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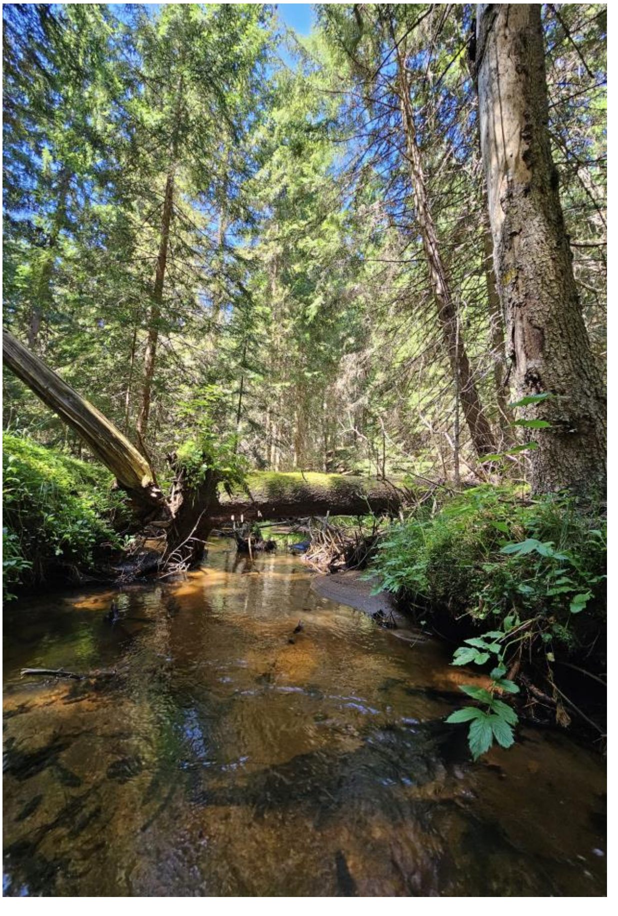

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GENEPOOL OF WOODY SPECIES IN THE STRICT NATURE RESERVE "FELJEŠANA"

Ivona KERKEZ JANKOVIĆ[1], Dragica VILOTIĆ[1], Marina NONIĆ[1], Filip MAKSIMOVIĆ[2], Mirjana ŠIJAČIĆ-NIKOLIĆ[1]*

Abstract: *Forests of primeval character in Europe usually receive the highest protection status. The importance of these ecosystems is highlighted in the BIO2023 Strategy, which outlines specific guidelines for the identification and protection of primeval forests within the European Union. Endemic ecosystems characteristic of Europe, such as pure beech forests, are facing numerous threatening factors in the context of climate change and are considered one of the most endangered habitats. Efforts to preserve and enhance forest ecosystems, as an initial step, involve conservation and long-term monitoring to gain insight into the adaptation and evolutionary strategies of the present species and ecosystems as a whole. The extremely strict protection conditions prescribed in strict reserves impose very limited human intervention, while non-invasive scientific research is considered a desirable activity. One of the first protected pure beech forests in Serbia is the Strict Nature Reserve "Felješana" which, despite being protected since 1950, has not been thoroughly and systematically studied from the aspect of woody species diversity. The aim of this paper is to provide, for the first time,data on the available gene pool of woody species in the primeval beech forest "Felješana". The field research methodology included recording woody species in the tree, shrub, and ground layers at pre-determined monitoring points and identifying and georeferencing target species. For the georeferenced individuals of the target species, height, diameter at breast height, breast circumference, and horizontal crown projection were determined. A total of 27 native woody species were recorded, with 14 species in the tree layer, 25 in the shrub layer, and 19 in the ground layer. Although beech is the dominant species across all three vegetation layers throughout the area, the recorded number of species in the shrub and ground layers indicates the potential for changes in species distribution and composition in this reserve in the future. All recorded species are of native origin, among which six species belong to one of the categories of rare, endangered, and vulnerable species in the forest fund of Serbia. Georeferencing and determining the basic characteristics of the target species individuals have provided a solid foundation for long-term monitoring of the gene pool and the conservation of woody species in SNR "Felješana".*

Keywords: old-growth forest, European beech, species diversity, monitoring, conservation.

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GENOFOND DRVENASTIH VRSTA NA PODRUČJU STROGOG REZERVATA PRIRODE „FELJEŠANA“

Sažetak: *Šume prašumskog karaktera u Evropi obično imaju najviši oblik zaštite. Značaj ovih ekosistema ističe i Strategija BIO2023, koja predviđa posebne smernice za izdvajanje i zaštitu šuma prašumskog karaktera u okvirima Evropske Unije. Endemični ekosistemi karakteristični za Evropu su i čiste bukove šume, koje se u kontekstu klimatskih promena susreću sa nizom ugrožavajućih faktora i predstavljaju jedno od najugroženijih staništa. Napori da se sačuvaju i unaprede šumski ekosistemi kao inicijalni korak podrazumevaju sprovođenje konzervacije i dugoročnog monitoringa kako bi se stvorio uvid u adaptaciju I evolucione strategije prisutnih vrsta i ekosistema u celini. Izuzetno strogi uslovi zaštite propisani u strogim rezervatima imaju veoma ograničavajuće devovanje čoveka, neinvazivna naučna istraživanja se smatraju poželjnim aktivnostima. Jedna od prvih zaštićenih čistih bukovih šuma u Srbiji je i Strogi rezervat prirode „Felješana”, koji iako je zaštićen još od 1950. godine, nije detaljno i sistematičo izučavan sa aspekta diverziteta drvenastih vrsta. Cilj ovog rada je da, po prvi put, pruži podatke o dostupnom genofondu drvenastih vrsta u bukovoj prašumi „Felješana”. Metodologija za terenska istraživanja obuhvatila je evidentiranje drvenastih vrsta u spratovima drveća, žbunja i prizemne vegetacijei na unapred određenim monitoring tačkama, kao i izdvajanje i georeferenciranje ciljnih vrsta. Georefernciranim individuama ciljnih vrsta su određeni visina, prsni prečnik, prsni obim i horizontalna projekcija krošnje. Ukupno je evidentirano 27 autohtonih drvenastih vrsta, od toga, 14 vrsta se javlja u spratu drveća, 25 u spratu žbunja, a 19 u spratu prizemne flore. Iako je bukva dominantna vrsta u sva tri sprata vegetacije na celom području, evidentirani broj vrsta u spratu žbunja i prizemne vegetacije ukazuje na mogućnost promene distribucije i sastava vrsta u rezervatu u budućnosti. Sve evidentirane vrste su autohtonog porekla, među kojima čak šest vrsta pripada jednoj od kategorija retkih, ugroženih i ranjivih vrsta šumskog fonda Srbije. Georeferenciranje i određivanje osnovnih karakteristika jedinki ciljnih vrsta pružilo je čvrstu osnovu za dugoročno praćenje genofonda i konzervaciju drvenastih vrsta u SRP „Felješana”.*

Ključne reči: prašuma, Evropska bukva, specijski diverzitet, monitoring, konzervacija.

1. INTRODUCTION

Nature reserves, as in situ conservation units, provide protected habitats for maintaining genetic diversity, understanding the adaptation and evolutionary strategy and by that represent a very important conservation units for gene pool protection (Higgs, Usher, 1980; Gray, 1996; Alexandre et al., 2006). Strict nature reserves are highly valuable conservation units worldwide, among all, for research of genetic diversity adaptation and species evolution in changing environment (Fonseca et al., 2019). According to EC 2022 (EU Commission Staff Working Document) strictly protected areas are defined as „*...legally protected areas designated to conserve and/or restore the integrity of biodiversity-rich natural areas with their underlying ecological structure and supporting natural environmental processes*.“ According to IUCN Guidelines for Applying Protected Area Management Categories (Dudley, 2008) one of the strictly protected areas is Nature Reserve (Ia) which, among all, serve as area for scientific research and monitoring.

About 3.37 percent of the EU's surface area is protected within 9,382 strict protected areas in the EU (Cazzolla Gatti et al. 2023). According to EU Biodiversity Strategy for 2030such a small percentage is planned to increase to 10% within the EU territory (EC 2020, EC 2023).One of the key commitments by 2030, according to EU BIO 2023, is addressing strict protection of all remaining EU primary and old-growth forests. Among other, one of the habitats characteristic of Europe are pure beech forests. As such, they were recognized by UNESCO and World Natural Heritage Beech Forests has been created, counting 94 forest areas in 18 states.

The European beech forest are complex ecosystems endemic to Europe which cover approximately 14-15 mil. hectares indicating ecological and economical value of these forests (EEA, 2006; Kulla et al., 2023). They are assertive and adaptable, but due to climate change belong to one of the most endangered habitats. Species and genetic composition of virgin beech forest can provide a valuable information in adaptation of species under different weather conditions in long-term chronosequence.

In Serbia, there are a total of 11 beech reserves, including 6 nature reserves with pure beech virgin (old-growth) forests: "Danilova Kosa", "Felješana", "Kukavica", "Vinatovača", "Golema reka" and "Busovata" (ZZP). Forest "Felješana" is virgin forest of European beech with trees more than 300 years old in it terminal phase. It has been declared as a strict nature reserve in 1950 by the Government of the Republic of Serbia, but even before protection there were no intensive management treatments, given the inaccessible location (Kanjevac et al., 2023).

Aim of this paper is to provide the data about available gene pool of woody species recorded in old-growth beech forest "Felješana" for the first time, as a base for long-term monitoring activities and establishing dynamic *in situ* conservation unit.

2. MATERIAL AND METHODS

2.1. Study site

The Strict Nature Reserve "Felješana" (44°20′ N; 21°53′ E) is a protected area of Category I, of national and exceptional significance. It was designated for the preservation of a unique, autochthonous stand of mountain beech with primeval forest characteristics, where trees can reach up to 300 years of age and heights exceeding 40 meters. The reserve is covering an area of 15.28 hectares located in Forest Management Unit "Crna Reka", compartment 134, subcompartment "a". Until 1960, the forest complex remained untouched and unlogged, giving it the characteristics of a primeval forest. The reserve is situated at an altitude of 520-560 meters above sea level, with a terrain slope of 20-35°, and a northern to northeastern exposure (Kanjevac *et al.,* 2023).

2.2. Terrain reconnaissance

The methodology for terrain reconnaissance included two phases: preparatory work before field visits and data collection in the field. The preparatory phase involved gathering and analyzing available literature, creating a template for recording woody species, designing monitoring points, and creating digital data (.kmz file). By overlaying the boundaries of the management unit with a satellite image, the area of the strict reserve was delineated. The monitoring points were designed according to the methodology described by Kanjevac et al. (2023) (Figure 1).

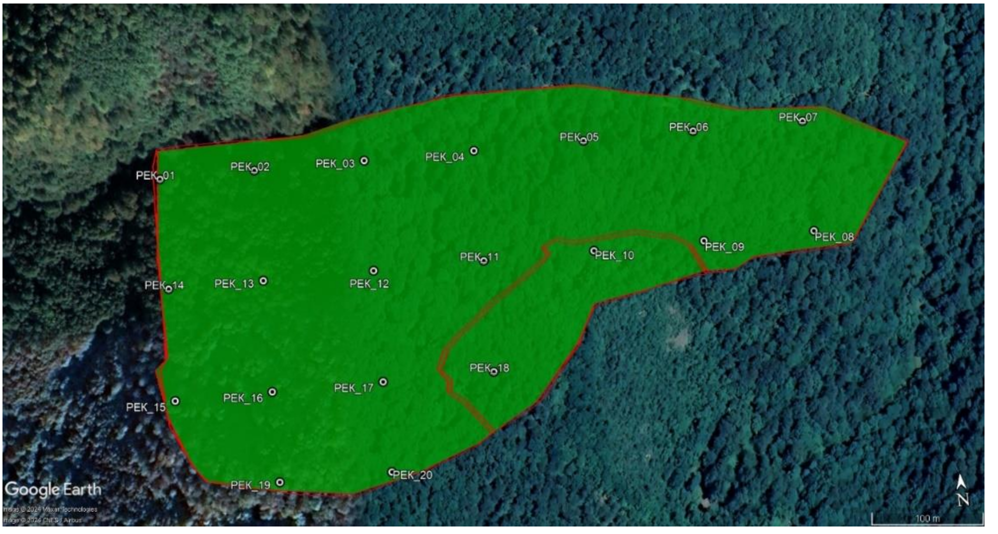

Figure 1. *Strict Nature Reserve "Felješana"with projected monitoring plots*

The data collection involved georeferencing individual trees within each monitoring point. All woody species present in the tree, shrub, and ground vegetation layer were evidented. Layers are defined by the vegetation height: ground vegetation layer up to 20 cm, shrub vegetation layer from 20 cm to 5 m height and tree vegetation layer above 5 m height. After the determination of all woody species, target species were selected based on the criteria described by Šijačić-Nikolić, Nonić (2023): vulnerability, representativeness, and scientific importance. These target species were planned to be included in monitoring and the conservation strategic planning process. For each georeferenced individual, both digital and manual data were collected. Digital data included coordinates gathered in the field, while manual data covered the dimensions of georeferenced individuals: total height [m], diameter at breast height (DBH) [cm], circumference at breast height (CBH) [cm], and maximum crown spread [m]. For georeferencing, two applications were used: UTM Geo Map (Y2 Tech.) and Google Earth Pro (Google).

2.3. Data processing

Based on the data collected during the field research, an overview of all woody species determined in the tree, shrub and ground vegetation layers in SNR "Felješana" was compiled. For each species, the following information was provided: scientific name and family of the species; origin (native or non-native); IUCN category (LC - Least Concern, stable population; NE - Not Evaluated; NT - Near Threatened; VU - Vulnerable); and the species' category in the forest inventory of the Republic of Serbia, according to Banković et al. (2009). The spatial distribution of georeferenced individuals of target species within the "Felješana" reserve was visualized using the Google Earth Pro application.

3. RESULTSAND DISCUSSION

A total of 27 woody species have been recorded in "Felješana" reserve. The species belong to the 11 families: Aceraceae, Araliaceae, Betulaceae, Cornaceae, Fagaceae, Malvaceae, Oleaceae, Rosaceae, Thymelaeaceae, Ulmaceae, and Viburnaceae. All species recorded are native. Although beech is the dominant species, the number of species recorded indicates a high level of species diversity in the reserve. Most species belong to the IUCN category "last concern" (LC), however, according to the national categorization in the forest fund of Serbia (Banković et al. 2009), six species belong to one of the categories of rare, endangered and species at risk (Table 1). All this information indicates significant species diversity in this Strict Nature Reserve, although this contradicts previous claims emphasizing low species diversity (Stojanović et al., 1999; Sekulić, Stojković, 2012).

Table 1. *Overview of the recorded woody species in the SNR "Felješana" with species endangerment status according to IUCN category: LC - last concern, stable population; NE - not evaluated; NT - near threatened; VU – vulnerable, and Republic of Serbia (RS) forest fund category (Banković et al., 2009)*

No	Family	Species	IUCN	RS
1	Aceraceae	*Acer campestre* L.	LC	-
2		*Acer platanoides* L.	LC	rare/endangered
3		*Acer pseudoplatanus* L.	LC	-
4	Araliaceae	*Hedera helix* L.	LC	-
5	Betulaceae	*Carpinus betulus* L.	LC	-
6		*Corylus avellana* L.	LC	-
7	Cornaceae	*Cornus mas* L.	NE	-
8		*Cornus sanguinea* L.	NE	-
9	Fagaceae	*Fagus sylvatica* L.	LC	-
10		*Quercus petraea* (Matt.) Liebl.	LC	-
11	Malvaceae	*Tilia cordata* Mill.	LC	-
12		*Tilia platyphyllos* Scop.	LC	-
13		*Tilia tomentosa* Moench	LC	-
14	Oleaceae	*Fraxinus excelsior* L.	NT	rare/endangered
15		*Fraxinus ornus* L.	LC	-
16		*Syringa vulgaris* L.	LC	-
17	Rosaceae	*Crataegus monogyna* Jacq.	LC	-
18		*Prunus avium* L.	LC	at risk
19		*Pyrus pyraster* (L.) Burgsd.	LC	at risk
20		*Rosa arvensis* Huds	NE	-
21		*Rosa canina* L.	LC	-
22		*Rubus fruticosus* L.	LC	-
23		*Ruscus hypoglossum* L.	LC	-
24		*Sorbus torminalis* (L.) Crantz	LC	at risk
25	Thymelaeaceae	*Daphne mezereum* L.	NE	-
26	Ulmaceae	*Ulmus glabra* Hud.	VU	rare
27	Viburnaceae	*Sambucus nigra* L.	LC	-

Among all recorded species, 14 occur in the tree layer, 25 in the shrub layer, and 19 in the ground vegetation layer (Table 2). The species present in all three layers include sycamore, field maple, Norway maple, hornbeam, beech, white ash, wild cherry, sessile oak, wild service tree, small-leaved lime, and large-leaved lime. Beech is the dominant species across all three layers throughout the entire area.

However, in warmer microclimates at higher elevations, species characteristic of drier habitats, such as lilac and wild pear, appear.

Table 2. *Overview of the recorded woody species in the SNR "Felješana" in three vegetation layers: tree, shrub and ground vegetation layer*

No	Species	Vegetation's layer		
		tree	shrub	ground
1	*Acer campestre* L.	■	■	■
2	*Acer platanoides* L.	■	■	■
3	*Acer pseudoplatanus* L.	■	■	■
4	*Carpinus betulus* L.	■	■	■
5	*Cornus mas* L.		■	■
6	*Cornus sanguinea* L.		■	
7	*Corylus avellana* L.		■	■
8	*Crataegus monogyna* Jacq.		■	
9	*Daphne mezereum* L.		■	■
10	*Fagus sylvatica* L.	■	■	■
11	*Fraxinus excelsior* L.	■	■	■
12	*Fraxinus ornus* L.	■	■	■
13	*Hedera helix* L.			■
14	*Prunus avium* L.	■	■	■
15	*Pyrus pyraster* (L.) Burgsd.	■	■	■
16	*Quercus petraea* (Matt.) Liebl.	■	■	■
17	*Rosa arvensis* Huds		■	
18	*Rosa canina* L.		■	
19	*Rubus fruticosus* L.		■	■
20	*Ruscus hypoglossum* L.			■
21	*Sambucus nigra* L.		■	■
22	*Sorbus torminalis* (L.) Crantz	■	■	■
23	*Syringa vulgaris* L.		■	
24	*Tilia cordata* Mill.	■	■	■
25	*Tilia platyphyllos* Scop.	■	■	■
26	*Tilia tomentosa* Moench		■	■
27	*Ulmus glabra* Hud.	■	■	

Among the recorded species, those belonging to the category of rare/endangered or at-risk species in the forest fund of the Republic of Serbia are particularly significant. In the studied area in tree vegetation layer, these species are represented by a very small gene pool, often consisting of individual trees or small groups of trees located in the peripheral areas of the reserve. However, in the shrub and ground vegetation layer, these species are represented in different micro-localities within the reserve. This is the reason why adult individuals of these species are also georeferenced even though they are located on the very border or even a bit outside of the reserve.

Based on vulnerability, representativeness and scientific importance criteria (Šijačić-Nikolić, Nonić, 2023), the following target species were selected: beech (*Fagus sylvatica* L.), wild pear (*Pyrus pyraster* (L.) Burgsd.), wild cherry (*Prunus avium* L.), wild service tree (*Sorbus torminalis* (L.) Crantz), white ash (*Fraxinus* *excelsior* L.), sessile oak (*Quercus petraea* (Matt.) Liebl.), mountain elm (*Ulmus glabra*Hud.), maple (*Acer campestre* L.), common maple (*Acer pseudoplatanus* L.) and hornbeam (*Carpinus betulus* L.) (Table 3).

Table 3. *Overview of the target species and the criteria based on which they were selected*

Species	Criteria		
	Vulnerability	Representativeness	Scientific importance
Acer campestre L.		+	+
Acer pseudoplatanus L.		+	+
Carpinus betulus L.		+	
Fagus sylvatica L.		+	+
Fraxinus excelsior L.	+	+	+
Prunus avium L.	+	+	+
Pyrus pyraster (L.) Burgsd.	+	+	+
Quercus petraea (Matt.) Liebl.)		+	+
Sorbus torminalis (L.) Crantz	+	+	+
Ulmus glabra Hud.	+		+

3.1. Basic parameters of target species's genepool in SNR "Felješana"

In total, 20 beech individuals (notable individual trees as a population's representatives, with over 250 cm DBH), 2 white ash individuals, 7 wild pear individuals, 2 wild cherry individuals, 5 service tree individuals, 7 sessile oak individuals, 2 mountain elm individuals, 3 hornbeam individuals, and one individual each of Norway maple and field maple were georeferenced and mapped (Fig 2, Table 4).

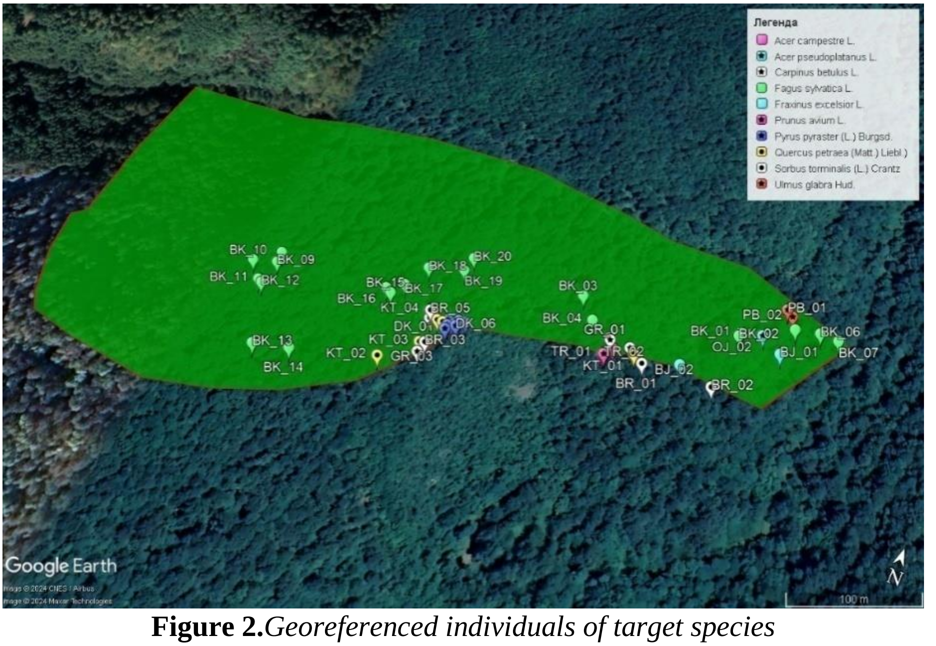

Figure 2.*Georeferenced individuals of target species*

Table 4. *Basic characteristics: HT - height, DBH - diameter at breast height, CBH - circumference at breast height, HPC - horizontal projection of the canopy, of the georeferenced individuals: BK - beech, BJ - white ash, BK - wild service tree, DK - wild pear, DT - wild cherry, KT - sessile oak*

No	Lable	HT [m]	DBH [cm]	CBH [cm]	HPC [m]
1	BK_01	40.0	79.6	250.0	9.0
2	BK_02	39.0	79.6	250.0	8.0
3	BK_03	43.0	85.4	268.0	10.0
4	BK_04	40.0	82.8	260.0	4.5
5	BK_05	41.0	79.6	250.0	8.0
6	BK_06	42.0	100.6	316.0	7.0
7	BK_07	39.0	90.8	285.0	10.0
8	BK_08	39.0	92.4	290.0	8.0
9	BK_09	37.0	82.8	260.0	6.0
10	BK_10	39.0	85.7	269.0	7.0
11	BK_11	37.0	80.3	252.0	8.0
12	BK_12	41.0	93.9	295.0	8.5
13	BK_13	40.0	89.8	282.0	8.0
14	BK_14	39.0	82.5	259.0	8.0
15	BK_15	37.0	80.6	253.0	6.5
16	BK_16	40.0	90.8	285.0	6.0
17	BK_17	38.0	86.9	273.0	8.0
18	BK_18	32.0	82.8	260.0	4.0
19	BK_19	36.0	84.1	264.0	7.0
20	BK_20	38.0	87.3	274.0	5.0
21	BJ_01	42.0	111.8	351.0	4.0
22	BJ_02	25.0	43.0	135.0	6.0
23	BR_01	11.0	24.5	77.0	4.0
24	BR_02	22.0	31.8	100.0	8.0
25	BR_03	24.0	44.3	139.0	7.0
26	BR_04	21.0	38.2	120.0	6.0
27	BR_05	10.0	15.6	49.0	6.0
28	DK_01	13.0	25.5	80.0	2.5
29	DK_02	11.0	21.3	67.0	4.0
30	DK_03	11.0	25.2	79.0	7.0
31	DK_04	8.0	31.2	98.0	5.5
32	DK_05	8.5	28.7	90.0	5.0
33	DK_06	8.0	32.2	101.0	5.5
34	DK_07	6.0	31.5	99.0	4.0
35	DT_01	20.0	19.7	62.0	5.0
36	DT_02	26.0	35.0	110.0	7.0
37	KT_01	23.0	66.9	210.0	10.0
38	KT_02	26.0	34.4	108.0	3.0
39	KT_03	20.0	36.6	115.0	5.0
40	KT_04	20.0	58.0	182.0	12.0
41	KT_05	21.0	30.9	97.0	6.0
42	KT_06	21.0	44.9	141.0	9.0
43	KT_07	19.0	86.0	270.0	16.0

Although dead trunks in various stages of decomposition and fallen trees are occasionally present (Fig 3), it can be noted that the beech population in "Felješana" is generally vital, with a good natural regeneration (Fig 4). These observations align with previous studies, which indicate that although the old-growth forest is in its terminal phase, characterized by aging and decay sub-phases, abundant regeneration appears as a sign of the initial phase (Stojanović et al., 1999; Kanjevac et al., 2023).

Figure 3. *Damaged and dead beech trees in the extinction phase in SNR "Felješana"*

Figure 4. *Natural regeneration of beech in the area of the SNR "Felješana"*

A total of 20 exceptionally healthy beech individuals were georeferenced. The height of the georeferenced trees ranged from 32 m to 43 m, with an average of 38.9 m. The diameter at breast height ranged from 79.6 cm to 100.6 cm, while the circumference at breast height varied from 250.0 cm to 316.0 cm, respectively (Table 4). Beech is dominant species, recorded in all three vegetation layers (tree, shrub, ground), but other species occurs also, individually or in small groups. White ash is species represented by only two adult vital and in good health old-growth individuals (Table 4). Species is present in all tree vegetation layers, but occurs very rarely, naturally regenerated by individual young trees. On warm dry micro-locations on rocky terrain with exposed bedrock at very edge of SNR "Felješana", small group of wild service tree, wild pear, wild cherry and sessile oak was found (Fig 2, Table 4). Wild service tree genepool is represented by large dimensions and in good health individuals, with strong regeneration near adult trees, but also across the reserve all the wild pear, wild cherry and sessile oak individuals have damaged crowns with a significant proportion of dead, mostly upper branches. In forest fruit species no fruiting was observed. Despite the poor condition, it seems that these individuals are old-growth, implying very well adaptation of local genepools.

Beasides target species (beech, white ash, wild service tree, wild pear, wild cherry, and sessile oak), individual specimens of sycamore, Norway maple, field maple, large-leaved lime, and mountain elm were also georeferenced. These individuals were selected to enable future gene pool monitoring as part of dynamic conservation efforts.

Table 5. *Basic characteristics: HT - height, DBH - diameter at breast height, CBH - circumference at breast height, HPC - horizontal projection of the canopy, of the georeferenced individuals: OJ – common maple, ML – Norway maple, KL – field maple, LI – large-leaved lime, PB – mountain elmand and GR – common hornbeam*

No	Lable	Height [m]	DBH [cm]	CBH [cm]	HPC [m]
1	OJ_01	40.0	58.9	185.0	7.0
2	LI_01	23.0	28.7	90.0	9.0
3	KL_01	17.0	30.6	96.0	5.0
4	KL_02	18.0	32.8	103.0	3.0
5	ML_01	24.0	62.1	195.0	9.0
6	PB_01	18.0	12.1	38.0	3.5
7	PB_02	16.0	21.7	68.0	5.0
8	GR_01	19.0	24.2	76.0	4.0
9	GR_02	20.0	36.9	116.0	7.0
10	GR_03	25.0	57.6	181.0	8.0

As Serbia is located in the central part of the Balkan Peninsula, genetic hotspot for many European tree species (Zhelev, 2017; Gomory et al., 2020), more efforts should be invested in monitoring and researching nature reserves, considering species and genetic diversity. Literary sources referring to any aspect of the vegetation of the "Felješana" reserve are very limited (Stojanović et al., 1999; Ostojić et al., 2008; Sekulić, Stojković, 2012; Kanjevac et al., 2023). Most of them focus on the condition and regeneration of beech and do not address the regeneration nor condition of other species. A significant number of species in the shrub and ground vegetation layers indicates the possibility of changing the species composition of the reserve in the future. It is known that changes in the distribution of species are expected in the context of climate change, emphasizing the need to increase proactive conservation efforts and long-term planning (e.g. Kuhn et al., 2016; Seidl et al., 2017; Liang et al., 2022; Doktor et al., 2023; Bonannella et al., 2024).Since this old-growth forest in its terminal phase (Stojanović et al., 1999) continuous monitoring of all species inthis Strict Nature Reserve can provide exact data on the regeneration and overall dynamics of the reserve. Georeferencing and determining the basic characteristics of the individuals of the target species provide a solid basis for long-term monitoring of the genepool and conservation of woody species in SNR "Felješana". Without detailed records of these species, whose genepool often represents only a small number of trees, affected by numerous factors leading to genetic erosion, species may disappear, resulting in a biodiversity loss and a significant reduction in the diversity of our forests.

4. CONCLUSION

The positioning and mapping of the target species was initiated through this research and should be continued, not only as a form of scientific research, but also through regular activities focusing on rare and endangered species. Although beech (*Fagus sylvatica* L.) is the dominant species, the number of woody species (27) in tree, shrub and ground layers indicates a high level of species diversity in the Strict Nature Reserve "Felješana". All woody species are of native origin, with six species belonging to one of the categories of rare, endangered and species at risk, including wild pear (*Pyrus pyraster* (L.) Burgsd.), wild cherry (*Prunus avium* L.), wild service tree (*Sorbus torminalis* (L.) Crantz), white ash (*Fraxinus excelsior* L.), mountain elm (*Ulmus glabra* Hud.), and common maple (*Acer pseudoplatanus* L.). Although the SNR "Felješana" is one of the oldest strict nature reserves in Serbia, this paper describes a number of woody species in detail for the first time and thus creates a knowledge base for further monitoring and conservation measures.

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GENEPOOL OF WOODY SPECIES IN THE STRICT NATURE RESERVE „FELJEŠANA"

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Filip MAKSIMOVIĆ, Mirjana ŠIJAČIĆ-NIKOLIĆ

Summary

Strictly protected areas occupy 3.37% of the EU's territory, which is protected within 9,382 strict areas. It is planned to increase this proportion to 10% by 2030, including commitments to protect primary and old-growth forests. One of the most protected nature reserves are the strict nature reserves. Among all, these areas serve for scientific research. Conservation and monitoring activities provide understanding the adaptation and evolutionary strategy of species and ecosystems as a whole. Beech is one of the most important species covering large areas and forming pure forests as complex endemic ecosystems in Europe. They are assertive and adaptable, but due to climate change belong to one of the most endangered habitats. In Serbia there are six pure beech forests protected. One of the first protected is "Felješana" declared a strict nature reserve in 1950. The aim of this paper is to provide the data about available genepool of woody species recorded in old-growth beech forest "Felješana" for the first time. The methodology for terrain reconnaissance included recording of woody species in tree, shrub and ground vegetation layers at designed monitoring points, definition and georeferencing of target species. For the georeferenced individuals, height, diameter at breast height, breast height circumference, and horizontal crown projection were determined. A total of 27 woody native species were recorded, belonging to the 11 families. Among all, 14 occur in the tree layer, 25 in the shrub layer, and 19 in the ground layer. Beech is the dominant species across all three layers throughout the entire area. The species present in all three layers include sycamore, field maple, Norway maple, hornbeam, beech, white ash, wild cherry, sessile oak, wild service tree, small-leaved lime, and large-leaved lime. A significant number of species in the shrub and ground vegetation layers indicates the possibility of changing the species composition of this Strict Nature Reserve in the future. Most of the species belong to the IUCN category "last concern" (LC), however, according to the national categorization in the forest fund of Serbia (Banković et al. 2009), six species belong to one of the categories of rare, endangered and species at risk. Georeferencing and determining the basic characteristics of the individuals of the target species provided a solid basis for long-term monitoring of the genepool and conservation of woody species in SNR "Felješana".

GENOFOND DRVENASTIH VRSTA NA PODRUČJU STROGOG REZERVATA PRIRODE „FELJEŠANA“

Ivona KERKEZ JANKOVIĆ, Dragica VILOTIĆ, Marina NONIĆ, Filip MAKSIMOVIĆ, Mirjana ŠIJAČIĆ-NIKOLIĆ

Rezime

Strogo zaštićena područja zauzimaju 3,37% površine EU, sa ukupno 9.382 izdvojenih područja. Planira se povećanje ovog procenta na 10% do 2030. godine, uključujući zaštitu šuma prašumskog karaktera. Među zaštićenim područjima, najstroži uslovi zaštite se sprovode u strogim rezervatima. Među malobrojnim, naučna istraživanja su jedna od dozvoljenih i poželjnih aktivnosti. Aktivnosti konzervacije i monitoringa pružaju uvid u adaptaciju i evolucione strategije vrsta i ekosistema u celini.Bukva je jedna od najvažnijih vrsta, pokrivajući velike površine i formirajući čiste šume kao složene endemične ekosisteme Evrope. Iako su prilagodljive i otporne, bukove šume su, usled klimatskih promena, među najugroženijim staništima. U Srbiji je zaštićeno šest čistih bukovih šuma. Jedna od prvih zaštićenih je „Felješana”, koja je proglašena strogim rezervatom prirode 1950. godine.Cilj ovog rada je da pruži podatke o dostupnom genofondu drvenastih vrsta zabeleženih po prvi put u bukovoj prašumi „Felješana”. Metodologija za terenska istraživanja obuhvatila je evidentiranje drvenastih vrsta u spratovima drveća, žbunja i prizemne vegetacije na unapred određenim monitoring tačkama i georeferenciranje ciljnih vrsta. Georefernciranim individuama su određeni visina, prsni prečnik, prsni obim i horizontalna projekcija krošnje. Ukupno je evidentirano 27 autohtonih drvenastih vrsta, koje su raspoređene u 11 porodica. Od toga, 14 vrsta se javlja u spratu drveća, 25 u spratu žbunja, a 19 u spratu prizemne flore. Bukva je dominantna vrsta u sva tri sprata na celom području.Vrste prisutne u sva tri sprata su i obični javor, klen, mleč, bukva, beli i crni jasen, divlja trešnja, divlja kruška, kitnjak, brekinja, sitnolisna i krupnolisna lipa. Značajan broj vrsta u spratu žbunja i prizemne vegetacije ukazuje na mogućnost promene sastava vrsta u

ovom strogom rezervatu prirode u budućnosti. Većina vrsta,prema IUCN-u, pripada kategoriji "najmanje zabrinjavajućih" (LC), međutim, prema nacionalnoj kategorizaciji šumskog fonda Srbije (Banković i sar., 2009), čak šest vrsta pripada kategoriji retkih, ugroženih ili ranjivih vrsta. Georeferenciranje i određivanje osnovnih karakteristika jedinki ciljnih vrsta pružilo je čvrstu osnovu za dugoročno praćenje genofonda i konzervaciju drvenastih vrsta u SRP „Felješana".

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WHITE WILLOW (*Salix alba* L.) VARIABILITY IN THE LANDSCAPES OF OUTSTANDING FEATURES "GREAT WAR ISLAND" BASED ON MORPHOLOGICAL TRAITS OF THE LEAVES: A BASIS FOR ASSESSMENT OF GENE POOL

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Abstract: *The gene pool assessment of woody species has multiple significance in biotechnology. This research paper studied the morphological traits of white willow leaves in the Landscapes of Outstanding Features (LOF) "Great War Island". The variability of leaf length, width, area, and circumference, as well as the petiole length of the white willow tested trees were determined. Different parameters show varying degrees of variability. The trees were grouped into multiple clusters based on the average distance of the tested parameters. The results provide a realistic basis for evaluating the gene pool and show great potential for the conservation and production of white willow reproductive material adapted to the changed habitat conditions in Serbia. In this way, the condition of this specific area, as well as other coastal forests in Serbia, is improved. It is possible to improve protection measures against harmful organisms, primarily pathogens of white willow leaves, by applying these findings and reducing the occurrence of certain types of harmful bacteria and fungi, which are associated with decreased vitality and poor physiological condition of trees. The results obtained in the research will facilitate the management and preservation of the white willow gene pool in these unique Landscapes of Outstanding Features.*

Keywords: white willow, variability assessment, gene pool, conservation.

VARIJABILNOST BELE VRBE (*Salix alba* L.) NA PODRUČJU PIO „VELIKO RATNO OSTRVO" PREMA MORFOLOŠKIM SVOJSTVIMA LISTOVA: OSNOVA ZA PROCENU STANJA GENOFONDA

Apstrakt: *Potreba za procenom stanja genofonda drvenastih vrsta ima višestruki značaj u biotehnologiji. Cilj ovog rada je istraživanje morfoloških karakteristika listova bele vrbe na području PIO Veliko ratno ostrvo. Utvrđena je varijabilnost u dužini, širini, površini i obimu listova, kao i dužini peteljke bele vrbe. Takođe, različiti parametri pokazuju nejednaku varijabilnost. Stabla su grupisana u više klastera na osnovu prosečne udaljenosti testiranih parametara. Dobijeni rezultati daju realnu osnovu za procenu genofonda i pokazuju da postoji veliki potencijal za konzervaciju i proizvodnju reproduktivnog materijala*

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bele vrbe prilagođenog izmenjenim stanišnim uslovima u Srbiji. Na taj način, postiže se unapređenje stanja konkretnog ispitivanog područja ali i drugih priobalnih šuma u Srbiju. Primenom ovih rezultata, moguće je unaprediti mere zaštite protiv štetnih organizama, prvenstveno patogena listova bele vrbe. Takođe, smanjuje se pojava određenih vrsta štetnih bakterija i gljiva koje su povezane sa umanjenom vitalnosti i lošim fiziološkim stanjem stabala. Rezultati dobijeni u istraživanju će olakšati upravljaču gazdovanje i očuvanje genofonda bele vrbe u ovom jedinstvenom predelu izuzetnih odlika.

Ključne reči: bela vrba, procena varijabilnosti, genofond, konzervacija.

1. INTRODUCTION

The *Salix* genus includes about 600 species in all continents except Australia (Cvjetićanin et al. 2016). The white willow (*Salix alba* L.) is one of the most widespread and well-known species of willow (Houston Durrant et al. 2016). This species is widely used in medicine to relieve pain and infections, reduce inflammation, and restore blood cells (Shara and Stohs, 2015; Maistro et al., 2019; Lin et al., 2023). Although it has limited commercial use in the wood industry, the willow plays a significant biological role in maintaining the structure of its habitat, particularly in high erosion areas, wet slopes of mountain regions with extensive drainage areas (Bosco et al., 2015), and in endangered Ramsar areas. Therefore, willow is often used in the control of erosive processes, it is an indispensable species in ecosystem restoration and for phytoremediation of polluted water and soil due to its tolerance to hypoxia and harmful agents (Urošević et al., 2024). It is also used for biomass production in short rotation conditions, thanks to its ability for simple vegetative propagation (Kovačević et al., 2010).

One of the significant challenges of the 21st century is climate change and the uncertain fate of various woody species in circumstances that test the limits of endurance. In Serbia, there are predictions of rising annual temperatures, changes in precipitation patterns, and prolonged droughts (Đurđević et al., 2018); these factors are already in force. Their influence on destabilizing the balance of existing ecosystems, soil drying, reduced water levels in rivers, and even complete riverbed drying is visible. Phylogenetic studies have identified the area of the Balkans, including Serbia, as one of the refuges ("refugium") of plant communities during the previous ice ages and the place where the subsequent recolonization of Europe began (Tzedakis, 2004). That is why the territory of Serbia is characterized by significant variability within and between populations of different plant species, which is the source and basis of adaptation to new climate changes, the fight against pathogens and diseases, pollution, and natural disasters. Considering the unpredictable nature of their habitats and variability as their constant feature, phenotypic plasticity and adaptability are some of the main characteristics of willows (Karrenberg et al., 2002). The knowledge of forests gene pool enhances the improvement of the global bio-economy (Orlović et al., 2014). A European tendency to preserve its coastal forests involves understanding the genetic diversity and environmental factors influencing trees (Alimpić et al., 2022). If trees fail to adapt to altering conditions, primarily adverse ecological factors or changed habitat conditions, the distribution range of certain tree species will decline. It is also necessary to focus on improving and preserving the current condition of various regions, especially those with exceptional environmental value. The dimensions of the leaves of woody species are very important in forestry as they indicate the trees' potential to adapt to different habitat conditions, including very warm or cold areas (Körner, 2016, Wang et al., 2019, Li et al., 2020, Liu et al., 2020, Wang et al., 2022). Leaves are the key photosynthetic organs of plants. They provide energy for other physiological processes, particularly important in stressful conditions and states of high sensitivity when the stored reserves play a vital role. Variability in leaf traits is closely linked to variations in local climatic factors, including temperature, precipitation, light, and elevation (Othón et al., 2020; Li et al., 2021). Plants demonstrate significant phenotypic plasticity, and leaves' diverse morphological and anatomical characteristics reflect their strategies for adapting to environmental conditions.

The white willow expresses morphological and anatomical variability, which allows it to adapt to various habitat conditions (Keleş 2021). Similarly, phenotypic plasticity and adaptability are the main characteristics of willows if have in mind the unpredictable nature and variability of their habitats (Karrenberg et al., 2002). The aim of this research was to investigate the variability of leaf morphological traits in different white willow trees. The results obtained will facilitate the assessment of the gene pool's condition, which serves as the basis for further efforts to enhance and protect the white willow in the LOF "Great War Island." Furthermore, these findings are the basis for additional research on genetic diversity, the beginning of species breeding, and the preservation of its gene pool.

2. MATERIAL AND METHODS

Study site

The Landscape of Outstanding Features (LOF) "Great War Island" (44° 49.826'N; 20° 25.951'E) is shaped by the Sava and Danube rivers by accumulating sand deposits and creating a sedimentary and alluvial accumulation. According to the Management Plan of the Protected Area "Great War Island" (2010), the shape and area of the island is changing due to the dynamic of rivers, with the area increasing from 167.90 hectares to 211.36 hectares between 1952 and 2006. The island is characterized by poor forest cover, with 61.6% of the thinned and 19.4% of devasted stands. Forest area occupies 59.6% (123.62 hectares), with dominant deciduous trees covering 92.6 hectares and a small portion of artificially established stands covering 7.4 hectares. (Forest Management Plan for the Management Unit "Great War Island", 2018-2027). Woody species diversity is low in this area, with 11 species in total, most of which are allochthonous. Invasive allochthonous species compete with allochthonous species, making natural regeneration and ecological restoration very challenging. According to the Management Plan of the Protected Area "Great War Island" (2010), three forest types are present on the island, of which are two dominated by white willow: the type of white willow forest (*Salicetum albae*) on beta-gley and the type of white willow forest (*Salicetum albae*) on recent, wet and layered sediment. The white willow population is located on the circle-like peripheral part of the island and is characterized by the significant presence of old, damaged trees within a significant part of dry, mostly top, branches in the crown.

Plant material

A total of twenty-six test trees, bearers of production of reproductive material in good health condition, were selected as representative individuals of the white willow population from the area of LOF "Great War Island". Each selected tree is marked with a number, and its basic characteristics, including height (m), circumference at breast height (cm), and horizontal crown projection (m), were determined. The tree's height was measured using the Vertex III hypsometer, and the circumference was measured with measuring tape. The diameter at breast height (cm) was later calculated from the circumference using the formula $2r=O/\pi$. Additionally, the test trees were georeferenced using the UTMGeoMap mobile application and visualized using the Google Earth Pro application.

In late July 2024, fully developed undamaged leaves were sampled. From each selected tree, twenty shoots were collected from the outer, well-lit part of the crown. Two to three leaves from the central part were randomly selected from each shoot for further analysis, as these are typically the most uniform. In total, 50 leaves were collected from each tree.

Morphological analyses

After being collected, a total of 1,300 leaves (per 50 leaves from 26 trees) were herbarized and scanned to measure the morphological parameters using the specialized software LAMINA. Five phenotypic traits were selected for measurement: leaf length (LL), leaf width (LW), leaf area (LA), leaf circumference (LC), and petiole length (PL).

Statistical methods

A general linear model (GLM) was used to test the difference in the morphological parameters of white willow leaves as a dependent variable concerning selected trees (independent variable). The normality of the residuals was confirmed using the Kolmogorov-Smirnov test with Lilliefors correction. The homogeneity and linearity of the model were analyzed based on dot plots. Tukey's post hoc test determined homogeneous groups within each analyzed parameter. The dendrogram cluster analysis used the average distance method to group trees by similarity based on the tested parameters. In order to determine the variability of the observed parameters the coefficient of variability was determined. All statistical analyses were performed using the SPSS 27 software package and Statgraphics Centurion XVI.

3. RESULTS AND DISCUSSION

All twenty-six selected trees are located within compartment 1 of the LOF "Great War Island", where the second and third degrees of protection are established (Figure 1). According to the Management Plan (2010), the area contains many clearings, agricultural and urban land, high white willow forests, high poplar forests, and high mixed poplar forests. The average height of the selected trees is 17.61 m, ranging from 6 m (BV_26) to 26.3 m (BV_14). The average diameter at breast height is 87.28 cm, while the average circumference is 273.23 cm. The tree BV_10 has the smallest circumference (47.9 cm and 150 cm, respectively), while the BV_11 tree (137.4 cm and 430 cm, respectively) has the highest (table 1). These values are consistent with the usual size characteristic of white willow trees (Houston Durrant et al., 2016). According to EUFGIS (European Information System on Forest Genetic Resources), there are only two white willow conservation units in Europe, namely in Romania. The trees selected in the area of the Great War Island could, with adequate measures, be candidates for establishing an *in situ* conservation unit to preserve, protect, and improve the available gene pool.

Table 1. *Basic characteristics of selected white willow trees in the area of LOF "Great War Island"*

Test Tree Mark	Height (m)	Diameter at 1.3m (cm)	Circumference at 1.3m (cm)	Horizontal crown projection (m)
BV_01	20.9	121.3	381	12
BV_02	22.7	118.2	370	9
BV_03	19.8	70.3	220	6
BV_04	17.9	102.2	320	8
BV_05	22.1	60.7	190	7,5
BV_06	21.7	71.9	225	12
BV_07	22.0	102.2	320	10
BV_08	20.3	115.0	360	11
BV_09	9.4	57.5	180	12
BV_10	11.6	47.9	150	11
BV_11	15.2	137.4	430	15
BV_12	17.7	95.8	300	8
BV_13	15.3	92.7	290	7
BV_14	26.3	127.8	400	11
BV_15	23.7	70.6	221	7
BV_16	13.3	70.9	222	6
BV_17	11.5	67.1	210	6
BV_18	17.0	79.9	250	9
BV_19	12.5	89.5	280	10
BV_20	20.0	89.5	280	8
BV_21	20.3	89.5	280	10
BV_22	20.0	124.6	390	10
BV_23	19.5	73.5	230	12
BV_24	14.3	55.9	175	11
BV_25	16.9	70.3	220	11
BV_26	6.0	67.1	210	10
AVERAGE	17.61	87.28	273,23	9,60
RANGE	6.0-26.3	47.9-137.4	150-430	6,0-15,0

Figure 1. *The spatial arrangement of the white willow test trees in the area of LOF "Great War Island"*

The results of one factorial analysis of variance indicate statistically significant differences ($p < 0.01$) between trees for all leaf morphological parameters analyzed: leaf length (F-value=21.53), leaf width (F-value=33.85), leaf area (F-value= 26.41), leaf circumference (F-value=28.39) and leaf petiole length (F-value=47.61) (Table 2). The result indicated a significant variability of the available gene pool, which may result from genetic factors and environmental conditions in which the trees are located. Given that the environmental conditions are relatively uniform and that the only environmental factor that can impact this area is the microlocality, it can be assumed that these are genetically distant trees.

Table 2. *Analysis of variance for measured leaf morphological traits*

Laef traits	Sum of squares	df	Mean square	F	p
Leaf length	126597.601	25	5063.904	21.530	< 0.01
Leaf width	7425.715	25	297.029	33.850	< 0.01
Leaf area	52150010.442	25	2086000.418	26.408	< 0.01
Leaf circumference	645109.275	25	25804.371	28.386	< 0.01
Leaf petiole length	2469.523	25	98.781	47.613	< 0.01

Among the analyzed morphological parameters, the leaf petiole length parameter has the highest coefficient of variability (CV=26.48%). The leaf area parameter (CV=21.57%) has a significant value of variation concerning the average value, while the other parameters - length, width, and leaf circumference have slightly lower variability (CV=13.30%, 13.60%, and 13.66%, respectively). The average value of leaf length is 75.47±10.04 mm, with the minimum value recorded for tree BV_10 (47.91±10.34 mm), while the highest value was recorded for tree BV_01 (91.65±18.91 mm). The average leaf width is 17.85±2.43 mm, with the minimum value recorded for tree BV_25 (12.98 ±1.42 mm), while the highest was recorded for tree BV_07 (21.32 ± 3.05 mm). The average value of the leaf area is 941.33±203.00 mm^2, where the minimum value was recorded for the tree BV_10 (462.28 ± 158.71 mm2), while the highest was recorded for the tree BV_01 (1394.76±408.26 mm2). The average value of the leaf circumference is 165.80±22.66 mm, with the minimum value recorded for tree BV_10 (104.26 ±19.94 mm), while the highest value was recorded for tree BV_01 (201.42±39.71 mm). The average value of the leaf petiole length is 5.53±1.41 mm, with the minimum average value recorded for the tree BV_18 (3.44±1.35 mm), while the highest was recorded for the tree BV_08 (8.61±1.42 mm). For most parameters, the highest average values occur for the tree BV_01 and the minimum values for the tree BV_10.

The dendrogram of cluster analysis (Figure 2) shows a grouping of two smaller and one larger clusters. The cluster distinguished at the most significant distance comprises the trees BV_5, BV_25, and BV_10. The second cluster consists of trees BV_01, BV_08, and BV12, while the third consists of all other trees. Trees BV_09 and BV_13, as well as trees BV_19 and BV_20, were grouped at the smallest distance.

Future studies regarding trees' adaptability are expected to provide more specific answers concerning the mechanisms of their adaptation to stress factors (Kijowska-Obrerc et al., 2020).

According to Ledinski’s research (2020), the leaf area and leaf petiole length showed the most variation, while leaf length showed the least. The same author states that trees from warmer (Mediterranean) terrains are characterized by smaller leaves than trees that are more profound in the continent. Also, in the same research, slightly lower average values for the researched parameters were observed in the total sample compared to the values obtained in this research. The genetic foundation significantly influences the leaf traits heritability in white willow clones, with maximum heritability observed for leaf width and area, indicating that these traits are reliable for selecting and breeding this species (Singh et al., 2012). The determined variability rate is a good starting point for the conservation of the available gene pool and directed production of the reproductive material that will be used for regeneration and distribution of this population in the future. The clustering in the sample may suggest a substructure in the population, which requires further investigation using molecular markers.

It was determined that the environmental conditions significantly impact the development of leaves in willow species (*Salix* spp.) (Cunniff et al., 2015). The Salix genus is phenotypically diverse and shows remarkable phenotypic plasticity and diversity in leaf dimensions (Karp et al., 2011). The noticeable variability of the morphological leaf characteristics is important in pioneer species where the white willow belongs. It will enable faster establishment of the species and survival of individuals when they take over a new habitat. The significant morphological variability of the leaves may be due to adaptability to certain habitat conditions, such as varying water levels or different content of nutrients in the soil (Tumpa et al., 2022). Research conducted by Marcysiak (2012a, 2012b) on the related species *S.*

herbacea and *S. reticulata* proved the correlation between leaf morphometric traits and climate conditions.

