - phanerophytes; **Ch** - chamaephytes; **H** - hemicryptophytes; **G** - geophytes; **T** - therophytes; and **S** - scandentophytes); **B** - Chorological spectrum of the flora in the rocky habitats of the Stara Planina Mts. in Serbia (**AA** - Arctic-Alpine; **BOR** - Boreal; **CE** - Central European; **COSM** - Cosmopolitan; **EA** - Eurasian; **EAM** - Eurasian Mountain; **HOL** - Holarctic; **MED-SMED** - Mediterranean-sub-Mediterranean; and **PONT** - Pontic)

The phytogeographical analysis classified all recorded taxa into nine area types (Fig. 5B). The Eurasian Mountain area type is predominant (32%), including taxa characteristic of chasmophytic communities on the Stara Planina Mts. in Serbia, such as *Campanula wanneri*, *Heliosperma pusillum* subsp. *pusillum*, *Silene flavescens* Waldst. & Kit., *S. lerchenfeldiana* Baumg., *Jovibarba heuffelii* (Schott) A. Löve & D. Löve, and *Saxifraga pedemontana* subsp. *cymosa* Engl. Some species from the Eurasian

continental limestone areas of southeastern Serbia (Stevanović & Stevanović, 1995). Thermophilous and xerophilous habitats within the study area, especially low-elevation or south-facing carbonate rock formations, provide suitable conditions for species of the Mediterranean-sub-Mediterranean area type (Jušković et al., 2010). Additionally, the Holarctic area type is well represented (11.2%), including chasmophytic ferns such as *Asplenium ruta-muraria* and *A. septentrionale* (L.) Hoffm.

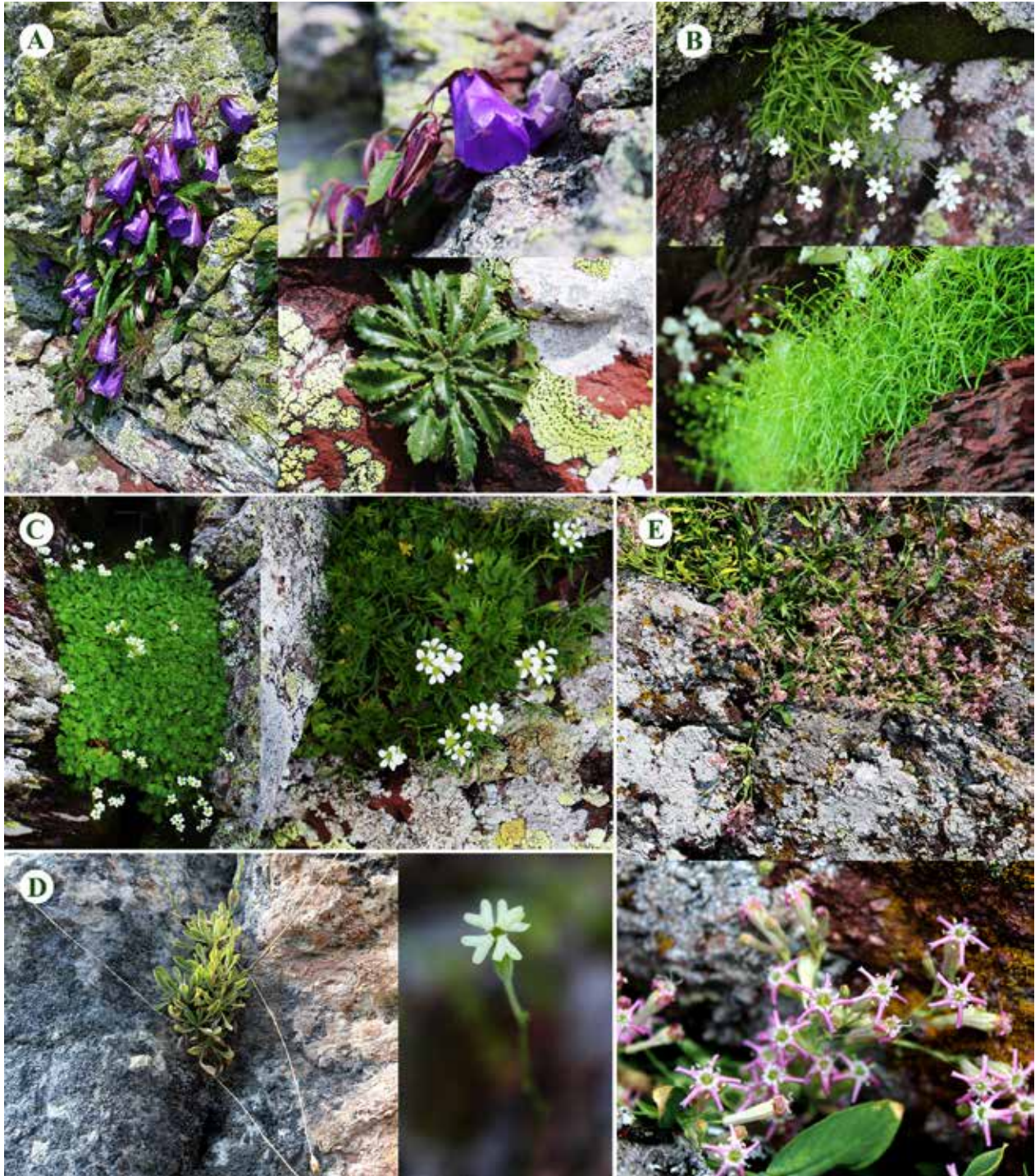


Fig. 6. Characteristic taxa of chasmophytic communities on the Stara Planina Mts. (Serbia) belonging to the Eurasian Mountain area type (**A** - *Campanula wanneri*, **B** - *Heliosperma pusillum* subsp. *pusillum*, **C** - *Saxifraga pedemontana* subsp. *cymosa*, **D** - *Silene flavescens*, and **E** - *S. lerchenfeldiana*). Photos by Jovana Stojanović

This diverse composition underscores the Balkan Peninsula, particularly its central part, as a key convergence zone blending floristic elements from Central Europe, the boreal and Arctic Eurasian regions, as well as the eastern and central Mediterranean (Stevanović et al., 1995).

The plant cover of rocky habitats is shaped by the bedrock composition, which influences the calcium carbonate levels in the soil. Species that thrive on limestone are typically calcicolous, while those preferring siliceous substrates are generally calcifugous (Kojić, 1984). The preference of

the recorded taxa for different bedrock types is presented in **Tab. 1**. The majority of taxa were found exclusively on siliceous rocks (90 species, 72% of all recorded taxa), followed by those documented only on limestone (20 species, 16%). A smaller proportion of taxa (15 species, 12%) were recorded on both bedrock types. Among the prominent chasmophytes exclusive to siliceous rocks are *Campanula wanneri*, *Silene lerchenfeldiana*, *Asplenium septentrionale*, and *Woodsia alpina* (Bolton) Gray, while those confined to limestone include *Aurinia saxatilis* subsp. *orientalis* and *Silene flavescens*. Some species, such as *Asplenium trichomanes* L., *Cystopteris fragilis*, *Saxifraga paniculata* Mill., and *Asplenium ruta-muraria*, were observed on both bedrock types. This is not surprising for *Asplenium trichomanes* and *Cystopteris fragilis*, as various subspecies of *A. trichomanes* are adapted to different substrates (e.g. *A. trichomanes* L. subsp. *trichomanes* prefers siliceous rocks, while *A. trichomanes* subsp. *quadrivalens* D.E.Mey. is more suited to calcareous rocks). Similarly, *Cystopteris fragilis* demonstrates a broad ecological tolerance for different substrate pH levels (Sádlo & Chytrý, 2009). On the other hand, *Saxifraga paniculata* and *Asplenium ruta-muraria* are generally considered calcicolous species (Axmanová, 2022). In the study area, *Asplenium ruta-muraria* is primarily found on calcareous rocks, while *S. paniculata* was more prevalent on siliceous rocks. This pattern can be explained by the presence of calcium compounds in acidic rocks, which may contribute to the formation of alkaline soil (Oettli, 1905; Lundquist, 1968). For example, silicate rocks like gneiss can contain calcium that accumulates in cracks, creating conditions conducive to the growth of calcicolous species (Lüth, 1993). As a result, microhabitats on different rock types can exhibit similar soil pH values (Larson et al., 2000), which in turn allows the development of the same plant species.

Rocky habitats are often regarded as microclimatic refugia (Speziale & Ezcurra, 2015; Bátori et al., 2017; Fitzsimons & Michael, 2017), offering long-term shelter from harsh climatic conditions and enabling the survival of numerous relict species. These microhabitats act as buffers against extreme environmental conditions, making rock crevices vital refuges for arctic-alpine species, especially those found south of the Arctic belt (García et al., 2020). The presence of arctic-alpine species in rock vegetation is a legacy of climatic fluctuations during glaciation and deglaciation, which confined their earlier distribution to mountainous regions and cliffs (Larson et al., 2000). Relict species thrive in low-competition microhabitats, such as crevices, where limited space restricts the growth of competing

plants (Crawford, 1989). In the study area, 9% of the recorded species are considered glacial relicts, including *Aster alpinus* L., *Arabis alpina* subsp. *caucasica* (Willd.) Briq., *Cerastium alpinum* L., *Sedum annuum* L., *Juncus trifidus* L., *Luzula spicata* (L.) DC., *Poa alpina* L., *P. laxa*, *Primula minima* L., *Saxifraga paniculata*, and *Woodsia alpina*.

Chasmophytic plant communities are of significant biogeographical importance due to the high number of endemic taxa they support. These endemic species flourish in steep, rocky environments with challenging soil conditions, where limited vegetation cover minimizes biotic interactions (Panitsa & Kontopanou, 2017). In this study, two Balkan endemic taxa were identified: *Centaurea stoebe* subsp. *serbica* (Prodan) Ochsmann and *Dianthus moesiacus* Vis. & Pančić (Tomović et al., 2014).

Several species recorded on the rock outcrops within the study area are designated as strictly protected or protected under national legislation (Official Gazette of the Republic of Serbia, No. 5/2010, 47/2011, 32/2016, and 98/2016). Strictly protected species include *Campanula wanneri*, *Dianthus moesiacus*, and *Veronica barrelieri* Roem. & Schult. Protected species encompass *Silene lerchenfeldiana*, *Juniperus communis* subsp. *nana* Syme, *Vaccinium myrtillus* L., *Geranium macrorrhizum* L., *Hypericum maculatum* Crantz, *Satureja kitaibelii*, *Primula minima*, *Drymocallis rupestris* (L.) Soják, *Galium odoratum* (L.) Scop., and *Saxifraga pedemontana* subsp. *cymosa*.

Conclusion

This study highlights the remarkable floristic diversity and ecological significance of rock outcrops in the Stara Planina Mts. in Serbia. It identifies a wide range of vascular plant species, including several new regional records. The adaptation of chasmophytes to harsh environmental conditions emphasizes their essential role in these unique ecosystems, which host a variety of endemic and relict species. The findings highlight the urgent need for conservation efforts, particularly for species protected by national legislation, in light of threats from habitat degradation and climate change. Furthermore, the study calls for further research to fully assess the biodiversity of these habitats and to develop effective conservation strategies to preserve these valuable ecological resources.

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