The variability of phenotypic characteristics, including leaf size, was also described in the species *S. psammophila* by Hao et al. (2019). Tumpa et al. (2022) studied several populations of the related species *S. triandra* and found higher variability of traits related to leaf size between populations than within populations. They attributed this result to the most likely founder effect, where a small number of individuals participated in establishing populations, with relatively equal conditions prevailing in each population. Changes in leaf morphology are one of the main mechanisms of adaptation to different environmental conditions in plants (Radersma et al., 2020). Not all sampled trees from the investigated willow population live in identical conditions. Namely, some individuals are along the coast, while others are withdrawn inside the island, which could lead to specific changes in the soil characteristics and further cause different values of the examined characteristics. A different sunlight regime also characterized the studied trees. Larger leaves often adapt to lower insolation, higher rainfall, and warmer temperatures (Gong et al., 2023). Since the specific research was carried out in the same locality, the obtained results indicate the existence of a large genetic variability of the tested trees.

Table 3. *Descriptive statistical parameters of the analyzed leaf morphological traits*

Test tree	Leaf length (mm)	Leaf width (mm)	Leaf area (mm^2)	Leaf circumference (mm)	Leaf petiole length (mm)
BV_01	91.65 ± 18.91j	21.20 ± 3.18f	1394.76 ± 408.26i	201.42 ± 39.71j	8.21 ± 2.28k
BV_02	73.40 ± 19.40cdef	17.74 ± 3.55cd	944.05 ± 333.23ef	165.17 ± 39.72defghi	6.96 ± 1.33ij
BV_03	85.14 ± 10.94ghij	14.60 ± 1.83ab	832.32 ± 152.68cde	186.71 ± 18.49ij	4.85 ± 1.67cdefg
BV_04	78.06 ± 15.83defgh	19.67 ± 2.86def	1042.74 ± 308.77fgh	170.46 ± 32.29efghi	5.62 ± 1.53gh
BV_05	63.96 ± 10.69bc	14.91 ± 1.54ab	649.76 ± 133.36abc	146.70 ± 16.81bcd	3.61 ± 1.01a
BV_06	79.32 ± 14.23defghi	18.15 ± 2.83cd	1001.75 ± 268.71efgh	170.22 ± 26.63efghi	6.35 ± 1.38hi
BV_07	69.996 ± 14.19cd	21.32 ± 3.05f	1011.56 ± 302.60efgh	148.50 ± 31.01bcde	6.88 ± 1.34ij
BV_08	90.20 ± 17.35ij	16.59 ± 3.51bc	1042.95 ± 267.87fgh	201.24 ± 32.44j	8.61 ± 1.42k
BV_09	76.35 ± 12.98 defg	18.16 ± 3.96cd	953.27 ± 293.46ef	167.07 ± 23.11defghi	5.21 ± 1.56efg
BV_10	47.91 ± 10.34a	14.19 ± 2.68a	462.28 ± 158.71a	104.26 ± 19.94a	3.84 ± 0.81abcd
BV_11	76.90 ± 11.84defgh	13.92 ± 2.77a	716.00 ± 201.50bcd	167.56 ± 23.92defghi	6.29 ± 1.54hi
BV_12	85.38 ± 19.82ghij	19.77 ± 3.17def	1176.64 ± 365.25gh	186.91 ± 42.08ij	7.62 ± 1.89jk
BV_13	76.41 ± 23.21defg	18.54 ± 3.31cde	999.11 ± 420.17efgh	170.44 ± 47.25efghi	5.53 ± 1.25fgh
BV_14	63.63 ± 18.13bc	19.24 ± 3.23def	895.41 ± 323.70def	140.20 ± 36.38bc	5.20 ± 1.42efg
BV_15	76.32 ± 15.61defg	18.88 ± 2.94de	992.04 ± 296.00efg	166.59 ± 28.99defghi	4.90 ± 1.33defg
BV_16	63.39 ± 14.52bc	18.41 ± 4.09cde	827.90 ± 321.02cde	135.85 ± 27.08b	3.76 ± 1.41ab

BV_17	87.83 ± 15.30hij	16.66 ± 2.60bc	1014.70 ± 248.51efgh	197.30 ± 29.31j	4.48 ± 1.52abcdef
BV_18	75.59 ± 15.87defg	17.66 ± 2.07cd	948.78 ± 191.13ef	170.32 ± 23.39efghi	3.44 ± 1.35a
BV_19	78.89 ± 15.26defghi	18.21 ± 3.56cd	997.57 ± 286.80efgh	174.36 ± 31.81ghi	3.80 ± 1.30abc
BV_20	78.25 ± 15.75defh	18.89 ± 2.79de	996.41 ± 295.81efgh	171.71 ± 33.94fghi	4.36 ± 1.59abcde
BV_21	83.59 ± 13.83 fghij	20.49 ± 2.92ef	1200.73 ± 303.44hi	185.33 ± 28.50hij	4.73 ± 1.46bcdefg
BV_22	82.56 ± 17.32defghij	17.86 ± 2.38cd	998.90 ± 249.56efgh	180.84 ± 32.96hij	4.80 ± 1.39bcdefg
BV_23	71.05 ± 14.20c	21.16 ± 4.05f	1054.55 ± 339.30fgh	150.97 ± 28.23bcdef	5.17 ± 1.33efg
BV_24	71.35 ± 11.21cde	14.36 ± 2.10a	699.51 ± 142.33bcd	158.43 ± 20.57cdefg	5.21 ± 1.19efg
BV_25	58.57 ± 7.99ab	12.98 ± 1.42a	532.89 ± 102.26ab	129.15 ± 15.09b	4.37 ± 0.93abcde
BV_26	76.47 ± 14.97defg	20.47 ± 2.44ef	1087.98 ± 278.59fgh	163.16 ± 28.96defgh	4.42 ± 1.52abcde
AVERAGE	75.47±10.04	17.85±2.43	941.33±203.00	165.80± 22.66	5.53±1.41
CV %	13.30	13.60	21.57	13.66	26.48

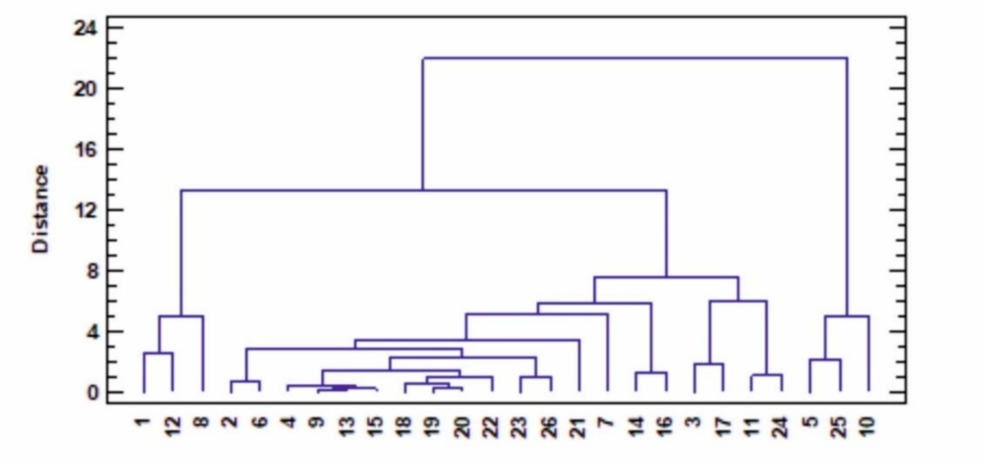

Figure 2. *Dendrogram of leaf morphological traits*

In the context of sustainable use of the available gene pool, special attention should be paid to the development and damage present on the leaves when selecting individual genotypes. In the case of white willow, inadequate adaptation of the trees to the habitat conditions can lead to an imbalance in the uptake of nutrients, resulting in bacterial diseases (De Vos et al., 2007). Besides that, high species diversity of parasitic and saprophytic fungi have been found in willow trees, mostly causing serious damage to the leaves of young individuals (Marković and Karadžić 2006), which may vary depending on the monitoring year (Pusz and Urbaniak 2017).

4. CONCLUSION

This research demonstrated a high variability rate of the studied morphological traits of the leaves of twenty-six white willow test trees which represent the population of this species in the LOF “Great War Island”. These results are the basis for further study, which is necessary to provide guidelines and recommendations for the conservation and targeted use of white willow genetic resources. The LOF "Great War Island" has the potential to preserve and produce white willow reproductive material adapted to different environmental conditions. In this way, the different biotic damages that occur due to the physiological weakening of trees in unfavorable conditions can be prevented. Furthermore, the protection measures against harmful factors deteriorating trees will give better results if the genotypes adapted to environmental conditions are used for the natural or artificial restoration of forests.

The findings on the variability within the white willow population on the Great War Island will facilitate the management and preservation of the white willow gene pool in this unique area with outstanding features.

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WHITE WILLOW (*Salix alba* L.) VARIABILITY IN THE LANDSCAPES OF OUTSTANDING FEATURES „GREAT WAR ISLAND" BASED ON MORPHOLOGICAL TRAITS OF THE LEAVES: A BASIS FOR ASSESSMENT OF GENE POOL

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Summary

Knowledge of the gene pool of trees is the basis of various works on improving the existing state of forests. To get to know the gene pool of white willow from the area "Landscape of Extraordinary Characteristics Great War Island," sampling of different trees and analysis of the morphological traits of the leaves of white willow (*Salix alba*) was carried out. Trees were sampled after the stage of full leaf development and analyzed using the LAMINA software package. The results revealed significant variability in the length and width of the leaves, including their area, circumference, and petiole length. Based on these findings, the white willow trees were categorized into distinct clusters depending on their leaf characteristics. This categorization simplifies the selection and production of reproductive material and guides further research. By better understanding the gene pool, we can enhance the white willow's adaptation to different habitat conditions, contributing to the preservation and growth of coastal forests in Serbia, particularly in response to global changes. This study also aids in improving and conserving the "Landscape of Extraordinary Characteristics Great War Island," making it easier for managers to oversee and maintain the gene pool of white willow. The findings can be applied to protect the white willow trees from various biotic and abiotic factors, ultimately enhancing their vitality and overall condition.

VARIJABILNOST BELE VRBE (*Salix alba* L.) NA PODRUČJU PIO „VELIKO RATNO OSTRVO” PREMA MORFOLOŠKIM SVOJSTVIMA LISTOVA: OSNOVA ZA PROCENU STANJA GENOFONDA

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Rezime

Poznavanje genofonda drveća predstavlja osnov različitih radova na unapređenju postojećeg stanja šuma. U cilju upoznavanja genofonda bele vrbe sa područja PIO Veliko ratno ostrvo izvršeno je uzorkovanje različitih stabala i analiziranje morfoloških karakteristika listova bele vrbe (*Salix alba*). Stabla su uzorkovana posle faze potpune razvijenosti listova i analizirana primenom softverskog paketa LAMINA. Dobijeni rezultati su pokazali veliku varijabilnost u dužini i širini listova, odnosno njihovom površini i obimu, kao i dužini peteljke. Testirana stabla bele vrbe se mogu razdvojiti u više klastera u zavisnosti od dimenzija morfoloških parametara listova. Korišćenjem ovih klastera pojednostavljuju se radovi vezani za njihovu selekciju i proizvodnju reproduktivnog materijala, odnosno dalja istraživanja. Bolja adaptiranost bele vrbe na različite stanišne uslove će doprineti očuvanju i razvoju priobalnih šuma u Srbiji, naročito usled vidljivih globalnih promena. Pre svega, ova studija omogućava unapređenje stanja i očuvanje PIO Veliko ratno ostrvo, olakšaava upravljaču gazdovanje i očuvanje genofonda bele vrbe. Primenom dobijenih rezultata olakšavaju se mere zaštite protiv pojedinih biotičkih i abiotičkih faktora koji utiču na smanjenje vitalnosti i pogoršanja opšteg stanja stabala bele vrbe.

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CHARACTERISTICS OF SOILS IN FOREST MANAGEMENT UNIT „MALA UKRINA“

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Abstract: *The paper presents the results of pedological research in the area of the forest management unit "Mala Ukrina", the forest management area "Usorsko-ukrinsko". The research covered five compartments. In each compartment, a basic pedological profile was opened, a detailed study of the external and internal morphology was carried out, as well as sampling of genetic horizons for laboratory study of physical and chemical properties. According to the Soil Classification of Yugoslavia (Škorić et al., 1985) distinguished three types of soil: ranker, dystric brown soil and ilimerized soil. The geological substrates of the open profiles are sandstone and peridotite. Vegetation in the studied sections consists of Austrian and Scots pine forest crops. The analysis of the pedological cover showed the presence of all types of soil that are characteristic for this area. The aim of the work is to analyse the characteristics of the soil in this forest management unit, while defining the ecological production value.*

Keywords: soil, ranker, dystric brown soil, ilimerized soil, characteristics.

KARAKTERISTIKE ZEMLJIŠTA U PRIVREDNOJ JEDINICI „MALA UKRINA“

Apstrakt: *U radu su prikazani rezultati pedoloških istraživanja na području privredne jedinice „Mala Ukrina“, šumskoprivredno područje „Usorsko-ukrinsko“. Istraživanjem je obuhvaćeno pet odjeljenja. U svakom odjeljenju otvoren je po jedan osnovi pedološki profil, izvršeno je detaljno proučavanje spoljašnje i unutrašnje morfologije, kao i uzimanje uzoraka po genetičkim horizontima za laboratorijsko proučavanje fizičkih i hemijskih osobina. Prema Klasifikaciji zemljišta Jugoslavije (Škorić i sar., 1985) izdvojena su tri tipa zemljišta: humusno-silikatno zemljište, kiselo smeđe zemljište i ilimerizovano zemljište. Geološke podloge otvorenih profila su pješčar i peridotit (serpentinisani). Vegetaciju u istraživanim odjeljenjima čine šumske kulture crnog i bijelog bora. Analiza pedološkog pokrivača pokazala je zastupljenost svih tipova zemljišta koji su karakteristični za ovo područje. Cilj rada je analiza karakteristika zemljišta u ovoj privrednoj jedinici, uz definisanje ekološko-proizvodne vrijednosti.*

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Ključne reči: zemljište, humusno-silikatno zemljište, kiselo smeđe zemljište, ilimerizovano zemljište, karakteristike

1. INTRODUCTION

The productivity of forest soils depends on physical and chemical properties, i.e. their variability (Kapović *et al.*, 2011). Soil with its ecological and productive values represents an important component of environment and forest ecosystems. It regenerates slowly, so its preservation requires application of principles of sustainable management, while respecting not only productive, but also ecological functions of the soil (Blagojević, 2016). Knežević & Košanin (2008) state that the soil is the basic factor of the habitat through which the influence of climatic elements and relief elements on the ecological conditions and production potential of habitat are refracted. The researched area is characterized by moderate continental climate. Geological substrate in the researched area consists of silicate and ultrabasic rocks. On silicate rocks (sandstones and cherts) dystric brown and ilimerized soils are formed, while on peridotite and serpentinized peridotite ranker and ilimerized soils are developed. Knežević *et al*. (2011) state that dystric brown soils are formed on different types of silicate rocks, while Kapović *et al*. (2011) highlight large distribution of dystric brown soil in submontane and mountainous area on terrains whose geological structure is made of silicate rocks. Ultrabasic rocks on our territory occupy the space from Kozara, Ljubić, Borja, then Ozren, Konjuh, Kladanj and Olovo, up to Višegrad (Pamić, 1964; Trubelja *et al.*, 1974; Kapović Solomun *et al*., 2015). Peridotites are igneous, ultrabasic rocks formed mostly from olivine, and contain pyroxene and chlorite, along with one important characteristic, that they have high percentage of magnesium (18-24%) and a significant presence of heavy metals (Novaković-Vuković, 2015). Altinözlü *et al.* (2012) state that soils on ultramafites can contain several hundred times more nickel than other soils, while Šumatić *et al*. (2013) state there is an increased content of nickel in certain plant species on different types of ultrabasic soils. The vegetation of the researched area consists of artificially raised forest cultures of Austrian pine and Scots pine, which are located in the belt of sessile oak and hornbeam forests (*Querco-Carpinetum*). Gačić & Govedar (2020) state that forest plantations on Forest management unit Usorsko-ukrinsko occupy 9.69% of the total forest growing stock. The research of the associations of Austrian pine and Scots pine in correlation with the research of properties and production potential of soil should be the starting point and the framework for long-term planning of management in these forests and preservation of their ecological and production value (Novaković-Vuković, 2015). Blagojević (2016) states the importance of determining the conditions which suit the best to the growth of useful forest plantations, which is realized with knowledge and respecting of pedological conditions. In order to minimize the risks, before erecting pure artificial stands, it is necessary to research ecological conditions of the given habitat, whereby the analysis of soil (depth, structure, texture, content of certain micro or macro elements) is indispensable. The quality of artificially raised stands can be significantly conditioned by physical and chemical properties of the soil (Kapović & Keren, 2012). The objective of the research in this paper is determining of the types of pedological cover, the analysis of the properties of different types of soil, along with the estimate of ecological and production potentials of each type of soil on this area.

2. MATERIAL AND METHODS

Determining the types and properties of the soil in the territory of forest management unit Mala Ukrina was realized through the field research phase and laboratory soil analysis phase. The field research phase, within which collection of available references for the field of research was carried out, included reconnaissance of the terrain, getting to know the vegetation and orographic characteristics, then selection of locations for opening of pedological profiles, opening of pedological profiles, description of environmental conditions on the location of opening the profiles, separation of genetic horizons, analysis of the external and internal morphology and soil sampling in impaired condition for laboratory study of the soil properties. Five basic pedological profiles were opened, one profile in each of the compartments. Thirteen soil samples were taken for laboratory analyses. The laboratory analyses of soil samples, after the drying of sampled soil up to an air-dry state, were carried out in pedological laboratory of the Institute of Forestry in Belgrade according to the following methodology:

- Textural (mechanical) composition of the soil by sedimentation method with application of Na-pyrophosphate as a peptizing agent (Racz, 1971). Based on the textural composition of the soil textural class was determined using ISSS triangle.
- Active and substitutional acidity potentiometrically in H_2O and KCl (Cencelj, 1966; Živković, 1966), and classification of the soil according to the reaction of the soil solution was determined according to the US Natural Resources Protection Service (Knežević & Košanin, 2007).
- Hydrolytic acidity (Y1) and sum of adsorbed alkali cations (S) by Kappenn method (Živković 1966).
- Content of total humus was determined by wet combustion in the mixture of potassium dichromate ($K_2Cr_2O_7$) and sulfuric acid (H_2SO_4) by Tyurin method (Škorić & Racz, 1966), and classification of soil according to the content of humus was determined by Gračanin method (Škorić & Sertić, 1966).
- The content of total nitrogen by Kjeldahl method (Džamić *et al.*, 1966), and classification of soil according to the content of total nitrogen according to Wohltmann (Knežević & Košanin, 2007).
- Carbon and nitrogen ratio – computationally.
- The content of phosphorus and potassium easily accessible to plants by AL-method according to Egner-Richm, using colorimetric technique of phosphorus determination and flame photometric technique of potassium determination, and supply of these elements in the soil according to the limit values for AL-method (Džamić *et al*., 1996).

3. RESULTS

Forest management unit Mala Ukrina is situated within forest management area Usorsko-ukrinsko, which is situated in North-western part of the Republic of Srpska (Figure 1). According to the ecological-vegetational zoning of Bosnia and Herzegovina (Stefanović *et al*., 1983) the area of research belongs to the region of inner Dinarides, Zavidovićko-Teslićki district. This area is characterized by very heterogeneous orographic situations, and it belongs to Srednjebosanska ophiolitic zone.

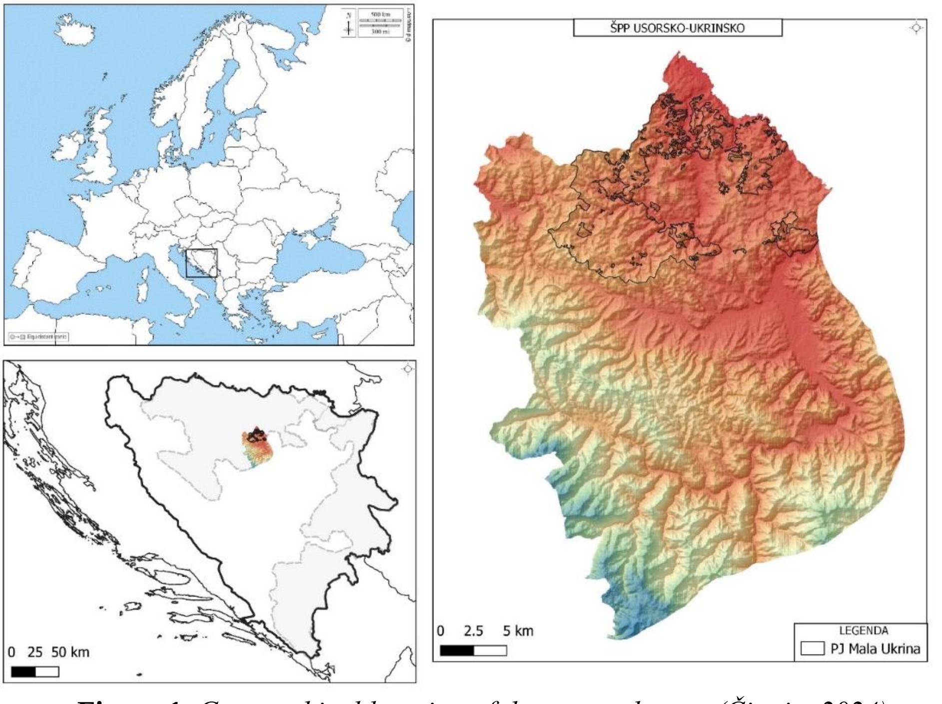

Figure 1. *Geographical location of the research area (Čigoja, 2024)*

The research was carried out in the compartments: 37, 44, 136, 142 and 143. The height range of the object of research is from 152 to 591 m above sea level. According to Kapović Solomun *et al*. (2015) Usorsko-ukrinsko forest management area is characterized by typical moderate continental climate, with mean annual air temperature of 9.8°C and mean amount of precipitation of 1026 mm (period from 1961 to 1990). The same authors state that according to the amount of annual climate index in this area moderate humid climate – B2 is dominant. Geological properties of the researched area show the presence of silicate rocks (cherts and sandstones) in the compartments 44 and 143, while peridotite and serpentinized peridotite, out of the group of ultrabasic rocks, are represented in the compartments: 37, 136 and 142. Vegetation properties in the researched compartments are characterized by the presence of artificially raised plantations of Austrian pine and Scots pine. According to the classification of soils of Yugoslavia (Škorić *et al*., 1985) three types of soils are singled out:

1. Ranker – compartment 136;
2. Dystric brown soil – compartment 44;
3. Ilimerized soil – compartments 37, 142 and 143.

Ranker (Profile structure: O-A-R)

Figure 2. *Appearance of pedological profile and vegetation (© Kapović Solomun, 2021)*

Pedological profile is opened on southern exposure on the terrain with a pronounced slope, without surface rockiness and visible erosion processes. Total depth of the pedological profile is 24 cm. Organogenic horizon is less developed and has a thickness of only 3 cm. Gradually and relatively irregularly it transitions into humus-accumulative horizon with thickness of 21 cm. The horizon is water-permeable, drained, with coarse grained structural aggregates, which are relatively stable to the touch. It is very loose and airy. Novaković-Vuković (2015) for humus silicate soils states that they are mostly of shallow solum, with a high content of skeleton, and a low capacity for water. Soil has a small depth, on sunny exposure which additionally increases its xerothermophilic character. The presence of skeletons is medium. Blagojević & Govedar (2009) state that rankers have from 20 to 40% of skeletons. The content of total sand in the profile is 15.50%, total clay 9.25%, while the content of dust is 75.25%. Textural class is silty loam. The research of Kapović Solomun *et al*. (2015) show that rankers in the territory of FMU Donja Velika Usora have sandy loamy textural composition, which corresponds to the research of Košanin & Knežević (2005), while Blagojević (2016) states that mechanical composition of rankers can be sandy loamy, silty loamy to sandy clay loamy. Knežević & Košanin (2009) state that rankers have silty loamy texture. This textural composition is more typical for silicate substrates, than for ultrabasic rocks, at which they are characterised by higher content of clay and clay loamy texture (Kapović Solomun & Marković, 2022). Silty loamy textural composition indicates certain hazard of this type of soil from soil erosion. The pH reaction in H_2O and KCl is very acidic (Table 1), which was contributed by the unfavourable composition of forest litterfall of coniferous origin. Sizes that characterize adsorption complex of the soil indicate that it is poorly saturated and poor. Total capacity of adsorption has the value of 17.07 mLNaOH/50g, while the degree of saturation by bases is lower than 50%. Košanin & Knežević (2005) for rankers state that the degree of saturation by bases ranges from 27.04 to 45.89% and that is why it is singled out as a dystric subtype. According to the content of humus (5.19%) the soil is very rich in humus, while the supply of nitrogen (0.20%) is on the limit between well provided and rich in nitrogen, which is in direct correlation with the content of humus. The ratio of carbon and nitrogen is 15.35, which indicates a good decomposition of organic residues and is in direct correlation with good supply with humus and nitrogen. The soil is poor in readily available phosphorus (<1 mg/100g) and potassium (Table 2). Although it is a soil formed on ultrabasic substrate, which is rich in bases (mainly magnesium), the values of pH reaction and adsorption complex of the soil are such that this profile of rankers is classified as dystric subtype. The shallowness of the profile, content of skeletons, pronounced acidophility, but also poor adsorption complex indicate that humus silicate soils in this area have low ecological and productive potential. Due to the pronounced relief and susceptibility to erosion of this type of soil, the management of forest plantations in this compartment should be adapted also to edaphic factor, in order not to destroy the pedolayer, as this would degrade the entire ecosystem. Rankers have low efficiency, low biological activity, high content of skeletons and weak ability to retain water, which influences their low ecological and productive potential (Blagojević *et al.*, 2016; Kapović Solomun *et al.*, 2015).

According to the Classification of soils of Yugoslavia (Škorić *et al.*, 1985) the analysed profile belongs to the **class of humus-accumulative soils, to the type of ranker, subtype dystric, variety lithic, form silty loam.**

Dystric brown soil (Profile structure: O-A-AE-(B)v-C)

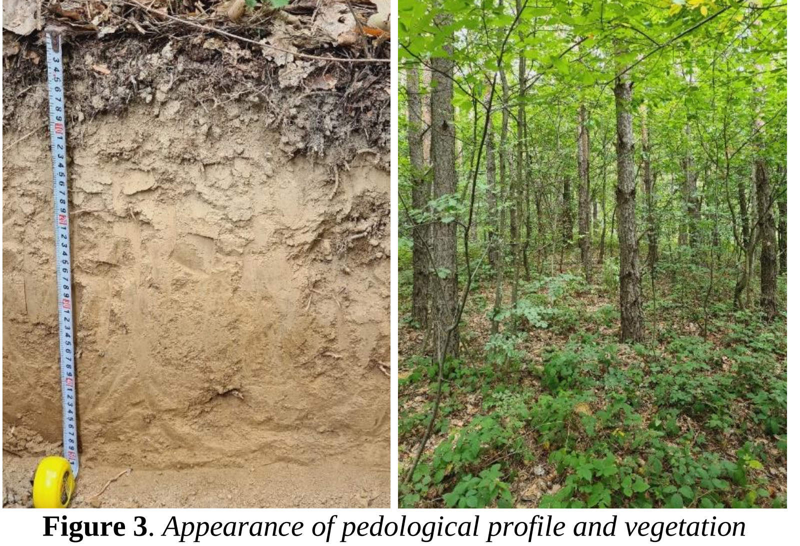

Figure 3. *Appearance of pedological profile and vegetation (©Kapović Solomun, 2021)*

Pedological profile of dystric brown soil is opened in one compartment, on the terrain with a gentle slope, where the geological substrate consists of sandstones and cherts. Total depth of the pedological profile is 51 cm. The organogenic horizon reaches thickness of 5 cm, it is characterized by the presence of less decomposed litterfall. Gradually and relatively irregularly it transitions into faded A horizon 8 cm thick, with weakly expressed structural aggregates, which are fine-grained and spheroidal in shape. They are unstable to touch. Košanin & Knežević (2003) state for dystric brown soils the existence of powdery up to fine-grained structural aggregates. This horizon texturally belongs to the class powdery loam, with dominant participation of powder fraction (79.40%). The pH reaction in H_2O is very strongly acidic (4.93), while in KCl is strongly acidic (3.80). Richness in humus (7.27%) causes that this horizon is richer in bases, than it is typical of dystric brown soils, and it is directly connected with the fact that the soil in this part is rich in nitrogen. Ratio C/N is lower than 20 (Table 2) which indicates that the conditions for decomposition of organic residues are favourable, which is visible also from the content of humus. According to the content of readily available phosphorus and potassium in this horizon, the soil is poor. It transitions irregularly into eluvial AE horizon, 14 cm thick, of granular to pea-sized structural aggregates, also unstable to touch, of silty loamy texture. The pH reaction in this part of the profile, determined in H_2O, is very strongly acidic, while the value in KCl is strongly acidic. The content of humus, nitrogen, the degree of base saturation (Table 2) are lower than in the horizon above. Below is a cambic horizon 24 cm thick, of polyhedral structure. The pH reaction in H_2O (4.62) and KCl (3.48) shows that this horizon has also very strongly acidic, i.e. strongly acidic reaction of soil solution. The reaction of soil solution of dystric brown soils ranges from extremely acidic to acidic (Košanin & Knežević, 2003, 2004; Kapović & Keren, 2012; Čigoja *et al.*, 2024). Cambic horizon is compressed and poorly permeable, compact and with increased content of clay, but the relation of textural fractions indicates that the texture of this horizon is silty loam. Textural evenness of the profile of dystric brown soil is one of the typical characteristics of dystric brown soil (Kapović & Keren, 2012). The structure in this part of the profile is polyhedral, which has a positive effect on water and air properties in this part, since it enables forming of macro and micro pores. The content of humus in this horizon is 1.11%, which indicates the existence of the ilimerization process, i.e. movement of humus particles from higher to lower parts of the profile. The water permeability and aeration of the soil gradually decreases with depth, due to the greater participation of the clay fraction in deeper parts of the profile. By analysing the properties of dystric brown soil on the said territory we can conclude that physical properties are more favourable compared to chemical. The depth and structure of this soil affect somewhat more favourable environment for the development of plants, which is certainly contributed also by abundance of humus and bases in humus-accumulative horizon, in contrast to more pronounced acidity and weaker supply of phosphorus and potassium. For the above reasons, dystric brown soil of the said area has a low to medium ecological productive potential.

According to the Classification of the soils of Yugoslavia (Škorić *et al.*, 1985) the analysed profile belongs to **the class of cambic soils, the type dystric brown soil, subtype ilimerized, variety on sandstones-cherts, form medium deep.**

Ilimerized soil – (Profile structure: O-Aoh-E-Bt-C)

Figure 4. *Appearance of pedological profiles of ilimerized soil (©Kapović Solomun, 2021)*

Pedological profiles of ilimerized soil are opened in three compartments, out of which one profile in compartment 143 on sandstone, while profiles in compartments 37 and 142 were on peridotite. All profiles were opened under the cultures of Austrian pine and Scots pine. Total depth of pedological profiles ranges from 52 to 68 cm. According to the depth of solum analysed profiles can be classified as medium deep to deep (Knežević & Košanin, 2007). Organogenic horizon is developed up to 2 to 6 cm, with the presence of less decomposed organic residues. In all profiles O horizon gradually and irregularly transitions into humus-accumulative horizon, of lighter color, from 8 to 17 cm thick (Figure 4). A horizon is relatively water permeable, drained, with spheroid structural aggregates, fine- to coarse-grained, mostly unstable, moderately pronounced. Textural class of A horizon is silty loam. The pH reaction determined in H_2O is very strongly, i.e. strongly acidic, while in KCl it is strongly acidic (Table 4). According to the humus content the soils are quite to very rich in humus (4.09 - 6.70%). The ratio C/N is lower than 20. The soils are poorly supplied with readily available phosphorus in A horizon, while the supply of potassium ranges from poor (8.9 mg/100g) to good (21.8 mg/100g). It transitions gradually into eluvial horizon, from 20 to 22 cm thick. Basic morphological property of ilimerized soil is the presence of eluvial horizon of light-brown color, which is morphologically very pronounced, from 2 to 25 cm thick (Knežević *et al*., 2011). E horizon is washed with polyhedral structural aggregates, except in profile in compartment 37, where it is structureless, unsaturated. Texturally it belongs to class silty loam, of very acidic reaction of soil solution. It is poorly supplied with readily available forms of phosphorus and potassium. Diffusely it transitions into illuvial horizon 22 to 28 cm thick, which is characterised by increased content of clay, density and compactness. Kapović & Keren (2012) state that clay in the deeper parts of the profile is not desirable for the development of the root system of plants, since in addition to anaerobic conditions it also provides mechanical resistance. It has the smallest water permeability in the profile, and presence of concretions, which indicates the presence of the process of gleying in the period with increased amount of precipitation (Figure 4). The structural aggregates are well pronounced, polyhedral. Texturally it is differentiated, with silty clay loamy texture (compartments 37 and 143), while soil rich in clay is at the profile in compartment 142. Content of clay in Bt horizon is 1.5 to 2.9 times higher than in E horizon. Kapović Solomun & Marković (2022) state that ilimerized soils in illuvial horizon have from 1.5 to 2.5 times more clay than in eluvial horizon. The values of hydrolytic acidity are the highest in the A horizon and they decrease with the increase of depth, due to lower content of humus matters. The degree of soil saturation with bases increases with depth and it is the highest in the illuvial horizon (59.98-81.04%). Bt horizon is poor in readily available phosphorus, while in terms of K_2O supply it is poorly to moderately supplied. The largest amount of nitrogen is in the humus-accumulative horizon. Out of all analysed profiles in the territory of FMU Mala Ukrina, pedological profiles of ilimerized soil have the deepest solum. The condition of physical and chemical properties indicates that this type is the most favourable for the development of forest cultures of the researched area, so compared to other types of soil of this site, it stands out as the soil of high ecological and productive potential. Kapović Solomun & Eremija (2017) state that ecological and productive properties of ilimerized soil are conditioned by the depth, supply of nutrients and water and physical properties.

According to the Classification of soils of Yugoslavia (Škorić *et al.*, 1985) analysed profile belongs to the **class of eluvial-illuvial soils, type ilimerized soil, subtype on silicates-ultrabasites, varieties pseudogley and typical, form silty loamy.**

Table 1. *Physical properties of soil*

Tip zemljišta / Soil type	Odjeljenje / Compartment	Dubina / Depth (cm)	Granulometrijski sastav zemljišta / Granulometric composition of soil (%)								Teksturna klasa/ Soil texture class
			2.0-0 . 2 (mm)	0.2 - 0.06 (mm)	0.06 – 0.02 (mm)	0.02 – 0.002 (mm)	<0.002 (mm)	Pijesak / Sand	Prah / Silt	Glina / Clay	
Humusno-silikatno zemljište / Ranker	136	3-24	6.34	13.97	25.98	39.33	14.38	20.31	65.31	14.38	Praškasta ilovača / Silty loam
Kiselo smeđe zemljište / Dystric brown soil	44	5-13	3.18	0.16	31.96	47.44	17.25	3.34	79.40	17.25	Praškasta ilovača / Silty loam
		13-27	1.76	0.37	26.65	52.09	19.13	2.13	78.74	19.13	Praškasta ilovača / Silty loam
		27-51	1.58	1.92	25.10	45.50	25.90	3.50	70.60	25.90	Praškasta ilovača / Silty loam
Ilimerizovano zemljište / Ilimerized soil	37	2-10	3.06	8.22	25.26	46.52	16.94	11.28	71.78	16.94	Praškasta ilovača / Silty loam
		10-32	2.80	0.65	24.55	48.22	23.78	3.45	72.77	23.78	Praškasta ilovača / Silty
		32-52	1.97	9.12	19.80	33.95	35.17	11.09	53.75	35.17	Praškasto-glinovita ilovača / Silty clay loam
Ilimerizovano zemljište / Ilimerized soil	142	2-19	8.62	11.27	25.04	42.75	12.32	19.90	67.79	12.32	Praškasta ilovača / Silty loam
		19-40	4.64	10.03	22.03	42.20	21.10	14.67	64.23	21.10	Praškasta ilovača / Silty loam
		40-68	2.60	10.40	10.29	15.28	61.43	13.01	25.57	61.43	Glinuša / Clay
Ilimerizovano zemljište / Ilimerized soil	143	6-17	2.12	11.97	28.19	44.99	12.72	14.09	73.18	12.72	Praškasta ilovača / Silty loam
		17-37	1.53	8.39	24.94	44.38	20.76	9.92	69.31	20.76	Praškasta ilovača / Silty loam
		37-65	2.05	11.44	18.93	35.73	31.86	13.48	54.66	31.86	Praškasto-glinovita ilovača / Silty clay loam

Table 2. *Chemical properties of soil*

Tip zemljišta / Soil type	Odjeljenje / Compartment	Dubina / Depth (cm)	pH		Adsorptivni kompleks / Adsorption complex					Humus / Humus	N	C	C/N	Pristupačn / Available	
					T	S	T-S	V	Y1					P_2O_5	K_2O
			H_2O	KCl	cmol/kg			%	mLNaOH/50g	%				mg/100g	
Humusno-silikatno zemljište / Ranker	136	3-24	5.29	4.06	33.70	16.63	17.07	49.34	26.26	5.19	0.20	3.01	15.35	<1	8.1
Kiselo smeđe zemljište / Dystric brown soil	44	5-13	4.93	3.80	34.02	14.28	19.74	41.97	30.37	7.27	0.26	4.22	16.32	<1	5.6
		13-27	4.63	3.57	28.51	9.66	18.85	33.88	29.00	3.36	0.14	1.95	14.38	<1	16
		27-51	4.62	3.48	27.73	10.61	17.11	38.28	26.33	1.11	0.04	0.64	14.56	<1	9.3
Ilimerizovano zemljište / Ilimerized soil	37	2-10	5.20	4.03	47.91	31.37	16.55	65.47	25.45	6.70	0.28	3.89	13.73	<1	21.8
		10-32	5.17	3.55	42.26	28.10	14.16	66.50	21.78	1.98	0.13	1.15	8.52	<1	14.8
		32-52	5.42	3.64	53.81	42.12	11.69	78.27	17.99	1.04	0.09	0.60	6.99	<1	3.8
Ilimerizovano zemljište / Ilimerized soil	142	2-19	5.04	3.76	28.95	12.89	16.06	44.52	24.71	4.09	0.13	2.37	18.48	<1	16.4
		19-40	5.06	3.55	25.88	12.29	13.59	47.48	20.91	1.07	0.04	0.62	16.23	<1	4
		40-68	5.93	4.04	48.64	39.41	9.22	81.04	14.19	0.82	0.01	0.47	31.75	<1	13
Ilimerizovano zemljište / Ilimerized soil	143	6-17	5.09	3.67	33.54	13.80	19.74	41.15	30.37	5.28	0.18	3.06	17.46	<1	8.9
		17-37	5.31	3.51	23.60	10.65	12.94	45.15	19.92	2.29	0.05	1.33	28.09	<1	4.4
		37-65	5.51	3.77	27.19	16.31	10.88	59.98	16.74	1.13	0.02	0.66	33.65	<1	5

4. CONCLUSION

- FMU Usorsko-ukrinsko is located in the North-western part of the Republic of Srpska, and is composed of five economic units: Mala Usora, Mala Ukrina, Velika Ukrina, Donja Velika Usora and Gornja Velika Usora.
- Climate properties of the said area are characterized by moderate continental climate. The geological substrate of the object of research was represented by silicate substrates, sandstones and cherts and ultrabasic rocks, peridotite and serpentinized peridotite. The vegetation in the researched compartments consists of forest cultures of Austrian pine and Scots pine, established in the belt of forests of sessile oak and hornbeam (*Querco-Carpinetum*).
- Edaphic component is represented by three types of soil: humus silicate soil, dystric brown soil and ilimerized soil.
- Ranker is represented by one pedological profile in the compartment 136. This is at the same time the only representative of soil from the class of humus-accumulative soils. Physical and chemical properties of the researched profile in the area of research indicate that it is the type of the soil that has limited capability for supply of plants with sufficient amounts of nutrients, which affects low ecological and productive capability of the above-mentioned soil.
- Dystric brown soil belongs to class of cambic soils. The analysis included one pedological profile opened in the compartment 44, on sandstones and cherts. Physical and chemical properties of this type of soil indicate there is an initial phase of the process of ilimerization, sufficient quantities of humus and depth provide the existing vegetation with more favourable conditions for growth and development of the root system, but small amounts of phosphorus and insufficient supply of potassium in all profiles, along with lighter textural composition, as well as strong acidity are the crucial factors that in the sense of ecological and productive potential this type of soil is characterized as low or medium.
- Ilimerized soil belongs to class of eluvial illuvial soils, as the deepest of all the researched profiles in this forest economic unit it is represented by three pedological profiles, in three different compartments (37, 142 and 143). The geological substrate of the researched profiles consists of sandstone and peridotite. Out of all the researched soils of this area, ilimerized soil has the best properties and provides the best conditions for growth and development of vegetation, which in combination with other physical and chemical properties certainly has a decisive influence on the fact that this type stands out as the soil that has high ecological and productive potential.

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CHARACTERISTICS OF SOILS IN FOREST MANAGEMENT UNIT „MALA UKRINA“

Alen GAČIĆ, Marijana KAPOVIĆ SOLOMUN, Ilija ČIGOJA, Saša EREMIJA

Summary

Soil research is of great importance in the forestry profession and science. Understanding soil types, their spatial distribution, and their physical-chemical properties certainly contributes to better foundational frameworks for creating basic planning documents in forestry. The soil research in the forest management unit (FMU) "Mala Ukrina" aimed to enhance knowledge of the physical-chemical properties of the most common soil types and to ensure that future management plans for forest cultures in this area are closely correlated with edaphic characteristics. Field research identified three types of soil from three different soil classes. Investigations were conducted in five different compartments, with one basic pedological profile opened in each compartment from which soil samples were taken for laboratory studies according to genetic horizons. The class of humus-accumulative soils was represented by one type – humus-silicate soil; from the class of cambic soils, dystric brown soil was represented, while illimerized soil was a representative of the class of eluviated-illuviated soils. Among the mentioned soil types, illimerized soil provides the best conditions for the growth and development of forest vegetation in this area, while humus-silicate soil is the most limiting.

KARAKTERISTIKE ZEMLJIŠTA U PRIVREDNOJ JEDINICI „MALA UKRINA“

Alen GAČIĆ, Marijana KAPOVIĆ SOLOMUN, Ilija ČIGOJA, Saša EREMIJA

Rezime

Istraživanje zemljišta ima veliki značaj u šumarskoj struci i nauci. Poznavanje tipova zemljišta, njihove prostorne distribucije, kao i fizičko-hemijskih osobina doprinosi svakako boljim polaznim osovama za izradu osnovnih planskih dokumenata u šumarstvu. Istraživanja zemljišta u privrednoj jedinici (PJ) „Mala Ukrina“ imala su za cilj da doprinesu poznavanju fizičko-hemijskih osobina najzastupljenijih tipova zemljišta, kao i da budući planovi gazdovanja šumskim kulturama na ovom području budu u uskoj korelaciji sa edafskim karakteristikama. Terenskim istraživanjem identifikovana su tri tipa zemljišta, iz tri različite klase zemljišta. Istraživanja su sprovedena u pet različitih odjeljenja, u svakom odjeljenju otvoren je po jedan osnovni pedološki profil iz koga su uzimani uzorci zemljišta za laboratorijska proučavanja po genetičkim horizontima. Klasa humusno-akumulativnih

zemljišta zastupljena je sa jednim tipom – humusno-silikatno zemljište, iz klase kambičnih zemljišta zastupljeno je kiselo smeđe zemljište, dok je ilimerizovano zemljište predstavnik klase eluvijalno-iluvijalnih zemljišta. Od navedenih tipova zemljišta najbolje uslove za rast i razvoj šumske vegetacije na ovom području ima ilimerizovano zemljište, dok je najviše limitarno humusno-silikatno zemljište.

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PHYTOCOENOLOGICAL ANALYSIS OF SESSILE OAK AND TURKEY OAK FORESTS (*QUERCETUM PETRAEAE-CERRIDIS* B. JOVANOVIĆ 1979. S.L.) IN THE TERRITORY OF KOSMAJ

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Abstract. *Phytocoenological characteristics of the association of sessile oak and Turkey oak (Quercetum petraeae-cerridis B. Jovanović 1979. s.l.) in the territory of Kosmaj are presented in the paper. This phytocoenosis has large ecological amplitude on the researched territory, it is spread over a wide range of altitudes (phytocoenological relevés are from the altitudes ranging from 348 to 573 m), on all aspects (it appears more frequently on warmer aspects) and slopes from 8° to 28°. Bedrock on which this association appears is flysch, and the soils are eutric cambisol and dystric cambisol. Based on the floristic composition and habitat conditions the association is divided into two sub-associations: typicum and caricetosum silvaticae. According to the spectrum of range types the studied association Quercetum petraeae-cerridis B. Jovanović 1979. s.l. has Central European character, while according to the life-form spectrum it is of hemicryptophyte-phanerophyte character with an increased share of geophytes.*

Key words: Sessile oak and Turkey oak forest, sub-association, floristic composition, Kosmaj.

FITOCENOLOŠKA ANALIZA ŠUMA KITNJAKA I CERA (*QUERCETUM PETRAEAE-CERRIDIS* B. JOVANOVIĆ 1979. S.L.) NA PODRUČJU KOSMAJA

Abstract. *U radu su prikazane fitocenološke karakteristike zajednice kitnjaka i cera (Quercetum petraeae-cerridis B. Jovanović 1979. s.l.) na području Kosmaja. Ova fitocenoza na istraživanom području ima veliku ekološku amplitudu, rasprostranjena je u širokom dijapazonu nadmorskih visina (fitocenološki snimci su sa nadmorskih visina 348-573 m), na svim eskpozicijama (češće se pojavljuje na toplijim) i nagibima od 8°-28°. Geološka podloga na kojima se javlja ova zajednica je fliš, a zemljište eutrični kambisol i distrični kambisol. Na osnovu florističkog sastava i stanišnih uslova izvršena je podela zajednice na 2 subasocijacije: typicum i caricetosum silvaticae. Prema spektru areal tipova proučena zajednica Quercetum petraeae-cerridis B. Jovanović 1979. s.l. ima srednjeevropski karakter, dok je prema spektru životnih oblika hemikriptofito-fanerofitskog karaktera, sa povećanim učešćem geofita.*

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Keywords: Šuma kitnjaka i cera, subasocijacija, floristički sastav, Kosmaj.

1. INTRODUCTION

It has been determined in Serbia that sessile oak is an aggregate which consists of three species (Jovanović, 2007): European sessile oak (*Quercus petraea* (Matt.) Liebl), Dalechampii oak (*Quercus dalechampii* Ten.) and Transilvanian sessile oak (*Quercus polycarpa* Schur.), which are named after the oldest described species of sessile oak (*Quercus petraea* agg. Ehrendorfer 1967). Sessile oak (*Quercus petraea* (Matt.) Liebl.) represents one of the most valuable tree species in Serbia, and larger complexes of sessile oak forests in Serbia are located on Fruška Gora, Avala, Kopaonik, Rtanj, Suva Planina, Majdanpečka Domena, Miroč, Deli Jovan, Stara Planina, Đerdap, Čemerno, Suvobor, Zlatibor, Stolovi, Kukavica and others. (Cvjetićanin *et al*., 2007). According to the data from the Second National Forest Inventory (2023) the total volume of sessile oak forests in the forest growing stock of the Republic of Serbia has been estimated to 32,062,038.23 m^3, which is why this species is on the third place in our country (share in the total volume is about 5.7%).

In the whole Serbia, on warmer aspects in submontane region (as a transition between climazonal forest of Hungarian oak and Turkey oak and the lowest clima-regional belt of mountainous beech) xeromesophilous forests of sessile oak and Turkey oak appear – alliance *Quercion petraeae-cerridis* R. Lakušić & B. Jovanović 1980. (Tomić and Rakonjac, 2013). The association of sessile oak and Turkey oak (*Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.) has been defined only in recent literature. Until then in the larger number of papers these forests had been treated as pure forests of sessile oak. In terms of characteristic assemblages, ecosystem stability and degradation processes, mixed forests of sessile oak and Turkey oak are very similar to sessile oak forests. Sessile oak and Turkey oak forest alternates with Hungarian oak and Turkey oak forests or is located between them, where it precedes pure sessile oak forests or beech forests (Cvjetićanin *et al.*, 2007). The association appears on different altitudes, from about 300 up to 1000 m, on warm aspects and larger slopes than Turkey oak forests. Bedrock is different, mostly acidic silicate rocks, but they occur also on limestones and serpentinites. Soils are developed, brown and leached, but very often also skeletal and eroded. Floristic composition of this association is similar to sessile oak forests, since besides the xerothermic species of *Quercetalia pubescentis* order, there are also some more mesophilic elements of sessile oak and even beech forests (Tomić and Rakonjac, 2013).

This association appears more frequently and is more widespread than monodominant Turkey oak forests. On some sites: Kopaonik (Rajevski and Borisavljević, 1956), Miroč and Crni Vrh (Glišić, 1976) and Rudnik (Gajić, 1961), where there are no typical sessile oak forests, these mixed associations, alternating with beech forests, build submontane belt. It occupies particularly large areas in Northwestern and Western Serbia, on Gučevo, Maljen, Cer, parts of Tara and Zlatibor (Vukićević, 1966; 1976), in submontane part of Kopaonik (Rajevski and Borisavljević, 1956), and it was found also on Pešter (Rakonjac, 2002; Rakonjac *et.al.,* 2008). This association occurs also on Fruška Gora, on somewhat lower altitudes, up to 400 m (Janković and Mišić, 1960; Jović *et al*., 1989), on Vršačke mountains (Pekanović, 1991), while in eastern Serbia it is represented only in fragments in National Park Đerdap (Jović, *et al.* 1997).

Since this phytocoenosis is widely spread in the protected area of Kosmaj, detailed research of this forest vegetation may serve as a starting point for planning of cultivation needs, as important factors in ensuring special purposes that these forests have.

2. MATERIAL AND METHODS

Kosmaj is a low (626 m) and according to its area relatively small mountain, greater part of which was placed under protection in 2005. The forest vegetation of the area of Kosmaj syntaxonomically belongs to deciduous oak and beech forests of the *Querco-Fagetea* class.

Figure 1 and 2. *Protected area Kosmaj*

According to the Thornthwaite climate classification subhumid wet climate – type C_2 dominates in the territory of Belgrade (Stajić, 2016). From a geological point of view Mount Kosmaj can be characterized as an isolated island massif of chalk flysch and limestone with a few breakthroughs of serpentinites and granitoids which also caused significant pedological diversity of Kosmaj.

For the analysis of floristic composition of the researched association 15 phytocoenological relevés were used, which were done according to the standard method of Braun-Blanquet (Braun–Blanquet,1964). Plant species were determined based on the literature sources: *Flora Srbije I-X* (Josifović *et al.* 1972-1977, Sarić *et al*. 1986; 1992; Stevanović *et al.* 2012), while nomenclature was harmonised with Euro+Med database of vascular flora of Europe (Euro+Med 2006 -). Names of syntaxons of forest vegetation are given according to Tomić and Rakonjac (2013). Spectra of floristic elements are done based on the systematization of plant-geographic elements according to Gajić (1980), and life-form spectra according to the method of Kojić *et al.* (1997).

3. RESULTS

3.1. Ecological conditions

On Kosmaj the forest of sessile oak and Turkey oak (*Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.) has a large ecological amplitude, it is spread over a wide range of altitudes (phytocoenological relevés are from altitudes from 348 to 573 m), on all aspects (it occurs more often on warmer aspects) and slopes from 8° to 28°. These forests are most widespread on the slopes of Veliki Kosmaj, where they alternate with forests of Hungarian oak and Turkey oak (less often Turkey oak forests), where they precede mixed beech and sessile oak forests or pure beech forests.

Association of sessile oak and Turkey oak on Kosmaj occurs on flysch, and in terms of soils in this association eutric cambisol and dystric cambisol were found.

3.2. Floristic composition

In phytocoenological table (Table 1) 15 relevés are presented from different parts of Kosmaj, where the association of sessile oak and Turkey oak was found. The floristic composition of this association is diverse, since plants from thermophilic and mesothermal oak forests and also mesophilic types of beech forests occur. The stands originate from sprout forest. The canopy is in some cases sparsely closed, in stands that are more degraded and it ranges from total (0.7) to dense (0.9).

In the tree layer, in addition to dominant edifiers, sessile oak (*Quercus petraea* (Matt.) Liebl) and Turkey oak (*Quercus cerris* L.) there are also: Field maple (*Acer campestre* L.), Hungarian oak (*Quercus farnetto* Ten.), European hornbeam (*Carpinus betulus* L.), beech (*Fagus sylvatica* L.), sweet cherry (*Prunus avium* L.), Manna ash (*Fraxinus ornus* L.), field elm (*Ulmus minor* Mill.), European ash (*Fraxinus excelsior* L.), common hawthorn (*Crataegus monogyna* Jacq.), European wild pear (*Pyrus pyraster* (L.) Burgsd.), Eurasian aspen (*Populus tremula* L.).

Shrub layer is floristically diverse (24 present species in total). Shrub canopy varies from very opened (0.1) to well developed (0.9). The most present species are Manna ash (*Fraxinus ornus* L.), field maple (*Acer campestre* L.), field elm (*Ulmus minor* Mill.) and common hawthorn (*Crataegus monogyna* Jacq.). They are followed by: *Cornus mas* L., *Prunus avium* L., *Prunus spinosa* L., *Cornus sanguinea* L., *Rosa canina* L., *Carpinus betulus* L., *Ligustrum vulgare* L., *Pyrus pyraster* (L.) Burg., *Crataegus oxyacantha* L., *Sambucus nigra* L., *Corylus avellana* L., *Quercus petraea* (Matt.) Liebl), *Fraxinus excelsior* L., *Euonymus verrucosus* Scop., *Populus tremula* L., *Cotoneaster integerrimus* Medik., *Euonymus europaeus* L., *Acer pseudoplatanus* L., *Quercus farnetto* Ten., *Quercus cerris* L.

Degree of coverage of ground flora ranges from 0.3 to 1.0. In the ground flora layer there are typical species such as: *Brachypodium sylvaticum* (Huds.) Beauv., *Mycelis muralis* (L.) Dum., *Lonicera caprifolium* L., *Helleborus odorus* Waldst. & Kit. ex Willd., *Crataegus monogyna* Jacq. i *Tamus communis* L. They are followed by: *Geranium robertianum* L., *Circaea lutetiana* L., *Rubus canescens* DC., *Rosa canina* L., *Euphorbia amygdaloides* L., *Calamintha vulgaris* L., *Quercus cerris* L., *Alliaria petiolata* (M.Bieb.) Cavara & Grande, *Acer campestre* L., *Geum* *urbanum* L., *Fallopia convolvulus* (L.) Á. Löve, *Prunus avium* L, *Fragaria vesca* L. and others.

Based on the floristic composition and habitat conditions the association *Quercetum petraeae-cerridis* B. Jovanović 1979. s.l. was divided into two sub-associations: *typicum* and *caricetosum silvaticae*.

Table 1. *Phytocoenological table of the association Quercetum petraeae-cerridis*

Association	***Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.**															
Sub-association	*Typicum*												*caricetosum silvaticae*			Degree of presence
Facies													*rubosum*			
Locality	Kosmaj															
Relevé	2	5	11	12	16	18	20	40	41	90	91	24	6	51	44	
Size (m2)	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	
Altitude (m)	573	436	508	505	478	391	465	415	364	407	356	383	430	435	348	
Aspect	SE	SW	SE	S-SE	W	W-NW	W-SW	NW	N-NW	NW	NW	S	N-NE	NE	N-NW	
Slope (°)	21	8	20	23	20	20	28	15	13	14	11	11	14	20	27	
Bedrock	Flysch															
Soil	Eutric Cambisols											Dystric Cambisol	Eutric Cambisols			
Layer I																
Tree crown canopy	0,8	0,8	0,9	0,8	0,8	0,9	0,8	0,8	0,7	0,9	0,8	0,8	0,8	0,7	0,8	
Mean height (m)	22,0	22,0	23,0	22,0	20,0	25,0	22,0	14,0	18,0	20,0	20,0	14,0	24,0	23,0	20,0	
Mean diameter (cm)	28,0	20,0	25,0	20,0	25,0	35,0	37,0	20,0	22,0	25,0	30,0	20,0	17,0	30,0	23,0	
Spacing (m)	7,0	4,0	4,0	4,0	6,0	8,0	8,0	4,0	5,0	7,0	7,0	6,0	5,0	10,0	8,0	
Quercus petraea	3.1	3.1	5.5	3.1	3.1	2.1	3.1	4.4	3.1	5.5	5.5	5.5	2.1	3.1	2.1	V
Quercus cerris	3.1	3.1	1.1	3.1	4.4	4.4	3.1	1.1	4.4	1.1	1.1	1.1	5.5	4.4	4.4	V
Acer campestre	1.1	1.1	1.1		1.1	1.1				+.1						III
Quercus farnetto				1.1	1.1	+			1.1			+.1	+	+		II
Carpinus betulus				1.1	1.1		1.1						1.1		+	II
Fagus sylvatica					+		1.1						1.1	1.1	+.1	II
Prunus avium								2.1	+.1	1.1			+.1		+.1	II
Fraxinus ornus	2.1						+		+							I
Ulmus minor				2.1		1.1										I
Fraxinus excelsior			+											+.1		I
Crataegus monogyna		1.1														I
Pyrus pyraster														+.1		I
Populus tremula													+			I
Layer II																
Crown canopy	0,6	0,4	0,6	0,7	0,6	0,2	0,9	0,3	0,6	0,3	0,3	0,2	0,1	0,3	0,2	
Mean height (m)	3,0	4,5	3,0	3,5	2,0	3,0	4,0	2,5	3,0	1,5	3,0	2,0	3,0	3,0	1,0	
Fraxinus ornus	4.4	1.1	1.1	1.1	1.1	1.1	2.1			+.1	1.1	+.1	1.1	1.1	2.1	V
Acer campestre	1.1	2.1	2.1	2.3	4.4	3.1	3.3	1.1	1.1	1.1			1.1	1.1	1.1	V
Ulmus minor		1.1	2.1	2.1	1.1	1.1	1.1	1.1	1.1	2.1	1.1	1.1	1.1	1.1		V

Crataegus monogyna	1.1	2.1	1.1	2.1	3.1	2.1	3.1	3.1	3.1	2.1		1.1	1.1		1.1	V
Cornus mas	1.1	2.1	3.2		1.1	3.1	2.2			2.2		2.2			+	III
Prunus avium			1.1	1.1				3.1	1.1	1.1	2.3	+		+.1		III
Prunus spinosa		1.1	1.1					1.1	2.1		1.1	2.1			+	III
Cornus sanguinea				3.2	2.2			1.1		1.1	1.1		1.1		+.1	III
Rosa canina			1.1	2.3				2.2		+.1		2.1			1.1	II
Carpinus betulus				1.2	1.1							+			1.1	II
Ligustrum vulgare			1.1	3.3				2.3	4.4							II
Pyirus pyraster				1.1			1.1		1.1							I
Crataegus oxyacantha														1.1		I
Sambucus nigra			2.1							1.1				+		I
Corylus avellana								1.2							1.1	I
Quercus petraea				1.1								1.1				I
Fraxinus excelsior														2.1		I
Euonymus verrucosus					1.3											I
Populus tremula													1.1			I
Cotoneasterintegerrimus		1.2														I
Evonymus europaeus			1.1													I
Acer pseudoplatanus			1.1													I
Quercus farnetto												1.1				I
Quercus cerris												+.1				I
Layer III																
Cover	0,7	0,6	0,9	0,8	0,9	0,6	0,3	0,7	0,9	0,7	0,7	0,3	0,8	1,0	1,0	
Brachypodium syvaticum	3.3	2.2		2.1	3.3			3.2	3.2	1.2	1.2	2.2		1.2	2.3	IV
Mycelis muralis	3.1	1.1	3.1	2.1	1.1			1.1	2.1		1.1	2.1	2.1	1.1	3.1	IV
Lonicera caprifolium	1.2	2.3	1.1	2.3	2.3	1.1		3.3	2.3	1.2		1.2	1.1			IV
Helleborus odorus	1.1	2.1	1.1	1.1	1.1	2.1	2.1	1.1	1.1	1.1			1.1	1.1		IV
Crataegus monogyna	2.1	1.1	2.1	2.1	2.1	1.1			2.1	1.1	1.1	1.1	1.1			IV
Tamus communis		1.1	1.1	1.1	1.1	1.1	1.1	+.1	1.1	1.2		1.1	2.1			IV
Geranium robertianum		2.2	2.2					1.1	3.3	3.3	4.4		2.1		2.2	III
Circaea lutetiana			2.3				+	1.1	2.1	2.3	2.1			3.3	2.3	III
Rubus canescens	3.3	2.2		1.1	2.1				2.2			2.1			4.4	III
Rosa canina		1.1		3.3	3.3	1.1		2.1	1.1			2.3				III
Euphorbia amygdaloides	1.1		2.1	3.3	1.2	2.1	2.1						1.1		1.1	III
Calamintha vulgaris	2.1	2.1		1.1	2.1		+.1		1.1			1.1		1.1	2.2	III
Quercus cerris	3.1	1.1		1.1	2.1		2.1			1.1		1.1	1.1		1.2	III
Alliaria petiolate		2.2	1.1	1.1	2.1		2.1			2.3			3.1			III

Acer campestre		1.1			2.1	1.1	2.2	1.1	1.1				1.1	1.1		III
Geum urbanum		1.1			2.1			2.2	1.1		1.1		1.1	1.1	1.1	III
Fallopia convolvulus		1.1	1.1			1.1	1.1			1.2	1.2			+.1		III
Prunus avium		1.1		1.1		1.1		2.1			1.1	1.1	+			III
Fragaria vesca	1.1				1.1		1.1			1.1		+	1.1		1.1	III
Galium aparine		1.1	1.1		+.1				1.2	1.2	1.1			+.1		III
Galeopsis speciosa		+	2.3						1.1	2.1	1.1		1.1		+	III
Rubus hirtus								3.3		3.3	2.3		4.4	3.3	2.3	II
Glechoma hirsuta		2.3	3.3		1.2	4.3	1.2							2.2		II
Quercus petraea	2.1				1.1		1.1			2.3	4.3	3.1				II
Lysimachia punctata	3.3	2.1		2.3								+.1		2.3	+.1	II
Ajuga reptans	1.2			+	1.1	2.3							1.2			II
Cornus mas	1.1	1.1	2.1	3.3		1.1	1.1									II
Lapsana communis			1.1		1.1			1.1			2.1				2.1	II
Rumex acetosella			1.1		1.1	+			1.1				1.1	3.3		II
Melica uniflora	1.2		3.3		3.3	3.2	3.2									II
Fraxinus ornus	3.1	2.1		1.1		1.1	2.1									II
Ligustrum vulgare	+.2			2.3					2.3	1.1	1.2					II
Clematis vitalba									2.3	1.1	1.1		1.1		1.1	II
Stachys silvatica						1.1			1.1				+	2.3	1.1	II
Viola odorata				+		1.1	1.1		1.1				1.1			II
Cynanchum vincetoxicum	2.3			1.1	1.1		1.2		+.1							II
Hypericum perforatum	2.1			1.1	1.1							1.1		1.1		II
Viola hirta						1.1	1.2	1.1				+				II
Cornus sanguinea				3.3				2.1					1.1	1.1		I
Stenactis annua	+.1								+.1			1.1		1.1	+.1	II
Carex sylvatica													2.2	2.2	3.2	I
Carpinus betulus	1.1						1.1						1.1			I
Poa nemoralis	2.2											3.2			1.2	I
Carex Pilosa					3.3									1.2	2.3	I
Moehringia trinervia		2.3								1.2			2.2		+.2	I
Hedera helix						1.1						1.1			1.1	I
Dryopteris filix-mas									+.1	1.1			+.2		1.2	I
Hypericum hirsutum	1.1				1.1										+.1	I
Campanula patula	1.1				+.1										1.1	I
Veronica chamaedrys								1.1					+.1		1.2	I
Cardamine bulbifera							3.1						3.1			I

Urtica dioica			1.1						+					3.3		I
Scrophularia nodosa		+												1.1	3.1	I
Aremonia agrimonoides	1.1						1.2	2.2								I
Rumex sanguineus		2.1								1.1	1.1					I
Ulmus minor						1.1	1.1			1.1						I
Lychnis coronaria				1.2	1.1							+				I
Viola alba	1.1	+.1											+.1			I
Sambucus nigra			2.1										+.1			I
Rubus caesius			1.1				2.2									I
Evonymus europaeus			2.1			1.2										I
Lamium maculatum			1.1											3.3		I
Prunella vulgaris	1.1				1.2											I
Euphorbia cyparissias					1.1							+.1				I
Pyrus pyraster							1.1					+.1				I
Campanula persicifolia								+					1.2			I
Chaerophyllum aureum					+.1		+.1									I
Lilium martagon				+		+										I

The following species were recorded in only one phytocenological relevé: *Carex hirta* 4.4 (6); *Rosa arvensis* 3.3 (2); *Chaerophyllum temulum* 3.1 (41); *Doronicum columnae* 2.3 (91); *Pteridium aquilinum* 2.3 (11); *Festuca heterophylla* 2.2 (2); *Symphitum tuberosum* 2.2k (5); *Poa pratensis* 2.2. (16); *Galium sylvaticum* 2.2. (44); *Lathyrus venetus* 2.1 (20); *Prunus spinosa* 2.1 (24); *Hieracium sabaudum* 2.1 (24); *Dactylis glomerata* 2.1 (40); *Carex divulsa* 1.2 (5); *Asperula odorata* 1.3 (6); *Euonymus verrucosus* 1.3 (16); *Lamium galeobdolon* 1.3 (44); *Dryopteris filix-mas* 1.2 (51); *Festuca rubra* 1.2 (2); *Danaa cornubiensis* 1.2 (5); *Asarum europaeum* 1.2 (6); *Vicia pisiformis* 1.2 (16); *Stellaria media* 1.2 (41); *Sanguisorba minor* 1.1 (2); *Hieracium murorum* 1.1 (2); *Galium schultesii* 1.1 (5); *Acer pseudoplatanus* 1.1 (6); *Viola sylvestris* 1.1 (6); *Populus tremula* 1.1 (6); *Anthriscus sylvestris* 1.1 (11); *Heracleum sphondylium* 1.1 (11); *Quercus farnetto* 1.1 (12); *Melitis melissophyllum* 1.1 (16); *Asparagus tenuifolius* 1.1 (16); *Robinia pseudoacacia* 1.1 (41); *Euphorbia platyphyllos* +.2 (51); *Polygonatum odoratum* +.1 (2); *Juglans regia* +.1 (40); *Athyrium filix femina* +.1 (40); *Chamaecytisus supinus* + (16); *Stachys germanica* + (12); *Fagus sylvatica* + (18); *Inula conyza* + (24); *Scilla bifolia* + (90); *Cephalanthera longifolia* + (44).

3.3. Spectrum of floral elements

Spectrum of range types of the association of sessile oak and Turkey oak (*Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.) is presented in Table 2. Plant species of Central European range type are predominant in this association, and they are represented by 35%. Plant species of Eurasian range type have a somewhat smaller representation (22%), while they are followed by plants of Pontic range type (11%), Sub-Mediterranean (10%), Sub-Atlantic (7%), Circumpolar (7%), Balkan (2%), Cosmopolitan type (3%), and the least floristic element of desert regions (1%). There is 2% of adventive plants in this association.

Table 2. *Spectrum of floral elements in the association Quercetum petraeae-cerridis*

Individual range types	Number	Aggregate range types	Number	Share (%)	
Sub-Pontic	2	Pontic	13	11%	23%
Sub Pontic- Sub-Pannonian	1				
Pontic-Pannonian	1				
Pontic- Central Asian	2				
Pontic-Sub-Mediterranean	5				
Pontic-Eastern sub-Mediterranean	2				
Sub-Mediterranean	7	Sub-Mediterranean	11	10%	
Eastern sub-Mediterranean	4				
Sub Balkan-Apennine	1	Balkan	3	2%	
Mesian	1				
Central Balkan	1				
Central European	12	Central European	40	35%	42%
Sub-Central European	28				
Sub-Atlantic-Sub-Mediterranean	8	Sub-Atlantic	8	7%	
Sub-Iranian-Eastern sub-Mediterranean	1	Floral elements of desert landscapes	1	1%	1%
Eurasian	12	Eurasian	26	22%	25%
Sub-Eurasian	9				
Sub-South Siberian	5				
Cosmopolitan	4	Cosmopolitan	4	3%	
Circumpolar	3	Circumpolar	8	7%	7%
Sub-Circumpolar	5				
Adventive	2	Adventive	2	2%	2%
Total:	116	Total:	116	100%	100%

3.4. Life-form spectrum

Life-form spectrum in the association od sessile oak and Turkey oak (*Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.) is presented in Table 3.

Hemicryptophytes (41%) are predominant in this association, followed by phanerophytes with 30% (phanerophytes 16%, nanophanerophytes 13% and phanerophytic lianas 1%). Geophytes are represented with 17%, which indicates favourable edaphic conditions (moisture, structure and soil depth). Annual species therophytes are represented with only 3%, while the transitional group of plants between therophytes and chamaephytes is represented by 6%. Out of the group of chamaephytes in this association there is 2% of plants (herbaceous chamaephytes 1% and woody chamaephytes 1%). Plants with this life form in syngenetic and synecological sense belong to different plant associations which inhabit habitats with warm and dry Mediterranean climate, as well as landscapes in conditions of continental climate of the Pannonian Plain.

Table 3. *Life-form spectrum of plants in the association Quercetum petraeae-cerridis*

Life forms								
P	Np	Pl	Zc	Dc	H	G	T	Th
16%	13%	1%	2%	1%	41%	17%	3%	6%
30%			3%					

Legend: P- phanerophytes; Np-nanophanerophytes; Pl-phanerophytic lianas; Zc-herbaceous chamaephytes; Dc-woody chamaephytes; H-hemicryptophytes; G-geophytes

4. DISCUSSION

The phytogeographical position of Kosmaj in the region where two floristic subregions in Serbia meet – the Central European-Balkan-Illyrian and Pannonian-Wallachian (Stevanović, 1995), the specific geological composition of the terrain, the altitude up to 630 m, as well as the historical development of the flora and vegetation of the entire Balkans have influenced significantly the floristic and vegetational diversity of this area.

Forests of sessile oak and Turkey oak (*Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.) are widely spread on Kosmaj, where in alternation with the forests of Hungarian oak and Turkey oak (rarely the forests of Turkey oak), they precede mixed beech and sessile oak forests or pure beech forests. The ground flora layer in the researched association is very rich (114 species were registered in total) and some species of beech forests are included in its composition, besides the species from oak forests. Most of the phytocoenological relevés contain over 30 species in the ground flora layer, which is significantly more than in some other researched associations in this area (Stajić *et al.*, 2021). The floristic abundance is a consequence of the characteristics of the association and characteristics of stands in which the research was carried out.

Based on the floristic composition and habitat conditions the association was divided in two sub-associations. Sub-association *typicum* is floristically rich, with stable, typical assemblage Altitudes range from 356 to 573 m, aspects are mostly warmer, slope from 8 to 28°.

Sub-association *caricetosum silvaticae* is more mesophilous variant of sessile oak and Turkey oak forest, which here occurs on colder aspects (North, Northeast, Northwest), on somewhat deeper variants of eutric brown soils and slope from 14° to 27°. In the tree and shrub layers, besides the species that occur in typical variant, some mesophilous species like *Fraxinus excelsior* L., *Populus tremula* L, *Crataegus oxyacantha* L. are also registered. This sub-association is characterized by the presence of the species *Carex sylvatica* Huds. in the ground flora layer. Out of other species that are not present in typical variant of sessile oak and Turkey oak forest the following are registered: *Carex hirta* L., *Asperula odorata* L., *Lamium galeobdolon* (L.) Crantz., *Dryopteris filix-mas* (L.) Schott., *Asarum europaeum* L., *Acer pseudoplatanus* L., *Viola sylvestris* Lam., *Euphorbia platyphyllos* L., *Cephalanthera longifolia* (L.) Fritsch. As can be seen, this sub-association, as a more mesophilous one, stands out by the presence of the larger number of species characteristical for beech forests. In this sub-association also are present the facies rubosum.

The analysis of the spectrum of floral elements shows that in association of sessile oak and Turkey oak (*Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.) the most represented are mesophilous plants with 42% (of Central European and Sub-Atlantic range types). It is known that these forests are somewhat more mesophilous than monodominant forests of Turkey oak, so besides the xerophilous species of the order *Quercetalia pubescentis* some more mesophilous elements of sessile oak forests and even beech forests occur (Tomić, 2004). Considering such floristic composition of this association, such share of mesophilous plants is expected. In order of representation in this association, plants of wide ecological amplitude follow with 25% (of Eurasian and Cosmopolitan range types), and then also xerothermophilous plants with 23% (of Pontic, sub-Mediterranean and Balkan range types).

Based on the life -form spectrum of plants, the association of sessile oak and Turkey oak is hemicryptophytic-phanerophytic. Similar biological spectrum of the association of sessile oak and Turkey oak was registered also on Vršačke mountains (Pekanović, 1981). The forest of sessile oak and Turkey oak on the territory of Đerdap, which is situated on the transitional habitat between climatogenic forest of Hungarian oak and Turkey oak and sessile oak forest in its composition has 48% of hemicryptophytes (Krstić, 2000).

5. CONCLUSION

Association of sessile oak and Turkey oak (*Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.) on Kosmaj has a large ecological amplitude, i.e. it is spread in the wide range of altitudes (phytocoenological relevés are from altitudes ranging from 348 to 573 m), on various aspects (it appears more often on warmer aspects) and slopes from 8° to 28°. These forests are the most widespread on the slopes of Veliki Kosmaj, where they alternate with the forests of Hungarian oak and Turkey oak (rarely Turkey oak) and precede mixed beech and sessile oak forests or pure beech forests.

Based on floristic composition and habitat conditions the association was divided on two sub-associations. Sub-association *typicum* is floristically rich, with stable, typical assemblage. Sub-association *caricetosum silvaticae* is more mesophilous variant of sessile oak and Turkey oak forest, which occurs here on colder aspects (North, Northeast, Northwest), on somewhat deeper variants of eutric soils and slope ranging from 14° to 27°, and differential species *Carex sylvatica* Huds is present in it.

According to the spectrum of range types the researched association has a Central European character, while according to the life-form spectrum it is of hemicryptophytic-phanerophytic character, with an increased share of geophytes.

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PYTOCOENOLOGICAL ANALYSIS OF SESSILE OAK AND TURKEY OAK FORESTS (*QUERCETUM PETRAEAE-CERRIDIS* B. JOVANOVIĆ 1979. S.L.) IN THE TERRITORY OF KOSMAJ

Snežana STAJIĆ, Vlado ČOKEŠA, Ljubinko RAKONJAC,Saša EREMIJA, Suzana MITROVIĆ, Zoran PODUŠKA, Branka PAVLOVIĆ

Summary

The results of phytocoenological research of sessile oak and Turkey oak forest (*Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.) which is carried out in the protected area Kosmaj are presented in this paper. On the researched territory the forest of sessile oak and Turkey oak has a large ecological amplitude, it is spread in the wide range of altitudes (phytocoenological relevés are from altitudes ranging from 348 to 573 m), on all aspects (more often it occurs on warmer aspects) and slopes from 8° to 28°. These forests are the most widespread on the slopes of Veliki Kosmaj, where they alternate with the Hungarian oak and Turkey oak forests (rarely Turkey oak forests), and precede mixed forests of beech and sessile oak or pure beech forests. The association of sessile oak and Turkey oak on Kosmaj occurs on flysch, and the soils found in this association are eutric cambisol and dystric cambisol.

Ground flora layer is very rich (114 species were registered in total) and its composition includes, in addition to species from oak forests, some species of beech forests. The largest number of phytocoenological relevés contains over 30 species in the ground flora layer, which is significantly more than in some other researched associations in this area. Floristic abundance is a consequence of the characteristics of the association and characteristics of stands in which the research was carried out. The degree of coverage by ground flora ranges from 0.3 to 1.0. Based on the floristic composition and habitat conditions the association was divided into two sub-associations: *typicum* and *caricetosum silvaticae*.

By analysis of the spectrum of range types it was determined that the researched association of sessile oak and hornbeam has a Central European character, while according to the life-form spectrum it is of hemicryptophytic-phanerophytic character, with increased share of geophytes.

FITOCENOLOŠKA ANALIZA ŠUMA KITNJAKA I CERA (*QUERCETUM PETRAEAE-CERRIDIS* B. JOVANOVIĆ 1979. S.L.) NA PODRUČJU KOSMAJA

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Rezime

U radu su prikazani rezultati fitocenoloških istraživanja šume kitnjaka i cera (*Quercetum petraeae-cerridis* B. Jovanović 1979. s.l.) koja su sprovedena u zaštićenom području Kosmaj. Na istraživanom području šuma kitnjaka i cera ima veliku ekološku amplitudu, rasprostranjena je u širokom dijapazonu nadmorskih visina (fitocenološki snimci

su sa nadmorskih visina 348-573 m), na svim eskpozicijama (češće se pojavljuje na toplijim) i nagibima od 8°-28°. Ove šume najviše su rasprostranjene na padinama Velikog Kosmaja, gde alterniraju sa šumama sladuna i cera (ređe šumama cera), gde prethode mešovitim bukovo-kitnjakovim ili čistim bukovim šumama. Zajednica kitnjaka i cera na Kosmaju se javlja na flišu, a od zemljišta u ovoj zajednici su konstatovani eutrični kambisol i distrični kambisol.

Sprat prizemne flore je vrlo bogat (registrovano ukupno 114 vrsta) i u njegov sastav, pored vrsta iz hrastovih šuma, ulaze i neke vrste bukovih šuma. Najveći broj fitocenoloških snimaka sadrži preko 30 vrsta u spratu prizemne flore, što je znatno više nego u nekim drugim istraživanim zajednicama na ovom području. Florističko bogatstvo je posledica osobina same zajednice i karakteristika sastojina u kojima su vršena istraživanja. Pokrovnost prizemnom florom kreće se od 0.3 do 1.0. Na osnovu florističkog sastava i stanišnih uslova izvršena je podela zajednice na 2 subasocijacije: *typicum* i *caricetosum silvaticae*.

Analizom spektra areal tipova utvrđeno je da istraživana zajednica kitnjaka i graba ima srednjeevropski karakter, dok je prema spektru životnih oblika hemikriptofito-fanerofitskog karaktera, sa povećanim učešćem geofita.

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PLANT SPECIES AS HABITAT INDICATORS IN BEECH FORESTS FOLLOWING CLEARCUTTING

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Abstract: *In the winter of 2015, extensive damage affected forest ecosystems in eastern Serbia due to severe ice-induced tree breakage and falls. As a result, clearcutting was necessary in certain forest stands. This study evaluates the ecological characteristics of plant species that emerged on clearcut sites five years after clearcutting. The research was conducted within the Timok Forest Region, encompassing both natural beech stands and artificially established conifer plantations on beech sites (Helleboro odori-Fagetum moesiacae Soó & Borhidi 1960). This investigation focuses only on the stocked areas within the Timok Forest Region (natural forests and artificially established stands) managed by the state-owned company "Srbijašume" in Belgrade. Vascular flora was categorised based on their affiliation with specific ecological plant groups according to the following key environmental parameters: soil moisture (V), soil acidity (K), nitrogen availability (N), light (S), and temperature (T). Spontaneously colonised plants, serving as bioindicators, reflect changes in ecological (particularly microclimatic and edaphic) conditions. Additionally, these bioindicators reveal the degradation of forest habitats post-clearcutting, which manifests as increased light penetration, xerothermic microclimatic shifts, surface soil acidification, and diminished nutrient availability.*

Keywords: Timok Forest Region, beech habitat, phytodindicators, ecological factors, forest degradation.

BILJNE VRSTE KAO INDIKATORI STANIŠTA BUKOVIH ŠUMA NAKON ČISTE SEČE

Apstrakt: *Na području istočne Srbije u zimu 2015. godine, u šumskim ekosistemima nastale su štete velikih razmera u vidu ledoloma i ledoizvala. U pojedinim satojinanama morala je biti izvedena čista seča. U radu su analizirane ekološke karakteristike biljnih vrsta koje su se pojavile na sečinama pet godina nakon izvršene čiste seče. Istraživanja su vršena u Timočkom šumskom području, u prirodnim bukovim i veštački podignutim sastojinama četinara na bukovom staništu (*Helleboro odori-Fagetum moesiacae Soó & Borhidi 1960.*). Predmet ovog istraživanja su samo obrasle površine Timočkog ŠP (prirodne šume i veštački podignute sastojine) u državnom vlasništvu kojima gazduje JP „Srbijašume“Beograd. Izvršeno je diferenciranje vaskularne flore na osnovu pripadnosti određenoj ekološkoj grupi*

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biljaka, prema najvažnijim ekološkim faktorima: vlažnost zemljišta (V), kiselost zemljišta (K), količini azota u zemljištu (N), svetlosti (S) i temperaturi (T). Spontano naseljene biljke, kao indikatori ukazuju na promene ekoloških (pre svega mikroklimatskih i edafskih) uslova. Takođe ukazuju i na degradaciju šumskih staništa nakon čiste seče koja se manifestuje kroz veći priliv svetlosti, kserotermizaciju mikroklime, zakišeljavanje zemljišta u površinskim slojevima i slabiju obezbeđenost hranljivim materijama.

Ključne reči: Timočko šumsko područje, bukovo stanište, fitoindikatori, ekološki faktori.

1. INTRODUCTION

The continental climate in the Timok Krajina region of eastern Serbia frequently results in ice formation. In the winter of 2015, an influx of extremely cold air masses from the east and the Carpathians led to substantial ice accumulation on infrastructure and forest trees (Pavlović et al., 2022). The large quantities of ice (weighing several tons per tree in some cases) exceeded the structural resilience of the trees, resulting in widespread ice breakage and tree falls (Marković et al., 2018). The most severely impacted forest management units (FMUs) in the Timok Forest Region included: MU Rtanj, MU Tupižnica, MU Šaška – Studena – Selačka Reka, MU Zaglava I, MU Tresibaba, MU Vrška Čuka – Babajona – Treći Vrh, MU Markov Kamen – Mečji Vrh, MU Čestobrodica, MU Dubašnica, MU Zaglavak II, and MU Stol (Pavlović et al., 2023). The severe weather events in certain parts of the Timok Forest Region caused extensive damage, necessitating clearcutting on more than 1,200 hectares of forest stands (Pavlović et al., 2023).

Knowledge of the ecological conditions specific to each habitat is crucial for selecting appropriate tree species when restoring degraded forest sites and reforesting cleared areas (Krstić, 2000). The more closely the ecological requirements of selected species align with site conditions, the more successful the reforestation and rehabilitation of degraded areas will be (Kojić et al., 1997). It is well-established that each plant species thrives only within specific habitat parameters, making it a reliable ecological indicator of environmental conditions. Therefore, by analysing the floristic composition of a plant community and the bioindicator values of the species it comprises, it is possible to determine the ecological conditions of a given habitat.

Numerous researchers have investigated the relationship between plants and environmental conditions, as well as the indicator role of plants and plant cover. The foundations of bioindicator ecology were laid by Linnaeus (1751), who, in his seminal work *Philosophia Botanica*, classified several groups of indicator plants. The term bioindicator was first introduced by Clements (1920) to denote organisms that, through their presence in a specific habitat, clearly reflect its ecological characteristics. Raunkiaer (1934) emphasised plant life forms as significant indicators of habitat conditions, especially climatic factors. The phytogeographical analysis and spectra of plant life forms discussed in this paper have been previously conducted. (Pavlović et al., 2024). Ellenberg made a profound impact on the field of indicator geobotany by introducing ecological indices as quantitative indicators of individual plant species' ecological relationships with habitat conditions (Kojić et al., 1997). Building on this, Swiss phytoecologist Landolt (1977) developed ecological indices for ten specific factors as indicators of ecological conditions. Hungarian phytoecologist Soó (1980) also made considerable contributions to the field. Ecological indices for the native flora of Serbia were established by Kojić et al. (1994, 1997).

This study focuses on natural stands of submontane beech forests (*Helleboro odori-Fagetum moesiacae* Soó & Borhidi 1960) and artificially established stands within sites of this community. It also investigates the ecological changes in beech habitats five years following clearcutting in the Timok Forest Region. The primary aim is to identify the ecological characteristics of plant species, which serve as bioindicators of habitat conditions in these stands. According to Tomić and Rakonjac (2013), the *Helleboro odori-Fagetum moesiacae* Soó & Borhidi 1960 subassociation encompasses sub-Pannonian beech forests found at lower altitudes across sites ranging from Gučevo and Cer, through Šumadija, Avala, Fruška Gora, and Đerdap, reaching into the Timok Krajina.

2. MATERIALS AND METHODS

To assess ecological changes in stands affected by clearcutting, eight sample plots of 1,000 square meters each were established at various sites within the Timok Forest Region. These plots were placed in forests managed by “Srbijašume” State Enterprise from Belgrade, specifically within the FE “Timok Forests” Boljevac. The plots covered altitudes ranging from 580 to 830 meters, predominantly on cool, north-facing slopes typical of beech forests, with slopes varying from 5° to 32°. The bedrock included carbonate and silicate formations; on carbonate substrates, soils were classified as eutric brown (Calcaric Cambisol), while on silicates, they were acidic brown (Dystric Cambisol). All plots were within the submontane beech forest community (*Helleboro odori-Fagetum moesiacae* Soó & Borhidi 1960). Four plots were located in areas previously occupied by natural beech stands (within the Tresibaba, Šaška-Studena-Selačka Reka, and Čestobrodica Forest Management Units). The remaining four plots were established in areas where artificial coniferous stands had been planted on beech habitats (within the Zaglavak I, Šaška-Studena-Selačka Reka, and Rtanj Management Units).

For each plot, baseline ecological conditions were recorded, and a survey of vascular flora was conducted based on sample methods to systematise the floristic composition in areas subjected to clearcutting. Species identification was conducted using the keys provided in *Flora of the Socialist Republic of Serbia*, Volumes I-IX, Josifović, ed. (1970-1977). Plant species were then categorised into ecological groups based on critical environmental factors: soil moisture, soil acidity, soil nitrogen content, light requirements, and temperature preferences. This classification utilised the ecological indices for Serbian flora developed by Kojić et al. (1997).

3. RESULTS AND DISCUSSION

Table 1 presents the forest management units (FMUs), compartments, and subcompartments (C/SC) where sample plots (SPs) were established. Key ecological conditions include altitude (ALT), aspect, average slope, bedrock, and soil type.

Stand characteristics are represented by origin classification—either natural beech stands or artificially established stands (AES) on beech sites.

Table 1. *Spatial Data and Basic Ecological Conditions at Sample Plots (SP)*

SP	MU	C/SC	Alt.	Aspect	Slope (°)	Origin	Bedrock	Soil type
1	Zaglavak I	28b	695	W-WS	20	AES	amphibole-biotite plagiogranites	Dystric Cambisol
2	Tresibaba	46b	714	N	10	natural	limestone	Calcaric Cambisol
3	Šaška-Studena-Selačka reka	40c	761	SW	30	AES	amphibole-biotite plagiogranites	Dystric Cambisol
4	Šaška-Studena-Selačka reka	25a	823	NW	25	natural	phyllitoids and greenstones	Dystric Cambisol
5	Čestobrodica	90g	582	N-NE	12	natural	organogenic limestone	Calcaric Cambisol
6	Rtanj	29a	779	N	25	AES	limestones	Calcaric Cambisol
7	Rtanj	28c	675	NE	5	AES	limestone breccia	Calcaric Cambisol
8	Čestobrodica	100/1	575	E	32	natural	conglomerates and sandstones	Dystric Cambisol

Source: *author*

Table 1 indicates that the stands most affected by ice-induced tree breakage and falls are situated at elevations between 580 and 830 meters, with cold exposures, primarily north-facing, typical of submontane beech forests. Slopes in these areas range from 5° to 32°. The bedrock across the study area varies from carbonate to silicate. On carbonate bedrocks, the soil type is eutric brown (Calcaric Cambisol), whereas on silicate bedrocks, it is acidic brown (Dystric Cambisol).

A survey of vascular flora on clearings recorded 176 taxa of vascular plants (Pavlović et al., 2023). Typical of submontane beech forests, the site supports mesophilic species from lower elevations as well as xerophytic elements from neighbouring oak forests. In addition to beech young growth (*Fagus sylvatica* ssp. *moesiaca* (Maly) Czeczott), characteristic species include *Lamium galeobdolon* (L.) Crantz, *Cardamine bulbifera* (L.) Crantz, *Acer campestre* L., *Helleborus odorus* Waldst. & Kit., *Mycelis muralis* (L.) Dum., *Circaea lutetiana* L., *Stachys sylvatica* L., *Carex sylvatica* Huds., and *Moehringia trinervia* (L.) Clairv.

Among the accessory species observed, many are characteristic of beech forests, such as *Dryopteris filix-mas* (L.) Schott, *Alliaria officinalis* (M. Bieb.) Cavara & Grande, *Tamus communis* L., *Viola odorata* L., *Geranium robertianum* L., *Hedera helix* L., *Euphorbia amygdaloides* L., *Sambucus nigra* L., *Viola sylvestris* Lam., *Ruscus aculeatus* L., *Prunus avium* L., *Bilderdykia convolvulus* (L.) Dumort., and *Polygonatum odoratum* (Mill.) Druce (Stajić et al., 2018).

3.1. Species affiliation and relationships with ecological factors

Understanding the ecology, or the relationship of forest trees to environmental conditions, as well as the biological characteristics of species, is of great importance in forest cultivation. This knowledge forms a solid foundation for selecting appropriate silvicultural approaches, treatment methods, and strategies for natural regeneration and forest care (Krstić, 2003). As previously noted, species classification into specific ecological plant groups was determined based on their indicator values for the analysed factors, as outlined by Kojić et al. (1997).

Table 2. *Ecological Factors and Plant Ecological Groups*

Ecological factor	Plant Ecological Group (index and classification)
Soil moisture	1. Xerophytes
	2. Subxerophytes
	3. Submesophytes
	4. Mesophytes
Soil Acidity	1. Acidophiles
	2. Acidophilic-Neutrophiles
	3. Neutrophiles
	4. Neutrophilic-Basophiles
	5. Basophiles
Soil Nitrogen Content	1. Oligotrophs
	2. Oligotrophic-Mesotrophs
	3. Mesotrophs
	4. Mesotrophic-Eutrophs
	5. Eutrophs
Light Requirements	1. Sciophytes
	2. Sciophytes-Partial Sciophytes
	3. Partial Sciophytes
	4. Partial Sciophytes-Heliophytes
	5. Heliophytes
Temperature Preferences	1. Frigoriphiles
	2. Frigoriphiles-Mesophiles
	3. Mesophile
	4. Mesophile-Thermophile
	5. Thermophile

Source: *author*

3.1.1. Plant Distribution by Soil Moisture Levels

The moisture index indicates the average soil moisture during the growing season, with low values representing dry conditions and high values indicating increased moisture (Landolt, 1977). Analysis of the ecological moisture index values reveals that in the submontane beech forest community (*Helleboro odori-Fagetum moesiacae*, Soó & Borhidi, 1960), submesophytes dominate at 63.07%. These are plants commonly found in mesophytic habitats, though they also occur in some xerophytic communities. Mesophytes account for 6.82% of species, while subxerophytes, found in both extremely dry and somewhat mesophytic habitats, make up 26.70%. Xerophytes – plants specifically adapted to extreme drought conditions – constitute approximately 3.41% of the sampled stands (Figure 1).

A comparable pattern can be observed in the submontane beech forest community (*Helleboro odori-Fagetum moesiacae*, Soó & Borhidi, 1960) in the

Kosmaj area, where submesophytes similarly prevail, comprising 71% of species (Stajić et al., 2018). Here, however, subxerophytes represent a smaller proportion at 15%, and xerophytes are absent. Research in the "Vinatovača" beech primeval forest further confirms this pattern: submesophytes dominate across all ecological units with an average of 64.5%, while subxerophytes are present at 9%, and xerophytes at only 0.5% (Čokeša et al., 2022).

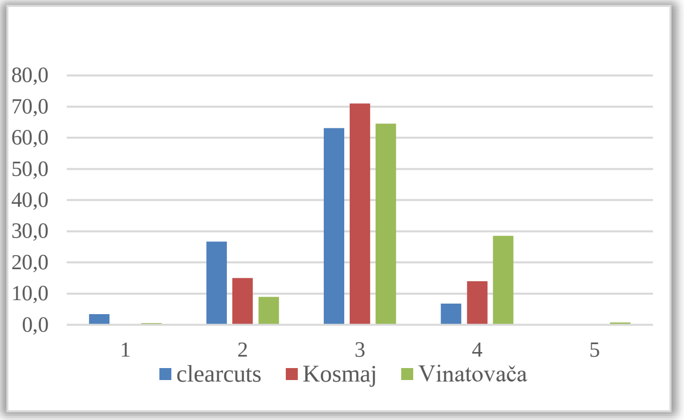

Figure 1. *Plant Distribution by Soil Moisture Levels*

The preceding analysis indicates that submesophytes are characteristic of submontane beech forests, occurring both across barren areas five years post-clearcutting and in managed beech forests, as well as in undisturbed primeval forests, with minimal variation between these environments. However, subxerophytes were the most responsive to the drastic ecological changes following clearcutting, showing their highest abundance in clearcut areas and lowest presence in pristine primeval forests. The reverse trend is observed with mesophytes. As anticipated, their numbers decline significantly in clearcut areas compared to managed forests, with the lowest presence in primeval forest ecosystems.

Additionally, typical xerophytes have been observed to colonise clearcut areas yet are nearly absent in both managed and unmanaged forests. Hygrophilous plants are entirely absent from clearcut areas. These findings suggest a xerothermic shift in the microclimate of clearcut areas relative to managed forests, and even more so when compared to untouched, fully natural primeval forest ecosystems.

3.1.2. Plant Distribution by Soil Acidity

Beech trees belong to the ecological group of neutrophilic plants in terms of soil acidity, as they thrive best in neutral to slightly acidic soils (Stajić et al., 2018). In Figure 2, the distribution of plants based on soil acidity shows that neutrophilic plants are predominant, occurring primarily on neutral to slightly acidic soils (64.20%), followed by neutrophilic-basophilic plants (26.70%). Basophilic plants are the least represented (0.57%). Transitional acidophilic-neutrophilic species make up 6.82%, while acidophilic plants, which are confined to acidic soils, account for only 1.70%. Similar findings have been reported in the submontane beech forest community (*Helleboro odori-Fagetum moesiacae* Soó & Borhidi 1960.) in the

Kosmaj region (Stajić et al., 2018) and in "Vinatovača" beech forest reserve (Čokeša et al., 2022).

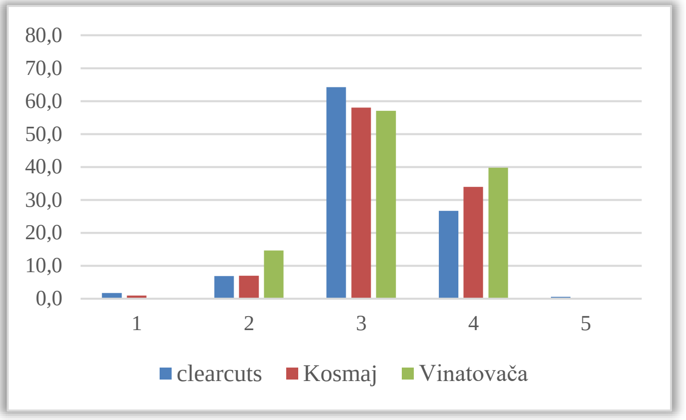

Figure 2. *Plant Distribution by Soil Acidity*

Soil acidity indicators are influenced by bedrock and soil type. In the study area, different bedrock and soil types are present, making direct comparisons challenging. However, when results are averaged and viewed on a broader scale, the highest concentrations of plants indicating neutral to slightly acidic and acidic soil reactions appear in clearcut areas, while indicators of slightly alkaline reactions are most prevalent in primeval forests. Managed natural forests fall somewhere in between. This pattern may suggest increased leaching of base cations from surface soil layers in exposed areas, leading to soil acidification. To draw valid conclusions, it would be beneficial to analyse these changes individually for each soil type, though this is beyond the scope of the present study. Five years is still a relatively short timeframe to detect substantial shifts in soil properties. The spontaneous growth of natural vegetation in these habitats also slows down such soil evolution.

3.1.3. Plant Distribution by Soil Nitrogen Content

As shown in Figure 3, mesotrophic plants – species that thrive in soils moderately rich in mineral nutrients – are the most prevalent, comprising 49.43% of the total. These are followed by transitional groups: plants between oligotrophic and mesotrophic conditions (27.27%) and those between mesotrophic and eutrophic conditions (18.75%). True eutrophic (nitrophilic) plants, which require soils exceptionally high in mineral content, and oligotrophic (nitrophobic) plants, adapted to nutrient-poor soils, are both rare, each representing just 2.27% of the total. In terms of soil nitrogen content, the submontane beech forest community in the Kosmaj Region also demonstrates a predominantly mesotrophic profile (Stajić et al., 2018). Similarly, mesotrophic plants are dominant across all ecological units within the beech forest reserve “Vinatovača” (Čokeša et al., 2022).

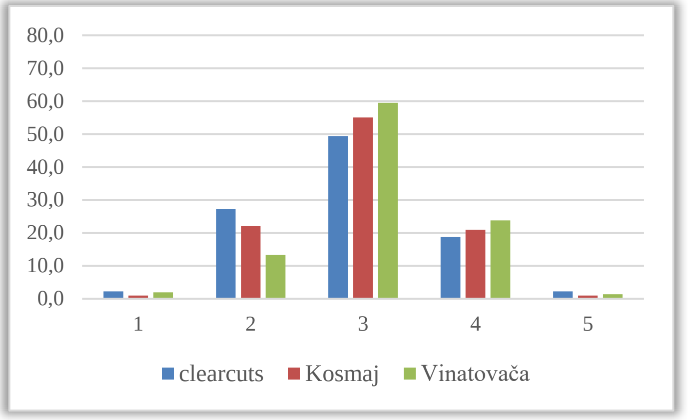

Figure 3. *Plant Distribution by Soil Nitrogen Content*

The preceding analysis reveals that beech habitats, irrespective of their preservation status, have moderate mineral nutrient levels. However, some differences are evident. Mesotrophic plants are least represented in clearcut areas and most abundant in primeval forests. The relative proportion of transitional oligotrophic-mesotrophic species further suggests that soils in clearcuts are nutrient-poor, with clearcuts showing the highest relative share of these species, while primeval forests have the lowest. Conversely, within the transitional group of mesotrophic-eutrophic plants, their presence is most prominent in primeval forests and least in clearcut areas. Managed natural forests fall in between these three habitat types. Overall, these findings support the conclusion that "the more ecosystems are disrupted, the poorer their soils become in mineral nutrients."

3.1.4. Plant Distribution by Light Requirements

The light index reflects the average light intensity during the growing season under which plants develop (Landolt E., 1977).

Figure 4 shows that the most prevalent plant types are the ones with semi-sciophytic (49.43%) and semi-sciophytic-heliophytic (28.98%) characteristics. The transitional category, comprising sciophytes and semi-sciophytes, represents 19.32%. True sciophytes—plants adapted to conditions of extreme shade (up to 3% of full daylight)—account for only 1.70%, while typical heliophytes, or plants adapted to full sunlight, constitute just 0.57%. In the investigated community of submontane beech forest in the Kosmaj Region, the transitional category of semi-sciophytes-heliophytes is represented by only 8%, while in the beech primeval forest, it is even lower at 3%. However, there is a significantly higher share of the transitional category of sciophytes-semi-sciophytes, with 41% in the submontane beech forest on Kosmaj and as much as 66.9% in the beech primeval forest. Additionally, a higher presence of true sciophytes is also recorded.

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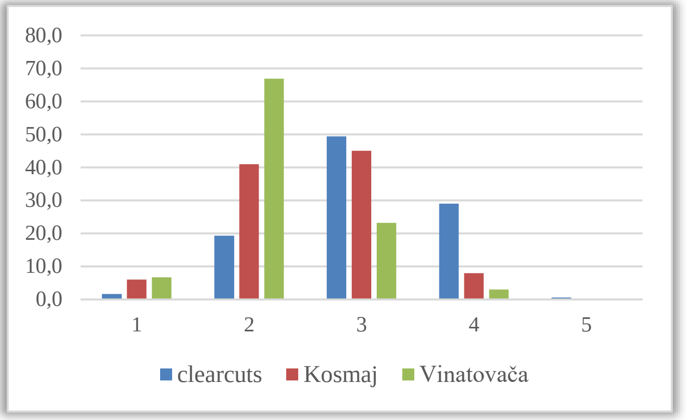

Figure 4. *Plant Distribution by Light Requirements*

As expected, increased ecosystem disturbance results in a greater influx of light, leading to a higher prevalence of light-demanding plant species. In the primeval forest, the category of sciophytes-semi-sciophytes is the most dominant. In contrast, clearcut areas are characterised by a predominance of semi-sciophytes and semi-sciophyte-heliophytes. Managed beech forests consistently occupy an intermediate position. True sciophytes are relatively rare in the primeval forest due to the abundance of canopy gaps and light penetration, coupled with a significant number of fallen trees. Conversely, clearcut areas also lack a substantial presence of true heliophytes because spontaneous woody vegetation has already closed the canopy within five years. It is likely that heliophytes were present during the first and second years after clearing but have since disappeared.

3.1.5. Plant Distribution by Temperature Preferences

The distribution of plants by temperature preferences (Figure 5) reveals that in the submontane beech forest community (*Helleboro odori-Fagetum moesiacae* Soó & Borhidi 1960) in the Timok Forest Region, mesothermic species—those that thrive in moderate heat—predominate, representing 65.91% of the total. Transitional mesothermic-thermophilic plants make up 30.11%, while strictly thermophilic species account for 2.84%. The least represented are frigophilic-mesothermic species, at 1.14%.

Regarding temperature as an ecological factor, the *Helleboro odori-Fagetum moesiacae* Soó & Borhidi 1960 community displays a predominantly mesothermic character, with an increase in presence of plants tending towards thermophilicity, likely due to the influence of oak forest species in the area. A similar pattern is observed in the Kosmaj Region (Stajić et al., 2018).

In the beech primeval forest, mesothermic (Central European) species are dominant across all ecological units, occupying mountainous zones of southern Europe and comprising about 73.7% of the total plant species. On average, these plants represent nearly three-quarters of the overall flora. The next largest group consists of transitional species between mesothermic and thermophilic types, at

23.65%, including many sub-Mediterranean species. On limestone, strictly thermophilic and transitional frigophilic-mesothermic species are scarce.

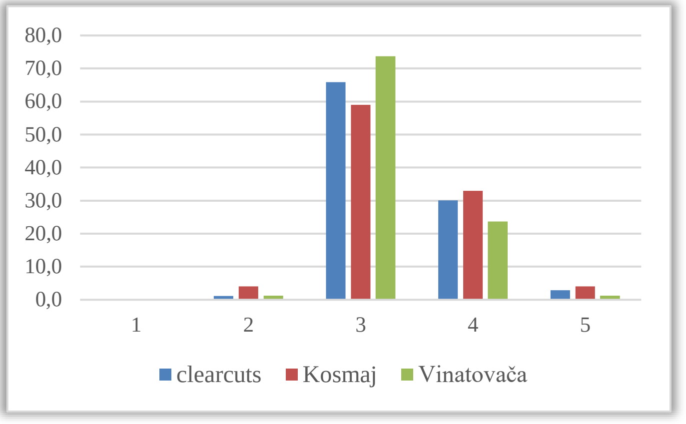

Figure 5. *Plant Distribution by Temperature Preferences*

The previous analysis indicates no major differences in temperature preferences across the three stand types. While mesothermic plants are the most dominant in all three types, there is a marked presence of mesothermic-thermophilic species from the oak belt in each stand. Importantly, despite ecosystem disturbances, there has been no significant increase in thermophilic species, and especially not in frigophilic species, within these habitats.

4. CONCLUSIONS

The severe ice storm that hit eastern Serbia in the winter of 2015 caused extensive damage to forest ecosystems, resulting in widespread ice-induced tree breakage and falls. This phenomenon is becoming increasingly common in Serbia, posing a significant threat to forest ecosystem stability. In the Timok Forest Region, certain beech stands were completely devastated, necessitating clearcutting. Five years after this intervention, substantial ecological changes were observed, with plants in these areas serving as indicators of the degradation level of natural beech habitats.

In terms of soil moisture preferences, sub-mesophytic plants dominate the submontane beech forest community (*Helleboro odori-Fagetum moesiacae* Soó & Borhidi 1960), whether in clearcut areas, managed forests, or untouched primeval forest. However, clearcut areas display a trend toward xerothermic microclimate conditions, marked by an increase in subxerophytes and xerophytes and a reduction in mesophytes compared to managed and primeval forests.

Regarding soil acidity, neutrophilic and neutrophilic-basophilic plants are predominant across all three stand types. Despite differences in bedrocks and soil types, clearcut areas tend to favour plants that indicate a neutral to slightly acidic reaction in the surface soil layers. This is due to intensified leaching of base cations from surface to deeper soil layers on degraded sites. In contrast, managed and primeval forests have a higher prevalence of plants associated with a slightly more alkaline soil reaction.

With respect to soil nitrogen content, mesotrophic species dominate across all three stand types. However, as phytocenosis degradation progresses, the share of oligotrophic-mesotrophic species increases, pointing to a certain depletion in nutrient availability. The more preserved an ecosystem is, the greater the proportion of mesotrophic-eutrophic species, reflecting richer soil nutrient availability.

In all three stand types, the presence of indicators showing the amount of light on the soil surface is binary. As expected, with increasing phytocenosis degradation, there is a greater influx of light and a rise in heliophilic species. Conversely, more preserved phytocenoses support a higher presence of sciophilic species.

Finally, mesothermic plants dominate in all three stand types, a fundamental characteristic of submontane beech forests. The increased presence of mesothermic-thermophilic species reflects the influence of nearby oak forests. They have not been significantly impacted by phytocenosis degradation.

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PLANT SPECIES AS HABITAT INDICATORS IN BEECH FORESTS FOLLOWING CLEARCUTTING

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Summary

Research was conducted in the Timok Forest Region, which was hit by a severe ice storm in the winter of 2015. The storm caused extensive damage to forest ecosystems,

resulting in ice-induced tree breakage and falls. In some stands, clear-cutting was necessary. Five years after the clear-cutting, significant ecological changes, primarily microclimatic and edaphic, were observed. In these conditions, plants served as indicators of the degradation level of natural beech habitats.

Regarding soil moisture, sub-mesophytic plants dominated in all stand types. However, in clearcut areas, a trend of microclimate xerothermisation emerged, with an increase in subxerophytic and xerophytic species and a decrease in mesophytic species compared to managed forests and primeval forest.

In terms of soil acidity, plants that indicate a neutral to slightly acidic reaction in the surface soil layers were predominant in clearcut areas. In managed forests and the primeval forest, plants indicative of a slightly more alkaline soil reaction were more common.

With respect to soil nitrogen content, mesotrophic species were the most represented in all three stand types. However, as phytocenosis degradation increased, the proportion of oligotrophic-mesotrophic species rose, indicating some depletion in soil nutrient availability.

As expected, with increased phytocenosis degradation, there was a greater influx of light and a higher proportion of heliophilic species. In more preserved phytocenoses, the share of sciophilic species increased.

In all three stand types, mesothermic plants dominated, a fundamental characteristic of submontane beech forests.

BILJNE VRSTE KAO INDIKATORI STANIŠTA BUKOVIH ŠUMA NAKON ČISTE SEČE

Branka PAVLOVIĆ, Vlado ČOKEŠA, Snežana STAJIĆ ,Violeta BABIĆ, Zoran PODUŠKA, Nikola MARTAĆ, Branko KANJEVAC

Rezime

Istraživanja su vršena u Timočkom šumskom području, koje je u zimu 2015. bilo pogođeno ledenim talasom. Došlo je do veoma ozbiljnih šteta u šumskim ekosistemima u vidu ledoloma i ledoizvala. U pojedinim satojinanama morala je biti izvedena čista seča. Pet godina nakon čiste seče je došlo do značajnih ekoloških promena (pre svega mikroklimatskih i edafskih). Biljke su u ovakvoj situaciji poslužile kao indikatori stepena degradacije prirodnih bukovih staništa.

U odnosu prema vlažnosti zemljišta, u svim satojinskim oblicima preovlađuju submezofite. Na sečinama je ipak došlo do kserotermizacije mikroklime i povećanog učešća subkserofita i kserofita, a smanjenog učešća mezofita u odnosu na gazdovane šume i prašumu.

Prema kiselosti zemljišta, na sečinama preovlađuju biljke koje ukazuju na neutralnu do slano kiselu reakciju površinskih slojeva zemljišta. U gazdovanim šumama i u prašumi preovlađuju biljke koje ukazuju na nešto alkalniju reakciju zemljišta.

U odnosu na količinu azota u zemljištu, u sva tri sastojinaska oblika su najzastupljenije mezotrofne vrste. Međutim, sa porastom degradacije fitocenoze, povećava se učešće oligotrofno-mezotrofnih vrsta, što ukazuje na izvesno osiromašenje u pogledu obezbeđenosti hranljivim elementima.

Kao što se i očekivalo, sa povećanjem degradacije fitocenoze, veći je priliv svetlosti i učešće heliofilnijih vrsta. Što je fitocenoza više očuvana povećava se učešće sciofilnijih vrsta.

U sva tri sastojinska oblika dominiraju mezotermne biljke, što je osnovna karakteristika submontanih bukovih šuma.

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Original scientific paper

SPONTANEOUS DEVELOPMENT OF MIXED STANDS OF FIR, SPRUCE AND BEECH ON MT. TARA

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Abstract: *The main objective of this study is to analyze the structural production and dynamic changes of mixed forests of fir, spruce and beech on Mt. Tara, in permanent sample plots which were exempt from the regular management over a period of more than 60 years (1955-2017). The results of the research indicate that during the analyzed period mixed forests of fir, spruce and beech have undergone a number of changes in structural and production terms. The significant presence of trees of large dimensions (volume accumulation) slowed down the developmental dynamics of these stands and made regeneration and recruitment difficult, which had a negative impact on their structural development and, in general, on the stability of these stands. The results show that selection forests are possible to achieve only with a permanent management approach and adherence to the modern principles of close-to-nature forest management. In this sense, selection cutting in the context of close-to-nature forest management is imposed as a means of accelerating the dynamics of development of these forests, repairing their structural development (by achieving and preserving their selection structure), ecological stability and functional values. On the contrary, the absence of activity and spontaneous development of these stands leads to a general devitalization and a deviation from the desired goals.*

Keywords: Mt. Tara, forests of fir, spruce and beech, spontaneous stand development, stand structure, stand dynamics

SPONTANI RAZVOJ MEŠOVITIH SASTOJINA JELE, SMRČE I BUKVE NA TARI

Sažetak: *Osnovni cilj ovih istraživanja jeste da se analiziraju strukturne, proizvodne i dinamičke promene mešovitih šuma jele, smrče i bukve na Tari, na stalnim oglednim površinama, koje su izuzete iz redovnog gazdovanja u periodu dužem od 60 godina (1955-2017). Rezultati istraživanja ukazuju na to da su u analiziranom periodu mešovite šume jele, smrče i bukve pretrpele niz promena u strukturnom i proizvodnom smislu. Značajno prisustvo stabala jakih dimenzija (nagomilavanje zapremine) usporilo je dinamiku razvoja ovih sastojina i otežalo podmlađivanje i urastanje, što se negativno*

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odrazilo na njihovu strukturnu izgrađenost i, generalno, na stabilnost ovih sastojina. Rezultati pokazuju da je prebirna šuma moguća jedino uz permanentan gazdinski pristup i poštovanje savremenih principa prirodi bliskog gazdovanja. U tom smislu, prebirna seča, u kontekstu prirodi bliskog gazdovanja, nameće se kao sredstvo ubrzanja dinamike razvoja ovih šuma, popravke njihove srukturne izgrađenosti (postizanja i očuvanja prebirne strukture), ekološke stabilnosti i funkcionalne vrednosti. Suprotno, odsustvo aktivnog delovanja i spontani razvoj sastojina vode ka njihovoj devitalizaciji i udaljavanju od željenih ciljeva.

Ključne reči: Tara, šume jele, smrče i bukve, spontani razvoj, struktura sastojine, dinamika sastojine

1. INTRODUCTION

The forest of fir, spruce and beech *Piceo-Abietetum* Col. 1965 (syn. *Piceo-Fago Abitetum* Chol. 1965; *Piceo-Abieti-Fagetum moesiacum* Mišić et al., 1978) is a specific three-dominant community, which can be found in Serbia on Mt. Tara, Mt. Zlatar, Mt. Golija, the Mojstirsko-Draške mountains, Mt. Kopaonik, Mt. Stara planina, and Pešter Plateau, etc. In Mt. Tara and the Pešter Plateau, this community occurs as a climate regional belt (Gajić, 1992; Tomić, Rakonjac, 2013). The ratio of spruce, fir, and beech in the association changed during the historical development of the vegetation, depending on the climatic conditions and the way of management (Tomić, Rakonjac, 2013).

These forests are characterized by structural diversity, i.e. a series of transitions from diverse to complex selection structural forms. In recent decades, there has been a growing interest of the international forestry circles in selection (uneven-aged) forest management systems, as these systems have been recognized as more natural, associated with more pronounced diversity and a greater social value of forests (Schütz, 2002). Increasingly, the focus is placed on the management methods and systems that are in harmony with nature and at the same time oriented toward multifunctional use. It is precisely the selection forest that is a silvicultural form suitable for producing multiple effects. It can therefore be referred to as a system in which the interests are balanced and the use is regulated as a compromise.

The selection forest is not created naturally, but solely in a way that continuously supports this concept by silvicultural measures. The structural changes, productivity and dynamics of development of the selection forests of fir, spruce and beech on Mt. Tara have been monitored since 1955 in a series of permanent sample plots (SPs). These SPs were exempt from regular management and left to spontaneous development and self-regulatory processes. The aim was to identify and analyze certain laws and trends in the development of these forests, as well as to implement new knowledge into a management process that aims at structurally and ecologically stable and highly functional selection forests. In those terms, from a time distance of more than 60 years, the goal of these studies was defined, and the following hypotheses were formulated:

- in the analyzed period (1955-2017) there were structural disturbances of the stands,
- the developmental dynamics of the stands was slowed down and regeneration and recruitment became difficult,
- the stability and functional value of these forests were reduced.

2. MATERIAL AND METHODS

2.1 Research object

The research was carried out in the "Tara" MU, which is an integral part of the national park with the same name. From the series of permanent SPs in this locality, sample plots SP-1, SP-2 and SP-4 were selected, which are located in the type of spruce, fir and beech forest (*Piceo - Abieti - Fagetum typicum*), on deep to medium deep brown soils on limestone. They were established in 1955 and subsequently largely left to spontaneous development. The basic spatial features of the SPs are shown in Table 1.

Table 1. *The basic spatial features of the SPs*

SP	Area (*ha*)	Altitude (*m*)	Exposure	Terrain slope (°)	Coordinates WGS N	Coordinates WGS E
SP-1	1.44	1099-1116	East	10-15 °	43 ° 55'10 " N 43 ° 55'16 " N	19 ° 25 '06"E 19 ° 25'11"E
SP-2	1.04	1157-1174	Southeast	5- 10 °	43 ° 54'46"N 43 ° 54'51"N	19 ° 24'33"E 19 ° 24'40"E
SP-4	1.00	1152-1174	West	10-15 °	43 ° 54'43"N 43 ° 54'48"N	19 ° 25'42"E 19 ° 25'45"E

The average annual air temperature on Mt. Tara is 5.2°C, the coldest month being January, while the warmest is July, with an average temperature of 13.8°C. The average air temperature in the vegetation period is 10.8°C, while in autumn the mean temperature is 6.1°C, which makes it warmer than spring (4.6 ° C). Annual precipitation is 1,005 mm of water sediment. The rainiest month is May and January and March are the driest months. Rainfall is more abundant during the vegetation period (584 mm of water sediment), which favors the development of forest vegetation.

2.2 Data collection and processing

The surveys used data from periodic measurements (1955, 1975, 2005 and 2017) of permanent SPs in the Mt. Tara forests, which are in the database of the Chair of Forest Management Planning of the Faculty of Forestry in Belgrade. The SPs were spatially defined by marking their boundaries and determining their coordinates, altitude, slope and exposure, while each tree in them was numbered. During periodic measurements, the boundaries of the SPs and the tree numbers were renewed, and the numbering of newly-recruited trees was also performed.

The measurement in the SPs involved a cross measurement of the diameter at breast height and a measurement of the height of each tree above the forest estimation threshold of 10 cm. The diameter was measured with an accuracy of 1 mm and height with an accuracy of 0.1 m.

To enable a reliable comparative analysis, the data of periodic measurements were processed using the same methodology. The volume was calculated by the volume tables method, using the local tables for fir and spruce on Mt. Tara (Banković, 1991) and general tables for high beech forests of Serbia (Mirković, 1969). The current volume increment method was used to calculate the current volume increment, whereby the increment percentage was determined by regression models expressing its dependence on the number of trees per unit area, the share of a particular tree species in the mixture and the diameter and height of the mean stand tree (Banković et al. 2000, 2002).

The diversity of tree dimensions in the SPs was estimated on the basis of the Gini coefficient (GCy) (Lexerød & Eid, 2006; Klopčič & Bončina, 2011), which was obtained using the formula:

$$GCy = \frac{\sum_{j=1}^{n}(2j - N - 1) \times g_j}{\sum_{j=1}^{n} g_j \times (N - 1)}$$

in which:
y- is the year in which the measurement was performed,
j- is the rank of trees ordered from 1 to n (from the thinnest to the thickest),
N- is the total number of trees,
g- is the basal area of a tree.

Statistical data processing was performed by applying descriptive statistics. Using the data of periodic measurements, the arithmetic mean, minimum, maximum and variation coefficient were calculated in each SP as the basic measures of variation in the number of trees (N), basal area (G), volume (V) and current volume increment (Iv) per hectare.

Within this chapter there can be subtitles of first and second line. In the description of material, it should be given enough information to allow other researchers to repeat the experiment at a different location. It is necessary to provide information on the material, subject of the study that precisely defines its origin, physical characteristics etc. If a device or instrument is used to obtain experimental results should be specified: name of the device or instrument, model, manufacturer's name and country of origin. If a scientifically recognized method is used it has to be cited in the References, without the explanation of the steps of the used method. If changes were made in a scientifically recognized method should be provided the original literature references that will support – justify those changes.

3. RESULTS AND DISCUSSION

The variation coefficient of the number of trees is 26.6% in SP-1, 19.3% in SP-2 and 33.6% in SP-4 (Table 2), indicating a more pronounced variation of this element over time. There is an evident decrease in the total number of trees compared to the beginning of the analyzed period and it amounts to 30.9% in SP-1, 32.1% in SP-2 and 50.5% in SP-4. The accumulation of trees of large dimensions (d ≥ 50 *cm*) (Figure 1) resulted in the reduction of light in the stand, the reduction of growth space, as well as the absence of recruitment, which led to the extinction of thin trees (trees of lower storeys), i.e. to a decrease in the total number of trees in the observed period. Such a trend led to structural disturbances and tree distribution curves developed a flatter form, thus moving away from the shape that is typical of selection forests (Figure 1). The consequence of these changes is also a decrease in dimensional diversity, as indicated by the Gini coefficient, which declines over time (Figure 1). The trend of this coefficient in the observed period ranged from 0.556 to 0.547 in SP-1, i.e. from 0.557 to 0.536 in SP-2 and from 0.493 to 0.451 in SP-4.

Table 2. *Measures of variation in the basic numerical elements in the SPs*

SP	$\bar{N}$ (trees · ha^{-1})	min.	max.	C_N (%)	$\bar{G}$ ($m^2 \cdot ha^{-1}$)	min.	max.	C_G (%)
SP-1	436	327	564	26.6	47.1	36.2	52.4	7.4
SP-2	550	422	650	19.3	47.5	35.2	55.7	9.9
SP-4	609	384	789	33.6	46.3	36.7	51.9	6.8
SP	**$\bar{V}$ ($m^3 \cdot ha^{-1}$)**	**min.**	**max.**	**C_v (%)**	**$\bar{I}v$ ($m^3 \cdot ha^{-1}$)**	**min.**	**max.**	**C_{Iv} (%)**
SP-1	715	498	828	20.8	13.3	10.6	15.1	14.9
SP-2	701	450	898	31.6	14.1	10.2	17.3	22.4
SP-4	659	457	796	21.8	13.8	13.1	15.1	5.7

The basal area increased significantly in all SPs, i.e. by 44.3% in SP-1, 57.4% in SP-2 and by 26.4 % in SP-4 compared to the 1955 diameter. At the end of the period in 2017, the value of the basal area was high and it amounted to 52.4 $m^2 \cdot ha^{-1}$ in SP-1, 55.4 $m^2 \cdot ha^{-1}$ in SP-2 and 46.4 $m^2 \cdot ha^{-1}$ in SP-4. The significant increase in the basal area can only be explained by the accumulation of trees of large dimensions.

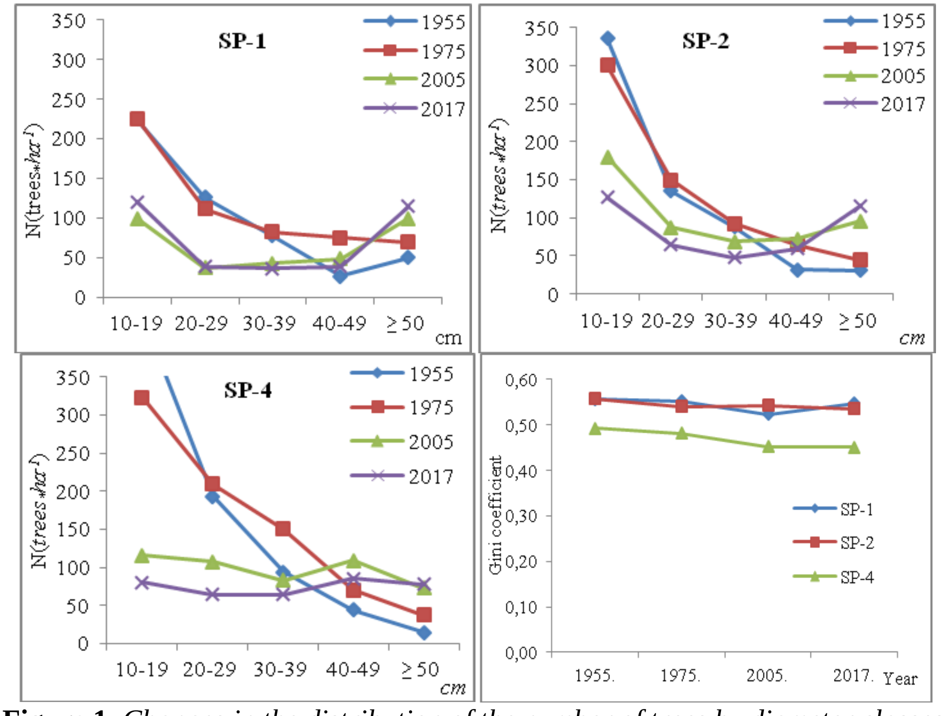

Figure 1. *Changes in the distribution of the number of trees by diameter classes and the Gini coefficient*

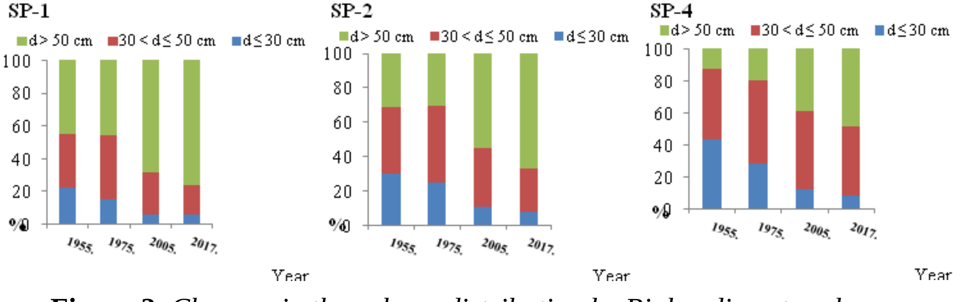

Figure 2. *Changes in the volume distribution by Biolay diameter classes*

In 62 years' time the volume per hectare increased by 66.1% in SP-1 and 94.9% in SP-2 and by 52.2% in SP-4. The current volume values are high and range from 659.1 $m^3 \cdot ha^{-1}$ in SP-4 to 866.1 $m^3 \cdot ha^{-1}$ in SP-2. The volume structure by Biolay diameter classes also varied in favor of the category of trees of large dimensions. In all SPs, the share of thin and medium-sized trees in the total volume declined from one period to another, and the share of trees with diameters of over 50 cm increased (Figure 2). It is worrying that the share of thin trees in all SPs was lower than 10%, and according to Biolay, it should not be less than 20%, i.e. according to more recent research by Schütz (2001), lower than 15%.

The current volume increment increases over time. At the end of the analyzed period, the increase was high and it amounted to 14.4 $m^3 \cdot ha^{-1}$ in SP-1, 15.9 $m^3 \cdot ha^{-1}$ in SP-2 and 12.9 $m^3 \cdot ha^{-1}$ in SP-4.The aforementioned amount of increase indicates a still high production of the stands, but the pronounced disturbances regarding the reduction of the share of thinner, and as a rule, more vital and trees with a more intensive increment, indicate that this trend of current volume increment will not last long (Obradović, 2015).

4. CONCLUSION

The starting hypotheses of this research have been confirmed. Structural disturbances of fir, spruce and beech forests in the analyzed SPs in Mt. Tara were found. They arose as a result of the decrease in the total number of trees, which also resulted in a decrease in dimensional diversity. The decrease of the share of thin trees is particularly pronounced, as well as the increase in the share of trees of large dimensions ($d \geq 50$ cm). The distribution curves have developed a flatter form and are moving further away from the distribution that is typical of the selection forest.

Despite the reduction in the total number of trees, the accumulation of trees of large dimensions resulted in high values of basal area and volume per hectare. High absolute values of the current volume increment were also noted, which all together indicate a good production potential of a particular site. However, high volume does not always mean the desired state, especially if it is distributed among old trees (of large dimensions), of reduced technical value and if it slows down the development of the stand.

Insufficient regeneration and recruitment are the consequence of the stated distribution of trees by diameter classes, that is, reduced space for growth, with a negative impact on the preservation of these stands as stable and functional forms.

The trends observed in the fir, spruce and beech forests of Mt. Tara indicate that it is necessary to conduct permanent monitoring of all developmental processes, implement appropriate silvicultural and management measures that regulate them, and over time adjust and direct them towards the set goal, which is a structurally stable, socio-economically and ecologically valuable selection forest as a sustainable category. The leaving of stands to spontaneous development and self-regulation processes that happen over time, as is the case in the investigated SPs, moves us further away from this goal.

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SPONTANEOUS DEVELOPMENT OF MIXED STANDS OF FIR, SPRUCE AND BEECH FROM PERMANENT SAMPLE PLOTS ON MT. TARA

Snežana OBRADOVIĆ, Milan MEDAREVIĆ, Damjan PANTIĆ, Biljana ŠLJUKIĆ, Nenad PETROVIĆ, Dragan BOROTA, Aleksandar POPOVIĆ

Summary

The forest of fir, spruce and beech Piceo-*Abietetum* Col. 1965 (syn. Piceo-*Fago Abitetum* Chol. 1965; *Piceo-Abieti-Fagetum moesiacum* Mišić et al., 1978) is a specific three-dominant community, which can be found in Serbia on Mt. Tara, Mt. Zlatar, Mt.

Golija, the Mojstirsko-Draške mountains, Mt. Kopaonik, Mt. Stara planina, and Pešter Plateau, etc. These forests are characterized by structural diversity, i.e. a series of transitions from diverse to complex selection structural forms. The structural changes, productivity and dynamics of development of the selection forests of fir, spruce and beech on Mt. Tara have been monitored since 1955 in a series of permanent sample plots (SPs). These SPs were exempt from regular management and left to spontaneous development and self-regulatory processes. The surveys used data from periodic measurements (1955, 1975, 2005 and 2017) of permanent SPs in the Mt. Tara forests, which are in the database of the Chair of Forest Management Planning of the Faculty of Forestry in Belgrade. The results of the research indicate that during the analyzed period mixed forests of fir, spruce and beech have undergone a number of changes in structural and production terms. The significant presence of trees of large dimensions (volume accumulation) slowed down the developmental dynamics of these stands and made regeneration and recruitment difficult, which had a negative impact on their structural development and, in general, on the stability of these stands. The results show that selection forests are possible to achieve only with a permanent management approach and adherence to the modern principles of close-to-nature forest management. In this sense, selection cutting in the context of close-to-nature forest management is imposed as a means of accelerating the dynamics of development of these forests, repairing their structural development (by achieving and preserving their selection structure), ecological stability and functional values. On the contrary, the absence of activity and spontaneous development of these stands leads to a general devitalization and a deviation from the desired goals.

SPONTANI RAZVOJ MEŠOVITIH SASTOJINA JELE, SMRČE I BUKVE SA STALNIH OGLEDNIH POVRŠINAMA NA TARI

Snežana OBRADOVIĆ, Milan MEDAREVIĆ, Damjan PANTIĆ, Biljana ŠLJUKIĆ, Nenad PETROVIĆ, Dragan BOROTA, Aleksandar POPOVIĆ

Rezime

Šuma jele, smrče i bukve *Piceo-Abietetum* Čol. 1965. (syn. *Piceo-Fago Abitetum* Čol. 1965.; *Piceo-Abieti-Fagetum moesiacum* Mišić *et al.,* 1978.) je specifična trodominantna zajednica, koja je u Srbiji zastupljena na Tari, Zlataru, Goliji, Mojstirsko-Draškim planinama, Kopaoniku, Staroj planini, Pešterskoj visoravni itd. Ove šume se karakterišu strukturnom raznolikosti, tj. nizom prelaza od raznodobnih ka prebirnim strukturnim oblicima. Strukturne promene, proizvodnost i dinamika razvoja prebirnih šuma jele, smrče i bukve na Tari prate se od 1955. godine, na seriji stalnih oglednih površina (OP). Ove OP su izuzete iz redovnog gazdovanja i prepuštene su spontanom razvoju i samoregulacijskim procesima. U istraživanjima su korišćeni podaci periodičnih premera (1955, 1975, 2005. i 2017. godine) stalnih OP u šumama Tare, koji se nalaze u bazi podataka Katedre Planiranja gazdovanja šumama, Šumarskog fakulteta u Beogradu. Rezultati istraživanja ukazuju na to da su u analiziranom periodu mešovite šume jele, smrče i bukve pretrpele niz promena u strukturnom i proizvodnom smislu. Značajno prisustvo stabala jakih dimenzija (nagomilavanje zapremine) usporilo je dinamiku razvoja ovih sastojina i otežalo podmlađivanje i urastanje, što se negativno odrazilo na njihovu strukturnu izgrađenost i, generalno, na stabilnost ovih sastojina. Rezultati pokazuju da je prebirna šuma moguća jedino uz permanentan gazdinski pristup i poštovanje savremenih principa prirodi bliskog gazdovanja. U tom smisli, prebirna seča, u kontekstu prirodi bliskog gazdovanja, nameće se kao sredstvo ubrzanja dinamike razvoja ovih šuma, popravke njihove srukturne izgrađenosti (postizanja i očuvanja prebirne strukture),

ekološke stabilnosti i funkcionalne vrednosti. Suprotno, odsustvo aktivnog delovanja i spontani razvoj sastojina vode ka sveopštoj devitalizaciji i udaljavanju od željenih ciljeva.

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EFFECTS OF FERTILISATION ON SURVIVAL AND MORPHOLOGICAL GROWTH CHARACTERISTICS OF ONE-YEAR-OLD SEEDLINGS OF *PAULOWNIA ELONGATA*S.Y. HU. AND *PAULOWNIA FORTUNEI* SEEM. HEMSL. IN TWO DIFFERENT SITES IN SERBIA

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Abstract: *This study evaluates the influence of fertilisation during the initial year after planting on the survival and morphometric growth traits of one-year-old Paulownia elongata and Paulownia fortunei seedlings, aimed at assessing their adaptability for potential introduction to various sites in Serbia. Understanding fertilisation impacts on survival and growth parameters is essential for analysing indicators of species adaptability to specific soil types. Experimental plots were established at two distinct sites, Obrenovac and Pambukovica, where seedlings were monitored for key morphometric indicators: height, stem diameter at root collar, and leaf number. The morphometric data were statistically analysed, and findings indicated that fertilisation significantly enhanced all measured growth parameters in the first growing season. This suggests a positive effect of fertilisation on all analysed parameters.*

Keywords: fast-growing species, fertilisation, growth traits, stem diameter at root collar, leaf number, height

UTICAJ PRIHRANJIVANJA NA PREŽIVLJAVANJE I MORFOLOŠKE KARAKTERISTIKE ELEMENATA RASTA JEDNOGODIŠNJIH SADNICA *PAULOWNIA ELONGATA* S. Y. HU. I *PAULOWNIA FORTUNEI* SEEM. HEMSL. NA DVA RAZLIČITA STANIŠTA U SRBIJI

Abstract: *U radu su prikazani rezultati analize uticaja prihranjivanja biljaka u prvoj godini nakon sadnje, na preživljavanje i morfometrijske karakteristike elemenata rasta*

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kao pokazatelje mogućnosti introdukcije i adaptacije paulovnija na različita staništa u Srbiji. Dobijanje rezultata o uticaju prihranjivanja na analizirane parametre je značajno za analizu pokazatelja adaptibilnosti vrsta za gajenje na određenim tipovima zemljišta. Na dva lokaliteta u Obrenovcu i Pambukovici su osnovane ogledne površine sadnjom sadnica vrsta Paulownia elongata S. Y. Hu. i Paulownia fortunei Seem. Hemsl. U okviru oglednih polja vršeno su merenja morfometrijskih karakteristika pokazatelja rasta: visina, prečnik u vratu korena i broj listova. Dobijeni rezultati morfometrijskih merenja statistički su obrađeni i analizirani. Na osnovu rezultata preživljavanja biljaka i merenja morfometrijskih karakteristika pokazatelja rasta u prvoj vegetacionoj sezoni nakon sadnje, utvrđeno je da prihranjivanja ima pozitivan uticaj na sve analizirane parametre.

Keywords: brzorastuće vrste, prihranjivanje, visina, prečnik u vratu korena, broj listova

1. INTRODUCTION

Climate change and consequent ecological shifts have a significant impact on native vegetation. Assessing the potential for introducing various species and their adaptability to new climatic and environmental conditions is critical for identifying effective strategies to mitigate the adverse effects of global warming (Ogden and Innes, 2007; Schroeder, 2007; Aragao et al., 2008; Barlow and Peres, 2008; Betts et al., 2008; Innes et al., 2009; Lavadinović et al., 2010). The growing scarcity of wood resources, coupled with increasing demand, highlights the urgent need for selecting and promoting fast-growing species to enhance wood and biomass production. (Ivetić and Vilotić, 2014; Mishra et al., 2010; Drvodelić, 2015). Due to their rapid growth and high sprouting capacity, species of the genus *Paulownia* Sieb. & Zucc. offer substantial potential for biomass production (Lucas-Borja et al., 2011; Yadav et al., 2013; Mitrović, 2016).

Plant growth rates are influenced by the quality of planting material (DuPlissis et al., 2000), climatic conditions (Woods, 2008; Radošević and Vilotić, 2010), soil type (Melhuish et al., 1990; Madejón et al., 2014; Popović et al., 2015; Tu et al., 2017; Wozniak et al., 2022), fertilisation (Mitrović et al., 2012; García-Morote et al., 2014), and plant care practices (Rad and Mirkala, 2015; Moreno et al., 2017). Nutrient-poor soils are frequently chosen for afforestation projects, but their productivity can be enhanced by applying various fertilisers (Óskarsson et al., 2006; Tucović and Simić, 2002; Güsewell et al., 2003; Hawkins et al., 2005). Fertiliser type, application rate, and timing are determined based on soil conditions, biological characteristics, and developmental stages of the plants. To ensure the formation of biologically healthy material that is resilient to adverse environmental conditions, it is essential to provide plants with a well-balanced nutrient supply, ensuring the availability of necessary plant assimilates (Jacobs et al., 2005; Mitrović et al., 2012).

2. MATERIALS AND METHODS

Experimental plots were established across sites with varying orographic features, climatic conditions, and soil physical-chemical properties. Soil samples were analysed at an accredited soil and plant material laboratory at the Institute of

Forestry, Belgrade. The plots were created by planting paulownia trees grown from seeds of well-adapted genotypes of two paulownia species (*Paulownia elongata* S.Y. Hu. and *Paulownia fortunei* Seem. Hemsl.), sourced from plantations in Bela Crkva.

Seedlings of each species were planted in 12 rows, with each row consisting of 25 plants. Planting holes measured 30x30 cm, and seedlings were spaced at 4x4 m intervals within each row.

Table 1. *Overview of Experimental Plots at Obrenovac and Pambukovica Sites*

Site	**Obrenovac (I)**						**Pambukovica (II)**					
Treatment/ Number of Seedlings	te1/ n=25	te2/ n=25	te3/ n=25	tf1/ n=25	Tf2/ n=25	Tf3/ n=25	te1/ n=25	te2/ n=25	te3/ n=25	tf1/ n=25	Tf2/ n=25	Tf3/ n=25

te1 – *P. elongata* seedlings from the first treatment (fertilised with a higher amount of fertiliser); te2 – *P. elongata* seedlings from the second treatment (fertilised with a lower amount of fertiliser); te3 – *P. elongata* seedlings not fertilised (control); tf1 – *P. fortunei* seedlings from the first treatment (fertilised with a higher amount of fertiliser); tf2 – *P. fortunei* seedlings from the second treatment (fertilised with a lower amount of fertiliser); tf3 – *P. fortunei* seedlings not fertilised (control);

At the time of planting, each experimental plot was divided into six treatments (four rows of 25 plants per treatment, as shown in Table 1), which varied in the amount of fertiliser applied, with one control treatment receiving no fertilisation. Fertilisation was carried out using a slow-release chicken manure fertiliser, branded as Fertor (http://www.mrf-garden.com). The fertiliser composition consisted of 100% chicken manure, supplemented with organic plant-derived material to enhance its nutritional value. Fertiliser was applied at two rates: 240 grams per plant (treatment t1) and 120 grams per plant (treatment t2). No fertilisation was applied to the control plots (treatment t3).

During the first growing season following planting, the establishment and survival rates of the seedlings were assessed. Morphometric characteristics of the seedlings, including plant height, stem diameter at root collar, and leaf number, were measured monthly. The first measurements were taken in May and the last in October, resulting in six measurements in total. Plant height was recorded with an accuracy of 0.5 cm, while root collar diameter was measured to an accuracy of 0.01 mm. On each experimental plot, 25 plants per treatment were measured monthly throughout the growing season (six measurements).

The data were statistically analysed. The experimental design corresponds to a three-way and two-way analysis of variance (ANOVA III):

- factor A (site) with 2 levels: Site I (Obrenovac) and Site II (Pambukovica)
- factor B (species) with 2 levels: Species 1 (*P. elongata*) and Species 2 (*P. fortunei*)
- factor C (treatment) with 3 levels: Treatment 1, Treatment 2, and Treatment 3.

ANOVA III assesses the effect of each factor individually, as well as their interactions. The total sample size for ANOVA III was n = 900 (6 months × 2 species × 3 treatments × 25 plants = 900). The following traits were measured within this sample: plant height, stem diameter at root collar, number and length of nodes, and number of leaves.

3. RESULTS

The climate at the Obrenovac site is classified as temperate continental, characterised by mild winters and warm summers. The precipitation regime falls between a modified Mediterranean and a true continental climate, with a stronger expression of the latter. Temperature and precipitation are well-aligned throughout the year, with the warmest months also receiving the most rainfall, which coincides with the growing season. The climate at the Pambukovica site is also temperate continental, marked by moderately warm, dry summers and somewhat cooler winters.

The surface soil layer at the Obrenovac site is classified as sandy loam, while the deeper layer is classified as loam (Table 2). Despite the difference in textural classes, both layers exhibit similar physical properties, with minimal variation in texture throughout the soil profile. The textural fractions in both layers are close to the boundary values between sandy loam and loam. The soil demonstrates good water permeability and is well-aerated throughout the entire solum depth, with a relatively high clay content providing a significant water-holding capacity.

Table 2. *Physical Soil Properties*

Site	Physical Soil Properties	Coarse sand	Fine sand	Silt	Clay	Total sand	Total clay	Texture class
		%						
Obrenovac	0-20	0.60	44.50	29.00	25.90	45.10	54.90	Loam
	20-40	0.40	42.20	25.70	31.70	42.60	57.40	Sandy Clay Loam
Pambukovica	0-20	4.50	48.62	20.58	26.30	53.12	46.88	Sandy Loam
	20-40	4.20	46.60	22.30	26.90	50.80	49.20	Loam

At the Pambukovica site, the surface layer is classified as loam and exhibits good permeability for both water and air. With increasing depth, the texture shifts due to rising clay and fine sand content, resulting in a sandy clay loam class. This deeper layer has somewhat reduced water and air permeability.

At the Obrenovac site, the soil solution reaction is moderate. Total adsorption capacity is very high, largely due to the significant clay content in the texture. The sum of adsorbed base cations is also substantial. Based on the degree of base cation saturation, the soil is classified as eutric. Both analysed layers show low humus content; however, despite the low humus, the total nitrogen content is high, with a narrow carbon-to-nitrogen (C/N) ratio that supports effective organic matter mineralisation. Plant-available phosphorus is sufficiently present throughout the soil profile, while potassium availability is moderate (Table 3).

The Pambukovica profile exhibits a strongly acidic soil solution throughout the depth. Total adsorption capacity is high, and despite the low pH of the soil solution, the high sum of adsorbed base cations results in a base saturation level exceeding 60%, categorising this soil as eutric. The total nitrogen content is low, with a narrow C/N ratio. In both analysed soil layers, the amount of plant-available phosphorus across all four profiles is below the detection limit for the Al-method, indicating that this soil is extremely deficient in readily available forms of phosphorus for plants. The levels of plant-accessible potassium are within the range of low availability throughout the entire soil profile (Table 3).

Table 3. *Chemical Soil Properties*

Profile Number	Depth of Profile (cm)	pH		Adsorption Complex					Total		C/N	Plant available	
		H2O	KCl	T	S	T-S	V	Y1	humus	N		P_2O_5	K_2O
				ekv.m.mol/100g			%	cm^3	%	%		mg/100g	
Obrenovac (I)	0-20	5.91	4.74	32.50	24.94	7.56	76.74	11.63	2.55	0.19	7.59	23.55	19.39
	20-40	5.87	4.77	32.90	25.27	7.63	76.80	11.74	2.03	0.12	10.13	21.63	17.45
Pambukovica (II)	0-20	5.35	3.84	32.13	19.56	12.57	60.87	19.34	1.47	0.15	5.87	<LD	8.76
	20-40	5.41	3.94	32.66	21.51	11.15	65.86	17.15	0.98	0.13	4.41	<LD	7.94

To analyse plant survival at specific sites, the number of living seedlings was counted at three intervals: one month after planting, during the summer, and at the end of the first growing season.

Table 4. *Seedling Survival Rate from Planting to the End of the Growing Season*

Site	Species	Treatment	June	Aug.	Oct.
			%		
Obrenovac (I)	*Paulownia elongata*	te1	100	98	95
		te2	100	96	92
		te3	100	93	90
	Paulownia fortunei	tf1	100	94	87
		tf2	100	89	80
		tf3	100	84	76
Pambukovica (II)	*Paulownia elongata*	te1	100	96	92
		te2	100	93	87
		te3	100	90	82
	Paulownia fortunei	tf1	100	90	86
		tf2	100	87	78
		tf3	100	84	74

Paulownia elongata seedlings: te1 – fertilised with a higher amount of fertiliser; te2 – fertilised with a lower amount of fertiliser; te3 – not fertilised (control); *Paulownia fortunei* seedlings: tf1 – fertilised with a higher amount of fertiliser; tf2 – fertilised with a lower amount of fertiliser; tf3 – not fertilised (control).

At the end of the growing season, the survival rate of *Paulownia elongata* seedlings at the site in Obrenovac ranged from 90-95%, depending on the treatment. The highest percentage of surviving seedlings was in the treatment with a higher amount of fertiliser, while the lowest was in the control treatment. The same survival trend was observed for *Paulownia fortunei* seedlings, which ranged from 84-94%. A similar trend was noted at the site in Pambukovica, but with lower survival rates. At the end of the first growing season, the survival rate of *Paulownia elongata* seedlings was recorded at 82-92%, while for *Paulownia fortunei* it was 74-86%, depending on the treatment.

Regarding the height of seedlings at the sites in Obrenovac and Pambukovica during the first year (Table 5), there were differences in the mean values of groups (measurements) depending on the factors of site, species, and treatment. Seedlings at the Obrenovac site showed significantly higher mean height values in all six measurements compared to seedlings at the Pambukovica site. At the beginning of the growing season, the lowest mean height of seedlings at the

Obrenovac site was 13.28 cm, while at the Pambukovica site it was 9.06 cm. At the end of the growing season, the mean height of seedlings at the Obrenovac site was 32.95 cm, while at the Pambukovica site it was 25.32 cm. *Paulownia fortunei* seedlings showed higher mean height values compared to *Paulownia elongata* seedlings throughout the growing season. The difference between the species was significant during all six measurements. At the end of the first growing season, *Paulownia fortunei* seedlings had higher mean heights (31.18 cm) than *Paulownia elongata* seedlings (27.10 cm).

There was a statistically significant difference in the mean height values of seedlings between treatments (fertilisation and control) throughout the growing season. In the first measurement, there was no significant difference between seedlings in the treatment with a lower amount of fertiliser and the control treatment, and in the fourth measurement, there was no significant difference among seedlings from the fertilised treatments. Seedlings in the treatment with a higher amount of fertiliser showed greater mean height values throughout the growing season compared to seedlings from the second treatment and the control. At the end of the first season, the highest mean height was recorded for seedlings in the treatment with the higher amount of fertiliser (34.74 cm), followed by seedlings in the treatment with a lower amount of fertiliser (30.02 cm), while the smallest height was recorded in the control treatment (22.64 cm). Regarding the characteristic of mean height of seedlings, the interaction between the factors of species (*P. elongata* and *P. fortunei*) and treatment (fertilisation and control) was significant only in the last (sixth) measurement at the end of the first growing season. The interaction between the species factor (*P. elongata* and *P. fortunei*) and the site factor was significant only in the fifth measurement. The mutual interaction between the site factor (Obrenovac and Pambukovica) and the treatment factor (fertilisation and control) was statistically significant throughout the entire growing season.

Table 5. *Basic parameters of descriptive statistics and three-way ANOVA for six periodic measurements of seedling height (cm) during the first growing season, at the site in Obrenovac (I) and in Pambukovica (II)*

Factor	Level	Measurement I	Measurement II	Measurement III	Measurement IV	Measurement V	Measurement VI
Site (A)	Site I	[A] 13.28 (3.60)[b]	18.18 (6.67)[b]	23.51 (9.26)[b]	27.42 (10.96)[b]	31.76 (12.96)[b]	32.95 (13.14)[b]
	Site II	9.06 (2.59)[a]	12.48 (3.96)[a]	16.56 (4.89)[a]	19.85 (6.14)[a]	23.00 (6.89)[a]	25.32 (14.95)[a]
		[B] $F_{1.290}$ =155.11*	$F_{1.290}$ =113.94*	$F_{1.290}$ = 106.44 *	$F_{1.290}$ =93.65*	$F_{1.290}$ =107.59*	$F_{1.290}$ = 31.34*
Species (B)	*P. elongata*	10.70 (3.78)[b]	14.54 (6.09)[a]	18.99 (7.75)[a]	22.52 (8.96)[a]	26.09 (10.08)[a]	27.10 (9.87)[a]
	P. fortunei	11.63 (3.72)[a]	16.12 (6.17)[b]	21.08 (8.46)[b]	24.75 (10.20)[b]	28.67 (12.21)[b]	31.18 (17.88)[b]
		$F_{1.290}$ =7.55*	$F_{1.290}$ =8.75*	$F_{1.290}$ =9.63*	$F_{1.290}$ =8.19*	$F_{1.290}$ = 9.32*	$F_{1.290}$ = 8.97*
Treatment (C)	Treatment 1	11.85 (4.57)[b]	17.39 (7.84)[c]	22.65 (10.12)[c]	26.84 (11.41)[b]	31.61 (13.37)[c]	34.74 (20.48)[c]
	Treatment 2	11.02 (3.84)[a]	15.31 (6.01)[b]	20.85 (8.10)[b]	25.03 (9.64)[b]	29.06 (10.66)[b]	30.02 (10.41)[b]
	Treatment 3	10.63 (2.56)[a]	13.28 (3.00)[a]	16.59 (3.72)[a]	19.03 (4.91)[a]	21.46 (5.80)[a]	22.64 (6.11)[a]
		$F_{2.290}$ =4.56*	$F_{2.290}$ =19.71*	$F_{2.290}$ =28.47*	$F_{2.290}$ =36.43*	$F_{2.290}$ = 52.10*	$F_{2.290}$ = 26.70*
Interactions **(AXB)**		ns	ns	ns	ns	$F_{1.290}$ = 4.98*	ns
Interactions **(AXC)**		$F_{2.290}$= 15.7*	$F_{2.290}$= 39.0*	$F_{2.290}$ =61.1*	$F_{2.290}$ =67.8*	$F_{2.290}$ = 92.05*	$F_{2.290}$ = 32.07*
Interactions **(BXC)**		ns	ns	ns	ns	$F_{2.290}$ = 3.85*	$F_{2.290}$ = 3.56 *

Table 6. *Basic parameters of descriptive statistics and three-way ANOVA for six periodic measurements of root collar diameter (mm) of seedlings during the first growing season, at the site in Obrenovac (I) and in Pambukovica (II)*

Factor	Level	Measurement I	Measurement II	Measurement III	Measurement IV	Measurement V	Measurement I
Site (A)	Site I	4.33 (1.14)[b]	4.81 (1.27)[b]	5.21 (1.27)[b]	5.80 (1.47)	6.26 (1.60)	6.67 (1.71)
	Site II	3.60 (0.87)[a]	4.03 (1.01)[a]	4.78 (1.48)[a]	5.57 (1.37)	6.25 (1.49)	7.03 (4.33)
		$F_{1.290}$=39.26*	$F_{1.290}$=36.34*	$F_{1.290}$=10.67*	ns	ns	ns
Species (B)	*P. elongata*	4.06 (1.09)	4.59 (1.26)[b]	5.14 (1.30)[b]	6.01 (1.50)[b]	6.39 (1.61)	7.08 (4.37)
	P. fortunei	3.87 (1.05)	4.24 (1.13)[a]	4.84 (1.13)[a]	5.34 (1.40)[a]	6.12 (1.47)	6.61 (1.59)
		ns	$F_{1.290}$=7.10*	$F_{1.290}$=5.24*	$F_{1.290}$= 3.95*	ns	ns
Treatment (C)	Treatment 1	4.03 (1.17)	4.63 (1.41)[b]	5.18 (1.38)	6.01 (1.50)[b]	6.63 (1.58)[b]	7.08 (1.63)
	Treatment 2	3.94 (1.07)	4.44 (1.63)[ab]	4.95 (1.14)	5.71 (1.29)[b]	6.37 (1.34)[b]	6.88 (1.39)
	Treatment 3	3.92 (0.98)	4.18 (0.99)[a]	4.86 (1.14)	5.34 (1.40)[a]	5.77 (1.59)[a]	6.59 (5.29)
		ns	$F_{2.290}$=4.02*	ns	$F_{2.290}$= 6.85*	$F_{2.290}$= 10.37*	ns
Interactions **(AXB)**		ns	ns	ns	ns	ns	ns
Interactions **(AXC)**		ns	ns	$F_{2.290}$= 16.31*	$F_{2.290}$= 26.22*	$F_{2.290}$= 33.79*	$F_{2.290}$= 15.58*
Interactions **(BXC)**		ns	ns	ns	ns	ns	$F_{2.290}$= 3.36*

Three-way Analysis of Variance (ANOVA III). Factor A (Site) with 2 levels: Site 1 (Obrenovac) and Site 2 (Pambukovica); Factor B (Species) with 2 levels: Species 1 (*P. elongata*) and Species 2 (*P. fortunei*); Factor C (Treatment) with 3 levels: Treatment 1 (high fertiliser amount), Treatment 2 (low fertiliser amount), and Treatment 3 (control), along with their interactions. The total sample size (number of sample elements) is **n = 300** (2 sites × 2 species × 3 treatments × 25 = 300). [A] = mean value (standard deviation); [B] = F-test statistic with degrees of freedom; ns = no significant difference between population means (P> 0.05); * = statistically significant difference (P ≤ 0.05).

Descriptive statistics for the mean stem diameter at the root collar of seedlings at the Obrenovac and Pambukovica sites are presented in Table 6, based on six measurements taken throughout the first growing season.

At the Obrenovac site, the mean stem diameters at root collar were significantly larger in the first, second, and third measurements compared to those at the Pambukovica site. No statistically significant differences were observed in the remaining measurements. At the end of the first growing season, the mean stem diameters at root collar were greater for seedlings at the Pambukovica site (7.03 mm) compared to those at Obrenovac (6.67 mm).

Seedlings of *Paulownia elongata* exhibited larger mean stem diameters at root collar compared to *Paulownia fortunei* seedlings in the second, third, and fourth measurements, with these differences being statistically significant. For the remaining measurements, no significant differences were observed. By the end of the first growing season, *P. elongata* seedlings had a greater mean stem diameter (7.08 mm) than *P. fortunei* seedlings (6.61 mm).

A statistically significant difference in the mean stem diameter at root collar was observed between treatments in the second, fourth, and fifth measurements. For the remaining measurements, while no significant differences were found, the highest mean stem diameters were consistently observed in seedlings from the treatment with the higher fertiliser application. In the second measurement, no statistically significant difference in mean stem diameter was detected between the lower fertiliser treatment and the control. However, the treatment with the higher fertiliser dose resulted in a statistically significant increase in stem diameter compared to the control. In the fourth and fifth measurements, no significant differences were found between fertilised treatments, though both differed significantly from the control treatment. Seedlings from the treatment with a higher fertiliser dose had consistently larger mean stem diameters at root collar compared to those in the other treatments and the control across all six measurements.

The interaction between the site factor (Obrenovac and Pambukovica) and the species factor (*P. elongata* and *P. fortunei*) was not statistically significant in any of the six measurements. However, the interaction between the species factor (*P. elongata* and *P. fortunei*) and the treatment factor (fertilisation and control) was significantly different in the fifth and sixth measurements, with no significant differences in the remaining measurements. The interaction between the site factor (Obrenovac and Pambukovica) and the treatment factor (fertilisation and control) was statistically significant in the third, fourth, fifth, and sixth measurements.

The average number of leaves of seedlings at the Obrenovac and Pambukovica sites throughout the growing season is shown in Table 7, based on all six measurements. The effect of the interaction between site, treatment, and species factors on leaf number is presented in Table 8, covering all six measurements throughout the growing season.

Table 7. *Average Number of Leaves of Seedlings at Obrenovac and Pambukovica Sites During the First Growing Season*

Site	Species	Treatment	Measurement I	II	III	IV	V	VI
Obrenovac (I)	*P.elongata*	te1	4.88	7.04	10.72	11.12	10.32	8.00
		te2	4.80	6.88	10.80	12.32	13.52	7.76
		te3	4.80	6.72	8.72	10.32	11.44	6.32
		aver.	**4.83**	**6.88**	**10.08**	**11.25**	**11.76**	**7.36**
	P.fortunei	tf1	4.72	6.80	10.96	12.48	14.88	8.64
		tf2	4.96	7.44	10.64	12.08	14.32	8.88
		tf3	5.36	7.44	10.64	12.80	14.32	8.32
		aver.	**5.01**	**7.23**	**10.75**	**12.45**	**14.51**	**8.61**
Pambukovica (II)	*P.elongata*	te1	5.36	6.40	8.16	9.44	9.44	6.08
		te2	4.56	6.16	8.48	10.72	12.32	6.88
		te3	4.96	6.40	8.80	10.32	11.04	6.00
		aver.	**4.96**	**6.32**	**8.48**	**10.16**	**10.93**	**6.32**
	P.fortunei	tf1	5.68	8.48	11.04	11.76	13.52	7.28
		tf2	6.08	7.76	10.08	12.32	13.36	7.04
		tf3	5.36	7.44	10.64	12.80	14.32	8.32
		aver.	**5.71**	**7.89**	**10.59**	**12.29**	**13.73**	**7.55**

(I) – Obrenovac site; (II) – Pambukovica site; te1 – *P. elongata* seedlings under Treatment 1 (fertilised with a higher amount of fertiliser); te2 – *P. elongata* seedlings under Treatment 2 (fertilised with a lower amount of fertiliser); te3 – *P. elongata* seedlings with no fertilisation (control); tf1 – *P. fortunei* seedlings under Treatment 1 (fertilised with a higher amount of fertiliser); tf2 – *P. fortunei* seedlings under Treatment 2 (fertilised with a lower amount of fertiliser); tf3 – *P. fortunei* seedlings with no fertilisation (control).

Table 8. *Effects of Interactions Between Site, Species, and Treatment on Leaf Count of Seedlings at the Obrenovac (I) and Pambukovica (II) Sites During the First Growing Season*

	Measurement I	**Measurement II**	**Measurement III**	**Measurement IV**	**Measurement V**	**Measurement VI**
	count of leaves	**count of leaves**	**count of leaves**	**count of leaves**	**count of leaves**	**count of leaves**
***interactions* (AXB)** $^{B}\boldsymbol{F}_{1,290}$=	ns	4,17*	5,74*	ns	ns	ns
***interactions* (AXC)** $\boldsymbol{F}_{2,290}$=	ns	ns	8,39*	14,18*	16,55*	19,22*
***interactions* (BXC)** $\boldsymbol{F}_{2,290}$=	6,60*	8,21*	5,47*	ns	6,39*	9,94*

Derived from a three-way analysis of variance (ANOVA III). AXB = interactions between the factors of site and species, AXC = interactions between the factors of site and treatment, and BXC = interactions between the factors of species and treatment. Total sample size (number of elements in the sample), n = 300 (2 sites × 2 species × 3 treatments × 25 = 300). ns = nonsignificant difference between population means (P > 0.05); ^{B} = *F*-test statistic with degrees of freedom; *= a statistically significant difference (P ≤ 0.05).

The *Paulownia fortunei* seedlings consistently exhibited a higher average leaf count than *Paulownia elongata* seedlings across all six measurements. The first measurement of *Paulownia elongata* seedlings, and the first and second measurements of *Paulownia fortunei* exhibited a higher average leaf count at the site in Pambukovica, However, in subsequent measurements, seedlings at the Obrenovac site displayed a greater average leaf count. *Paulownia elongata* seedlings achieved the highest average leaf count in fertilised treatments. Specifically, in the first, second, and sixth measurements, the highest average leaf count in Obrenovac was recorded for seedlings treated with a higher fertiliser dose, whereas in the third, fourth, and fifth measurements, seedlings fertilised with a lower amount showed the highest leaf counts.

For *Paulownia fortunei* seedlings at this site, the control treatment resulted in the highest average leaf count during the first and fourth measurements, the lower fertilisation treatment yielded the highest counts in the second and sixth measurements, and the higher fertilisation treatment showed the highest counts in the third and fifth measurements. At this site, both species reached peak average leaf counts during the fifth measurement, with *Paulownia elongata* averaging 11.76 leaves and P*aulownia fortunei* 14.51 leaves.

At the Pambukovica site, *Paulownia elongata* seedlings in the first and second measurements had the highest average leaf count in the higher fertilisation treatment. The third measurement showed the highest count in the control treatment, while subsequent measurements indicated the highest counts for seedlings treated with lower fertilisation levels. *Paulownia fortunei* seedlings in Pambukovica showed the highest average leaf count in the first measurement under the lower fertilisation treatment, in the second and third measurements under the higher fertilisation treatment, and in the fourth, fifth, and sixth measurements in the control treatment. In Pambukovica, peak average leaf counts for both species were observed during the fifth measurement, with *Paulownia elongata* averaging 10.93 leaves and *Paulownia fortunei* 13.73 leaves (Table 8).

For leaf count, the interaction between site and species (AxB) was statistically significant in only two measurements, while the interaction between site and treatment (AxC) was significant in four measurements. The interaction between species and treatment (BxC) was statistically significant in five out of six measurements (Table 8).

4. DISCUSSION

Plants possess the remarkable ability to modulate their growth, development, and physiological processes in response to environmental conditions, enabling them to mitigate stress impacts and sustain development (Murchie and Horton, 1997; Walters et al., 2003). The results obtained from our field trials demonstrate significant differences in phenotypic stability between two paulownia species, *Paulownia elongata* S. Y. Hu and *Paulownia fortunei* Seem. Hemsl., in relation to different sites and treatments.

Analysis of morphological characteristics indicates that nutrient supplementation substantially promotes seedling development (Madejón et al., 2016). Studies by Campoe et al. (2013) and García-Morote et al. (2014) also show that fertilisation significantly enhances growth in paulownia plantations, though growth rate largely depends on water availability and soil fertility (Carpenter and Smith, 1979; Beckjord, 1984; Donald, 1990; Rad et al., 2015). Seedling parameter values for *Paulownia elongata* and *Paulownia fortunei* in Obrenovac (Site I) and Pambukovica (Site II) fell below those reported in previous studies on these species

(Johnson et al., 2003; Šoškić et al., 2003; Woods, 2008; Vilotić et al., 2011; Tisserat et al., 2013; Olave et al., 2015).

Marović et al. (1989) report a notably higher survival rate among fertilised seedlings, which is consistent with our findings at both Obrenovac and Pambukovica sites, where survival rates were highest among seedlings receiving higher fertilisation. According to Zhu et al. (1986), *Paulownia elongata* demonstrates better tolerance to lower temperatures than *Paulownia fortunei*, which likely contributes to its higher survival rate across the study sites. Consistent findings by Olave et al. (2015) in Northern Ireland reveal survival rates of 70.8% and 32% for two paulownia genotypes (Spanish and Moroccan, respectively) under cold conditions by the end of the third year.

The heavy soil texture in the experimental plots also affected the root system development of paulownia seedlings during the first year after planting. According to studies by Hu (1959), Dhiman (1997), Longbrake et al. (2001), and Johnson et al. (2003), this period marks a phase of intensive root system development for paulownia. Limited nutrient availability and specific soil properties affected the aboveground growth of the seedlings, which exhibited low mean height values throughout the study period. At the end of the first growing season, the men height of the seedlings differed significantly between species, reaching 27.10 cm for *Paulownia elongata* and 31.18 cm for *Paulownia fortunei* (Table 5). Monitoring growth parameters of these species under controlled nursery conditions, Ayan et al. (2006) reported mean heights of 69.06 cm for *Paulownia elongata* and 48.09 cm for *Paulownia fortunei* by the end of the first growing season. Comparative studies by Zhu et al. (1986) and Woods (2008) revealed that *Paulownia fortunei* tolerates heavier soils with higher clay content and lower pH values better than *Paulownia elongata*, although both species thrive best in well-drained soils with pH values between 5.5 and 7.5 (Kays et al., 1998; Mitchem et al., 2002; Barkley, 2007). The results from this study support these findings, indicating that seedlings at the Pambukovica site, where the soil had a heavier mechanical composition with over 55% clay content and lower pH (5.35–5.66), showed poorer growth compared to seedlings at the Obrenovac site, which had an average clay content of 53% and a soil pH of 5.87–6.13.

Extensive research has demonstrated that fertilisation positively impacts the development of a well-structured root system with a higher number of lateral roots and a stem with a greater number of leaves, thereby enhancing overall seedling vigour and promoting more uniform plant growth (Mead and Gadgil, 1978; Marović et al., 1989; Marković and Marković, 1989; Veselinović, 1989; Cromer and Jarvis, 1990; Šijačić-Nikolić et al., 2006; Brown, 2007; Brown et al., 2011; Ćirković-Mitrović, 2015; Mitrović et al., 2022). Results from the Obrenovac and Pambukovica sites showed that height differences between seedlings treated with varying amounts of fertiliser and those in unfertilised control plots were statistically significant. The impact of fertilisation varied and showed a greater effect at the Obrenovac site, where seedlings of both species achieved better results. At the end of the first growing season, seedlings in the high-fertiliser treatment reached an average height of 34.74 cm, compared to 22.64 cm in the control treatment.

Johnson et al. (2003) reported similar findings regarding mean height on acidic and heavy soils, with seedlings reaching a mean height of 27.60 cm by the end of the first growing season. Although *Paulownia fortunei* shows greater tolerance to heavier soils compared to *Paulownia elongata*, both species achieve optimal height and diameter growth on loose, well-drained, and moist soils (Zhu et al., 1986; Woods, 2008). Results from the Obrenovac and Pambukovica sites, where *Paulownia fortunei* seedlings displayed greater mean heights than those of *Paulownia elongata* in the first year, confirm that *P. fortunei* is more resilient on heavy soils. The interaction between site and species factors was significant only in the fifth measurement, whereas the interaction between treatment and species was significant in the last two measurements. Throughout the first growing season, the interaction between site and treatment factors significantly affected mean seedling height across all measurements, with superior results observed at the Obrenovac site (Table 5).

Stem diameter at root collar, a key indicator of plant quality at the juvenile stage (Stilinović, 1987), further suggests that in such soil conditions, neither paulownia species exhibits the growth rates that characterise them as woody species with the highest annual increases (Šijačić-Nikolić et al., 2009).

According to Radošević and Vilotić (2010), the culmination of diameter growth is periodic, with the first peak occurring as early as the second or third year of tree age. This finding aligns with studies by Hu (1959), Dhiman (1997), Longbrake et al. (2001), and Johnson et al. (2003), who observed that the aboveground portion of paulownia seedlings grows more slowly during the first year, as physiological processes are directed primarily towards the intensive development of the root system.

A statistically significant difference in the mean root collar diameters between species (Table 6) was observed only in the second half of the first growing season, while no significant differences were found in the other measurements. At the end of the growing season, *Paulownia elongata* seedlings exhibited larger mean root collar diameters (7.08 mm), with higher values recorded at the Pambukovica site. The mean root collar diameters reported by Ayan et al. (2006) at the end of the first growing season were greater than those observed in the trials at Obrenovac and Pambukovica, with *Paulownia elongata* averaging 9.04 mm and *Paulownia fortunei* averaging 8.71 mm. These results were obtained under controlled nursery conditions, where plants grew in enriched forest soil and received more intensive care, contributing to larger root collar diameters.

During both growing seasons, seedlings at the Obrenovac site had larger mean root collar diameters in the first five measurements, except for the final measurement. This difference is likely due to climatic factors; although temperatures were slightly higher at the Obrenovac site at the end of the growing season, rainfall was significantly lower starting in August, with a continuing downward trend into September. As a result, seedlings at the Pambukovica site continued to increase in diameter at root collar throughout the growing season. According to Zhu et al. (1986), diameter growth cessation coincides with leaf drop, while height growth typically ceases earlier.

As with height, the interaction between site and treatment had a significant effect on root collar diameter in both growing seasons, particularly in the final two measurements (Table 6). The soil at Obrenovac contains a lower clay percentage and has a lighter mechanical composition compared to the soil at Pambukovica. The pH of the soil solution at Obrenovac ranges from 5.87 to 6.13, which is more favourable for paulownia growth than the pH range of 5.33 to 5.66 at Pambukovica. According to Kays et al. (1998) and Barkley (2007), most paulownia species thrive in soils with a pH range of 5.5 to 7.5. Consequently, the high clay content (>55%) at the Pambukovica site limits nutrient availability, which has likely impacted seedling growth.

Paulownia fortunei demonstrates greater tolerance to lower soil pH values compared to *Paulownia elongata* (Zhu et al., 1986), a finding confirmed in this study, where seedlings of *P. fortunei* achieved higher mean heights. In contrast, *P. elongata* seedlings exhibited larger mean root collar diameters, as *P. fortunei*—with its faster growth rate (Barton, 2007) – directed more energy into height growth. Statistically significant differences in mean root collar diameters were observed between seedlings in different treatments, with those receiving higher fertiliser applications exhibiting greater growth. The interaction between species and treatment was statistically significant only in the final measurement of the first growing season, where seedlings of both species showed larger root collar diameters in the high-fertiliser treatment compared to those in the lower-fertiliser and control treatments.

The findings of this study confirm the results of previous research investigating the impact of fertilisation on plant growth (Jey, 1998; Šijačić-Nikolić et al., 2011). García-Morote et al. (2014) concluded that the application of water and fertilisers significantly enhances plant growth in plantations, although the rate of growth primarily depends on the availability of water and soil fertility. Similar conclusions were reached by Carpenter and Smith (1979), Beckjord (1984), and Donald (1990). Besides these two crucial factors, several studies (Zhu et al., 1986; Kays et al., 1998; Barkley, 2007; Woods, 2008; Innes, 2009) have highlighted that the mechanical composition of the soil is a limiting factor for the growth and development of paulownia species, as was observed at the trial sites in Obrenovac and Pambukovica.

Fast-growing species are characterised by large and numerous leaves (Ceulemans et al., 1990; Gardner et al., 1995). The average number of leaves observed during the study was higher for seedlings at the Obrenovac site (Tables 7 and 8) for both paulownia species, except in the first measurement of the first growing season, which was not statistically significant. This could likely be attributed to the uneven quality of the initial planting material. Seedling growth and quality improve when cultivated in soils with higher calcium content (Tucović and Simić, 2002; Nešković et al., 2003), higher pH values (Stanković, 2006; Krstić et al., 2011; Škvorc et al., 2014), and greater concentrations of carbon (Fender et al., 2011) and nitrogen (Vukadinović and Vukadinović, 2011), as well as a lower C/N ratio (Bown et al., 2011). Pedological analysis of the soils at the study sites (Tables 2 and 3) indicates that the Obrenovac site had significantly higher levels of calcium, nitrogen, and humus compared to the Pambukovica site. Additionally, the pH values and C/N ratios were more favourable at Obrenovac. Considering the lighter soil texture, which is a key factor in seedling development (Beckjord, 1984; Stringer, 1986; Graves, 1989; Graves and Stringer, 1989; Donald, 1990; Torbert and Johnson, 1990; Johnson et al., 1992; Kays et al., 1998), the results from the Obrenovac site, where seedlings produced a greater number of leaves compared to those at

Pambukovica, align with previous research. In contrast, the heavy mechanical composition and highly acidic soil at Pambukovica limit nutrient availability, which adversely affects plant growth (Tucović and Simić, 2002; Stanković, 2006; Krstić et al., 2011). The average number of leaves at the Obrenovac site did not show a clear pattern relative to the treatments (Tables 7 and 8).

The success of afforestation or plantation cultivation is closely linked to plant survival rates (Óskarsson and Brynleyfsdottir, 2009), which are influenced by numerous factors. As noted by Tackett and Graves (1983), survival rates of paulownia vary considerably, ranging from very high to very low, depending on environmental conditions (Beckjord and McIntosh, 1983; Pollio and Davidson, 1992; Mitchem et al., 2002; Johnson et al., 2003; Kadlec et al., 2021). According to Johnson et al. (2003), although plants are highly sensitive during their first years of development, survival rates in the first year can reach up to 99.5% under favourable conditions.

5. CONCLUSIONS

The primary objective of this study was to assess the impact of fertilisation on the survival and morphological growth characteristics of one-year-old P*aulownia elongata* S.Y. Hu. and *Paulownia fortunei* Seem. Hemsl. seedlings across various sites.

Through a comparative analysis of the phenotypic stability of paulownia seedlings in the juvenile phase, it was determined that in sites with heavy soil textures, and insufficient water and nutrient availability, both survival and growth of the plants were significantly reduced. The underdeveloped and stunted root system, which is a primary cause of poor seedling establishment and growth, is further influenced by the mechanical properties and acidic reaction of the soil, decreasing nutrient uptake. At sites with a heavier texture and less favourable conditions for paulownia, seedlings in fertilised treatments exhibited higher survival rates, better growth, and increased biomass production, owing to more favourable nutritional conditions.

The analysis of seedling height, root collar diameter, and leaf number at these sites confirmed that paulownia seedlings grown in loose, permeable, well-aerated soils with optimal water-holding capacity, combined with appropriate fertilisation during the first year, did not express their characteristic fast-growing traits.

Our findings suggest the potential of paulownia for plantation use; however, to conclusively determine its success in energy plantations in our region, further research is needed. This should focus on the species' growth and development at ages beyond two years, considering the influence of climatic factors, different care practices, and preventive measures for protection against diseases and pests.

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EFFECTS OF FERTILISATION ON SURVIVAL AND MORPHOLOGICAL GROWTH CHARACTERISTICS OF ONE-YEAR-OLD SEEDLINGS OF *PAULOWNIA ELONGATA*S.Y. HU. AND *PAULOWNIA FORTUNEI* SEEM. HEMSL. IN TWO DIFFERENT SITES IN SERBIA

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Summary

This study was conducted on two experimental plots where seedlings of *Paulownia elongata* S.Y. Hu. and *Paulownia fortunei* Seem. Hemsl. were planted. The plots were established in areas with different orographic features, climatic conditions, and soil physicochemical properties. The seedlings, derived from well-adapted genotypes of both species, were produced generatively from seeds collected from plantations in Bela Crkva. The research presents the results of examining the impact of fertilisation during the first year after planting on seedling survival and the morphometric characteristics of their growth. The analysis demonstrated that fertilisation significantly influenced both survival rates and all measured parameters. Additionally, the results highlighted the relevance of fertilisation in assessing the adaptability of these species to various soil types.

The survival rates suggest a potential for these species, while the analysis of seedling height, root collar diameter, and leaf size confirms that paulownia did not exhibit its characteristic fast growth in the studied environments. Future research should focus on evaluating the growth and development of these species at two years of age and older to validate their potential for cultivation in energy plantations.

UTICAJ PRIHRANJIVANJA NA PREŽIVLJAVANJE I MORFOLOŠKE KARAKTERISTIKE ELEMENATA RASTA JEDNOGODIŠNJIH SADNICA *PAULOWNIA ELONGATA* S. Y. HU. I *PAULOWNIA FORTUNEI* SEEM. HEMSL. NA DVA RAZLIČITA STANIŠTA U SRBIJI

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Rezime

Istraživanja su vršena na dve ogledne površine sadnjom sadnica vrsta *Paulownia elongata* S. Y. Hu. i *Paulownia fortunei* Seem. Hemsl. Ogledna polja su osnovana na lokalitetima različite orografskih osobina, klimatskih uslova i fizičko-hemijskih osobina zemljišta sadnjom sadnica paulovnija proizvedenih generativnim putem od semena dobro adapriranih genotipova dve vrste paulovnije, iz zasada u Beloj Crkvi. U radu su prikazani

rezultati istraživanja uticaja prihranjivanja biljaka u prvoj godini nakon sadnje, na preživljavanje i morfometrijske karakteristike elemenata rasta. Analiza ovih rezultta je pokazala da je prihranjivanje sadnica imalo signifikantan uticaj na preživljavanje i na sve analizirane parameter. Takođe, utvrđeno je da su dobijeni rezultati uticaja prihranjivanja značajni za analizu pokazatelja adaptibilnosti vrsta za gajenje na određenim tipovima zemljišta.

Dobijeni rezultati preživljavanja ukazuju na potencijal ove vrste. Analiza rezultata visine sadnica, prečnika u vratu korena, veličine listova potvrđuje da paulovnija na istraživanim staništima ne iskazuje svoje osobine kao brzorastuća vrsta. Istraživanja treba nastaviti u pravcu sagledavanja njenog rasta i razvoja u stadijumu dve i više godina starosti kako bi se potvrdila pretpostavka da je potencijal ovih vrsta u gajenju energetskih zasada.

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CONDITION OF DOUGLAS FIR TREES IN THE URBAN AREA OF BELGRADE (SERBIA)

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Abstract: *A total of 179 Douglas fir trees (Pseudotsuga menziesii /Mirb./ Franco) were examined in the municipality of Savski Venac, Belgrade, to assess the condition of this non-native species in Serbia and its adaptability to urban environments. Tree measurements (trunk diameter, tree height and crown diameter) were taken, and the trees were rated for vitality and decorativeness. The trees were found to be in a very good condition, with 89.05% of them showing no visible signs of disease. The average vitality rating was 3.94, and the average rating of decorativeness was 3.57. The results for vitality and some physical measurements exceeded values reported in the literature, suggesting that Douglas fir has adapted well to the urban environment of Belgrade. Although further research is needed, it can be concluded that Douglas fir is a suitable species for landscape planting in urban areas of Serbia.*

Keywords: *Pseudotsuga menziesii* (Mirb.) Franco, vitality, decorativeness, tree measurements, species adaptability, Belgrade.

STANJE STABALA DUGLAZIJE U GRADSKOJ SREDINI BEOGRADA (SRBIJA)

Sažetak: *Ispitano je 179 stabala duglazije (Pseudotsuga menziesii /Mirb./ Franco) na teritoriji GO Savski venac u Beogradu, radi utvrđivanja stanja ove alohtone vrste u Srbiji i njene sposobnosti prilagođavanja urbanim sredinama. Stablima su izmerene dimenzije i ocenjena je njihova vitalnost i dekorativnost. Analizirana stabla su u vrlo dobrom stanju, pri čemu 89,05% stabala nije pokazivalo vidljive znake bolesti. Prosečna ocena vitalnosti je 3,94, a prosečna ocena dekorativnosti – 3,57. Dobijene vrednosti za vitalnost i pojedine dimenzije stabala su veće od onih navedenih u literaturi, što sugeriše da se duglazija dobro prilagodila urbanoj sredini Beograda. Premda su neophodna dalja istraživanja, na osnovu ovih rezultata, duglazija se smatra pogodnom vrstom za sadnju u urbanim sredinama Srbije.*

Ključne reči: *Pseudotsuga menziesii* (Mirb.) Franco, vitalnost, dekorativnost, dimenzije stabala, adaptibilnost vrste, Beograd.

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1. INTRODUCTION

Urban green areas regulate the microclimate of city districts, reduce air pollution, mitigate wind blows and control soil erosion, reduce the negative effects of precipitation, and reduce the noise level in cities (Prpić, 1992; Vuletić et al., 2010).

In Belgrade, the capital of the Republic of Serbia, urban green areas cover around 2,907 ha, including parks and squares, greenery of residential areas, green areas of roads, urban forests, coasts and shores, protective areas and other categories of greenery (Milanović, 2006). The dendroflora of the area was gradually enriched by man. In addition to native species of coniferous trees, there is also a large number of species brought from other climates. According to literature (Maksimović et al., 1979), among the domestic conifer species – Austrian pine (*Pinus nigra* J.F.Arnold) and Norway spruce (*Picea abies* /L./ Karst.) are the most common. As for the introduced genera and species of conifers, the most represented are silver fir (*Abies alba* Mill.), cedar (*Cedrus* spp.), yew (*Taxus baccata* L.), junipers (*Juniperus* spp.), etc.

The selection of plant species for planting should maximally correspond to the targeted environmental conditions. The selected species should have fast growth and productivity, and decorative properties. Hence, when selecting plant species for urban green areas, species that are extremely sensitive to air pollution should be avoided (Anastasijević, 2011).

Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco, Pinaceae] is a conifer species native to North America. Under optimal conditions, this species reaches a height of over 100 m, a diameter of 4 m, and an age of 1,300 years or more (Hermann & Lavender, 1990). It is notable for its adaptability and has been successfully introduced to Europe, where it thrives in diverse climates, including urban areas (Castaldi et al., 2020).

The health and stability of urban trees are increasingly important due to environmental stressors, such as pollution and limited root space. In this paper, Douglas fir trees growing in the area of Belgrade city were examined to assess their condition and adaptability to urban environments. The results of this study can guide future efforts to maintain and expand urban greenery, ensuring that green spaces of Belgrade city continue to offer vital ecological, social and aesthetic benefits to its residents.

2. MATERIAL AND METHODS

2.1. Study area

In the present study, Douglas fir trees were examined in the municipality of Savski Venac (Figure 1). This is one of the oldest and most significant municipalities in the city of Belgrade, serving as a major traffic, tourist and business center. Home to about 40,000 residents, and twice as many workers, this area highlights the need for thoughtful urban green space management (Beogradska opština Savski venac, 2022). The municipality covers an area of 15.8 km², with its northernmost point located at 44°48'54" N and its southernmost at 44°45'15" N. The westernmost point is at 20°25'29" E and the easternmost at 20°28'26" E. The municipality stretches 6.91

km from south to north and 5.20 km from west to east (Vojnogeografski institut, 1990). Geographically, the highest elevation in Savski Venac is found at the Royal Complex (210 m), while the lowest point is at the confluence of the Topčider River with the Sava River (75 m). The geological substrate of the area comprises Holocene-age sediments and the alluvial plain of the Sava River, while the soils are mostly anthropogenically modified. The climate of Savski Venac is temperate and continental, characterized by long, hot summers and cold winters. Due to the high density of residential areas and heavy traffic, the municipality experiences a localized increase in temperatures, contributing to an urban heat island effect. However, the abundant green spaces help counteract this effect (Gradski zavod za javno zdravlje Beograd, 2022). The flora in Savski Venac is diverse, with deciduous trees, such as oak, birch, maple, cherry plum, apple, and poplar being common, alongside conifers like pines and spruces (Gradski zavod za javno zdravlje Beograd, 2022).

2.2. Data and methodology

A total of 179 Douglas fir trees were sampled in the yards of public institutions of Savski Venac municipality. The investigation included measuring tree parameters – trunk diameter (at breast height), tree height and crown diameter – as well as assessing the vitality and decorativeness of the trees.

Trunk diameter was measured using a diameter tape (Bandmass 10 m, Weiss, Germany). Tree height was measured with a height measuring instrument (Vertex 4, Haglöf, Sweden). Crown diameter was determined by projecting the crown edges to the ground and measuring along one axis with a measuring tape (Fast Winder Frame 30 m, Weiss, Germany). The vitality and decorativeness of the trees were assessed using the Visual Tree Assessment (VTA) method (Mattheck & Breloer, 1994), according to predefined scales, as shown in Table 1. Vitality was evaluated based on tree health, including signs of disease or physical damage, while decorativeness was based on the aesthetic value and structural form of trees.

Table 1. *Rating scales for vitality and decorativeness of trees*

Grade	Vitality	Decorativeness
5	Excellent, healthy and strong trees, with no visible insect damage or indication of disease and no mechanical wounds.	Visually imposing and aesthetically valuable trees.
4	Trees in good condition, healthy, with only slight signs of injury, disease or physiological weakness.	Trees with a visually balanced form.
3	Trees with some mechanical, phyto-pathological or entomological damage.	Trees that have a clearly outlined crown in silhouette.
2	Trees with clearly visible mechanical damage from insects and/or diseases.	Trees of a disharmonious and disproportionate silhouette with insufficiently clearly delineated habitus.
1	Dead or nearly dead trees.	Trees without aesthetic value.

The collected data was processed using descriptive statistical procedures. The statistical analysis included the following basic statistical parameters: minimum value, maximum value, variation range, mean value, standard deviation and coefficient of variation. The statistical analysis was performed using Statgraphics Centurion software (ver. XVI.I, 2009, Statpoint Technologies, Inc., Warrenton, VA).

Figure 1. *Locations of the analyzed Douglas fir trees in Savski Venac municipality, Belgrade, Serbia*

3. RESULTS AND DISCUSSION

The descriptive statistics for Douglas fir trees in Belgrade revealed high variability in their physical measurements (Table 2; Figure 2). The trunk diameter varied from 12.50 cm to 65.00 cm, with a mean value of 30.98 cm, and a coefficient of variation of 35.29%. The crown diameter measurements ranged from 1.25 m to 13.50 m, with a mean value of 6.70 m, and a coefficient of variation of 35.47%. The height of the trees ranged from 4.50 m to 20.00 m, with a mean value of 13.84 m, and a coefficient of variation of 29.89%. The obtained results suggest that the sample included trees of various ages.

Table 2. *Descriptive statistics for the vitality, decorativeness and physical measurements of Douglas fir trees in the urban area of Belgrade*

Property	Mean value	Standard deviation	Coeff. of variation (%)	Minimum value	Maximum value	Variation range
Vitality (1–5)	3.94	1.07	27.07%	1.00	5.00	4.00
Decorativeness (1–5)	3.57	1.02	28.63%	1.00	5.00	4.00
Trunk diameter (cm)	30.98	1.09	35.29%	12.50	65.00	52.50
Crown diameter (m)	6.70	2.38	35.47%	1.25	13.50	12.25
Tree height (m)	13.84	4.14	29.89%	4.50	20.00	15.50

On the other hand, the vitality and decorativeness were somewhat less variable traits of the analyzed Douglas fir trees (coefficients of variation 27.07% and 28.63%, respectively). The vitality ranged from grade 1 to grade 5, with a mean value of 3.94, whereas the grades of decorativeness ranged from 1 to 5, with a mean value of 3.57 (Table 2). In addition, it was found that the analyzed trees are in very good condition based on their health status, considering that most of them (89.95%) had no visible indication of disease.

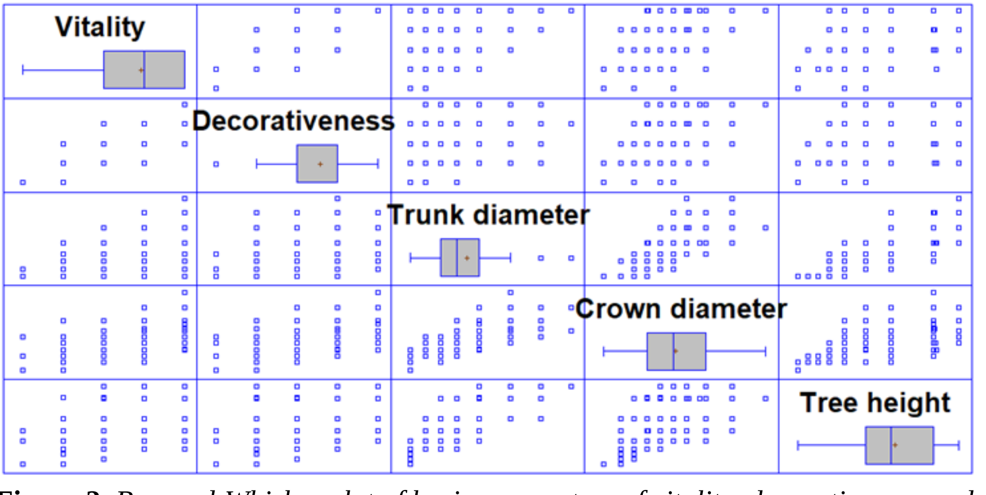

Figure 2. *Box-and-Whisker plot of basic parameters of vitality, decorativeness and physical measurements of Douglas fir trees in the urban area of Belgrade. Legend: middle sign = mean, middle line = median, box = lower and upper quartile, whisker = variation range*

In comparison with literature data, the mean trunk diameter of the analyzed Douglas fir trees, which was 30.98 cm, exceeded the mean value reported by Ratknić and Rakonjac (2010) for Douglas fir plantations on various sites in Serbia. For trees aged 15 to 30 years, they reported an average trunk diameter of 23.60 cm. Similarly, Rais et al. (2013) studied 133 Douglas fir trees and found an average trunk diameter ranging between 22.30 cm and 23.40 cm. In contrast, Smolnikar et al. (2018) studied 1,061 Douglas fir trees in Slovenia and reported slightly higher mean trunk diameter of 31.2 cm. In addition, Pretzsch et al. (2015) analyzed 1,613 Douglas fir trees and calculated a mean trunk diameter of 32.7 cm.

As for the crown diameter, the mean value in our study was 6.70 m, which is notably larger than the 3.10 m mean crown diameter reported by Pretzsch et al. (2015). On the other hand, the mean tree height observed in our study was lower than the average values reported by Pretzsch et al. (2015) (21.29–22.70 m), but higher than the value found by Smolnikar et al. (2018) (6.05 m).

Assessing the vitality of park species and identifying the biotic and abiotic factors that directly or indirectly threaten their condition is crucial to applying appropriate care and protection measures (Mladenović et al., 2020). This process ensures that targeted interventions can be implemented to promote the health and longevity of park vegetation, preserving both ecological balance and aesthetic value. The vitality of the sampled trees of Douglas fir in this study was in average 3.94 on a scale 1–5, which is higher than the mean value reported by Smolnikar et al. (2018) for 1061 trees of Douglas fir in Slovenia (2.21 on a scale 1–3). Given that the trees have been sampled in yards of public institutions, the observed high tree vitality is probably a result of tending measures applied in these areas.

For the successful establishment of functional green areas in urban environments, it is essential to use healthy planting stock and carefully selected plant species. This should be coupled with proper tending and protection measures, including the replacement of sensitive species with more resilient ones (Mladenović et al., 2018). Although further research is needed, based on the results of this study, and by comparison with literature data, it can be argued that the Douglas fir has adapted well to the urban environment of Belgrade, displaying very good health and proper physical characteristics. As a result, this species, which to date has not shown invasive behavior in Serbia, can be recommended for planting in the urban areas of Serbia as a landscape tree.

4. CONCLUSION

Based on the obtained results for the vitality, decorativeness, and physical measurements of Douglas fir trees in the urban area of Belgrade, the following conclusions can be drawn:

- the physical measurements of Douglas fir trees in Belgrade (trunk diameter, tree height, and crown diameter) are highly variable, indicating that the sampled trees represent a wide range of ages;
- vitality and decorativeness are variable traits of the Douglas fir trees in the area;
- the analyzed Douglas fir trees are in very good health, with 89.05% of the trees showing no visible signs of disease. The mean vitality rating

is 3.94, and the mean rating of decorativeness is 3.57, both on a scale of 1 to 5.

- the observed values for vitality and some physical measurements, such as crown diameter and in some cases trunk diameter, were greater than those reported in the literature for the same species in similar environments.

Although further research is needed, Douglas fir has demonstrated good adaptation to the urban environment of Belgrade and should be considered a suitable species for landscape planting in urban areas of Serbia.

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CONDITION OF DOUGLAS FIR TREES IN THE URBAN AREA OF BELGRADE (SERBIA)

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Đorđe FILIPOVIĆ, Đorđe JOVIĆ, Aleksandar LUČIĆ

Summary

In the present paper, Douglas fir trees (*Pseudotsuga menziesii* /Mirb./ Franco) were examined in the urban area of Belgrade to assess the condition of this non-native species in Serbia and its adaptability to urban environments.

A total of 179 trees of Douglas fir were examined in the area of the municipality of Savski Venac (Figure 1). The trunk diameter, tree height and crown diameter of the sampled trees were measured using adequate tools and instruments (Weiss Bandmass 10 m; Haglöf Vertex 4; Weiss Fast Winder Frame 30 m). The vitality and decorativeness of the trees were assessed according to the VTA method (Visual Tree Assessment) (Mattheck & Breloer, 1994) using the rating scales given in Table 1. The obtained data was processed employing descriptive statistical procedures.

The results show that the trunk diameter of the analyzed trees has a range of values 12.5–65.00 cm and a mean value of 30.98 cm; the crown diameter ranged from 1.25 m to 13.5 m, with a mean value of 6.70 m, and the tree height ranged from 4.50 m to 20.00 m,

with a mean value of 13.84 m, indicating a wide range of age of the sampled trees. On the other hand, the vitality and decorativeness were less variable features. The mean rating of vitality is 3.94, and the mean rating of decorativeness is 3.57 (Table 2). In addition, the analyzed trees are in very good condition based on their health status (89.05% of trees are with no visible indication of disease). In comparison with the literature data (Pretzsch et al., 2015; Rais et al., 2013; Ratknić & Rakonjac, 2010; Smolnikar et al., 2018), the obtained values for the vitality and physical measurements (crown diameter and, in some cases, trunk diameter) of the sampled trees were greater than those stated for the same species in similar environments.

Although further research is needed, it can be concluded that Douglas fir has adapted well to the urban environment of Belgrade and it should be considered a suitable landscape tree species for planting in urban areas of Serbia.

STANJE STABALA DUGLAZIJE U GRADSKOJ SREDINI BEOGRADA (SRBIJA)

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Rezime

U radu se analiziraju stabla duglazije (*Pseudotsuga menziesii* /Mirb./ Franco) u urbanom području grada Beograda, kako bi se procenilo stanje ove alohtone vrste u Srbiji i njena adaptabilnost na urbane uslove.

Ispitano je 179 stabala na području GO Savski Venac (slika 1). Prečnik debla, visina stabala i prečnik krošnje mereni su korišćenjem odgovarajućih alata i instrumenata (Weiss Bandmass 10 m; Haglöf Vertex 4; Weiss Fast Winder Frame 30 m). Vitalnost i dekorativnost stabala procenjeni su prema VTA metodi (Mattheck & Breloer, 1994) na skali 1–5 (tabela 1). Podaci su obrađeni u skladu sa deskriptivnim statističkim metodama.

Rezultati pokazuju da prečnik debla analiziranih stabala varira od 12,5 cm do 65,00 cm, s prosečnom vrednošću 30,98 cm; prečnik krošnje varira od 1,25 m do 13,5 m, s prosečnom vrednošću 6,70 m, dok visina stabala varira od 4,50 m do 20,00 m, s prosečnom vrednošću 13,84 m, što ukazuje na širok raspon starosti uzorkovanih stabala. S druge strane, vitalnost i dekorativnost su manje promenljive karakteristike stabala. Prosečna vrednost vitalnosti iznosi 3,94, a prosečna vrednost dekorativnosti je 3,57 (tabela 2). Analizirana stabla su u vrlo dobrom stanju na osnovu procene zdravstvenog stanja (89,05% stabala nema vidljivih znakova bolesti). U poređenju sa literaturnim podacima (Pretzsch et al., 2015; Rais et al., 2013; Ratknić & Rakonjac, 2010; Smolnikar et al., 2018), dobijene vrednosti za vitalnost i pojedine dimenzije (prečnik krošnje i, u nekim slučajevima, prečnik debla) uzorkovanih stabala su veće od onih navedenih za istu vrstu u sličnim okruženjima.

Premda su neophodna dalja istraživanja, na osnovu ovih rezultata se može zaključiti da je duglazija dobro prilagođena vrsta gradskoj sredini Beograda i da se može preporučiti za sadnju u urbanim područjima Srbije.

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THE MOST COMMON FUNGI ASSOCIATED WITH A DECLINE OF TURKEY OAK (*QUERCUS CERRIS* L.) IN URBAN CONDITIONS IN SERBIA

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Abstract: *Turkey oak (Quercus cerris) is one of the most important tree species in park forests and parks in Serbia. Despite this, there has been no available information in domestic literature about the parasitic fungi that affect Turkey oak in urban areas. Research carried out between 2016 and 2023 identified 19 taxa of parasitic and saprotrophic fungi that colonize Turkey oak in urban conditions: one on the roots, two on the leaves, two on the bark, seven on the trunk, two on the branches, two on the fruits, two on the stumps, and one on both leaves and fruits. The most significant fungi found were Fomes fomentarius, Inonotus nidus-pici, and Fuscoporia torulosa, which cause heart rot and are typically found on individual trees. Most of the fungi identified occurred in succession. Following primary damage, the most frequently occurring fungus was Stereum hirsutum, while after mechanical injuries, Schizophullym commune was most frequently recorded. Alternaria spp. was found on old leaves and heavily damaged leaves. To protect the urban Turkey oak trees, measures should be focused on reducing tree density and preventing mechanical injuries. The findings from this research also contribute to understanding the ecological characteristics of these fungal taxa based on their frequent occurrence in urban conditions.*

Keywords: oak decline, causes, urban areas, first record.

NAJČEŠĆE GLJIVE POVEZANE SA PROPADANJEM STABALA CERA (*QUERCUS CERRIS* L.) U URBANIM PODRUČJIMA SRBIJE

Sažetak: *Cer (Quercus cerris) predstavlja jednu od najvažnijih vrsta drveća u park šumama i parkovima Srbije. Do sada u domaćoj literaturi nije bilo podataka vezano za parazitski komples gljva koje kolonizuju cer u urbanim uslovima. Istraživanje izvršeno u periodu 2016-2023 je pokazalo 19 taksona parazitskih i saprofitskih gljiva; jedan na korenu, dva na listovima, dva na kori, sedam na deblu, dva na гранама, dva na plodovima, dva na panjevima i jedan na listovima i plodovima. Najvažnije gljive su bile Fomes fomentarius, Inonotus nidus-pici i Fuscoporia torulosa prouzrokovači centralne truleži, koje su konstatovane na pojedinačnim stablima. Većina konstatovanih gljiva se javljala u sukcesiji. Posle primarnih uzročnika oštećenja, najčešća je Stereum hirsutum, dok je posle mehaničkih oštećenja najčešće konstatovana Schizophyllum commune. Alternaria spp. je zabeležena na*

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starim listovima, kao i posle teških oštećenja listova. Mere zaštite cera treba da budu usmerene u smanjenju gustine i izbegavanju mehaničkog oštećenja stabala. Dobijeni rezultati takođe doprinose poznavanju ekoloških karakteristika taksona gljiva na osnovu njihove česte konstatacije u urbanim sredinama.

Ključne reči: propadanje hrastova, uzročnici, urbana područja, prvi nalaz.

1. INTRODUCTION

The *Quercus* genus comprises approximately 500 tree species in the northern hemisphere (Cvjetićanin et al., 2016). One particularly significant species in Europe and Asia Minor is the Turkey oak (*Quercus cerris* L.), which can be found in mixed forests in the Mediterranean basin and is commonly planted in parks due to its ability to withstand urban conditions (Cvjetićanin et al., 2016; de Rigo et al., 2016). Climate change is influencing the increasing importance of Turkey oak because of its enhanced adaptability to drier conditions and ability to recover after periods of drought. Its adaptability is somewhat lower in Southern Europe (Kasper et al., 2022; Mészáros et al., 2022; Šimková et al., 2023). Consequently, it is crucial to initiate research on the biotic factors contributing to the decline of these trees to enhance the likelihood of preserving as many trees as possible. Currently, there is limited detailed information available in domestic literature on the diseases affecting Turkey oak trees, particularly in urban areas where the trees are more exposed to air pollution and extremely high temperatures.

Fungi that harm Turkey oak can be found at all stages of its growth. To properly assess the impact of these fungi, it is important to know the stage of development of the tree's vegetative organs (Bercea, 2010). Additionally, in the case of Turkey oak, drought, and insect defoliation can contribute to the appearance of specific pathogens, such as *Biscogniauxia mediterranea* (De Not.) Kuntze (Capretti & Battisti, 2007; Vannini et al., 2009).

The health status of trees in urban areas reflects the development and quality of life in those areas (Solomou et al., 2019). Moreover, specific genera of fungi, such as *Alternaria* and *Cladosporium*, which appear on trees, can cause allergic reactions in humans (Kasprzyk et al., 2021). Experiences from various parts of Europe have demonstrated that fungal diseases are the most common cause of decay in Turkey oak trees (Georgieva et al., 2018).

In light of the above, a multi-year study was conducted in Serbia to investigate the diversity of fungi associated with symptoms of Turkey oak deterioration. The initial hypotheses were: i) there are not the same symptoms caused by different fungi on Turkey oak trees; ii) the causes of Turkey oak decay in urban areas are not different from those in rural areas.

2. MATERIAL AND METHODS

2.1 Field methods

Field research was conducted in all major cities of Serbia, with a focus on Belgrade. The research involved inspecting symptomatic trees and collecting samples from these trees for laboratory analysis. The trees were inspected three times a year: in spring, summer, and autumn. Every part of the trees was visually inspected, and samples were taken for laboratory analysis in case of visible damage. Samples of tree parts or fruiting bodies of fungi were placed in paper bags and stored in a refrigerator until the analyses began.

2.2 Laboratory methods

The fungi were isolated and identified based on their morphological characteristics from the samples collected. When identifying fungi directly from plant material, we used temporary histological preparations following the procedure described by Muntanola Cvetković (1990). We followed the description by Ellis & Ellis (1985) to identify microfungi from histological preparations. The fungi were isolated using MEA (30 g/l Biolab, Hungary; 20 g/l Torlak, Serbia) and PDA (LAB M, UK) nutrient media. Pure culture identification was carried out using the keys provided by Nobles (1948, 1964) and Stalpers (1978).

3. RESULTS AND DISCUSSION

Based on the samples taken, 19 parasitic and saprophytic fungi taxa were identified on Turkey oak in urban areas of Serbia (see Table 1).

Table 1. *Identified fungi on Turkey oak in urban areas of Serbia*

Species	Tree part	Type of damage	Frequency	Significance
Alternaria spp.	Leaves, fruits	- Fruit rot	++	+
Armillaria mellea (Vahl) Kumm.	Root	Butt rot	+	+++
Botrytis cinerea Pers.	Fruits	Fruit rot	++	+++
Cladosporium spp.	Fruits	Fruit rot	++	+
Cytospora ambiens (Pers.) Sacc.	Bark	Bark necrosis	+	++
Diplodia spp.	Leaves	Spotting	+	++
Fomes fomentarius (L.) Fr.	Trunk	Heart rot	+	+++

Species	Tree part	Type of damage	Frequency	Significance
Gnomonia quercina Kleb.	Leaves	Leaf anthracnose	+	+++
Inonotus hispidus (Bull.) Karst.	Trunk	Heart rot	++	+++
Irpex lacteus Fr.	Stump	-	+	+
Inonotus nidus-pici Pilát	Trunk	Heart rot	+++	+++
Peniophora spp.	Branches	Sap rot	+	+
Peniophora quercina (Pers.) Cooke	Branches	Sap rot	++	+
Peziza spp.	Bark	-	+	+
Omphalotus olearius (DC.) Singer	Stump	-	++	+
Fuscoporia torulosa (Pers.) Wagn. & Fisch.	Trunk	Heart rot	+	+++
Schizophyllum commune Fr.	Trunk	Sap rot	+++	++
Stereum hirsutum (Willd.) Pers.	Trunk	Sap rot	+++	++
Trametes hirsuta (Wulf.) Pil.	Trunk	Sap rot	+++	++

Addendum to the table: + Fungus appears rarely or has no significant importance

++ Fungus occurs moderately often and is important

+++ Fungus appears often and has great importance

The largest number of taxa was found on the trunk (Table 1). It was also found that fungi from this group cause the most damage to trees (Table 1, Figure 1). Fungi from this group are categorized as those that directly cause damage to trees (*Fomes fomentarius*, *Inonotus hispidus, Inonotus nidus-pici* and *Fuscoporia torulosa*), and others that occur on damaged trees (Table 1, Figure 1).

The fungus *Schizophyllum commune* was found on both uninjured and injured trees (see Figure 1). Description of the damaged wooden substrate type and fungi occurrence is shown in Table 2.

Table 2. *The condition of the tree damage and the presence of fungi*

Damage type	**Fungus species**
Separated bark	*Schizophyllum commune* *Stereum hirsutum*
Widened radial fissures on the bark	
Windbreaks	
Stumps	*Fuscoporia torulosa** *Irpex lacteus* *Omphalotus olearius*

* The fungus causes tree cutting

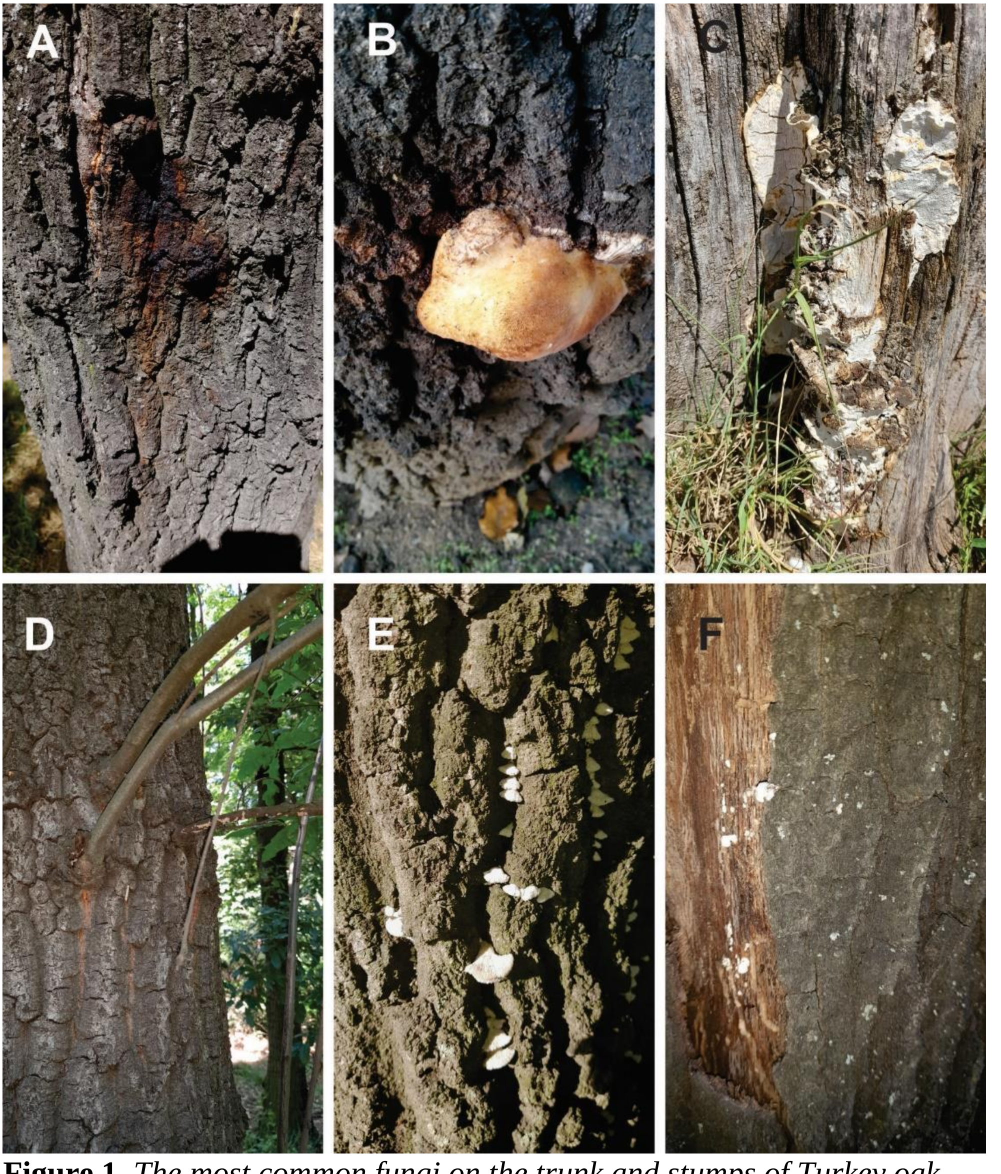

Figure 1. *The most common fungi on the trunk and stumps of Turkey oak trees in the cities of Serbia: A – Inonotus nidus-pici, B – Inonotus hispidus, C – Irpex lacteus, D – Peniophora spp., E-F – Schizophyllum commume*

Figure 2. *The most common fungi on the trunk, leaves, and stumps of Turkey oak trees in the cities of Serbia: A – Omphalotus olearius, B – Alternaria spp., C – Fuscoporia torulosa*

The number of fungal species found on Turkey oak in urban areas was lower compared to the number of fungi found in natural stands in Serbia (Karadžić et al., 2017). This could be due to the negative impact of urbanization on the presence of fungi (Meyer et al., 2021). In urban environments, there is a reduction in the diversity of fungi in the air, which is not the case with the fungi in the soil (Abrego et al., 2020). However, it is worth noting that most fungi found on Turkey oak in this study were facultative parasites, indicating that these species are actively dispersed through the air in urban conditions, unaffected by the environment. Additionally, the limited number of fungi found on the roots of Turkey oak does not necessarily mean a decrease in soil fungal diversity, as only the most common and noticeable fungi were examined for Turkey oak.

It is necessary to pay attention to *Inonotus nidus-pici*, which causes the most damage on Turkey oak in natural and urban areas (Karadžić & Milenković, 2015; Milenković et al., 2022). This fungus was recorded in Serbia on *Fraxinus angustifolia* and *Tilia platyphyllos* in urban areas, where infection spreads through wounds, probably due to climate change (Milenković et al., 2023). Most recorded fungi occur in the natural Turkey oak stands (Karadžić et al., 2017). Also, different fungi taxa have been found on previously damaged trees, causing white rot. Therefore, the first null hypothesis was rejected and the alternative hypothesis that different fungi on Turkey oak trees cause the same symptoms was accepted.

The findings are consistent with previous research (Ragazzi et al., 2003), which suggests fewer fungi on Turkey oak trees in urban areas than forests. The study also indicates that urban temperatures and conditions may contribute to the increased pathogenicity of endophytic fungi. The study identified the same fungal species in urban areas as in natural stands. As a result, the hypothesis that the causes of Turkey oak decline in urban areas are not different from those in natural areas has been rejected, and the alternative hypothesis has been accepted. Additionally, the study found no previously recorded individual species that rarely appear on Turkey oak trees (Vemić & Milenković, 2019). The researchers recommend monitoring rarely occurring fungi, such as the recently identified species *Trametes trogii* (Radulović et al., 2023), especially on other oak species to prevent the spread of infection, particularly in the context of globalization.

4. CONCLUSION

For the first time, this study detailed the diversity of the most common parasitic and saprophytic fungi on Turkey oak trees in urban conditions in Serbia. The results obtained are as follows:

- Nineteen taxa were identified, most of which were found for the first time on Turkey oak in urban areas in Serbia.
- The most important were the fungi found on the trunk. From this group, the most important were *Fomes fomentarius, Inonotus nidus-pici*, and *Fuscoporia torulosa*, causing white rot.
- The fungi *Schizophyllum commune* and *Stereum hirsutum* are often found on trees mechanically damaged by abiotic factors.

- The obtained results enable better planning of Turkey oak tree protection measures in the urban conditions of Serbia.

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THE MOST COMMON FUNGI ASSOCIATED WITH A DECLINE OF TURKEY OAK (*QUERCUS CERRIS* L.) IN URBAN CONDITIONS IN SERBIA

Aleksandar VEMIĆ, Zlatan RADULOVIĆ, Katarina MLADENOVIĆ, Ljubinko RAKONJAC

Summary

A multi-year study examined the mycoflora associated with symptoms in Turkey oak trees (*Quercus cerris*) in Serbian cities due to the need to preserve trees in urban areas. Nineteen fungi taxa were identified, and their distribution varied on different parts of the Turkey oak trees. The most significant number of taxa, including *Fomes fomentarius, Inonotus hispidus, Inonotus nidus-pici, Fuscoporia torulosa, Schizophyllum commune, Stereum hirsutum*, and *Trametes hirsuta*, was found on the trunk. Fewer taxa, such as *Alternaria spp., Diplodia spp.,* and *Gnomonia quercina*, were found on the leaves; *Cytospora ambiens* and *Peziza spp.* were found on the bark; *Alternaria spp., Botrytis cinerea,* and *Cladosporium spp.* were found on the fruits; *Peniophora spp.* and *Peniophora quercina* were found on the branches; and *Irpex lacteus* and *Omphalotus olearius* were found on the stumps. The smallest number of taxa was found on the root, specifically *Armillaria mellea*.

The most significant damage was caused by *Fomes fomentarius, Inonotus nidus-pici,* and *Fuscoporia torulosa*, which resulted in breaks and premature felling of the affected trees. Long-term monitoring revealed that these species were present on trees with no mechanical damage, indicating their role as the primary cause of damage. Conversely, *Schizophyllum commune* and *Stereum hirsutum* were found on damaged trees, and *Peniophora quercina* was observed on fallen branches.

The number of pathogens on the leaves was not high enough to threaten the health of the trees. *Alternaria spp.* was commonly found on leaves before they fell and on leaves that were damaged by different biotic and abiotic factors. *Botrytis cinerea* was the primary fungus affecting the fruits, causing gray mold in the cupule and nut. Other fungi were also frequently seen, but their significance was not determined.

It is essential to control the number of Turkey oak trees in park forests and parks to prevent mechanical damage, which can lead to the growth of various fungi. All the different types of fungi found should be considered when developing forest protection plans to minimize the spread of their inoculum and reduce damage to Turkey oak trees in urban areas.

The study recorded many fungi for the first time on Turkey oak trees in urban areas in Serbia. These findings provide valuable insights into the ecology of the identified fungi in urban conditions based on their presence on Turkey oak trees.

NAJČEŠĆE GLJIVE POVEZANE SA PROPADANJEM STABALA CERA (*QUERCUS CERRIS* L.) U URBANIM PODRUČJIMA SRBIJE

Aleksandar VEMIĆ, Zlatan RADULOVIĆ, Katarina MLADENOVIĆ, Ljubinko RAKONJAC

Rezime

Usled potrebe očuvanja stabala u urbanim područjima, izvršeno je višegodišnje istraživanje mikoflore povezane sa simptomima na stablima cera (*Quercus cerris*) u gradovima Srbije. Utvrđeno je devetnaest taksona gljiva, čija distribucija je različita na različitim delovima stabala cera. Najveći broj taksona: *Fomes fomentarius, Inonotus hispidus*, *Inonotus nidus-pici*, *Fuscoporia torulosa*, *Schizophyllum commune*, *Stereum hirsutum*, *Trametes hirsuta* je konstatovan na deblu. Manji broj taksona: *Alternaria* spp., *Diplodia* spp. i *Gnomonia quercina* su konstatovane na listovima, na kori: *Cytospora ambiens* i *Peziza* spp., plodovima: *Alternaria* spp., *Botrytis cinerea* i *Cladosporium* spp., granama: *Peniophora* spp. i *Peniophora quercina*, panjevima: *Irpex lacteus* i *Omphalotus olearius*. Najmanji broj taksona je konstatovan na korenu (*Armillaria mellea*).

Najveća oštećenja su zabeležena od *Fomes fomentarius, Inonotus nidus-pici* i *Fuscoporia torulosa*, koja su dovodila do lomova i prevremene seče zahvaćenih stabala. Takođe, višegodišnji monitoring je pokazao da su ove vrste konstatovane na pojedinačnim stablima na kojima nije bilo mehaničkih oštećenja, ukazujući na njihov značaj kao glavnih uzročnika oštećenja. Sa druge strane, *Schizophyllum commune* i *Stereum hirsutum* su konstatovane na oštećenim stablima, a *Peniophora quercina* na opalim granama.

Patogeni listova nisu zabeleženi u većoj brojnosti koja bi ugrozila vitalnost stabala. Najčešće je konstatovana *Alternaria* spp., na listovima pred opadanjem, kao i na listovima oštećenim usled različitih abiotičkih i biotičkih uzročnika. Na plodovima je bila najznačajnija *Botrytis cinerea* koja je izazivala sivu plesan kupula i orašica. Ostale gljive su takođe često konstatovane ali njihov značaj nije utvrđen.

Mere zaštite treba da budu usmerene u regulisanju gustine stabala cera u park šumama i parkovima, iz razloga smanjenja mehaničkog oštećenja koje pogoduje razvoju velikog broja konstatovanih gljiva. Sve konstatovane vrste gljiva treba uključiti u šire strategije zaštite šuma u cilju ograničenja prenosa njihovog inokuluma, kako bi se umanjile štete na ceru u urbanim uslovima.

Većina zabeleženih gljiva u ovoj studiji je prvi put konstatovana na ceru u urbanim uslovima Srbije. Dobijeni rezultati omogućavaju bolje poznavanje ekologije konstatovanih gljiva bazirano na njihovim nalazima na ceru u urbanim uslovima.

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A CONTRIBUTION TO THE KNOWLEDGE OF THE MITES (ACARI) FAUNA OF THE HORNBEAM IN SERBIA

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Abstract: *This paper provides an analysis of the biodiversity of species within the families Phytoseiidae and Tetranychidae found on common hornbeam (Carpinus betulus) in both forest and horticultural habitats. For the first time worldwide, three predatory mite species from the family Phytoseiidae – Amblyseius andersoni, Euseius finlandicus, and Phytoseius soleiger – have been identified on hosts from the family Betulaceae, specifically within the genus Carpinus and the species Carpinus betulus. Additionally, the presence of a phytophagous mite species, Eotetranychus carpini, from the family Tetranychidae has been documented on hornbeam.*

Keywords: predatory mites, spider mites, *Carpinus.*

PRILOG POZNAVANJU FAUNE GRINJA (ACARI) NA GRABU U SRBIJI

Sažetak: *U radu je dat prikaz biodiverziteta vrsta fam. Phytoseiidae i fam. Tetranychidae utvrđene na običnom grabu u šumskim i hortikulturnim staništima. Prvi put u svetu su tri predatorske vrste grinja fam. Phytoseidae - Amblyseius andersoni, Euseius finlandicus i Phytoseius soleiger utvrđene na fam. Betulaceae odnosno fam Corylaceae rodu Carpinus i na vrsti Carpinus betulus. Na grabu je zabeleženo prisustvo i jedne vrste fitofagne grinja iz fam. Tetranychidae - Eotetranychus carpin.*

Ključne reči: predatorske grinje, grinje paučinari, *Carpinus*.

1. INTRODUCTION

The prevailing spectrum of *Phytoseiidae* and *Tetranychidae* mite species on forest and horticultural broadleaf plants in Serbia has not yet been thoroughly investigated.

The importance of phytoseiid mites as potential biological control agents against phytophagous mites, particularly those in the *Tetranychoidea* and *Eriophyoidea* groups, as well as against thrips and whiteflies, continues to grow.

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Certain species of predatory mites are now used as commercial biocontrol agents in agriculture (Gerson et al., 2003; McMurtry et al., 2013). Natural reservoirs of predatory mites include native plant species in uncultivated ecosystems, as well as introduced species in urban habitats (Papaioannou-Souliotis et al., 2000; Tixier et al., 1998, 2000ab). The diversity of the *Phytoseiidae* family includes 2,880 described species across 101 genera (Demite et al., 2024). In Serbia, 51 species of phytoseiids from 15 genera have been recorded (Stojnić et al., 2023).

Spider mites are obligate phytophages and constitute the most significant group of pest mites in agriculture and forestry, currently comprising 1,356 phytophagous species, with over a hundred classified as pests and approximately ten as major pests (Migeon and Dorkeld 2024). Research on spider mites in Serbia has intensified over the past decade, with a total of 44 species documented to date (Đurkić 1955; Grujičić and Tomašević 1956; Marić et al., 2018; Mladenović et al., 2010ab, 2013ab, 2021ab; Petanović et al., 1983; Petanović and Stojnić 1995; Radivojević and Petanović 1984; Stojnić et al., 2002, 2014, 2018; Stojnić 1993; Tomašević 1964, 1965, 1967).

Carpinus betulus L., commonly known as the common or European hornbeam, was previously classified within the family *Corylaceae* Mirbel (Vukićević 1996). However, more recent classifications place the genus *Carpinus* within the family *Betulaceae* Gray (Cvijetićanin et al., 2016). This deciduous tree, growing up to 25 m tall, has a branched crown and spirally arranged leaves that are smooth on both sides. It is widely distributed across southern Europe (excluding the Iberian Peninsula), central Europe extending to southern England and southern Sweden, and, to the east, from the Black Sea to the Caucasus and northern Iran. Its altitudinal range reaches up to 700 m in central Europe, 1,000 m in the western Alps, and 1,800 m in Iran (Sikkema et al., 2016).

In Serbia, hornbeam is a common species, though it rarely forms pure stands, and is primarily found in mixed forests alongside oaks such as pedunculate oak and sessile oak. As a shade-tolerant species, it thrives in soils with excess moisture and is highly frost-resistant, playing an essential role in various mesophilic plant communities across lowland and hilly regions. These communities include sessile oak-hornbeam forests, pedunculate oak-hornbeam forests, Turkey oak and Hungarian forests, and montane beech forests up to 800 m a.s.l., where its leaf litter contributes mildly humic soil, which makes it a valuable understory species in oak forests (Cvijetićanin et al., 2016; Vukićević 1996).

Hornbeam wood is extremely hard and durable—the hardest among Serbia’s woody species (Cvijetićanin et al., 2016)—and is used for making tool handles, wooden pegs, drumsticks, billiard cues, piano mechanisms, and more. With its high calorific value, it is also an excellent firewood choice and sometimes serves as a substitute for maple (Sikkema et al., 2016). Numerous horticultural forms of hornbeam are locally cultivated, and its robust sprouting and suitability for pruning make it popular for hedging (Vukićević 1996).

2. MATERIALS AND METHODS

Leaf samples of comon hornbeam were collected during the 2020 growing season from forest and horticultural habitats at five locations on Mt. Goč and in the Vršac municipality.

Each sample, comprising 100 leaves, was treated with ethyl acetate (Stojnić et al., 2021) and then carefully examined under a Leica Wild M3Z binocular microscope to isolate mites. After clearing (Evans and Browning 1955), the mites were mounted on slides in Hoyer's medium (Baker and Wharton 1964; Krantz and Walter 2009).

Mite identification was conducted using a Leica DMLS phase contrast microscope, along with relevant keys and catalogs for the families *Phytoseiidae* and *Tetranychidae* (Baker and Tuttle 1994; Begljarov 1981; Bolland et al., 1998; Chant and McMurtry 2007; Karg 1993; Mitrofanov et al., 1987; Moraes et al., 2004; Pritchard and Baker 1955; Tixier et al., 2012).

Voucher specimens have been deposited in the Department of Forest Protection at the Institute of Forestry, Belgrade, and in the Department of Entomology and Agricultural Zoology at the Institute of Phytomedicine, University of Belgrade – Faculty of Agriculture.

3. RESULTS AND DISCUSSION

Three species of phytoseiid mites were identified on *C. betulus* leaf samples: *Amblyseius andersoni* (Chant, 1957), *Euseius finlandicus* (Oudemans, 1915), and *Paraseiulus soleiger* (Ribaga, 1904) (Table 1). These identified species represent the first recorded occurrence on the families *Betulaceae* and *Corylaceae*, as well as the genus *Carpinus* and the species *C. betulus* globally. According to the Phytoseiidae Database, 22 species of phytoseiid mites have been found on *Betulaceae* and eight species on *Corylaceae* to date, with only one species, *Typhlodromus (Typhlodromus) tulinae*, recorded on *C. betulus* in Turkey (Demite et al., 2024; Döker et al., 2023).

The species *A. andersoni* was found exclusively in the horticultural habitat in the Vršac location, while *E. finlandicus* and *P. soleiger* were identified in the forest ecosystems on Mt. Goč.

Table 1. *Phytoseiid mites (Acari: Phytoseiidae) found on hornbeam*

Host	Phytoseiidae Species	Habitat
Carpinus betulus	***Amblyseius andersoni***	Horticultural
	Euseius finlandicus	Forest
	Paraseiulus soleiger	Forest

Our research identified one species of spider mite, *Eotetranychus carpini* (Oudemans, 1905) on *C. betulus*, confirming earlier findings by Stojnić (1993) and

Marić et al. (2018). This tetranychid mite was found on hornbeam in both forest and horticultural habitats. To date, 37 species of spider mites have been recorded on the family *Betulaceae*, with 13 species on the genus *Carpinus* and nine species on *C. betulus*. In Serbia, in addition to *E. carpini*, three other tetranychid mite species from two subfamilies have been identified on hornbeam (Marić et al., 2018), bringing the total number of species to four.

A prey-predator complex was observed between *E. carpini* and *E. finlandicus* in the forest habitat, as well as between *E. carpini* and *A. andersoni* in the horticultural habitat.

The most common phytoseiid species in Serbia are *E. finlandicus* and *A. andersoni* (Stojnić et al., 2023). *E. finlandicus* is classified as a Type IV generalist predator that prefers pollen, with spider mites serving as a supplementary food source (McMurtry and Croft 1997; McMurtry et al., 2013). This species has been noted as a regulator of *Panonychus ulmi* (Koch, 1836), the European red mite, in temperate zones (McMurtry 1982). It is most commonly found on smooth leaves and hides in domatia when disturbed (Kabiček 2005, 2008). Furthermore, it is a cosmopolitan species (Demite et al., 2024).

A. andersoni is classified as a III-b subtype generalist, primarily preying on spider mites and eriophyids, with alternative food sources including pollen, honeydew, and phytopathogenic fungi (McMurtry et al., 2013; Pozzebon and Duso 2008). This species is frequently found on smooth leaves and has been documented as an efficient predator of various spider mites, including *E. carpini* (Camporese and Duso 1995; Duso et al., 2003; Duso and Camporese 1991). It is present in the Palearctic and Nearctic regions (Demite et al., 2024).

P. soleiger belongs to I-c subtype and is a specialised predator of tydeoids (*Tydeoidea*) (McMurtry et al., 2013). It is also found in the Palearctic and Nearctic regions (Demite et al., 2024).

E. carpini, commonly known as the yellow vine spider mite, has been recorded on 31 plant species across 15 families. It is distributed in the Palearctic and Nearctic regions (Migeon and Dorkeld 2024). It has been identified as a pest in vineyards in southern Europe (Malagnini et al., 2012).

4. CONCLUSIONS

This study contributes to the understanding of the species diversity of phytoseiid and tetranychid mites identified on the significant forest and horticultural woody species *C. betulus* in Serbia.

In Serbia, three species of predatory mites from the family *Phytoseiidae* were identified on hornbeam. They are *A. andersoni*, *E. finlandicus*, and *P. soleiger*, along with one species of phytophagous mite from the family *Tetranychidae*: *E. carpini*.

The findings of *A. andersoni, E. finlandicus* and *P. soleiger* represent the first recorded occurrences of these species globally within the family *Betulaceae* (formerly *Corylaceae*), the genus *Carpinus*, and the species *C. betulus***.**

Associations between predatory and phytophagous mites were observed in both examined habitats—forest and horticultural—specifically between *E. carpini* and *E. finlandicus*, as well as between *E. carpini* and *A. andersoni*.

Further research on acarofauna in Serbia is essential, particularly focusing on the fauna of phytoseiids as significant biological agents in forest and urban ecosystems.

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CONTRIBUTION TO THE STUDY OF MITE FAUNA (ACARI) ON HORNBEAM IN SERBIA

Katarina MLADENOVIĆ, Aleksandar VEMIĆ, Sabahudin HADROVIĆ, Milan KABILJO, Đorđe JOVIĆ

Summary

This study explores the diversity of mites associated with hornbeam in Serbia, offering a comprehensive overview of predatory and phytophagous mite species from the families *Phytoseiidae* and *Tetranychidae* identified in forest and horticultural habitats. We documented three predatory mite species from the *Phytoseiidae* family: *Amblyseius andersoni*, *Euseius finlandicus*, and *Phytoseius soleiger*, as well as one phytophagous mite species from the Tetranychidae family: *Eotetranychus carpini*. The three identified predatory species from the family *Phytoseiidae* represent the first documented findings for the family *Betulaceae*, specifically for the genus *Carpinus* and the species *Carpinus betulus*.

Our samples revealed a complex of prey-predator interactions between *E. carpini* and *E. finlandicus* in the forest habitat, as well as between *E. carpini* and *A. andersoni* in the horticultural setting. Both *A. andersoni* and *E. finlandicus* were categorised as generalist predators of different subgroups, effective against spider mites, including *E. carpini*. Conversely, *P. soleiger* is classified as a specialist predator that exclusively feeds on tydeid mites, a group not found in association with spider mites in our observations.

Further research on the diversity of *Phytoseiidae* and *Tetranychidae* on forest plant species, which serve as natural reservoirs for predatory mites, is necessary, as they regulate the populations of economically significant phytophagous mite pests.

PRILOG POZNAVANJU FAUNE GRINJA (ACARI) NA GRABU U SRBIJI

Katarina MLADENOVIĆ, Aleksandar VEMIĆ, Sabahudin HADROVIĆ, Milan KABILJO, Đorđe JOVIĆ

Rezime

U radu je prikazan diverzitet grinja na grabu u Srbiji gde je dat pregled vrsta predatorskih i fitfagnih grinja iz familije Phytoseiidae i Tetranychidae utvrđenih na šumskim i hortikulturnim staništima. Na grabu je zabeleženo prisustvo tri vrste predatorskih grinja iz fam. Phytoseiidae - *Amblyseius andersoni*, *Euseius finlandicus* i *Phytoseius soleiger* i jedne vrste fitofagne grinja iz fam. Tetranychidae - *Eotetranychus*

carpin. Tri determinisane predatorske vrste fam Phytoseiidae su u svetu prvi nalaz za fam. Betulaceae odnosno fam. Corylaceae, rod *Carpinus* i vrstu *Carpinus betulus*.

U uzorcima utvrđen je specijski kompleks plen-predator između *E. carpini* i *E. finlandicus* u šumskom staništu *odnosno E. carpini* i *A. andersoni* na hortikulturnom staništu. *A. andersoni* i *E. finlandicus* su prema životnom stilu grupisani u predatore generaliste različitih podgrupa koje su zabeleženi kao efikasni predatori paučinara među kojima je plen i *E. carpini*. *P. soleiger* je u grupi predatora specijalista koja se hrani tideidama, vrsta koja u našim nalazima nije nadjena u zajednici sa paučinaima. Potrebno je nastaviti dalja istraživanja diverziteta fitozeida I tetranihida na šumskim biljnim vrstama koje su prirodni rezervoari predatorskih grinja a koje su regulatori brojnosti fitofagnih grinja koje su ekonomski značajne štetočine.

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USE OF A DATABASE FOR DETERMINING THE SPATIAL DISTRIBUTION OF PESTS AND DISEASES IN THE FORESTS OF SERBIA

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Abstract: *The paper presents the monitoring of biotic damage agents over a five-year period (from 2018 to 2022) at bio-indication point BIT I Štubik near Negotin, which includes oak trees (7/8 of all trees) and maple trees (1/8 of the total number of trees at the site). The presence of several types of biotic damage agents was recorded, some of which are very dangerous and significant. The most common were harmful insects, among which the most notable was the gypsy moth Lymantria dispar. At the end of the study in 2022, the highest number of undamaged trees was recorded (83.3%), while the most damage was present in 2019 when only 1/4 of the trees were undamaged. It can be said that the condition of the crowns is directly related to the percentage of biotic damage agents.*

Keywords: Sample plot, Defoliation, Forest pathology

KORIŠĆENJE BAZE PODATAKA NA BIT I U CILJU UTVRĐIVANJA PROSTORNOG RASPOREDA ŠTETOČINA I BOLESTI U SASTOJINAMA SRBIJE

Apstrakt: *U radu je prikazano praćenje biotičkih uzročnika šteta u petogodišnjem periodu praćenja (od 2018. do 2022. godine) na BIT I Štubik kod Negotina koja obuhvata stabla hrasta (7/8 svih stabala) i klena (1/8 od ukupnog broja svih stabala na tački). Registrovano je prisustvo više tipova biotičkih uzročnika oštećenja od kojih su neka vrlo opasna i značajna, a najčešći su štetni insekti od kojih je najznačajniji gubar Lymantria dispar. Na kraju istraživanja 2022. je zabeležen najveći broj stabala bez oštećenja (83,3%), dok je najviše oštećenja bilo prisutno 2019. godine kada je svega 1/4 stabala bila bez oštećenja. Može se reći da je stanje kruna u direktnoj vezi sa procentualnim učešćem biotičkih uzročnika šteta.*

Ključne reči: bioindikacijske tačke, defolijacija, šumska patologija

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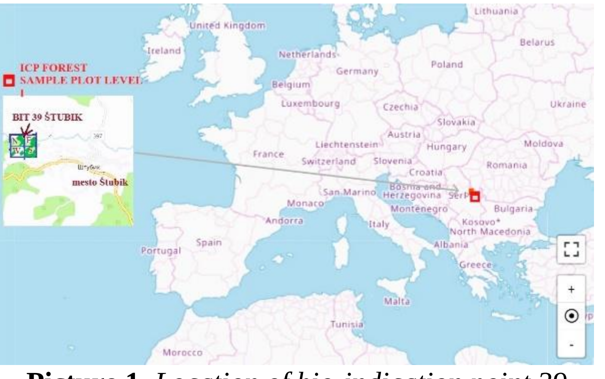
1. INTRODUCTION

The forest health information system is the result of certain activities within sustainable forest management, which is the basis of many international and national policies (FAO, 2010; UNECE, FAO, 2011). Monitoring plant diseases and pests is a key element of ecological policy, and without it, standards for forests and the environment cannot be applied. Data processing and reporting invariably follow uniform methodologies compiled according to international standards (Gregoire and Valentine, 2008). The results of the monitoring must be easily accessible and support the system of ecological indicators. Studies and monitoring are conducted by scientific institutions that prepare the database, assessments, and analyses at the national level.

The Republic of Serbia has been involved in the ICP Forests program since 2003 through its National Focal Centre for Forest Condition Monitoring (NFC), which, in collaboration with the National Expert Group (NEG), conducts data analysis and interpretation of results, assists in the scientific management of the Program, and participates in international expert panels (IEP) and working groups (WG). The primary goal of monitoring crown conditions is to provide periodic insights into the spatial and temporal variations in forest conditions, in relation to anthropogenic and natural stress factors within European and national systematic large-scale observation networks. Exposure to stress or constant attacks by insects and diseases makes forest ecosystems more susceptible to epidemics and epiphytotics (Wulff, 2011, Gagić-Serdar *et al*, 2021), and therefore, monitoring the occurrence and spread of biotic harmful factors is imperative.

In the last year of the presented study, in 2022 in Serbia, the total number of all bio-indication points at Level I, set up in a sixteen-kilometer and a four-kilometer grid, was 130 – of which 117 were in central Serbia and 13 in Vojvodina. The total number of examined trees was 2886. The total number of points with oak as the dominant species was 69, meaning that oaks are the edifiers at almost half of all points that have been monitored for more than 20 years.

The trees examined and presented in this paper, cited as examples of the database use, belong to bio-indication point level I, no. 39 (Picture 1) located in Štubik near Negotin (coordinates: 7602947; 4907150).



Picture 1. *Location of bio-indication point 39*

The point is located on a geological substrate of gneiss, with Cambisols, Calcaric Cambi soil type, at an altitude of 330 meters, facing south. The crown cover is high at 90%, and water availability is sufficient. The trees are between 25 and 100 years old, with a pronounced multi-layered structure.

The point includes the following tree species: *Quercus cerris* - 17 trees (70.8%), *Quercus frainetto* - 4 trees (16.7%), *Acer campestre* - 3 trees (12.5%). Therefore, oaks account for a total of 87.5% (or 7/8 of all trees), and field maple accounts for 12.5% (or 1/8 of the total number of trees).

2. MATERIAL AND METHODS

The methods are described in the first Manual as Visual Assessment of Crown Condition, and in the Submanual on Visual Assessment of Crown Condition on Intensive Monitoring Plots (Eichhorn et al, 2010). The Manual has been redesigned to provide harmonized data and a more flexible approach to monitoring crown conditions, with improved and more transparent quality. All parameters described in the latest version of the Manual have been tested in several countries in Europe or North America, while the parameter values are continuously monitored under the control of international expert panels. Any necessary adjustments will be recommended at the annual ICP Forests Task Force meetings in the coming years.

All marked trees at the points are numbered in a clockwise direction, starting from geographic north, and each tree is identified taxonomically. Damages observed in the field are recorded in intervals of 5% (de Lourdes Saavedra-Romero *et al*., 2021). Considering that approximately one-fifth of defoliation can be attributed to abiotic or biotic damages (Nevalainen *et al*., 2010), the assessment of chlorosis (discoloration or color change of leaf mass) and defoliation (branch drying) is performed on marked trees every year during the vegetation period. The severity of chlorosis and drying is indicated in percentages from 0 to 100. Crown defoliation is an indicator of tree condition assessment, although the causes of defoliation can be non-specific and the result of a range harmful agents, making them difficult to quantify with certainty. Therefore, it is necessary to understand the most significant factors causing damage to trees. In addition, damages by types and causes are recorded in the manuals and marked with codes.

For biotic causes, in addition to the code, the Latin name of the damage-causing agent, the developmental stage of the harmful agent, a description of the affected part of the plant, the age of the affected needles, etc., are recorded.

Visual assessments of tree defoliation are subjective; therefore, the consistency of the assessment, which is the most commonly used indicator of tree condition, has often been the focus of scientific criticism (Nakajima et al., 2011). Despite high correlations and disagreements among observers, there is a possibility of systematic error (Eickenscheidt & Wellbrock, 2013). To minimize the possibility of error, efforts are made to have the same team visit the same sites each year for visual assessments of crown condition.

3. RESULTS

Table 1 presents the results of crown condition monitoring and the incidence of biotic damage at bio-indication point 39 over the five-year period from 2018 to 2022.

As seen from the table below, the condition of the crowns slightly varied from 2018 to 2022. The highest percentage of trees in class 1 (no drying or with very low symptoms of drying) was in 2021 (91.7%) and 2018 (54.2%), while the most trees in class 1 (drying up to 25%) were in 2019 (75.0%) and 2022 (58.3%). There were very few trees (8.3%) in class 2 (drying up to 60%), and only in 2018 and 2019, while in classes 3 and 4 (severe drying up to 100.0%) there were no trees throughout the entire study period. Generally speaking, the health condition of the examined trees has improved over time.

Table 1. *Crown condition and percentage of biotic damage on bio-indication point 39 in the period 2018 – 2022*

Defoliation (%)						
Classes of defoliation	Drying of branches	**2018**	**2019**	**2020**	**2021**	**2022**
0	0 - 10 %	**54.2**	16.7	79.2	**91.7**	41.7
1	10 - 25%	37.5	**75.0**	20.8	8.3	**58.3**
2	25 - 60 %	8.3	8.3	0.0	0.0	0.0
3	60 - 100 %	0.0	0.0	0.0	0.0	0.0
4	100 %	00	0.0	0.0	0.0	0.0
Biotic damage (%)						
Defoliators from the order Lepidoptera		8.3	16.7	0.0	0.0	0.0
Miners from family Gracilaridae		0.0	0.0	12.5	0.0	0.0
Leafrollers from family Tortricidae		8.3	0.0	0.0	0.0	0.0
Witches' brooms of species *Taphrina* sp.		0.0	4.2	0.0	0.0	0.0
Bacterial galls (*Bacterium tumefaciens*)		0.0	0.0	4.2	0.0	0.0
Branch-decay and wood-decay fungi from division Basidiomycota		12.5	20.8	4.2	12.5	0.0
Gall wasps from families Cynipidae and Cecidomydae		12.5	12.5	12.5	16.7	0.0
Neuroterus quercus baccarum		20.8	25.0	12.5	16.7	0.0
Lymantria dispar		0.0	4.2	0.0	0.0	16.7
Without agents of biotic damage		**37.5**	**25.0**	**54.2**	**58.3**	**83.3**

Regarding the incidence of biotic damage on the trees, it should be noted that multiple types and species of biotic damage were recorded on some trees. During the study period, the presence of insects from the order Lepidoptera was recorded, but only at the beginning of the study - in 2018 and 2019. Leaf miners from the family Gracillariidae were present only in 2020, while the presence of leaf rollers from the family Tortricidae was noted only at the beginning of the study, in 2018. Wood-decay fungi from the class Basidiomycota were not observed only in the last year of the study, while their highest incidence was recorded in 2019. The same applies to gall makers from the families Cynipidae and Cecidomyiidae, as well as the species *Neuroterus quercusbaccarum*, which were not recorded only in the last year of the study. Among the less significant species, witches' broom caused by *Taphrina* sp. and crown gall caused by the bacterium *Bacterium tumefaciens* were recorded. Gypsy moth (*Lymantria dispar*) egg masses were observed at a low incidence in 2019 (4.2% of trees) and at four times that incidence in the last year of the study (16.7%) (Figures 2 and 3). It is important to note that gypsy moth egg masses have been present at this point since 2019, and their numbers have gradually increased. However, they were not recorded on the marked trees in all years, so they are not shown in the table.


Pictures 2 and 3. *Gypsy moth egg masses on bio-indication point BIT 39 (August 2022)*

At the end of the 2022 study, the highest number of undamaged trees was recorded (83.3%), while the most damage was present in 2019 when only 1/4 of the trees were undamaged. Practically, it can be said that the condition of the crowns is directly related to the percentage of biotic damage causes, and in the years with the most damage, the highest class of defoliation was also recorded.

4. DISCUSSION

Among all the observed types of biotic damage causes on the trees, the most important is the gypsy moth, as it is a gradation species and can cause extensive damage. The most damage is usually suffered by Turkey oak forests and Hungarian oak, which are dominant at the location presented in this paper. The egg masses were observed in August and were full of fertilized eggs, mostly undamaged by birds and other predators.

It is important to note that the gypsy moth in Serbia is in latency and almost nowhere has the presence of egg masses been registered. The few egg masses found throughout Serbia were located in the understory, very low, and were irregular, small, and damaged.

5. CONCLUSION

In the period from 2018 to 2022, on the examined bio-indication point 39, the presence of several types of biotic damage causes was recorded, some of which are very dangerous and significant, with the most common being harmful insects and wood-decay fungi.

Of all the observed types of biotic damage causes on the trees, the most important is the gypsy moth, given that it is a gradation species and can cause extensive damage. Considering that the gypsy moth has been in latency in Serbia in recent years and its presence has hardly been registered, special attention should be paid to oak sites near the examined area due to a high possibility of a significant increase in its population in the coming period. In such a case, mechanical removal would be necessary to prevent more serious damage to the stands. Besides defoliation, this could cause a chain of damages and would certainly affect tree growth.

The database in which data from bio-indication points Level I is collected can be used in segments, allowing searches by tree species, diseases, pests, periods, etc. The data from the database related to a specific tree species and the population density of the most important diseases and pests, as well as other types of mechanical and abiotic damage (within a specific time period), open up wide possibilities for the practical application of these studies.

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USE OF A DATABASE FOR DETERMINING THE SPATIAL DISTRIBUTION OF PESTS AND DISEASES IN THE FORESTS OF SERBIA

Miroslava MARKOVIĆ, Renata GAGIĆ-SERDAR, Goran ČEŠLJAR, Suzana MITROVIĆ, Đorđe JOVIĆ, Mihajlo MARKOVIĆ

Summary

The paper presents the monitoring of biotic damage agents over a five-year period (from 2018 to 2022) at bio-indication point BIT I Štubik near Negotin, which includes oak trees (7/8 of all trees) and maple trees (1/8 of the total number of trees at the site). The presence of several types of biotic damage agents was recorded, some of which are very dangerous and significant. The most common were harmful insects, among which the most notable was the gypsy moth Lymantria dispar. At the end of the study in 2022, the highest number of undamaged trees was recorded (83.3%), while the most damage was present in 2019 when only 1/4 of the trees were undamaged. It can be said that the condition of the crowns is directly related to the percentage of biotic damage agents, and in the years with the highest number of damages, the highest defoliation class was also recorded.

In the period from 2018 to 2022, on the examined bio-indication point 39, the presence of several types of biotic damage causes was recorded, some of which are very dangerous and significant, with the most common being harmful insects and wood-decay fungi.

Of all the observed types of biotic damage causes on the trees, the most important is the gypsy moth, given that it is a gradation species and can cause extensive damage. Considering that the gypsy moth has been in latency in Serbia in recent years and its presence has hardly been registered, special attention should be paid to oak sites near the examined area due to a high possibility of a significant increase in its population in the coming period. In such a case, mechanical removal would be necessary to prevent more serious damage to the stands. Besides defoliation, this could cause a chain of damages and would certainly affect tree growth.

The database in which data from bio-indication points Level I is collected can be used in segments, allowing searches by tree species, diseases, pests, periods, etc. The data

from the database related to a specific tree species and the population density of the most important diseases and pests, as well as other types of mechanical and abiotic damage (within a specific time period), open up wide possibilities for the practical application of these studies.

KORIŠĆENJE BAZE PODATAKA NA BIT I U CILJU UTVRĐIVANJA PROSTORNOG RASPOREDA ŠTETOČINA I BOLESTI U SASTOJINAMA SRBIJE

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Rezime

U radu je prikazano praćenje biotičkih uzročnika šteta u petogodišnjem periodu praćenja (od 2018. do 2022. godine) na BIT I Štubik kod Negotina koja obuhvata stabla hrasta (7/8 svih stabala) i klena (1/8 od ukupnog broja svih stabala na tački). Registrovano je prisustvo više tipova biotičkih uzročnika oštećenja od kojih su neka vrlo opasna i značajna, a najčešći su štetni insekti od kojih je najznačajniji gubar *Lymantria dispar*. Na kraju istraživanja 2022. je zabeležen najveći broj stabala bez oštećenja (83,3%), dok je najviše oštećenja bilo prisutno 2019. godine kada je svega 1/4 stabala bila bez oštećenja. Može se reći da je stanje kruna u direktnoj vezi sa procentualnim učešćem biotičkih uzročnika šteta i u godinama sa najvećim brojem oštećenja, zabeležena je i najviša klasa defolijacije.

U periodu od 2018. do 2022. godine na ispitivanoj BIT 39 godine registrovano je prisustvo više tipova biotičkih uzročnika oštećenja od kojih su neka veoma opasna i značajna, a najčešći su štetni insekti i gljive truležnice.

Od svih konstatovanih vrsta prouzrokovača biotičkih šteta na stablima, najvažniji je gubar jer spada u gradogene vrste i može izazvati štete velikih razmera. S obzirom da je gubar je u Srbiji poslednjih godina u latenci i gotovo nigde nije registrovano njegovo prisustvo, na hrastove lokalitete koji se nalaze u blizini ispitivane tačke treba obratiti posebnu pažnju jer postoji velika mogućnost da će u nastupajućem periodu tu doći do značajnog povećanja njegove brojnosti populacije. U tom slučaju bilo bi potrebno njihovo mehaničko uklanjanje, da ne bi došlo do pojave ozbiljnijih šteta u sastojinama – osim golobrsta, to bi moglo da prouzrokuje ulančavanje šteta, a svakako bi se odrazilo i na prirast stabala.

Baza u kojoj se sakupljaju podaci sa BIT Nivoa I može se koristiti po segmentima, što omogućava pretraživanje po vrstama drveća, bolestima, štetočinama, periodima itd. Podaci iz baze koji se odnose na određenu vrstu drveća i gustinu populacije najvažnijih bolesti i štetočina, kao i druge tipove oštećenja mehaničkog i abiotičkog porekla (u okviru određenog vremenskog perioda), otvaraju široke mogućnosti u praktičnoj primeni ovih istraživanja.

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ANALYSIS OF THE CHEMICAL COMPOSITION OF THREE FUNGAL SPECIES WITH MEDICINAL PROPERTIES TO INVESTIGATE THEIR MEDICAL AND ECOLOGICAL POTENTIAL

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Abstract: *This study analyzes the chemical composition of three medicinal fungal species: Fomes fomentarius, Ganoderma lucidum, and Trametes versicolor, with the aim of examining their mineral content, essential elements, trace elements, macroelements, and pH in order to evaluate their medical and ecological potential. The fungi are rich in bioactive compounds, including polysaccharides, triterpenes, and phenolic compounds, which are being studied for their potential therapeutic properties, such as anticancer, anti-inflammatory, and immunomodulatory effects. Additionally, the presence of essential minerals and trace elements, such as calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn), contributes to their nutritional value. The study revealed that the pH values of these fungi vary. Furthermore, the analysis indicated the presence of toxic metals, such as cadmium (Cd), lead (Pb), and mercury (Hg), which may pose health risks if the fungi are consumed or used for medicinal purposes in pharmaceutical preparations. This paper also discusses the potential of these fungifungis within the context of circular bioeconomy and bioremediation, as well as their role in sustainable production and biodiversity conservation. The results suggest that these fungi have a wide range of potential applications, though further research is required to optimize their use in medicine and ecological processes.*

Keywords: medical fungi, chemical composition, medical potentional, ecological potentional.

ANALIZA HEMIJSKOG SASTAVA TRI VRSTE GLJIVA SA LEKOVITIM SVOJSTVIMA U CILJU ISPITIVANJA NJIHOVOG MEDICINSKOG I EKOLOŠKOG POTENCIJALA

Apstrakt: *U ovom radu analiziran je hemijski sastav tri vrste lekovitih gljiva, F. fomentarius, G. lucidum i T. versicolor, s ciljem ispitivanja sastava ovih gljiva u smislu sadržaja minerala, esencijalnih elemenata, elementa u tragovima i makroelemenata kao i pH u svrhu ispitivanja njihovog medicinskog i ekološkog potencijala. Gljive su bogate bioaktivnim komponentama, uključujući polisaharide, triterpene i fenolna jedinjenja, koji se istražuju zbog svojih potencijalnih terapeutskih svojstava, kao što su antikancerogena,*

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antiinflamatorna i imunomodulatorna delovanja. Takođe, prisustvo esencijalnih minerala i elemenata u tragovima poput kalcijuma (Ca), magnezijuma (Mg), gvožđa (Fe) i cinka (Zn) doprinosi njihovim hranljivim svojstvima. Istraživanje je pokazalo da su pH vrednosti ovih gljiva različite. Takođe, analiza je ukazala na prisustvo toksičnih metala, poput kadmijuma (Cd), olova (Pb) i žive (Hg), koji mogu predstavljati rizik za ljudsko zdravlje ako se gljive konzumiraju ili upotrebljavaju u lekovite svrhe za lečenje i pripremu nekih farmaceutskih preparata.. Ovaj rad takođe razmatra potencijal ovih gljiva u kontekstu cirkularne bioekonomije i bioremedijacije, kao i njihovu ulogu u održivoj proizvodnji i zaštiti biodiverziteta. Rezultati pokazuju da ove gljive mogu imati širok spektar primene, ali je potrebno sprovesti dalja istraživanja kako bi se optimizovala njihova primena u medicini i ekološkim procesima.

Ključne reči: lekovite gljive, hemijski sastav, medicinki potencijal, ekoloski potencial.

1. INTRODUCTION

Most lignicolous fungi play a crucial role in the decomposition of organic materials within ecosystems, significantly influencing nutrient cycling. Beyond their ecological role, many fungal species, including *Fomes fomentarius* (L.) Fr., *Ganoderma lucidum* (Fr.) P. Karst., and *Trametes versicolor* (L.) Lloyd, are recognized for their potential therapeutic properties and are frequently used in traditional medicine (Karadžić, D., et al., 2022). These fungi contain bioactive compounds that may contribute to human health, but they also possess a chemical composition with significant ecological implications. Analyzing the chemical composition of these fungi, with particular emphasis on essential minerals and trace elements, provides insight into their potential for human health, as well as their possible impact on ecological systems.

In addition to their health-promoting potential, concerns have been raised regarding the accumulation of heavy metals in fungi, which may pose adverse effects on human health. Given the growing interest in biotherapy and bioremediation, it is crucial to conduct thorough analyses of various fungal species to ensure their safe and effective medical and ecological potential (Nicola, D., 2023).

According to Venturela et al. (2021) many species of fungi contain bioactive substances, such as polysaccharides, triterpenes, and phenolic compounds, which are being studied for their potential antibacterial, antifungal, anti-inflammatory, antioxidative, antiviral, cytotoxic, immunomodulating, antidepressive, antihyperlipidemic, antidiabetic, digestive, hepatoprotective, neuroprotective, nephroprotective, osteoprotective, and hypotensive activities.

Minerals are fundamentally metals and other inorganic substances, present in all body tissues and fluids, and necessary for the maintenance of certain physicochemical processes essential to life (Gupta & Gupta, 2014). Minerals can be classified as either major mi-nerals (that are required in the diet each day in amounts of >100 mg) or trace elements (that are required in the diet each day in amounts of <100 mg). The major minerals include calcium, potassium, sodium, magnesium, and phosphorus, which are present in edible fungi in sufficient quantity. On the other hand, the trace minerals encompass iron, zinc, selenium, copper, manganese, iodine, cobalt, chromium, and molybdenum (Awuchi, 2020).

Furthermore, trace elements such as zinc (Zn), iron (Fe), magnesium (Mg), and calcium (Ca) may contribute to their nutritional value. In terms of their ecological role, fungi can be a significant factor in maintaining ecosystem balance due to their impact on soil structure and pH.

This study examines the chemical composition of *F. fomentarius*, *G. lucidum*, and *T. versicolor*, focusing on beneficial minerals and trace elements, pH values that may influence the environment, and the potential of these fungi in the context of circular bioeconomy and biodiversity.

2. MATERIAL AND METHODS

Fruiting bodies samples (carpophores) were collected in the area of National Park Tara. Species identification was performed based on the appearance of the fruiting bodies (carpophores), type of decay, and the appearance of the obtained pure cultures. To confirm the fungi identification, descriptions of these species provided in the publications of the following authors were used: Breitenbach, J., Kränzlin, F. (1986), Hagara, L. (2014), Jahn, H. (1979), and Karadžić, D., Anđelić, M. (2002).

The fruiting bodies sampling was conducted in accordance with standardized procedures to minimize contamination risk and preserve the integrity of the samples. Three species of fungi were used for analysis: *F. fomentarius*, *G. lucidum*, and *T. versicolor*, collected between September and November 2022, from the aforementioned site, which is minimally exposed to anthropogenic influences, allowing for the analysis of pure natural samples.

The fruiting bodies samples were subjected to microwave digestion using the Ethos Easy device (Milestone) for complete mineralization and preparation for analysis. This method allows for efficient and rapid extraction of minerals from biological samples, enabling precise determination of concentrations of various elements and trace elements.

After digestion, the concentrations of minerals in the samples were analyzed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES Varian Vista pro), a standard method for quantifying metals and other trace elements in complex samples. This technique enables highly accurate determination of concentrations of elements such as aluminium (Al), calcium (Ca), iron (Fe), magnesium (Mg), zinc (Zn), and other minerals present in the fungi.

Chemical samples were analyzed following standardized procedures, and the pH value of the fungi was measured using a pH meter (Kacjan et al., 2020). All experiments were performed in triplicate, and the data were statistically processed using cluster analysis to compare mineral concentrations between different fungal species.

3. RESULTS AND DISCUSSION
3.1. Chemical Composition of the fungi

These data provide insight into the nutritional potential of three analysed fungi, which are used in both traditional and modern medicine for their numerous health benefits. The following table presents the laboratory analysis results of the mineral composition of the three fungal species.

Table 1. *Mineral Composition of Three fungal Species*

mg/kg	Al	Ba	Ca	Cd	Cr	Cu	Fe	Hg	K	Mg	Mn	Na	P	Pb	S	Se	Sr
FF	33.37	301.6	4408	0.496	0.474	4.76	42.03	0.045	1831	562.3	4.191	19.372	861	2.473	383.3	1.332	3.198
GL	57.17	121.3	2345	10.56	0.282	4.068	154.3	0.001	2054	638	10.43	60.28	1817	0.42	1197	4.514	0.183
TV	62.03	33.83	3952	0.005	0.087	3.155	122.3	0.001	2660	528.6	16.49	33.16	1457	0.001	633.4	1.617	0.218

FF-*F. fomentarius;GL- G. lucidum; TV-T. versicolor*

Toxins in the Fungi

Although medicinal fungi offer numerous health benefits, caution is advised due to the possibility of accumulating toxic elements, such as heavy metals. Although the concentrations of heavy metals like cadmium (Cd), lead (Pb), and mercury (Hg) in all analyzed species are not high, additional attention is needed when using these fungis in diet or medicine.

The presence of cadmium in Ganoderma lucidum (10.56 mg/kg) and F. fomentarius (0.496 mg/kg) can pose a significant health risk, especially when consumed in large amounts over extended periods. Cadmium is known for its nephrotoxic effects (kidney toxicity) and can lead to long-term health issues such as kidney damage, hypertension, and osteoporosis. Careful dosage and controlled use of these fungi for therapeutic purposes are recommended.

Lead and mercury are also heavy metals that can accumulate in fungi, and their presence in concentrations exceeding permissible limits can lead to neurotoxic effects, nervous system problems, and cardiovascular damage. The use of fungi with high concentrations of these metals can pose a long-term threat, especially to sensitive populations such as children and pregnant women.

Chemical Composition of the Fungi and Its Significance for Their Use

Fomes fomentarius (FF): This fungi is rich in calcium (4408 mg/kg) and potassium (1831 mg/kg), which are beneficial for bone health and electrolyte balance. Additionally, the concentrations of zinc (50.21 mg/kg) and manganese (4.191 mg/kg) confirm its role in the immune system and enzyme activity. However, the presence of cadmium (0.496 mg/kg), although within permissible limits, may pose long-term adverse effects on human health if consumed in excess.

Ganoderma lucidum (GL): While GL is rich in iron (154.3 mg/kg) and phosphorus (1817 mg/kg), which are useful for red blood cell production and energy metabolism, the presence of cadmium (10.56 mg/kg) presents a serious challenge for its safe use. The cadmium content in GL could cause severe toxic effects, particularly for individuals who consume it regularly, so controlling the doses and methods of application for therapeutic purposes is critical.

Trametes versicolor (TV): TV appears to be the most favorable fungi sample in terms of toxic metal concentrations, while being rich in calcium (3952 mg/kg) and potassium (2660 mg/kg), essential for electrolyte balance and bone health. Due to low cadmium and lead concentrations, TV can be considered safer for consumption and potential use in bioremediation.

According to research by El Sheikh, A.F. (2022), G. lucidum contains the highest amounts of potassium (432 mg/100 g), phosphorus (225 mg/100 g), and sulfur (129 mg/100 g), while iron (2.22 mg/100 g) and zinc (0.7 mg/100 g) are present in trace amounts.

According to Hobbs (2005), Schizophyllum commune contains phosphorus (408 mg/100 g), magnesium (277 mg/100 g), calcium (188 mg/100 g), iron (12.3 mg/100 g), magnesium (8.8 mg/100 g), zinc (5.7 mg/100 g), copper (0.9 mg/100 g), and chromium (133 μg/100 g).

Ahlawat, O.P., et al. (2016) state that Volvariella bombycina contains vitamin D (107 IU/g), calcium (25.61 mg/kg), phosphorus (4.12 mg/kg), iron (72.5 mg/kg), copper (50.2 mg/kg), zinc (119.95 mg/kg), and magnesium (0.12 mg/kg).

High concentrations of minerals such as calcium (Ca), iron (Fe), magnesium (Mg), phosphorus (P), and zinc (Zn) in fungi like F. fomentarius and G. lucidum indicate their potential as sources of nutrients that could benefit human health. For example, calcium is critical for bone and dental health, while iron is essential for oxygen transport in the blood, and magnesium plays a role in muscle function and metabolism. Additionally, the presence of minerals like manganese (Mn) and copper (Cu) can contribute to the body's defence against oxidative stress, which is often associated with the prevention of chronic diseases (Agarwal et al., 2021).

3.2. pH Values of the Fungi

In this study, the pH values of the fungi were analyzed, and the results were as follows:

- ***Fomes fomentarius* (FF):** pH 4.63
- ***Ganoderma lucidum* (GL):** pH 4.1
- ***Trametes versicolor* (TV):** pH 5.32

Significant differences between the species are evident: F. fomentarius and G. lucidum exhibit an acidic character, while T. versicolor shows a weaker acidic pH value.

3.3. Cluster Analysis as a Method of Grouping Parameters

Cluster analysis is a statistical method that enables the grouping of samples based on similarities in various chemical parameters, such as the content of polysaccharides, phenolic compounds, and micronutrients in medicinal fungi. This method is useful for identifying patterns in the chemical composition of fungi, which can help in understanding their therapeutic active properties and determining pH values that influence their biological activity. Cluster analysis allows for a detailed examination of the variations in composition between different species and their potential medicinal benefits (Zhou et al., 2020).

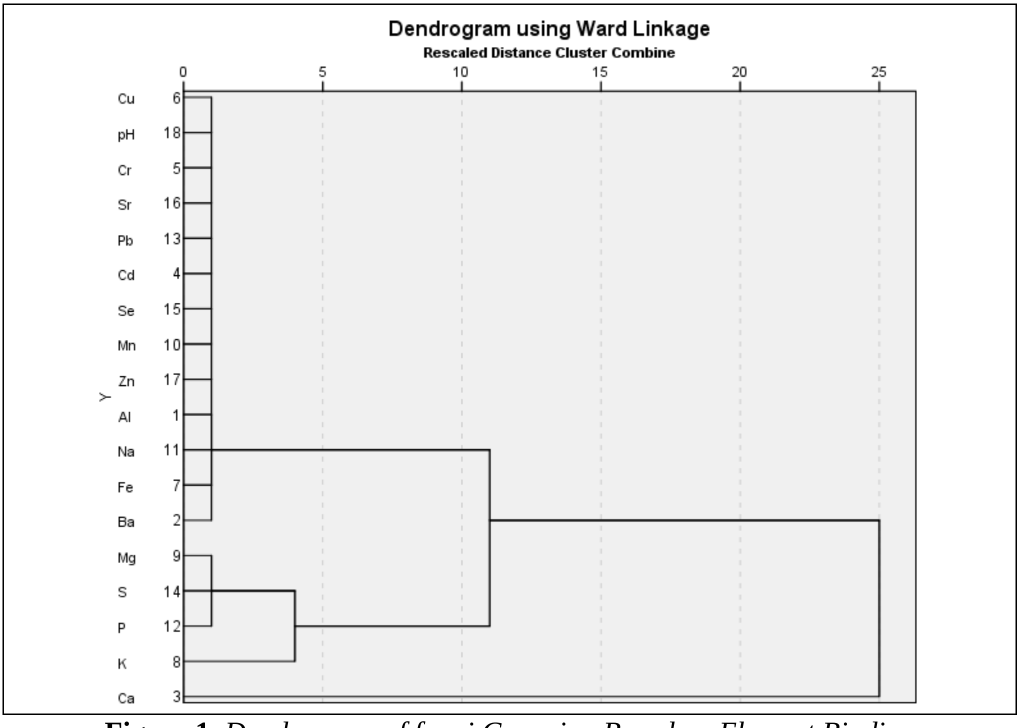

Figure 1. *Dendrogram of fungi Grouping Based on Element Binding*

As shown in Figure 1, different species of fungi are primarily grouped based on the binding of the investigated parameters. In the first cluster, pH value is grouped with most microelements, rather than with macroelements (Ca, Mg, K, P, S), due to the more significant impact of pH on the solubility and presence of microelements, as opposed to macroelements.

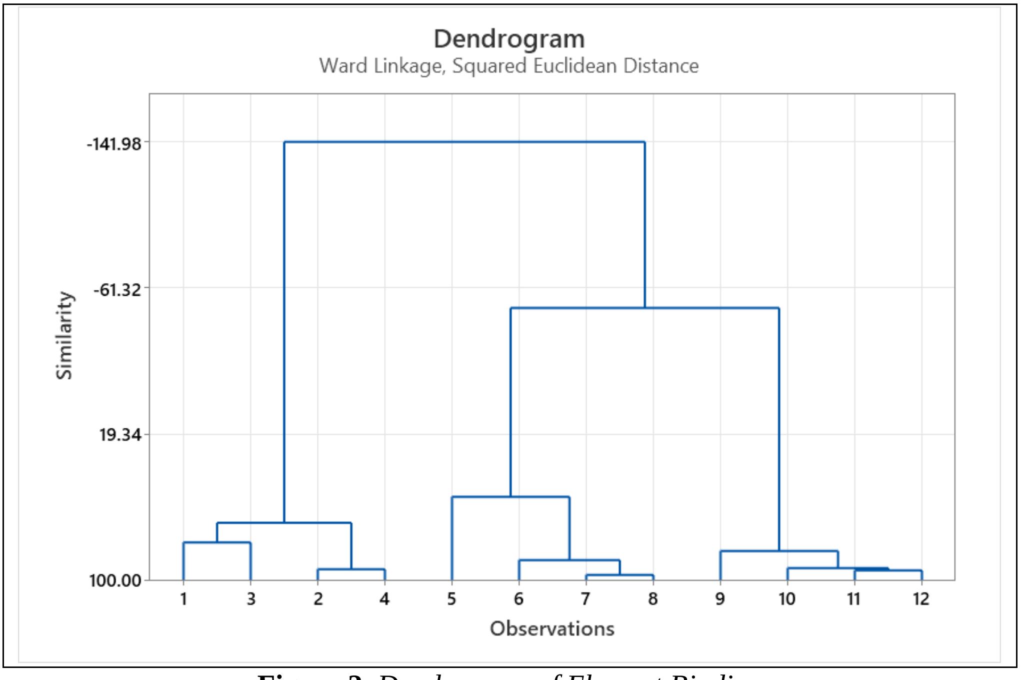

Figure 2. *Dendrogram of Element Binding*

Figure 2 illustrates how the fungi are grouped based on their mineral composition. Primarily, three clusters emerged, each representing a specific species of fungi, i.e. *F. fomentarius*, *G. lucidum*, and *T. versicolor*. Each cluster contains samples of only one species, indicating clear distinctions in their mineral content.

3.4. Circular Bioeconomy and the Role of Fungi in Sustainable Production

Circular bioeconomy promotes the use of biological resources in a way that minimizes waste and supports renewable energy and material sources. Fungi such as *F. fomentarius*, *G. lucidum*, and *T. versicolor* play a key role in this context, as they are utilized in bioremediation, biotechnology, and the pharmaceutical industry (Kavanagh, K., 2018). Due to their ability to break down organic matter, these fungi can aid in waste recycling and soil regeneration, reducing the need for artificial fertilizers and pesticides. Their application in biotechnology, such as the production of bioactive compounds, also contributes to reducing the ecological footprint of industrial production (Zhang et al., 2022).

Based on previous research, all three fungi possess medicinal properties and have potential applications in the pharmaceutical industry. Due to their solid fruiting bodies, they can be used after drying as powdered form, in tincture form (extraction of the fruiting bodies in alcohol), and in the form of an infusion (after pouring boiling water, allowing it to steep for 25 minutes).

According to Karadžić et al. (2022), *F. fomentarius* also exhibits medicinal properties, such as: antibacterial activity; inhibition of the growth of gastric cancer cells SGC-7901 and MKN-45; inhibition and apoptosis of lung cancer cells (A549); antiviral effects (against the H1N1 influenza virus and herpes simplex virus type

HSV-2, strain BH); immunomodulatory effects; antioxidant activity; and it is beneficial for the correction of hyperglycemia and prevention of additional complications caused by diabetes.

In Europe, *G. lucidum* are sold as dietary supplements. This fungi contains vitamins (primarily C, D, E, B1, B2, B6, and B12) and minerals (notably calcium, phosphorus, iron, silver, zinc, manganese, germanium, and barium). The content of natural, organic germanium is ten times higher than that of ginseng (El Sheikha, 2022; Huie et al., 2000). According to Chen (1999), *G. lucidum* is used to treat insomnia, anorexia, dizziness, chronic hepatitis, high cholesterol, coronary diseases, high blood pressure, cancer, and bronchial asthma. It is also used as an antidote for poisoning from certain toxic fungi and for prevention of altitude sickness in mountaineering.

T. versicolor has medicinal properties and is used for: reducing the toxicity of oncology treatments in the therapy of metastatic colorectal cancer, against liver, lung, gastrointestinal, and breast cancers, improving the immune system, and against hepatitis C (Hobs, C., 2004).

3.5. Biodiversity and Ecological Impact

Fungi play an irreplaceable role in maintaining biodiversity. By decomposing organic matter, fungi provide essential nutrients for plant and animal species, helping to maintain ecosystem stability. Lignin, second only to cellulose, is one of the most abundant polymers in nature. The dry mass of wood contains between 25% and 30% lignin. Fungi are rare organisms capable of decomposing lignin. The primary role in lignin degradation is played by fungi that cause white rot.

These fungi, as noted by Mount (1978), can completely decompose lignin, sometimes much faster than polysaccharides. In studying lignin degradation by white rot fungi, Kirk and Shimada (2012) report that the key enzymes involved are oxygenases, phenol oxidases (laccase and peroxidase), cellobiose:quinone oxidoreductases, and β-esterases. The biodegradation of lignin is a strictly anaerobic process that occurs in several stages. In the first stage, methoxy groups are removed, followed by oxidation of the polymer side chains and the breakdown of aromatic rings, with the final stage releasing aliphatic molecules (Schmidth, O.,1994). In addition to white rot fungi, some actinomycetes from the genera *Nocardia* and *Streptomyces*, and ascomycetes from the genus *Xylaria*, are also capable of lignin degradation (Priyanga, U., Kannahi, M., 2018).

Fomes fomentarius, *G. lucidum*, and *T. versicolor* cause white rot in hardwoods, and less frequently in conifer species. *Fomes fomentarius* develops on dead, living trees and continues its destructive process on fallen wood, but only in conditions of high humidity. According to research by Schwarze, F.W.M.R., et al. (2000), the hyphae of *F. fomentarius* primarily spread through the vascular tissue and along the medullary rays. The fungal action begins in the early wood inside the tracheids, where the S3 layer is first decomposed, and degradation proceeds toward the outer wall. The middle lamella remains intact in the initial stages of decay.

5. CONCLUSION

The chemical analysis of three fungal species, *F. fomentarius*, *G. lucidum*, and *T. versicolor*, demonstrates their potential as sources of essential minerals and bioactive compounds beneficial for human use, while also highlighting possible ecological implications, especially in terms of pH values and the presence of heavy metals. Given their bioactive components, these fungi have potential applications in biotechnology processes and the pharmaceutical industry. However, further research is needed to fully understand their ecological impacts and their potential use in sustainable production. All three species cause white rot and decompose lignin, thereby playing a significant role in the cycling of matter in nature. They can be utilized in the prevention and treatment of a wide range of diseases. In forestry, however, only *F. fomentarius* can cause substantial damage.

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ANALYSIS OF THE CHEMICAL COMPOSITION OF THREE FUNGAL SPECIES WITH MEDICINAL PROPERTIES TO INVESTIGATE THEIR MEDICAL AND ECOLOGICAL POTENTIAL

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Summary

The results of the analysis of three fungal species, F. fomentarius, G. lucidum, and T. versicolor, indicate that these fungi contain various bioactive components, such as polysaccharides, triterpenes, and phenolic compounds, which are being researched for their potential anticancer, anti-inflammatory, and immunomodulatory properties. In addition, the presence of minerals such as calcium, magnesium, iron, and zinc suggests that these fungi also possess nutritional properties that contribute to bone health, metabolism, and immune function.

However, the analysis also revealed the presence of toxic metals, including cadmium (Cd), lead (Pb), and mercury (Hg), which may pose a risk to human health, particularly if these fungi are consumed in excessive quantities. For example, cadmium concentrations in G. lucidum and F. fomentarius could lead to severe toxic effects on the kidneys, while the presence of lead and mercury may negatively affect the nervous system and heart. Although the concentrations of toxic metals were not high in the analyzed species, caution is advised in their use.

The pH value analysis showed significant differences among the species. F. fomentarius and G. lucidum have acidic pH (around 4.1-4.6), while T. versicolor exhibits a slightly acidic pH value (5.32).

Cluster analysis was employed to group the fungi based on their chemical composition, revealing patterns in mineral concentrations and pH values among the species. The results indicate significant variation in composition, which could be valuable for further research on therapeutic applications.

From an ecological perspective, these fungi have the potential for use in bioremediation, reducing ecological footprints, and promoting sustainable production in the biotechnology industry. Through the breakdown of organic materials, fungi can contribute to soil regeneration and reduce the need for synthetic fertilizers, aligning with the principles of circular bioeconomy.

Based on these findings, this study confirms the considerable medicinal potential of these fungi, but also underscores the need for further research to ensure the safety of their use and optimize their application in medicine, pharmaceuticals, and bioremediation. Future studies should focus on minimizing the risks posed by toxic elements and gaining a better understanding of their ecological implications.

ANALIZA HEMIJSKOG SASTAVA TRI VRSTE GLJIVA SA LEKOVITIM SVOJSTVIMA U CILJU ISPITIVANJA NJIHOVOG MEDICINSKOG I EKOLOŠKOG POTENCIJALA

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Rezime

Rezultati analize tri vrste gljiva, *F. fomentarius*, *G. lucidum* i *T. versicolor*, ukazuju na to da ove gljive sadrže brojne bioaktivne komponente, poput polisaharida, triterpena i fenolnih jedinjenja, koji se istražuju zbog svojih potencijalnih antikancerogenih, antiinflamatornih i imunomodulatornih svojstava. S obzirom na prisustvo minerala kao što su kalcijum, magnezijum, gvožđe i cink, ove gljive takođe imaju hranljiva svojstva, koja doprinose zdravlju kostiju, metabolizmu i imunološkoj funkciji.

Međutim, analiza je pokazala i prisustvo toksičnih metala, kao što su kadmijum (Cd), olovo (Pb) i živa (Hg), koji mogu predstavljati rizik za ljudsko zdravlje, naročito ako se ove gljive koriste u prekomernim količinama. Na primer, koncentracija kadmijuma u gljivama *G. lucidum* i *F. fomentarius* može izazvati ozbiljne toksične efekte na bubrege, dok prisustvo olova i žive može negativno uticati na nervni sistem i srce. Iako koncentracije toksičnih metala nisu bile visoke u analiziranim vrstama, preporučuje se oprez u njihovoj upotrebi.

Analiza pH vrednosti pokazala je značajne razlike među vrstama. *F. fomentarius* i *G. lucidum* imaju kiseli pH (oko 4.1-4.6), dok *T. versicolor* ima slabije kiselu pH vrednost (5.32).

Klasterska analiza je korišćena za grupisanje gljiva na osnovu njihovog hemijskog sastava, što je omogućilo uočavanje obrazaca u koncentracijama minerala i pH vrednostima među vrstama. Rezultati ukazuju na značajnu varijaciju u sastavu, što može biti korisno u daljim istraživanjima vezanim za terapeutske primene.

U kontekstu ekoloških aspekata, gljive imaju potencijal za upotrebu u bioremedijaciji, smanjenju ekološkog otiska i održivoj proizvodnji u biotehnološkoj industriji. Kroz procese razgradnje organskih materija, gljive mogu doprineti obnovi tla i smanjenju potrebe za veštačkim đubrivima, što je u skladu sa principima cirkularne bioekonomije.

Na osnovu rezultata, ovaj rad potvrđuje veliki medicinski potencijal ovih gljiva, ali i potrebu za daljim istraživanjima kako bi se osigurala sigurnost njihove upotrebe i optimizovala njihova primena u medicini, farmaciji i bioremedijaciji. Dalje studije treba da se fokusiraju na smanjenje rizika od toksičnih elemenata i na bolje razumevanje njihovih ekoloških implikacija.

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TRADITIONAL MEDICINAL USE OF PLANTS FROM THE GENUS *CRATAEGUS* IN THE PIROT DISTRICT (SERBIA)

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Abstract: *The informants in the rural areas of the Pirot District were surveyed on the knowledge and use of medicinal plants. The plants from the genus* Crataegus *were mentioned by 119 respondents.* C. laevigata *was mentioned against high blood pressure.* C. monogyna *was mentioned for the following applications: against high blood pressure, for the heart, improving heart rate, for circulation, and against sclerosis.* C. pentagyna *was mentioned against high blood pressure, for the heart, improving heart rate, strengthening the heart, against cardiac diseases, for circulation, immune system improvement, against the common cold, cough, and diabetes, for disease prevention (coffee replacement), as hot drink, and against kidney and bladder diseases. The medicinal uses, considered novelties in our research, were noted and stressed because they were not mentioned in previously published ethnobotanical papers on the Balkans.*

Keywords: *Crataegus laevigata*, *Crataegus monogyna*, *Crataegus pentagyna*, medicinal use, Pirot District.

TRADICIONALNA LEKOVITA UPOTREBA BILJAKA IZ RODA *CRATAEGUS* U PIROTSKOM OKRUGU (SRBIJA)

Apstrakt: *Ruralno stanovništvo Pirotskog okruga anketirano je o poznavanju i korišćenju lekovitih biljaka.. Vrste iz roda* Crataegus *su pomenute od strane 119 ispitanika.* C. laevigata *je pomenuta protiv visokog krvnog pritiska.* C. monogyna *je pomenuta za sledeće primene: protiv visokog krvnog pritiska, za srce, za regulaciju otkucaja srca, za cirkulaciju i protiv skleroze.* C. pentagyna *je pomenuta protiv visokog krvnog pritiska, za srce, poboljšanje rada srca, jačanje srca, protiv srčanih bolesti, za cirkulaciju, poboljšanje imuniteta, protiv prehlade, kašlja, dijabetesa, za prevenciju bolesti (zamena za kafu), kao topli napitak, i protiv bolesti bubrega i bešike. Zabeležene su lekovite upotrebe, koje se mogu smatrati novinama u našem istraživanju, jer nisu pominjane u ranije objavljenim etnobotaničkim radovima o Balkanu.*

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Ključne reči: *Crataegus laevigata*, *Crataegus monogyna*, *Crataegus pentagyna*, lekovita upotreba, Pirotski okrug.

1. INTRODUCTION

The plants from the genus *Crataegus*, commonly known as hawthorns, are trees and shrubs from the family Rosaceae, subfamily Maloideae. Approximately 280 species worldwide are distributed throughout the temperate regions in the northern hemisphere, including North America, Europe, and Asia (Kumar et al., 2012). Most of the species are shrubby. They are common in hedgerows and forest edges, while in open woodlands, they occupy the bushes' floor. The widespread presence of *Crataegus* species in forests can be attributed to their adaptability, effective seed dispersal, and ability to thrive in forest environments.

In Europe, the most common species from the genus *Crataegus* are *Crataegus monogyna* (common hawthorn) and *Crataegus laevigata* (midland hawthorn), which are found across a wide range, from the British Isles to the Mediterranean and Eastern Europe (Gosler, 1990).In the Pirot District (southeastern Serbia), three shrubby species from the genus *Crataegus* with medicinal properties were noted: *C. monogyna* Jacq., *C. laevigata* (Poiret) DC. (syn. *C. oxyacantha* L.), and *C. pentagyna* Waldst. & Kit. ex Willd. (Marković et al., 2020). *C. laevigata* inhabits thickets and forests, while *C. monogyna* and *C. pentagyna* have been noted in oak and beech forests, according to the same authors.

The species from the genus *Crataegus* contain significant amounts of cyanogenetic heterosides and flavonoids (Sarić, 1989; Marković et al., 2010, 2020). Oligomeric procyanidins, flavonoids, triterpenes, polysaccharides, and catecholamines have been identified in the genus, and many of these have been evaluated for biological activities (Kumar et al., 2012).

Gostuški (1973) mentioned the use of *C. laevigata* flowers in Serbia for the treatment of gout, stone-inflammation of female genital organs, kidney stones, heart diseases, and inflammation of female genital organs, kidney stones, heart diseases, and stone-inflammation of female genital organs, kidney stones, heart diseases, and blood pressure regulation. Tucakov (1990) and Tasić et al. (2001) mentioned the use of *C. laevigata* as a cardiac sedative, for blood pressure regulation, and sedation.

According to Sarić (1989), Tasić et al. (2001) and Marković et al. (2020), *C. laevigata* and *C. monogyna* flowers were used as spasmolytic, cardiac, geriatric, and against sore throat. The same authors state that the flowers and leaves were used against heart diseases as well as for blood pressure regulation, while the fruits were used against diarrhoea.

C. monogyna, *C. laevigata*, and *C. pentagyna* can only be harvested with appropriate permits, as they are the protected plant species in Serbia under national legislation (Službeni glasnik Republike Srbije, 2010).

This study aimed to collect and investigate traditional knowledge about the medicinal use of plant species from the genus *Crataegus* in the Pirot District. The research also aimed to find traditional forms of medicinal use of plants from the genus *Crataegus* that have not been recorded in previous ethnobotanical studies on the Balkans.

2. MATERIAL AND METHODS

Research on the traditional knowledge and use of medicinal plants was conducted in the form of a population survey. The questionnaires included residents of 144 villages in municipalities of the Pirot District: Pirot, Babušnica, Bela Palanka, and Dimitrovgrad. A total of 631 respondents were surveyed on knowledge and use of medicinal plants, of which 337 were men and 294 were women. The results of a study on the traditional use of plants from the genus *Crataegus* for medicinal purposes were compared with previous ethnobotanical studies on the use of the mentioned plant species in the Balkans.

3. RESULTS

Out of a total of 4817 reports collected in the Pirot District, 119 reports were about the medicinal use of plants from the genus *Crataegus* (2.47%), of which one report about use of *C. laevigata*, 33 reports about *C. monogyna*, and 85 reports about *C. pentagyna.* A total of 99 respondents (66 men, 33 women) mentioned the plants from genus *Crataegus* for medicinal purposes, of which one respondent (man) mentioned *C. laevigata*, 28 respondents (20 men, 8 women) mentioned *C. monogyna*, and 70 respondents (45 men, 25 women) mentioned *C. pentagyna*. The age of the respondents who mentioned the medicinal use of plants from the genus *Crataegus* was 34 to 83 years.

Regarding national structure, 83 respondents were of Serbian nationality, 15 were of Bulgarian nationality, and one was of Roma nationality. A respondent of Serbian nationality was mentioned *C. laevigata*. *C. monogyna* was mentioned by 23 respondents of Serbian nationality and 5 respondents of Bulgarian nationality. *C. pentagyna* was mentioned by 83 respondents of Serbian nationality, 15 respondents of Bulgarian nationality, and one respondent of Roma nationality.

In the municipality of Pirot, 77 reports on the medicinal use of plants from the genus *Crataegus* were given, of which one report was about the use of *C. laevigata*, 22 reports about the use of the *C. monogyna*, and 54 reports about the use of *C. pentagyna.* In the municipality of Babušnica, 16 reports on the medicinal use of plants from the genus *Crataegu*s were given, of which 5 reports about the use of *C. monogyna* and 11 reports about *C. pentagyna*. In the municipality of Bela Palanka, 15 reports on the medicinal use of plants from the genus *Crataegus* were given, of which 2 reports were about the use of *C. monogyna* and 13 reports were about *C. pentagyna*. In the municipality of Dimitrovgrad, 11 reports on the medicinal use of plants from the genus *Crataegus* were given, of which 4 reports about the use of *C. monogyna* and 11 reports about *C. pentagyna*.

One respondent mentioned the fruit of the plant species C. laevigata, with the local name “crveni glog”, for treating high blood pressure (Table 1).

Table 1. *Overview of the survey results on the use of* C. laevigata *in the population of the Pirot District.*

Municipality	Village	Nationality	Gender	Age	Plant part	Form	Medicinal use	Group
Pirot	Gostuša	Srb.	M	66	fruit	Decoction	High blood pressure	Cd

Note: Group of diseases: Cd – cardiovascular.

The plant species *C. monogyna* was mentioned by the local names "beli glog" and "glog". The flower of plant species *C. monogyna* was mentioned in the form of an infusion for the heart (anti-arrhythmic) (6 reports), for the treatment of high blood pressure (5 reports), for circulation (1 report), improving heart rate (1 report), and against sclerosis (1 report). The leaf of *C. monogyna* was mentioned as an infusion for improving heart rate (1 report). The fruit of *C. monogyna* was mentioned against high blood pressure (12 reports), for the heart (3 reports), improving heart rate (1 report), for circulation (1 report), and (Table 2). One respondent mentioned using *C. monogyna* fruit but did not know how to use it (Table 2).

Table 2. *Overview of the survey results on the use of* C. monogyna *in the population of the Pirot District.*

Municipality	Village	Nationality	Gender	Age	Plant part	Form	Medicinal use	Group
Pirot	Berilovac	Ser.	M	66	fruit	Decoction	For the heart	Cd
Pirot	Blato	Ser.	M	64	fruit	Decoction	High blood pressure	Cd
Pirot	Brlog	Ser.	M	79	leaf	Infusion	Improving heart rate	Cd
Pirot	Brlog	Ser.	M	46	flower	Infusion	Improving heart rate	Cd
Pirot	Brlog	Ser.	M	64	fruit	Decoction	Improving heart rate	Cd
Pirot	Gostuša	Ser.	M	56	flower	Infusion	Circulation	Cd
Pirot	Gostuša	Ser.	M	66	fruit	Decoction	High blood pressure	Cd
Pirot	Gostuša	Ser.	M	53	fruit	Decoction	High blood pressure	Cd
Pirot	Gostuša	Ser.	M	59	flower	Decoction	For the heart	Cd
Pirot	Gostuša	Ser.	M	59	flower	Infusion	High blood pressure	Cd
Pirot	Jelovica	Ser.	F	56	fruit	Infusion	High blood pressure	Cd
Pirot	Orlja	Ser.	M	65	fruit	Decoction	For the heart	Cd
Pirot	Orlja	Ser.	M	65	fruit	Decoction	High blood pressure	Cd
Pirot	Pokrevenik	Ser.	F	65	fruit	Decoction	Circulation	Cd
Pirot	Pokrevenik	Ser.	F	34	flower	Infusion	High blood pressure	Cd
Pirot	Poljska Ržana	Ser.	M	68	flower	Infusion	High blood pressure	Cd
Pirot	Ponor	Ser.	M	77	flower	Infusion	Sclerosis	Nr
Pirot	Rasnica	Ser.	F	38	fruit	Decoction	High blood pressure	Cd
Pirot	Srećkovac	Ser.	F	53	flower	Infusion	For the heart	Cd
Pirot	Sukovo	Ser.	M	63	fruit	Decoction	Uniknown use	Vr
Pirot	Cerova	Ser.	M	65	flower	Infusion	High blood pressure	Cd
Pirot	Crvenčevo	Ser.	F	74	flower	Infusion	For the heart	Cd

Babušnica	Rakita	Bul.	F	56	fruit	Decoction	For the heart	Cd
Babušnica	Resnik	Ser.	M	40	fruit	Decoction	High blood pressure	Cd
Babušnica	Studena	Ser.	M	59	flower	Infusion	For the heart	Cd
Babušnica	Studena	Ser.	M	59	flower	Infusion	High blood pressure	Cd
Babušnica	Crvena Jabuka	Ser.	M	67	fruit	Extract in alcohol	High blood pressure	Cd
Bela Palanka	Vrgudinac	Ser.	M	82	fruit	Decoction	High blood pressure	Cd
Bela Palanka	Ljubatovica	Ser.	F	62	fruit	Decoction	High blood pressure	Cd
Dimitrovgrad	Željuša	Bul.	M	43	flower	Infusion	For the heart	Cd
Dimitrovgrad	Kamenica	Bul.	F	36	flower	Infusion	For the heart	Cd
Dimitrovgrad	Poganovo	Bul.	M	74	fruit	Decoction	High blood pressure	Cd
Dimitrovgrad	Slivnica	Bul.	M	68	fruit	Decoction	High blood pressure	Cd

Note: Nationality: Ser. – serbian. Bul. – Bulgarian; Gender: M – male, F – female; Group of diseases: Cd – cardiovascular, Nr – nervous system diseases, Vr – various.

The plant species *C. pentagyna* was mentioned by local names “crni glog” and “gloginja”. The flower of plant species *C. pentagyna* was mentioned in the form of an infusion for the treatment of high blood pressure (13 reports), for the heart (3 reports), for circulation (1 report), improving heart rate (1 report), strengthening the heart (1 report). The leaf of *C. pentagyna* was mentioned as an infusion to improve heart rate (1 report) and prevent high blood pressure (1 report). The fruit of *C. pentagyna* was mentioned in the form of decoction against high blood pressure (53 reports), for the heart (13 reports), strengthening the heart (2 reports), immune system improvement (2 reports), against cardiac diseases (1 report), common cold (1 report), cough (1 report), diabetes (1 report), disease prevention (coffee replacement) (1 report), for circulation (1 report), as hot drink (1 report), improving heart rate (1 report), against kidney and bladder diseases (1 report) (Table 3).

Table 3. *Overview of the survey results on the use of* C. pentagyna *in the population of the Pirot District.*

Municipality	Village	Nationality	Gender	Age	Plant part	Form	Medicinal use	Group
Pirot	Berilovac	Ser.	M	83	fruit	Decoction	Disease prevention (coffee replacement)	Cd
Pirot	Berilovac	Ser.	M	76	fruit	Decoction	High blood pressure	Cd
Pirot	Blato	Ser.	M	59	fruit	Decoction	High blood pressure	Cd
Pirot	Blato	Ser.	F	58	flower	Infusion	High blood pressure	Cd
Pirot	Blato	Ser.	F	58	fruit	Decoction	High blood pressure	Cd
Pirot	Brlog	Ser.	M	64	leaf	Infusion	Improving heart rate	Cd
Pirot	Brlog	Ser.	M	64	flower	Infusion	Improving heart rate	Cd
Pirot	Brlog	Ser.	M	64	fruit	Decoction	High blood pressure	Cd
Pirot	Velika Lukanja	Ser.	M	62	flower	Infusion	Common cold	Rs
Pirot	Velika Lukanja	Ser.	M	62	fruit	Decoction	High blood pressure	Cd
Pirot	Velika Lukanja	Ser.	M	80	fruit	Decoction	High blood pressure	Cd
Pirot	Velika Lukanja	Ser.	F	74	flower	Infusion	High blood pressure	Cd

Pirot	Veliki Jovanovac	Ser.	F	55	flower	Infusion	High blood pressure	Cd
Pirot	Veliki Jovanovac	Ser.	F	55	fruit	Decoction	Immune system improvement	Pr
Pirot	Gostuša	Ser.	M	56	flower	Infusion	Circulation	Cd
Pirot	Gostuša	Ser.	M	59	fruit	Decoction	Hot drink	Vr
Pirot	Gostuša	Ser.	M	66	fruit	Decoction	High blood pressure	Cd
Pirot	Gostuša	Ser.	M	53	fruit	Decoction	High blood pressure	Cd
Pirot	Dojkinci	Ser.	F	46	fruit	Decoction	Unknown use	Vr
Pirot	Držina	Ser.	F	67	fruit	Decoction	High blood pressure	Cd
Pirot	Držina	Ser.	F	67	fruit	Decoction	Cough	Rs
Pirot	Držina	Ser.	M	77	fruit	Decoction	For the heart	Cd
Pirot	Zaskovci	Ser.	M	79	fruit	Decoction	High blood pressure	Cd
Pirot	Jelovica	Ser.	F	56	flower	Infusion	High blood pressure	Cd
Pirot	Krupac	Ser.	F	65	flower	Infusion	High blood pressure	Cd
Pirot	Kumanovo	Ser.	F	63	flower	Infusion	High blood pressure	Cd
Pirot	Kumanovo	Ser.	F	63	fruit	Decoction	High blood pressure	Cd
Pirot	Mali Jovanovac	Ser.	F	49	flower	Decoction	High blood pressure	Cd
Pirot	Mali Suvodol	Ser.	F	61	fruit	Decoction	Diabetes	En
Pirot	Nišor	Ser.	M	58	fruit	Infusion	For the heart	Cd
Pirot	Nišor	Ser.	M	58	fruit	Infusion	High blood pressure	Cd
Pirot	Novi Zavoj	Ser.	F	67	fruit	Decoction	For the heart	Cd
Pirot	Oreovica	Ser.	F	60	flower	Decoction	High blood pressure	Cd
Pirot	Oreovica	Ser.	F	56	fruit	Decoction	High blood pressure	Cd
Pirot	Orlja	Ser.	M	65	fruit	Decoction	For the heart	Cd
Pirot	Orlja	Ser.	M	65	fruit	Decoction	High blood pressure	Cd
Pirot	Osmakova	Ser.	F	65	fruit	Decoction	High blood pressure	Cd
Pirot	Pakleštica	Ser.	M	72	fruit	Decoction	High blood pressure	Cd
Pirot	Planinica	Ser.	F	50	fruit	Decoction	For the heart	Cd
Pirot	Planinica	Ser.	F	50	fruit	Decoction	High blood pressure	Cd
Pirot	Prisijan	Rom.	M	60	fruit	Decoction	Strengthening the heart	Cd
Pirot	Prisijan	Ser.	M	47	fruit	Decoction	High blood pressure	Cd
Pirot	Rasnica	Ser.	F	38	fruit	Decoction	High blood pressure	Cd
Pirot	Rudinje	Ser.	M	78	fruit	Decoction	Immune system improvement	Pr
Pirot	Sopot	Ser.	M	64	fruit	Decoction	Kidney and bladder diseases	Ur
Pirot	Sopot	Ser.	F	59	fruit	Decoction	High blood pressure	Cd
Pirot	Staničenje	Ser.	M	59	fruit	Decoction	Uniknown use	Vr
Pirot	Sukovo	Ser.	F	59	fruit	Decoction	High blood pressure	Cd
Pirot	Sukovo	Ser.	M	63	fruit	Decoction	Uniknown use	Vr
Pirot	Topli Do	Ser.	M	76	fruit	Decoction	Cardiac diseases	Cd
Pirot	Topli Do	Ser.	M	62	fruit	Decoction	High blood pressure	Cd

Pirot	Crvenčevo	Ser.	M	74	flower	Infusion	For the heart	Cd
Pirot	Crnoklište	Ser.	M	46	fruit	Decoction	High blood pressure	Cd
Pirot	Crnoklište	Ser.	F	52	fruit	Decoction	High blood pressure	Cd
Babušnica	Vučidel	Bul.	M	59	fruit	Decoction	For the heart	Cd
Babušnica	Dol	Ser.	M	62	flower	Infusion	High blood pressure	Cd
Babušnica	Zavidince	Ser.	F	44	fruit	Decoction	High blood pressure	Cd
Babušnica	Zvonce	Bul.	F	52	fruit	Decoction	For the heart	Cd
Babušnica	Zvonce	Bul.	F	72	fruit	Decoction	High blood pressure	Cd
Babušnica	Kaluđerevo	Ser.	F	72	fruit	Decoction	High blood pressure	Cd
Babušnica	Kaluđerevo	Ser.	M	76	fruit	Decoction	High blood pressure	Cd
Babušnica	Kambelevec	Ser.	M	67	fruit	Decoction	High blood pressure	Cd
Babušnica	Našuškovica	Bul.	M	70	fruit	Decoction	High blood pressure	Cd
Babušnica	Radoševac	Ser.	M	53	flower	Infusion	High blood pressure	Cd
Babušnica	Crvena Jabuka	Ser.	M	67	fruit	Extract in alcohol	High blood pressure	Cd
Bela Palanka	Vrgudinac	Ser.	M	68	fruit	Decoction	High blood pressure	Cd
Bela Palanka	Vrgudinac	Ser.	M	82	fruit	Decoction	High blood pressure	Cd
Bela Palanka	Donja Koritnica	Ser.	M	54	flower	Infusion	High blood pressure	Cd
Bela Palanka	Donja Koritnica	Ser.	M	54	leaf	Infusion	High blood pressure	Cd
Bela Palanka	Moklište	Ser.	M	60	fruit	Decoction	High blood pressure	Cd
Bela Palanka	Moklište	Ser.	F	68	fruit	Decoction	For the heart	Cd
Bela Palanka	Moklište	Ser.	F	68	fruit	Decoction	High blood pressure	Cd
Bela Palanka	Moklište	Ser.	M	50	flower	Infusion	For the heart	Cd
Bela Palanka	Moklište	Ser.	M	50	fruit	Decoction	For the heart	Cd
Bela Palanka	Mokra	Ser.	M	75	fruit	Decoction	Strengthening the heart	Cd
Bela Palanka	Mokra	Ser.	M	75	flower	Infusion	Strengthening the heart	Cd
Bela Palanka	Novo Selo	Ser.	F	46	fruit	Decoction	High blood pressure	Cd
Bela Palanka	Crvena Reka	Ser.	M	65	fruit	Decoction	High blood pressure	Cd
Dimitrovgrad	Gojin Dol	Bul.	M	60	flower	Infusion	High blood pressure	Cd
Dimitrovgrad	Donja Nevlja	Bul.	M	65	flower	Infusion	For the heart	Cd
Dimitrovgrad	Dragovita	Bul.	M	50	fruit	Decoction	High blood pressure	Cd
Dimitrovgrad	Kusa Vrana	Bul.	M	39	fruit	Decoction	High blood pressure	Cd
Dimitrovgrad	Radejna	Bul.	M	61	fruit	Decoction	For the heart	Cd
Dimitrovgrad	Slivnica	Bul.	M	68	fruit	Decoction	High blood pressure	Cd
Dimitrovgrad	Trnski Odorovci	Bul.	F	63	fruit	Decoction	High blood pressure	Cd

Note: Nationality: Ser. – serbian. Bul. – Bulgarian, Rom – Roma; Gender: M – male, F – female; Group of diseases: Cd – cardiovascular, Pr – preventive, Rs – respiratory, Ur – urinary diseases, Vr – various.

Fruits of plants from genus *Crataegus* were most often used in the form of a decoction (83 reports), of which 64 reports were about the use of *C. pentagyna*, 18 reports about the use of *C. monogyna*, one report was about the use of *C. laevigata*. Less often, the respondents have mentioned using flowers as an infusion (33 reports), of which 19 reports were about *C. pentagyna* and 14 reports about *C. monogyna*. The leaves in the form of infusion were mentioned the least (3 reports), of which *C. pentagyna* with 2 reports, and *C. monogyna* with 1 report.

Table 4. *Respondents mentioned medicinal uses of plants from the genus Crataegus and parts of plants and forms used.*

Medicinal use (Group of diseases)	Species	Number of reports	Part of the plant	Form
High blood pressure (Cd)	*C. pentagyna*	38	fruit	decoction
High blood pressure (Cd)	*C. pentagyna*	13	flower	infusion
For the heart (Cd)	*C. pentagyna*	19	fruit	decoction
High blood pressure (Cd)	*C. monogyna*	11	fruit	decoction
For the heart (Cd)	*C. monogyna*	6	flower	infusion
High blood pressure (Cd)	*C. monogyna*	5	flower	infusion
For the heart (Cd)	*C. pentagyna*	3	flower	infusion
Unknown use (Vr)	*C. pentagyna*	3	fruit	decoction
Immune system improvement (Pr)	*C. pentagyna*	2	fruit	decoction
Strengthening the heart (Cd)	*C. pentagyna*	2	fruit	decoction
Circulation (Cd)	*C. monogyna*	1	fruit	decoction
Circulation (Cd)	*C. monogyna*	1	flower	infusion
High blood pressure (Cd)	*C. laevigata*	1	fruit	decoction
High blood pressure (Cd)	*C. pentagyna*	1	fruit	extract in alcohol
High blood pressure (Cd)	*C. monogyna*	1	fruit	extract in alcohol
High blood pressure (Cd)	*C. pentagyna*	1	leaf	decoction
Cardiac diseases (Cd)	*C. pentagyna*	1	fruit	decoction
Common cold (Rs)	*C. pentagyna*	1	fruit	decoction
Cough (Rs)	*C. pentagyna*	1	fruit	decoction
Diabetes (En)	*C. pentagyna*	1	fruit	decoction
Disease prevention (Pr)	*C. pentagyna*	1	fruit	decoction
Circulation (Cd)	*C. pentagyna*	1	flower	infusion
Hot drink (Vr)	*C. pentagyna*	1	fruit	decoction
Improving heart rate (Cd)	*C. monogyna*	1	flower	infusion
Improving heart rate (Cd)	*C. monogyna*	1	fruit	decoction
Improving heart rate (Cd)	*C. monogyna*	1	leaf	infusion
Improving heart rate (Cd)	*C. pentagyna*	1	flower	infusion
Improving heart rate (Cd)	*C. pentagyna*	1	fruit	decoction
Improving heart rate (Cd)	*C. pentagyna*	1	leaf	infusion
Kidney and bladder disease (Ur)	*C. pentagyna*	1	fruit	decoction
Sclerosis (Nr)	*C. monogyna*	1	flower	infusion
Strengthening the heart (Cd)	*C. pentagyna*	1	flower	infusion
Unknown use (Vr)	*C. monogyna*	1	fruit	decoction

*Groups of diseases: Cd – cardiovascular, En – endocrinology, Nr – neurology, Pr – prevention, Rs – respiratory, Ur – urology, Vr – various.

The most significant number of respondents mentioned using plants from the genus *Crataegus* against high blood pressure (71 reports) in the form of a decoction (50 reports), infusion (19 reports), or alcoholic extract (2 reports) and for the heart (22 reports) in the form of decoction (13 reports) or infusion (9 reports). The twice-mentioned medicinal uses of fruits in the form of decoction were for strengthening the heart and immune system improvement (Table 4).

4. DISCUSSION

The results of our study are compared with previous ethnobotanical research on the traditional medicinal use of plant species from the genus *Crataegus* in the Balkan Peninsula.

Crataegus laevigata

Jarić et al. (2007) mentioned at Kopaonik Mt the use of *C. laevigata* for hypertensive properties, which had the same medicinal uses compared to our study. The same authors mentioned using *C. laevigata* as a cardiotonic, circulatory stimulant to strengthen the heart and regulate its rate, which were different medicinal uses compared to our study.

Jarić et al. (2015) recorded at Suva Mt. the use of *C. laevigata* as an antihypertensive agent, which was the same medicinal use as in our study.

Janaćković et al. (2019) in Negotin Krajina mentioned using *C. laevigata* to strengthen the heart muscles and blood vessels, which was a different use than our study.

Crataegus monogyna

Šarić-Kundalić et al. (2010) mentioned using *C. monogyna* in Bosnia to treat heart ailments, similar to our study's medicinal use. The same authors mentioned the use of powder for sedation, which was similar to medicinal use compared to our study.

Menković et al. (2011) recorded the use of *C. monogyna* against hypertension, senile heart, ischemia of the heart, mild forms of bradycardia arrhythmias, and cardiotonic, which were similar medicinal uses as in our study, and as sedative, which was different medicinal use, compared to our study.

Pieroni et al. (2011) reported at Pešter Plateau the use of *C. monogyna* against hypertension and for the heart, similar to medicinal uses as in our study. The same authors mentioned using *C. monogyna* against sore throat and as a diuretic, which were of different medicinal use compared to our investigation.

Popović et al. (2012) found that the population from Deliblato Sands used species *C. monogyna* as a cardiac, which is the same medicinal use as in our study, and as a relaxant and sedative, which are different medicinal uses compared to our research.

Kozuharova et al. (2013) noted that using *C. monogyna* for calming effects in Bulgaria was similar to our research.

Šavikin et al. (2013) mentioned the use of *C. monogyna* against heart failure in the Zlatibor District, which was the same use compared to our study.

Zlatković et al. (2014) found that the population at Rtanj Mt. used species *C. monogyna* as a cardiotonic and antihypertensive agent, which were similar uses compared to our study.

Koleva et al. (2015) found that the population of Bulgaria used *C. monogyna* for the treatment of heart disorders, which was the same as in our study. The same authors mentioned *C. monogyna* for prophylaxis and nervous disorders, which were used differently than our research.

Mustafa et al. (2015) mentioned the use of *C. monogyna* as an anti-hypertensive agent in Kosovo and Metohija, which had identical medicinal use compared to our research. The same authors mentioned the medicinal use for improving blood circulation as neuro relaxant, antidiabetic, and anti-cholesterolemia agent, which are different medicinal uses compared to our study.

Pieroni et al. (2015) noted that in the population of Rraicë and Mokra areas in Eastern Albania, the fruits of *C. monogyna* are consumed raw as a snack, which is a different use than our research.

In ethnobotanical research on Konjuh Mt. in Bosnia, Saric-Kundalic et al. (2016) noted that *C. monogyna* was used to decrease high blood pressure and arrhythmia, which are similar applications to our research. The same authors mentioned the applications for decreasing blood fats, strengthening the heart muscle, sedation, and against renal stones, which differed from our research.

Tsioutsiou et al. (2019) noted that in Central Macedonia (Greece), the use of *C. monogyna* to prevent cardiovascular diseases differed from our research.

Matejić et al. (2020) mentioned for the Svrljig and Timok regions the use of *C. monogyna* against cardiac insufficiency, which was similar to our research. The same authors mentioned using *C. monogyna* for immunity, for the treatment of cough, and against diarrhoea, which were different applications compared to our research.

Mustafa et al. (2020) mentioned using *C. monogyna* to treat hypertension in Štrpce in the southern part of Kosovo and Metohija, which the respondents in our research also mentioned. The same authors noted the use for blood circulation, influenza, warts, headaches, lungs, and in the treatment of respiratory complaints, which were different applications compared to our research.

Živković et al. (2020) in the Pčinja District mentioned using *C. monogyna* to treat heart failure, similar to our study. The same authors mentioned the use against respiratory complaints and as a source of vitamin C, which were different uses compared to our research.

Łuczaj et al. (2021) on the Adriatic Islands noted that flowers of *C. monogyna* in the form of infusion are suitable for the heart, which was the same use as in our research.

Crataegus pentagyna

Šarić Kundalić et al. (2010) mentioned using *C. pentagyna* in Bosnia against heart ailments, similar to our study's medicinal use. The same authors mentioned using powder for sedation, which was a different application than our research.

Pieroni et al. (2011) noted at Pešter Plateau the use of *C. pentagyna* for the treatment of hypertension and for the heart, which were identical medicinal uses as in our study. The same authors mentioned using *C. monogyna* against sore throat and as a diuretic, which were of different medicinal use compared to our investigation.

Zlatković et al. (2014) noted that the population at Rtanj Mt used species *C. pentagyna* as an antihypertensive agent, which was the same use compared to our research.

In the study on Konjuh Mt in Bosnia, Saric-Kundalic et al. (2016) found that *C. pentagyna* was used to decrease high blood pressure, strengthen the heart muscle, treat arrhythmia, and prevent renal stones, which are similar applications to our study. The same authors mentioned sedation use, which differed from our study.

Matejić et al. (2020) mentioned for the Svrljig regions the use of *C. pentagyna* for the treatment of hypertension, which was identical in comparison with our investigation. The same authors mentioned using *C. pentagyna* against stomach pain and hepatitis, different uses from our study.

The novelties of our research

The medicinal uses of *C. monogyna* flowers for circulation and *C. monogyna* flowers and fruits against sclerosis, as well as the use of *C. pentagyna* flowers for circulation, and *C. pentagyna* fruits against diabetes, for disease prevention (coffee replacement), immune system improvement, against the common cold, cough, kidney and bladder diseases, and as hot drink were not mentioned in previous ethnobotanical research on the Balkan Peninsula, so the mentioned uses can be considered the novelties of our research.

The protection

The protection of the populations of *C. laevigata, C. monogyna*, and *C. pentagyna* in the Pirot District should be considered because these species are on the list of protected species in Serbia (Službeni glasnik Republike Srbije, 2010).

5. CONCLUSION

Based on the presented data, it can be concluded that three species from the genus *Crataegus* (*C. laevigata, C. monogyna* and *C. pentagyna*) were usually used in the rural areas of the Pirot District. The most common uses were noted for the cardiovascular group of diseases (high blood pressure, for the heart, improving heart rate, strengthening the heart, against cardiac diseases, and for circulation. The less common uses were noted for the following groups: prevention (immune system improvement, disease prevention), respiratory (common cold, cough), endocrinology (diabetes), neurology (sclerosis), urology (kidney and bladder disease), and various (hot drink).

Respondents in the Pirot District mentioned different and new uses, which were compared with previous research on the Balkan Peninsula, including the use of *C. monogyna* for circulation and the treatment of sclerosis and the use of *C. pentagyna* for circulation, the treatment of diabetes, disease prevention (coffee replacement), immune system improvement, against common colds, coughs, kidney and bladder diseases, and as a hot drink.

Further chemical and pharmacological studies are necessary to make the mentioned plant species from the genus *Crataegus,* the possible candidates for the new pharmacological products.

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TRADITIONAL MEDICINAL USE OF PLANTS FROM GENUS *CRATAEGUS* IN THE PIROT DISTRICT (SERBIA)

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Summary

This paper investigated the traditional use of plants from the genus *Crataegus* for medicinal purposes in the Pirot District. The research was conducted through surveys among the rural population in four municipalities: Pirot, Babušnica, Bela Palanka, and Dimitrovgrad. The results were compared with previous ethnopharmacological studies on the medicinal use of this plant species in the Balkans.

The species *Crataegus laevigata* was mentioned for the treatment of high blood pressure (1 report). The species *Crataegus monogyna* was mentioned for the following applications: against high blood pressure (17 reports), for the heart (9 reports), improving heart rate (3 reports), for circulation (2 reports), and against sclerosis (1 report). The species *C. pentagyna* was mentioned against high blood pressure (53 reports), for the heart (13 reports), improving heart rate (3 reports), strengthening the heart (3 reports), against cardiac diseases (1 report), for circulation (1 report), immune system improvement (2 reports), against common cold (1 report), cough (1 report), diabetes (1 report), for disease prevention (coffee replacement) (1 report), as hot drink (1 report), and against kidney and bladder diseases (1 report).

The uses of species *C. monogyna* for circulation and the treatment of sclerosis, and the use of species *C. pentagyna* for circulation, the treatment of diabetes, disease prevention

(coffee replacement), immune system improvement, against the common cold, cough, kidney and bladder diseases, and as hot drink were not mentioned in previously published ethnobotanical papers on the Balkan Peninsula, so the mentioned applications can be considered the novelties of this study.

TRADICIONALNA LEKOVITA UPOTREBA BILJAKA IZ RODA *CRATAEGUS* U PIROTSKOM OKRUGU (SRBIJA)

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Rezime

Predmet ovog rada bilo je proučavanje tradicionalne upotrebe biljaka iz roda *Crataegus* za lekovite svrhe u Pirotskom okrugu (Jugoistočna Srbija). Istraživanje je sprovedeno u vidu ankete među ruralnim stanovništvom u četiri opštine: Pirot, Babušnica, Bela Palanka i Dimitrovgrad. Rezultati su upoređeni sa prethodnim etnofarmakološkim istraživanjima o lekovitoj upotrebi ove biljne vrste na Balkanu.

Vrsta *Crataegus laevigata* je pomenuta za lečenje visokog krvnog pritiska (1 izjava). Vrsta *Crataegus monogyna* je pomenuta za sledeće primene: protiv visokog krvnog pritiska (17 izjava), za srce (9 izjava), za poboljšanje srčane frekvencije (3 izjava), za cirkulaciju (2 izjave) i protiv skleroze (1 izjava). Vrsta *C. pentagina* je pomenuta protiv visokog krvnog pritiska (53 izjave), za srce (13 izjava), za poboljšanje rada srca (3 izjave), za jačanje srca (3 izjave), protiv srčanih bolesti (1 izjava), za cirkulaciju (1 izjava), poboljšanje imuniteta (2 izjave), protiv prehlade (1 izjave), kašlja (1 izjave), dijabetesa (1 izjave), za prevenciju bolesti (zamena kafe) (1 izjava), kao topli napitak (1 izjava) i protiv bolesti bubrega i bešike (1 izjava).

Upotrebe vrste *C. monogyna* za cirkulaciju i za lečenje skleroze, a vrste *C. pentagyna* za cirkulaciju, lečenje dijabetesa, za prevenciju bolesti (zamena za kafu), poboljšanje imuniteta, protiv prehlade, kašlja, bolesti bubrega i mokraćne bešike i kao topli napitak nisu pominjane u ranije objavljenim etnobotaničkim radovima na Balkanskom poluostrvu, pa se pomenute primene mogu smatrati novinama ove studije.

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Original scientific paper

THE POSSIBILITY OF CREATING AN EDUCATIONAL TRAIL INSPIRED BY THE MEDICINAL AND USEFUL PROPERTIES OF THE SHRUB SPECIES PRESENT IN THE ARBORETUM OF THE FACULTY OF FORESTRY

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Abstract: *Vegetation supports the life of many other organisms, ensures the development of ecosystem functions, and regulates geomorphological and atmospheric processes. Important coeenobionts of different types of vegetation are medicinal plants. Medicinal plants represent a significant, both biological and economic resource of every country. People use them as a source of active substances that have an important impact on human health, and at the same time they find their application in landscape design because they are characterized by great decorativeness. The aim of this work is the analysis of woody shrub species in order to determine the possibility of forming an educational trail in the Arboretum of the Faculty of Forestry, with a focus on medicinal, aromatic and edible species, as well as the research of existing biomimetic solutions, products and technologies based on plant species present in the Arboretum of the Faculty of Forestry in Belgrade.*

Keywords: educational trail, medicinal and aromatic plants, shrub species, Arboretum of the Faculty of Forestry, biomimetic.

MOGUĆNOST KREIRANJA EDUKATIVNE STAZE INSPIRISANE LEKOVITIM I UPOTREBNIM SVOJSTVIMA ŽBUNASTIH VRSTA PRISUTNIH U ARBORETUMU ŠUMARSKOG FAKULTETA

Sažetak: *Vegetacija podržava život mnogih drugih organizama, obezbeđuje odvijanje ekosistemskih funkcija, reguliše geomorfološke i atmosferske procese. Značajni cenobionti različitih tipova vegetacije jesu lekovite biljke. Lekovite biljke predstavljaju značajan, kako biološki, tako i ekonomski resurs svake zemlje. Ljudi ih koriste kao izvor aktivnih supstanci koje imaju važan uticaj na ljudsko zdravlje, a istovremeno one nalaze svoju primenu u pejzažnom dizajnu jer se odlikuju velikom dekorativnošću. Cilj ovog rada je analiza drvenastih žbunastih vrsta radi utvrđivanja mogućnosti formiranja edukativne staze u Arboretumu Šumarskog fakulteta, sa fokusom na lekovite, aromatične i jestive vrste kao i istraživanje postojećih biomimetičkih rešenja, proizvoda i tehnologija zasnovanih na biljnim vrstama prisutnim u Arboretumu Šumarskog fakulteta u Beogradu.*

Ključne reči: edukativna staza, lekovite i aromatične biljke, žbunaste vrste, Arboretum Šumarskog fakulteta, biomimetika.

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1. INTRODUCTION

Vegetation is a source of basic nutrients, bioactive substances and raw materials for industrial use for mankind. It is generally known that medicinal plants play an important role in human health due to their various beneficial properties and therapeutic effects (Reč, 2014).

In today's time of availability of affordable, commercial herbal preparations, their safety for human health and the potentially harmful effects they can cause with inadequate application are being questioned. In order to use them correctly and efficiently, it is necessary to educate ourrself about plant properties (Ekor, 2014). Plants, animals and entire ecosystems form components of traditional medicine, which is still important in supporting people's health worldwide, particularly in developing countries and remote, isolated areas. Around one third of modern pharmaceuticals have been directly derived from compounds found in the natural world, and many other drugs are designed to mimic natural products (Newman et al., 2020). Around 60 000 species – plants, animals, fungi and microbes – are used for their medicinal, nutritional and aromatic properties (www.cbd.int). A signifcant proportion of pharmaceuticals have been derived from nature: between 1981 and 2019, 185 small molecule drugs were approved to treat cancer, of which 65% were derived from or inspired by natural products (Newman et al. 2020).

Medicinal and aromatic plants not only represent a significant biological and economic resource, a source of active substances that have an important impact on human health, but many of them are characterized by distinct decorative characteristics and have had significant application in the field of landscape architecture and horticulture for centuries.

Decorative plants represent an important element in the urban environment, both because of their aesthetic values and because of their positive impact on the quality of the environment and the health of citizens (Zuo & Zhao, 2014).

Each woody species has a typical crown shape, which is different and is the result of hereditary factors but also the influence of external environmental factors (Ocokoljić & Ninić-Todorović, 2003).

According to estimates, shrubby plant species occupy 45% of the land area on the surface of the planet Earth (Götmark et al., 2016). Shrubs represent an important component of forest ecosystems, stabilize biocenoses and contribute to phytoremediation of forest soil. Shrubs also protect trees from the damaging effects of strong winds and their shoots, seeds and fruits are a source of food for many forest animals. Ornamental shrubs are used in landscape design due to their high aesthetic appeal, and are often planted in parks, green squares and along boulevards (Boyce, 2009).

Many botanical gardens have biomimetic trails with accompanying information boards through which visitors learn about the properties of a particular plant species, as well as how that species found its place in biomimetic, technical applications (Speck & Speck, 2023).

Biomimicry is a word that means "imitation of life". The term "biomimetics" implies the understanding of biological structures and processes and their technological application, method or procedure. Biomimetics is not a mere imitation of nature, neither in a material, functional nor creative sense, but an essential understanding of natural principles and models, translating them into solving current problems while ensuring the sustainability of the solution (Pohl, 2015, Jović, 2018).

Biomimetics "draws" inspiration from nature and imitates natural structures into systems in order to solve human problems (Bhushan, 2009) and thus plant structures and textures have always been inspirational (Barthlott et al., 2017).

The essence of biomimetics, among other things, is in the imitation of biological mechanisms of nature, which results in their imitation and the development of new nanomaterials, nanodevices and processes. The properties of biological materials and surfaces arise from complex interactions of surface morphology and physical and chemical properties. Desirable molecular properties such as: superhydrophobicity, self-cleaning, reduction of fluid flow resistance, energy conversion and conservation, high adhesion, reversible adhesion, aerodynamic lift, then materials and fibers with high mechanical strength, anti-reflection, structural coloration, thermal insulation, self-healing and sensory-assistive mechanisms some are examples found in nature whose imitation and implementation in the form of new materials would have great commercial importance (Bhusan, 2009).

Biological materials are developed using the information contained in the genetic code. As a result, hierarchical structuring at all levels creates biological tissues as a form of material whose form and structure would be adapted to a specific function and ability to adapt to changes (Fratzl & Weinkamer, 2007).

Arboretum of the Faculty of Forestry in the city of Belgrade represented a research location and a special healing environment with a high variety of species (Vujčić & Tomićević-Dubljević, 2017). The natural heritage Arboretum of the Faculty of Forestry is a green area with a specific purpose and is of exceptional botanical and landscape-horticultural value (University Heritage of Serbia, 2017).

As a Natural Monument, it was declared protected due to the unique, botanically diverse collection of dendroflora in the open space and for the purpose of preserving and improving the gene pool of autochthonous, non-native and exotic dendroflora, as well as rare, endemic and relict species, intended for scientific research and education (Management plan of the nature monument "Forestry Faculty Arboretum" 2021 – 2030) (Figure 1).

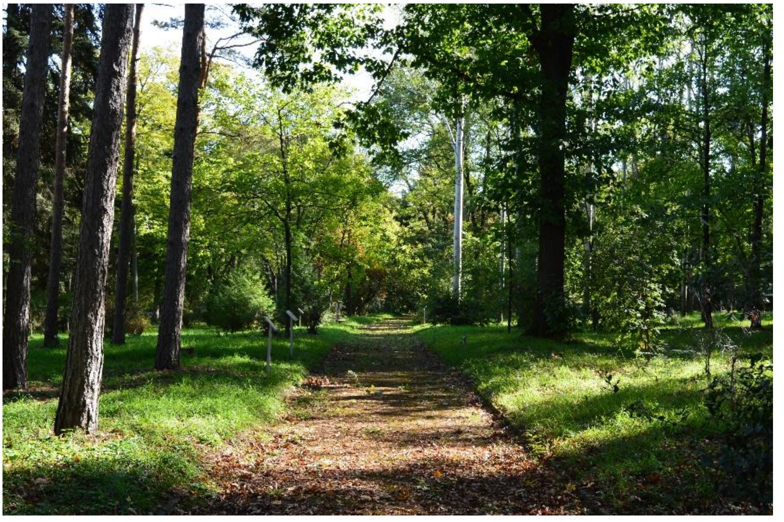

Figure 1. *Arboretum of the Faculty of Forestry, University of Belgrade (source: Olga Gajanić)*

It is primarily recognized for its educational and scientific purpose, followed by bio-ecological and sanitary-hygienic as well as cultural and aesthetic purposes (Management plan of the nature monument "Forestry Faculty Arboretum" 2021 – 2030).

The aim of this work is the analysis of woody shrub species in the Arboretum of the Faculty of Forestry in order to determine the possibility of forming an educational trail, with a focus on medicinal, aromatic and edible species, as well as the research of existing biomimetic solutions, products and technologies based on plant species present in the Arboretum of the Faculty of Forestry in Belgrade.

2. MATERIAL AND METHODS

The method of theoretical and field research was applied for the purposes of this work. Theoretical research was conducted through the collection, analysis, and synthesis of data obtained from a wide array of relevant scientific literature and professional studies. To ensure the accuracy and reliability of the information, various electronic database, search engines and specialized reference tools such as Scopus, Web of Science, Google Scholar, Google Earth Pro and scientific literature were used to find data. These tools made it possible to find reliable resources regarding taxonomy, distribution, and potential uses (medicinal, aromatic, and edible) of shrub species. Theoretical data was accompanied by the analysis of case studies of biomimetic solutions, products, and technologies inspired by plant species around the world, especially those in the Arboretum.

Based on data from the Management plan of the nature monument "Forestry Faculty Arboretum" 2021 - 2030 and other existing AutoCAD maps showing the distribution of shrub species present in the Forestry Faculty Arboretum (fields A, B, C, D, E, F, G and I) (Figure 2), field research was conducted that included detailed photographic documentation of the species, which was used as a visual record, but also for further analysis.

AutoCAD and Photoshop software were used to visualize the graphic conceptual representation of the map of the educational trail.

Figure 2. *Spatial organization of the nature monument "Arboretum of the Faculty of Forestry" (source: Management plan of the nature monument "Forestry Faculty Arboretum" 2021 – 2030)*

3. RESULTS

During the research, 51 shrub species were recorded in the Arboretum of the Faculty of Forestry in Belgrade. Many of them are characterized by distinct decorativeness, and at the same time they are used in traditional and official medicine. The Table 1: Review of decorative, medicinal properties and biomimetic solutions inspired by bushy plant species, shows the most common shrub species present in the Arboretum with a description of their decorative properties, medicinal properties and utility value, as well as existing inspirations for biomimetic solutions. Certain taxa of the plant species *Acer tataricum* L. and *Prunus cerasifera* L. are basically woody species, but have a shrub habit, as is the case in the Arboretum of the Faculty of Forestry in fields B, C and D.

Latin name of the species	Decorativeness	Medical characteristics / use in medicine	Inspiration for biomimetic solutions
Mahonia aquifolium (Mirb. Franco)	Spreading small evergreen shrub with glossy deep green pinnate leaves becoming purplish in winter. Abundant deep yellow flowers in large clusters, followed by black berries.	Rich source of anthocyanins, phenols, and antioxidants, resulting in potential nutritional value (Gunduz, 2013). Used in traditional medicine for the treatment of a wide range of health conditions, such as tuberculosis, periodontitis, dysentery, etc. Has antimicrobial, anti-inflammatory, hepatoprotective, antitumor, antioxidant and analgesic properties (He & Mu, 2015).	Middleton et al. (2024) in their work investigate the wide distribution of matte blue color - UV chromaticity of the fruit of photon effects that occur naturally in epicuticular wax. The reproduction of the structurally colored wax by in vitro recrystallization was performed and the epicuticular wax of the fruits of *Mahonia aquifolium* (Mirb. Franco), which has a high degree of reflection, was extracted (Middleton et al., 2024).
Berberis thunbergii DC. *Berberis juliane* Shneid. *Berberis gagnepainii* var. *lanceifolia* Ahrendt	This plant species is often used as a garden ornamental because in autumn the leaves take on shades of red and orange and the bright red berries persist until the following spring (Brunelle et al., 1996).	Have antioxidant, anti-inflammatory, antibacterial, antifungal, antinociceptive, antihypertensive, antidiabetic activity (Küpeli et al., 2002). Used in traditional medicine for the treatment of heart diseases, digestive complaints and problems with the urinary tract (Bober et al., 2018). The alkaloids berberine, berbamine, palmatine, oxyacanthine, jatrorhizine, magnoflorine and columbamine are present in most species of the genus Berberis (Brázdovlcová et al., 1979).	In their study, Jin et al. (2021) are trying to synthesize a new type of active compound berberine, present in plant species of the *Berberis* genus, for the treatment of asthma, based on nanotechnology.
Taxus baccata L.	Due to its great decorativeness and shaping possibilities, yew is often present in parks, as well as in dendrological collections of botanical gardens around the world.	Taxol is in high demand in the pharmaceutical industry for the preparation of drugs for the treatment of some forms of cancer (Thomas & Polwart, 2003). Used in kidney disease, Alzheimer's, bronchitis, asthma and as an aphrodisiac (Beckstrom-Sternberg & Duke, 1993).	In the field of biomimetics, attention is drawn to the phytochemical properties of certain plants and their mechanical and chemical defense mechanisms against insects. The adaptive mechanism of *Taxus baccata* L. is reflected in the chemical defense it possesses (Koch et al., 2009). Some of these defense strategies are of interest for the development of defense strategies against insect invasions in forests and in other applications. Nature has developed materials, objects and processes that function effectively at both the macro and micro levels (Bhusan, 2009).

Latin name of the species	Decorativeness	Medical characteristics / use in medicine	Inspiration for biomimetic solutions
Philadelphus coronarius L.	*Philadelphus coronarius* L. as an ornamental plant species that grows in the urban environment under constant anthropogenic influence, and is resistant to toxic effects and has a resistance index of 65%, and thus it is classified in the group of plants that are suitable for planting by the roadside or at a distance of 100 meters from the road (Dogadina et al., 2022). Biologically active coumarin is present in extracts of the plant species *P. coronarius* L. (Val'ko et al., 2011). a benzopyrone-based chemical compound that gives the species its scent.	Water extracts of *Philadelphus coronarius* L. flowers are used in traditional medicine and homeopathy. *Philadelphus* sp. are known for their cytotoxic, antibacterial and immunomodulatory effects (Val'ko et al., 2011), also has antiproliferative, apoptotic and antioxidant effects.	
Prunus laurocerasus L.	It is a popular plant species in the field of landscape architecture in temperate regions around the world. It is usually grown as a hedge (Sulusoglu, 2011).	In traditional medicine used for analgesic, antispasmodic, narcotic, sedative effects, treatment of asthma, cough and dyspepsia, while plant extracts showed antifungal antinociceptive and anti-inflammatory activity (Erdemoglu et al., 2003).	Biologically inspired artificial polydimethylsiloxane/polyphenylsulfone (PDMS/PPSU) membranes mimic the hydrophobic properties of natural membranes. Hydrophobicity was achieved by coating the surface sublayer of the membrane using a conventional silicon material, which mimics the character of the epicuticular wax of *Prunus laurocerasus* L. leaves (Jullok et al., 2013).
Prunus cerasifera L.	As an early flowering ornamental species, its application in landscape architecture is significant (Petrov et al., 2024). The color of the leaves is also very decorative.	The study shows that people who have consumed the fruits of *P. cerasifera* for many years have a much lower rate of cardiovascular disease. The fruits are rich in polyphenols, secondary plant metabolites, very effective in the fight against metabolic diseases (Ren et al., 2024).	Current research is based on the use of the *P. cerasifera* species for the biomimetic synthesis of PZO NFs. To obtain zinc, a simple and non-toxic method of obtaining oxide nanofalcates from the reducing agents of *P. cerasifera* pomological extract is applied. It is expected that zinc oxide nanoparticles produced in this way will be widely used in remediation and protection of plants from pathogens (Jaffri et al., 2018).

Latin name of the species	Decorativeness	Medical characteristics / use in medicine	Inspiration for biomimetic solutions
Lonicera tatarica L. *Lonicera ligustrina* var. *pileata* (Oliv.) Franch. *Lonicera x purpusii* Rehder	Some species are highly fragrant and colorful, so are cultivated as ornamental garden plants.	Contains iridoids including secologanin (Hallard et al., 1998) and high content of flavonoids. Has bactericidal properties that inhibit the growth and adhesion of *S. aureus* and *S. epidermidis* strains. *Lonicera* sp. is suitable for the development of new antimicrobial products or strategies to combat medical biofilms (Bubulica et al., 2012).	
Spirea japonica L.	*Spiraea* are shrubby plant species with a very low level of maintenance and a high degree of tolerance but above all they are used for their decorative characteristics, which are widely used for landscaping. The color of flowers and leaves gives the plant decorative properties.	Contains alkaloids and flavonoid glycoside and used as effective therapeutics for inflammation and malaria (Zhang & Wang, 1986). In traditional medicine, the young leaves, fruits, and roots are used as a diuretic, detoxifier, and pain reliever, as well as for the treatment of cough, headache and toothache (Wu, 1984).	
Ligustrum vulgare L.	A bushy, deciduous or semi-evergreen shrub with dark green, lance-shaped leaves and terminal panicles of small, white, pungently-scented flowers in summer, followed by small, shining black berries. Fast growing, if it is clipped regularly it will make a good dense hedge, but will not flower or fruit.	Used in traditional medicine for prevention of cardiovascular disease, chronic inflammation, hypertension, type II diabetes, and cancer (Huang et al., 2019). Contains various bioactive phytochemicals such as phenylethanoids, triterpenes, flavonoids, organic acids, lignans and characteristic iridoids associated with the Oleaceae family (Litewski et al., 2024).	
Pyracantha coccinea M. Roem.	Fire thorn is most often used as an ornamental garden plant, both because of its fast growth and resistance to almost all habitat conditions, and because of its autumn	Has polyphenols with powerful antioxidant properties (Prior & Cao, 2015) and	

Latin name of the species	Decorativeness	Medical characteristics / use in medicine	Inspiration for biomimetic solutions
	and winter appearance. The fruits, after which this species got its name, with their flaming colors represent an accent in the winter landscape (Grlić, 1986).	bioactive compounds such as polyphenols, fatty acids and vitamins (Keser, 2014). Keser in his study shows the presence of phenolic acids and flavonoids significant for the removal of free radicals.	
Deutzia scabra Thunb.	A medium to large-sized, deciduous shrub, growing to 2-3m high. Bears simple, opposite, lanceolate, apple-green, serrated foliage and flattish heads of single, white, star-shaped flowers in spring.	Has antipyretic, diuretic, insecticidal properties and ability to strengthen bone tissue (Yang, 1998). Contains iridoids and flavonoids that affect protection of the gallbladder and stomach, as well as hypoglycemic, antibacterial and anti-inflammatory properties (Gu et al., 2020).	
Junuperus x *pfitzeriana* (Spath) P.A. Schmidt.	*Junuperus* x *pfitzeriana* is an evergreen shrub with thick, upright branches clothed in sharply pointed needles that are light green with shades of blue. Depending on the variety, it works well as a ground cover and can be used for hedges, single or group planting. It requires very little maintenance and belongs to highly resistant varieties.	A precursor of the anticancer drug podophyllotoxin (PPT) with effective antiproliferative properties has been discovered in many species of the genus Juniperus, such as *J. × media Pfitzeriana* (Spath) Schmidt (Kusari et al., 2011).	In his study, Kim (2012) provides a detailed description of the surface structure of adult leaves of the plant species *Juniperus chinensis*. The micromorphological characteristics of the stomata and epicuticular waxes are responsible for the xeromorphic nature of the leaves. These results can be used in biomimetics to design hierarchical structures to mimic innate plant properties such as hydrophobicity and self-cleaning effects of the leaf surface.
Cornus sanguinea L.	*Cornus sanguinea* is a deciduous shrub that has oval, green leaves and tiny, cream-white flowers in May and June. In autumn, cornus sanguinea reveals its shiny stems as the golden leaves fall. The shoots begin to take on a yellow-orange hue, and the tips turn red as the season progresses, giving the bush the appearance of flames. It is good for adding color in the winter.	The leaves and fruits contain antioxidants, anti-inflammatory, cytoprotective, analgesic, antidiabetic and anticoagulant activity (Stanković & Topuzović, 2012). It is also used in the treatment of cancer, circulatory problems (such as edema) and diabetes (Tarayre & Lauressergues, 1979).	
Cotinus coggygria 'Royal Purple'	Cottonwood is a highly decorative plant species used to beautify outdoor and public	This plant is used in the Balkans and Anatolia to treat wounds and reduce inflammation, as well as to treat	Studies on the leaves of the plant species *Cotinus coggygria* indicate the possibility of designing textural surfaces with unexpectedly high non-wetting

Latin name of the species	Decorativeness	Medical characteristics / use in medicine	Inspiration for biomimetic solutions
	spaces in modern landscape architecture (Dirr, 1990).	gastrointestinal and respiratory disorders (Ploetz, 2000). In Asian countries, *C. coggygria* is often used against hepatitis and even anemia (Ajaib et al., 2010). *C. coggygria* is very rich in phenolic compounds and shows significant antimicrobial activity (Ivanova et al., 2005).	properties. Herminghaus pointed out that these leaves exhibit superhydrophobic properties (Herminghaus, 2000). Understanding the relationship between surface energy and roughness on the non-wetting ability of a surface has led to the development of numerous biomimetic superhydrophobic surfaces.The surfaces of numerous plants and insects have wetting properties that inspire the development of analogous engineering materials (Tuteja et al., 2007).
Hippophae rhamnoides L.	The oval or lightly roundish fruits grow in compact grapes varying from pale yellow to dark orange.	Has a large number of different bioactive compounds, vitamins, minerals, natural antioxidants, n-3 and n-6 fatty acids and proteins, as well as its antioxidant, cardioprotective properties, antiatherogenic, antidiabetic, hepatoprotective, anticancer, immunomodulatory, antiviral, antibacterial, anti-inflammatory and vasorelaxant effects (Krejcarová et al., 2015).	
Acer tataricum L.	In horticulture and landscape architecture, it is used in individual planting, massifs and rows of trees for streets of narrow dimensions. It is easy to maintain (Vukićević, 1996).		Nave et al. (2021) in their research they test the mechanical properties of maple seeds *Acer* sp. Based on the natural form, they created a 3D print model and tested the rotation speed and compared the properties with each other. It has been shown that natural seeds have better performance and it is planned to continue research on this topic. Plants as natural reservoirs of chemical compounds can be useful for the development of advanced nanomaterials through biomimetic principles (Jaffri et al., 2018).
Viburnum lantana L.	They are often planted in gardens and used in landscape design for their colorful appearance, fragrant flowers, size variation	The bark of *V. lantana* was used in folk medicine as a rubticis and antinociceptive. The genus *Viburnum* is	

Latin name of the species	Decorativeness	Medical characteristics / use in medicine	Inspiration for biomimetic solutions
	and highly ornamental fruits (Clement et al., 2012, Awan et al., 2013).	known to contain triterpenoids (Machida & Kikuchi, 1997) diterpenoids, sesquiterpenes, polyphenols (Fukuyama et al., 1996).	
Laburnum anagyroides Medic.	This species blooms in the spring when there are still not many attractive trees and shrubs. Precisely because of these properties, *Laburnum anagyroides* is recommended for urban plantings and gardens as a highly decorative and useful species for insects during the spring season (Stawiarz & Wróblewska, 2013).	Numerous studies conducted in different countries refer to the poisonous and medicinal properties of this taxon (Greinwald et al., 1990).	
Buxus sempervirens L	*Buxus sempervirens* is an evergreen, densely branched shrub that is often used in horticulture. It grows very slowly, but can reach a height of up to 3 m. The leaves are small and oval, green and shiny. It tolerates pruning well, so it is often used to make a variety of shapes in the garden. In planned gardens, boxwood is most often planted as a frame for rose beds or higher plums.	Boxwood is used as a medicinal plant for the treatment of rheumatism and malaria (Neves et al., 2009). According to the literature, *B. simpervirens* contains characteristic nor-triterpene alkaloids of the nor-cycloartane type in leaves, twigs, flowers and roots (Khodzhaev et al., 1983).	
Chimonanthus praecox (L.) Link	Prized for its attractive and sweetly scented winter blooms, *Chimonanthus praecox* is a decidous shrub that adds beuty and fragrance to the garden when most plants lie dormant.	Used to treat rheumatic arthritis, cough, dizziness, nausea, fever, and contributes to detoxification (Shang et al., 2020). The species is also recognized as a source of natural oil, which can be used in perfumery, cosmetics and aromatherapy (Deng et al., 2004).	
Physocarpus opulifolius (L.) Maxim.	*P. opulifolius* has decorative foliage, clusters of white flowers in spring, and red berries in autumn. Various varieties are used in planting due to compactness of growth, yellow or golden color of the leaves and conspicuousness of large flower clusters.	The bark of *Physocarpus opulifolius* is rich in triterpenoid compounds that show antitumor properties (Liu & Yu, 2011).	

The creation of an educational trail in the Arboretum of the Faculty of Forestry, similar to the model that already exists in many botanical gardens, would aim to enhance visitors' to understanding of the photochemical importance of plant species. Additionally it would emphases the variety of applications of biomimicry, using examples of certain biological models, found within woody plant species of the Arboretum and their possible functional application in different spheres of life.

The analysis of the spatial distribution of shrub species within the Arboretum revealed that fields D, E, F, G contain the largest number of impressive shrub species. Consequently, these areas have been identified as the most suitable for the formation of an educational path.

The trail would be further enriched by the installation of strategically placed information boards. On the information boards, significant phytochemical, decorative characteristics, as well as existing biomimetic solutions in various scientific fields related to a certain plant species, would be displayed. The aim is to create an engaging and educational environment where visitors can learn not only about the aesthetic and biological significance of these plants but also their broader impact on innovation.

The conceptual solution of the path of the educational trail which highlights these elements is shown in Figures 3 & 4.

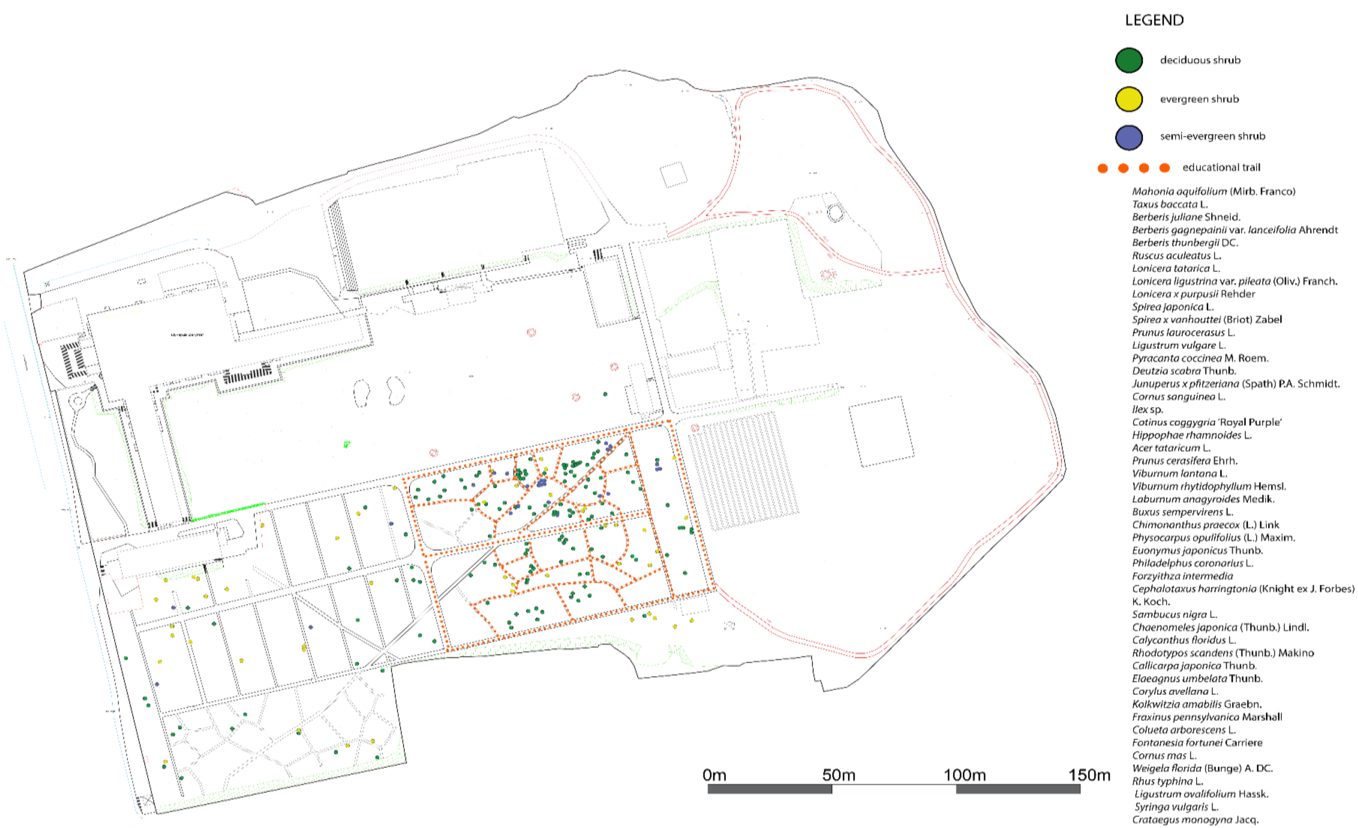

Figure 3. *Conceptual solution of an educational trail inspired by the species of the Arboretum (source: atuhors)*

Figure 4. *Suggested path of the educational trail inspired by the medicinal and useful properties of shrub species in the Arboretum of the Faculty of Forestry - fields D, E, F, G*

Field D: *Mahonia aquifolium* (Mirb. Franco), *Berberis thunbergii* DC., *Lonicera tatarica* L., *Lonicera ligustrina* var. *pileata* (Oliv.) Franch., *Lonicera x purpusii* Rehder, *Pyracanta coccinea* M. Roem., *Deutzia scabra* Thunb., *Cornus sanguinea* L., *Hippophae rhamnoides* L., *Viburnum lantana* L., *Viburnum rhytidophyllum* Hemsl., *Laburnum anagyroides* Medik., *Chimonanthus praecox* (L.) Link, *Philadelphus coronarius* L., Forzyithza intermedia , *Sambucus nigra* L., *Calycanthus floridus* L., *Callicarpa japonica* Thunb., *Elaeagnus umbelata* Thunb., *Kolkwitzia amabilis* Graebn., *Colueta arborescens* L. , *Fontanesia fortunei* Carriere, *Cornus mas* L., *Weigela florida* (Bunge) A. DC., *Rhus typhina* L., *Ligustrum ovalifolium* Hassk., *Syringa vulgaris* L., *Crataegus monogyna* Jacq.

Field E: *Lonicera tatarica* L., *Lonicera ligustrina* var. *pileata* (Oliv.) Franch., *Mahonia aquifolium* (Mirb. Franco), *Taxus baccata* L., *Berberis thunbergii* DC., *Spirea japonica* L., *Spirea x vanhouttei* (Briot) Zabel ,*Prunus laurocerasus* L., *Pyracanta coccinea* M. Roem., *Deutzia scabra* Thunb., *Viburnum lantana* L., *Chimonanthus praecox* (L.) Link, *Physocarpus opulifolius* (L.) Maxim., *Philadelphus coronarius* L., *Sambucus nigra* L., *Chaenomeles japonica* (Thunb.) Lindl., *Calycanthus floridus* L., *Rhodotypos scandens* (Thunb.) Makino, *Callicarpa japonica* Thunb., *Kolkwitzia amabilis* Graebn.

Field F: *Taxus baccata* L., *Prunus laurocerasus* L., *Ilex* sp. , *Viburnum rhytidophyllum* Hemsl., *Euonymus japonicus* Thunb., *Philadelphus coronarius* L., *Cephalotaxus harringtonia* (Knight ex J. Forbes) K. Koch., *Callicarpa japonica* Thunb.

Field G: *Mahonia aquifolium* (Mirb. Franco), *Ruscus aculeatus* L., *Lonicera x purpusii* Rehder, *Viburnum lantana* L., *Philadelphus coronarius* L., *Sambucus nigra* L., *Elaeagnus umbelata* Thunb., *Corylus avellana* L., *Kolkwitzia amabilis* Graebn.

4. DISCUSSION

Many botanical gardens have biomimetic trails with accompanying information boards through which visitors learn about the properties of a particular plant species, as well as how that species found its place in biomimetic, technical applications (Speck & Speck, 2023).

In addition to passive learning, scientists and gardeners offer guided biomimetic tours for interested visitors of all ages, using simple examples to explain functional biomimetic solutions to visitors. They also organize public lectures on numerous biomimetic topics and provide access to scientific and popular scientific publications, organize workshops and lectures for children of different ages, pupils and students (Speck & Speck, 2021, Jacobs et al., 2022).

A notable example is the botanical garden of Freiburg. There is a cactus-inspired pavilion as an illustration of a concrete biomimetic model inspired by the nucleus of the cladode of the cactus *Opuntia* sp. and the stem of the cactus *Carnegiea gigantean* Britton & Rose. Both plant species have a mesh structure, which served as a conceptual solution for the construction of pavilions connected by wooden fiber elements (ICD/ITKEUniversity of Stuttgart, Germany 2020-21, Speck et al., 2023).

The pavilion was built by architects and civil engineers from the University of Stuttgart, Germany, in collaboration with biologists from the University of Freiburg. The Biomimetic Pavilion thus demonstrates the use of natural materials and advanced digital technology in creating a sustainable building inspired by a biological model (Speck et al., 2023).

The formation of an educational path inspired by the medicinal and useful properties of the shrub species present in the Arboretum of the Faculty of Forestry, the area of specific purpose and exceptional botanical and landscape-horticultural value would further emphasize the educational, scientific and cultural function and importance of this natural monument. This type of educational trail would also include displays of various existing biomimetic solutions, products and technologies based on plant species present in the Arboretum of the Faculty of Forestry.

This type of interactive education in the natural environment, both for citizens, would be extremely significant for the students of the Faculty of Forestry, who would gain insight into various ways of applying models from nature through familiarization with various existing biomimetic solutions, which would also serve as inspiration for the creation of new biodesign models.

5. CONCLUSION

Janine Benyus in her book "Biomimicry", which has attracted the attention of many disciplines including biology and design, points out that she considers nature to be the greatest designer and emphasises the importance of turning to nature and biology to get the answers we need. All the answers lie in nature, it's just important that we know where to look.

Learning from living nature in order to learn about the importance of medicinal and aromatic plants as well as the development of biomimetic technical applications has a special role in botanical gardens and arboretums, which is reflected in educational trails and guided tours.

The continuation of the research would be focused on researching the medicinal and useful values of the remaining dendroflora and herbaceous ground flora of the Arboretum of the Faculty of Forestry, as well as existing biomimetic solutions inspired by those plant species, and in this way it would be possible to approach the design of a comprehensive educational botanical trail that would pass through the entire Arboretum.

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THE POSSIBILITY OF CREATING AN EDUCATIONAL TRAIL INSPIRED BY THE MEDICINAL AND USEFUL PROPERTIES OF THE SHRUB SPECIES PRESENT IN THE ARBORETUM OF THE FACULTY OF FORESTRY

Olga GAJANIĆ, Biljana JOVIĆ, Ivana BJEDOV, Marija NEŠIĆ

Summary

The aim of this work is the analysis of woody shrub species in order to determine the possibility of forming an educational trail in the Arboretum of the Faculty of Forestry, with a focus on medicinal, aromatic and edible species, as well as the research of existing biomimetic solutions, products and technologies based on plant species present in the Arboretum of the Faculty of Forestry in Belgrade. The method of theoretical and field research was applied for the purposes of this work. Theoretical research was conducted through the collection, analysis, and synthesis of data obtained from a wide array of relevant scientific literature and professional studies. growth forms, and distributions of shrubs were studied across different sections of the Arboretum of the Faculty of Forestry in the city of Belgrade (fields A, B, C, D, E, F, G, and I). This field research also included a detailed

photographic documentation of the species, which was used as a visual record and also for further analysis. AutoCad and Photoshop software were used for the graphic conceptual representation of the educational trail. The creation of an educational trail in the Arboretum of the Faculty of Forestry, similar to the model that already exists in many botanical gardens, would aim to enchance visitors' to understanding of the photochemical importance of plant species. Additionaly it would emphaze the variety of applications of biomimicry, using examples of certain biological models, found within woody plant species of the Arboretum and their possible functional application in different spheres of life. This type of intervention would contribute to a better way of using this natural space, not only by students but also by the wider population of citizens. The purpose of guided tours on educational trails in botanical gardens and arboretums is to learn about the importance of medicinal and aromatic plants by learning from nature and getting to know biomimetic technical innovations.

MOGUĆNOST KREIRANJA EDUKATIVNE STAZE INSPIRISANE LEKOVITIM I UPOTREBNIM SVOJSTVIMA ŽBUNASTIH VRSTA PRISUTNIH U ARBORETUMU ŠUMARSKOG FAKULTETA

Olga GAJANIĆ, Biljana JOVIĆ, Ivana BJEDOV, Marija NEŠIĆ

Rezime

Cilj ovog rada je analiza drvenastih žbunastih vrsta radi utvrđivanja mogućnosti formiranja edukativne staze u Arboretumu Šumarskog fakulteta, sa fokusom na lekovite, aromatične i jestive vrste kao i istraživanje postojećih biomimetičkih rešenja, proizvoda i tehnologija zasnovanih na biljnim vrstama prisutnim u Arboretumu Šumarskog fakulteta u Beogradu. Za potrebe izrade ovog rada primenjena je metoda teorijskog i terenskog istraživanja. Teorijsko istraživanje sprovedeno je kroz prikupljanje, analizu i sintezu podataka dobijenih iz obimnog izvora relevantne naučne literature i stručnih studija. Terensko istraživanje podarzumevallo je proučavanje forme rasta i rasprostranjenost žbunastih biljnih vrsta u različitim delovima Arboretuma Šumarskog fakulteta u Beogradu (na poljima A, B, C, D, E, F, G i I), kao i izradu fotodokumentacije koja je korišćena kao vizuelni zapis i materijal za dalju analizu. Za grafički konceptualni prikaz edukativne staze korišćeni su softveri AutoCad i Photoshop. Uvođenje edukativnih staza za cilj bi imao da posetiocima približi fotohemijski značaj biljnih vrsta, kao i raznovrsnost primene biomimikrije na primerima pojedinih bioloških modela, drvenastih biljnih vrsta Arboretuma i njihove moguće funkcionalne primene u različitim sferama života. Ova vrsta intervencije doprinela bi boljem načinu koršćenja ovog prirodnog prostora, ne samo od strane studenata nego i šire populacije građana. Svrha vođenih tura po edukativnim stazama u botaničkim baštama i arboretumima, sprovodi se u cilju upoznavanja značaja lekovitih i aromatičnih biljaka „učenjem" iz prirode i upoznavanjem sa biomimetičkim tehničkih inovacijama.

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CO-FIRING OF CONTAMINATED WILLOW BIOMASS (*SALIX* L.) WITH LIGNITE IN THE ENERGY PRODUCTION PROCESS

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Abstract: *The share of renewable energy sources (RES) in energy production processes is growing every day in many countries. Globally, there is a very pronounced tendency to eliminate fossil fuels for energy production, which are replaced by RES. The path to decarbonization involves the successive reduction of fossil fuels and their replacement by RES. One of the possibilities of using RES, which could be used in co-firing processes with coal, is biomass obtained from fast-growing woody species, such as poplars and willows. Willows, as effective hyperaccumulators of heavy metals, successfully remediate the soil, producing biomass that can be used in energy production, both independently and through co-firing with coal. The aim of this paper is to determine the energy potential of contaminated willow biomass, as well as to determine the most favourable type of willow that would be used to improve the calorific value of lignite in co-firing processes, in different percentage ratios. The biomass obtained from willows contaminated with heavy metals (Cd, Cu, Cr, Ni, Pb and As) is characterized by a higher calorific value than the value of the examined lignite samples. Two types of willows, basket willow (Salix viminalis) and white willow (S. alba), clone B-44, as well as three coal samples, sampled from three different locations in Kolubara Mining Basin, Elektroprivreda Srbije AD, were examined. The obtained results indicate the dependence of the calorific value of lignite on the coal deposit, while the calorific value of willow depends on the type of willow. White willow (clone B-44) has a higher energy potential than basket willow, and co-firing processes are economically justified, if lower percentage ratios (about 10%) of biomass were used.*

Keywords: heavy metals, willows, coal, co-firing, energy potential.

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KOSAGOREVANJE KONTAMINIRANE BIOMASE VRBA (*SALIX* L.) SA LIGNITOM U PROCESU PROIZVODNJE ENERGIJE

Apstrakt: *Uvećanje procenta upotrebe obnovljivih izvora energije (OIE) u procesima proizvodnje energije svakim danom raste u mnogim zemljama. U svetu je veoma izražena tendencija eliminacije fosilnih goriva za proizvodnju energije, čiju supstituciju vrše OIE. Put ka dekarbonizaciji uključuje sukcesivno umanjivanje fosilnih goriva i njihovu zamenu OIE. Jedna od mogućnosti upotrebe OIE, koja bi mogla da se koristi u procesima kosagorevanja sa ugljem, predstavlja biomasa dobijena od brzorastućih drvenastih vrsta, kao što su topole i vrbe. Vrbe, kao dobri hiperakumulatori teških metala, uspešno vrše rekultivaciju zemljišta, proizvodeći biomasu koja se može upotrebiti u proizvodnji energije, kako samostalno, tako i kroz kosagorevanje sa ugljem. Cilj ovog rada je utvrđivanje energetskog potencijala biomase kontaminiranih vrba, kao i utvrđivanje najpovoljnije vrste vrba koja bi se koristila za poboljšanje kalorijske vrednosti lignita u procesima kosagorevanja, u različitim procentualnim odnosima. Biomasu, dobijenu od vrba kontaminiranim teškim metalima (Cd, Cu, Cr, Ni, Pb i As), karakteriše veća kalorijska vrednost od vrednosti ispitivanih uzoraka lignita. Ispitivane su dve vrste vrba, košarasta vrba (Salix viminalis) i bela vrba (S. alba), klon B-44, kao i tri uzorka uglja, uzorkovana sa tri različita lokaliteta u RB Kolubara, Elektroprivreda Srbije AD. Dobijeni rezultati ukazuju na zavisnost kalorijske vrednosti lignita od ležišta uglja, dok je kalorijska vrednost vrba zavisna od vrste vrba. Bela vrba (klon B-44) ima veći energetski potencijal od košaraste vrbe, a procesi kosagorevanja su ekonomski opravdani, ukoliko bi se koristili manji procentualni odnosi (oko 10%) biomase.*

Keywords: teški metali, vrbe, ugalj, kosagorevanje, energetski potencijal.

1. INTRODUCTION

In order to mitigate climate change, many countries have decided to take the path of decarbonization. This path implies a successive reduction in the use of fossil fuels for energy generation. Therefore, in order to compensate for the shortfall in the daily base load diagram and ensure the energy stability of the system, the reduced amount of fossil fuels is supplemented with renewable energy sources (RES). As one of the renewable energy sources there is the biomass obtained from fast-growing deciduous trees, such as willows and poplars. Thijs et al. (2018) point out that willows, compared to other species such as poplars, have by far the highest absorption potential of heavy metals in field conditions. According to Rodzkin (2014), the use of willows for economic purposes is successful due to their intensive growth, geographical distribution and ability to easily adapt to different environmental conditions, which is why they are classified in the group of short rotation coppices and their harvesting from energy plantation is possible every other year, for 20 years. The biomass obtained from energy plantations, according to Nixon et al. (2001), can be used for the production of charcoal, for direct combustion, because it contains a low ash content, moisture and alkali metals, for the production of electricity in special generators, or simply as a source of carbon in atmospheric CO_2 .

On the one hand the existence of a developed industry is the main indicator of the progress of any country. Yet on the other hand, the negative side of the presence of a large number of factories and industrial plants results in the emission of significant amounts of greenhouse gases, but also of heavy metals, and the production of electricity, using fossil fuels, results in the release of a significant amount of pollutants that threaten the environment. It is the obligation of every country to carry out the remediation of soil polluted by heavy metals and it represents a significant expenditure to every business entity. If willows were used on such devastated land, due to their highly branched root system, they would solve the problem of erosion with simultaneous phytoremediation of heavy metals, and in addition, the treated area would also produce biomass, which would be used for energy production (Heller et al., 2003). Also, according to Jerba et al. (2020), willow plantations have the ability to perform biodrainage, where excess groundwater is removed through transpiration. By doing so, the land originally intended for remediation, which would have been an expense, would instead generate financial returns through energy production. It is precisely for this reason that a large number of countries use biomass for energy production, both independently and in co-firing with coal. A new approach to the system of forest cultivation - the establishment of shoot plantations of fast-growing tree species, i.e. energy (bioenergy) plantations, is increasingly being applied in the countries of Europe and North America (Vacek et al., 2009).

Decarbonization, as the ultimate goal adopted by many countries around the world, implies the elimination of fossil fuels, but the path to this ultimate goal is very complex, because the power system stability of many countries depends, to a high percentage, on fossil fuels. In order to ensure the power system stability, a successive reduction of fossil fuels was agreed accompanied by an increase in the percentage of RES. This was the main reason why many countries are signatories to the international agreement from 1997, the Kyoto Protocol, which obliges them to increase the share of renewable energy sources. An example of the above is the process of co-firing of coal and biomass, as a way to generate energy while reducing coal as a fossil fuel. If the biomass of willows, grown on land loaded with heavy metals, were to be used for energy production (either independently or in the process of co-firing with coal), at the same time it would benefit to the land reclamation while respecting the requirements related to the protection and preservation of the environment. Biomass is a form of solar energy accumulated by plant tissues, because it is produced by the process of photosynthesis, from solar energy, CO_2 from the atmosphere and water from the soil (Stolarski et al., 2013).

Willows belong to the genus *Salix L.* Oljača et al. (2017) state that there are a large number of willow species that can have different forms, but most often it is a tree that can be over 20 m high with a diameter of up to 1 m, although they can also have the form of a ground plant or bush. Arsenov (2018) points out willows as fast-growing woody plants that are managed according to the short rotation principle, because they are characterized by high biomass productivity, enviable intensity of transpiration, well-branched and strongly developed root system and genetic variability.

Willows are known as good hyperaccumulators of heavy metals and can be used to clean up devastated habitats. The formation of energy plantations on land contaminated with heavy metals, along with the simultaneous phytoextraction of heavy metals, also provides biomass with a significant calorific value, which does not differ much from the calorific value of biomass obtained from uncontaminated habitats. Rodzkin et al. (2024) indicate the effectiveness of using fast-growing species - willows for biomass production, emphasizing that willows can be grown both on uncontaminated land and on land loaded with heavy metals, while the degree of contamination does not affect the calorific value of willows, but only on the biomass yield which depends on the type and clone of the plants and the soil contamination itself. A significant amount of certain heavy metals, in the process of phytoremediation, is stabilized in the willow roots, so that during the burning of biomass, it is not emitted into the atmosphere.

Many countries utilize woody species biomass, such as willows and poplars, for energy production, either independently in bioenergy plants or through co-firing with lignite. This process enhances the calorific value of coal, resulting in economic benefits while primarily contributing to a cleaner, more sustainable environment. Tharakan et al. (2005) state that the co-firing of coal and wood biomass, in existing energy boilers, will be the most promising method of energy production, while Tillman (2000) believes that the production of electricity by burning willow biomass in combination with other wood biomass or with coal in existing power plants, has already become the most promising commercial option. In Poland, the production of electric and thermal energy is often provided by co-firing of biomass and coal (Dzikuć and Piwowar, 2016). Backreedy et al. (2005) states that in Great Britain, in some thermal power plants, energy is produced by co-firing of biomass (in the ratio of 2-4%) and coal. Hughes (2000) states that research in thermal power plants in New York State has shown that co-firing willows with coal is technically feasible, with the costs of such capital projects being significantly lower than projects involving individual combustion of biomass, wind turbines and most other RES technologies.

The energy community treats biomass as a "carbon-free" fuel with the explanation that the amount of CO_2 that is emitted during combustion represents the same amount that it absorbs during its growth (Heller et al., 2003). Tharakan et al. (2003) point out the biomass obtained from willows as an energy source which, compared to coal, has almost no sulphur, has significantly less trace metals and, depending on the method of combustion in plants, can result in significantly lower NO_x emissions.

The aim of this paper is to determine the energy potential of willow biomass grown on contaminated land in co-firing processes with lignite in different percentage ratios.

2. MATERIAL AND METHODS

In this paper, the calorific values of three lignite samples, biomass from two willow species, and lignite-biomass mixtures with varying biomass proportions (5%, 10%, 15%, and 20%) were measured. The examined willow species: basket willow (*Salix viminalis* L.) and white willow (*S. alba* L.) - clone B-44, were grown on soil contaminated with aqueous solutions of heavy metals. The plant material (cuttings) was obtained from the mother plantation of the "Ratno Ostrvo" nursery, Public Enterprise "Vojvodina Šume," Novi Sad Forestry Unit, Kać Forest Management Unit, ensuring that the cuttings were of approximately similar morphological dimensions. The cuttings were grown in soil in 10 l bags, taken from Kolubara Mining Basin, Elektroprivreda Srbije AD, which, at the beginning of each growing season, was additionally contaminated with aqueous solutions of salts of heavy metals [$Cd(NO_3)_2$, 112,4 ppm; $CuSO_4$*$5H_2O$, 63,5 ppm; $K_2Cr_2O_7$, 104,0 ppm; Na_2HAsO_4*$7H_2O$, 74,9 ppm; $NiCl_2$*6H2O, 58,7 ppm; P_bNO_3, 207,2 ppm] in the concentration of 10^{-3} mol/dm^3. The experiment was set up in the nursery of the Faculty of Forestry in Belgrade. After three years, willows were cut and air-dried for two months.

The first two lignite samples (U1 and U2), sampled at two localities in the eastern part of Kolubara Mining Basin, represent mixed coal from field B/C and field E, and the current total field E, Kolubara Mining Basin. The third sample (U3) is a sample from the western part of the Kolubara basin, at the loading point Drobilana-Kalenić and represents mixed coal from the area of Tamnava western field and field G. Lignite and biomass samples were prepared by grinding in laboratory coal mills.

The calorific values of all three coal samples, both willow species, as well as their mixtures were determined without correction using the calorimeter IKA C 5003 in the laboratory of the Organizational Unit for processing (OC Prerada) within the Kolubara Mining Basin of EPS AD.

The obtained calorific values were processed using descriptive and univariate statistical methods. Descriptive statistics included the determination of the mean value, standard deviation, coefficient of variation, as well as the range of values. The significance of differences among mean values was determined by analysis of variance (ANOVA) and *post hoc* Fisher's least significant difference (LSD) test. Statistical analyzes were performed in the software program Statgraphics Centurion v. XVI.I. (2009; Statpoint Technologies, Inc., Warrenton, VA, USA).

3. RESULTS AND DISCUSSION

The mean calorific values for willow biomass obtained by air drying were 18201 kJ/kg for *Salix viminalis* and 18219 kJ/kg for *S. alba.* The first species is characterized by a minimum calorific value of 18198 kJ/kg and a maximum value of 18206 kJ/kg, while the second is characterized by a minimum value of 18213 kJ/kg and a maximum of 18224 kJ/kg. The calorific values of the biomass obtained from the researched species are characterized by a low value of the coefficient of variation (0.02-0.03%). The results of the analysis of variance (ANOVA) indicate that the mean calorific values of the biomass of the two willow species are statistically significantly different from each other (p = 0.0116) (Tab. 1). Based on the above, it can be said that there is a dependence of the calorific value of biomass and species. The obtained results are in agreement with Karampinis and Hevas (2011), who state that the calorific value of willow is 18410 kJ/kg, while Kijo-Kleczkowska et al. (2016) state the calorific value of the willow species Salix viminalis, without "dry basis" drying, amount to 16824 kJ/kg. The species *S. viminalis* is characterized by lower calorific values (18201 kJ/kg) compared to the species *S. alba* (18219 kJ/kg), which is in agreement with Urošević et al. (in press) who point out that the calorific values of basket willow and white willow, grown in an uncontaminated area, amount to 17966 kJ/kg and 18046 kJ/kg, respectively.

Table 1. *Descriptive statistics and analysis of variance (ANOVA) for calorific values of willow species*

Species	Average	Standard deviation	Coeff. of variation (%)	Minimum	Maximum	Range	ANOVA	
							F-ratio	*p*-value
S. viminalis	18201.00 b	4.36	0.02	18198.0	18206.0	8.0	19.44	**0.0116**
S. alba	18219.00 a	5.57	0.03	18213.0	18224.0	11.0		

Note: *Different letters within a column denote statistically significant differences at the 95% confidence level*

Depending on the examined coal samples, the mean calorific values of the investigated coal samples (Tab. 2) ranged from 12,138.03 kJ/kg (the lower calorific value is 7,514 kJ/kg - sample U3) to 15,946.00 kJ/kg (the lower calorific value is 9,791 kJ/kg – sample U2). The minimum value (12,070 kJ/kg) was measured for coal sample U3, and the maximum (15,978 kJ/kg) for the sample U2. In relation to the calorific value of the examined coal samples, low values of the coefficient of variation (0.25-0.49%) were established. Based on the results of the analysis of variance (ANOVA), statistically significant differences (p = 0.0000) were found between the mean calorific values of the coal samples, whereby three homogeneous groups were formed. The calorific value of coal depends on the sample, whereby the sample U2 has the highest calorific value, and the sample U3 the lowest. The lower calorific value can be explained by the presence of a larger amount of clay in the sample U3 compared to the other samples.

Table 2. *Descriptive statistics and analysis of variance (ANOVA) for calorific values of coal samples (U1–U3)*

Coal sample	Average	Standard deviation	Coeff. of variation (%)	Minimum	Maximum	Range	ANOVA	
							F-ratio	*p*-value
U1	12,975.00 b	63.24	0.49	12,905.0	13,028.0	123.0	3,902.16	**0.0000**
U2	15,946.00 a	39.40	0.25	15,902.0	15,978.0	76.0		
U3	12,138.30 c	60.70	0.50	12,070.0	12,186.0	116.0		

Note: *Different letters within a column denote statistically significant differences at the 95% confidence level*

Table 3. *Descriptive statistics and analysis of variance (ANOVA) for calorific values of coal and mixtures composed of different coal samples (U1-U3) and biomass of two willow species (G1 – Salix viminalis, G2 – S. alba) added in different percentages (B5–B20)*

Biomass and coal mixture	Average	Standard deviation	Coeff. of variation (%)	Minimum	Maximum	Range	ANOVA	
							F-ratio	*p*-value
U1G1B5	13,113.00	40.63	0.31	13,079.0	13,158.0	79.0	3,064.29	**0.0000**
U1G1B10	13,534.00	31.43	0.23	13,506.0	13,568.0	62.0		
U1G1B15	13,758.00 g	26.85	0.20	13,727.0	13,774.0	47.0		
U1G1B20	13,959.00 f	45.57	0.33	13,926.0	14,011.0	85.0		
U1G2B5	13,279.00	19.08	0.14	13,259.0	13,297.0	38.0		
U1G2B10	13,819.00 g	193.16	1.40	13,596.0	13,934.0	338.0		
U1G2B15	13,936.00 f	13.23	0.09	13,921.0	13,946.0	25.0		
U1G2B20	14,123.00 e	24.43	0.17	14,106.0	14,151.0	45.0		

Biomass and coal mixture	Average	Standard deviation	Coeff. of variation (%)	Minimum	Maximum	Range	ANOVA	
							F-ratio	*p*-value
U2G1B5	16,262.00	17.52	0.11	16,244.0	16,279.0	35.0		
U2G1B10	16,248.00 d	20.66	0.13	16,231.0	16,271.0	40.0		
U2G1B15	16,530.00 ab	15.87	0.10	16,518.0	16,548.0	30.0		
U2G1B20	16,468.00 b	26.96	0.16	16,437.0	16,486.0	49.0		
U2G2B5	16,230.00 d	24.33	0.15	16,214,0	16,258,0	44,0		
U2G2B10	16,365.00 c	19.92	0.12	16,353.0	16,388.0	35.0		
U2G2B15	16,364.00 c	30.45	0.19	16,337.0	16,397.0	60.0		
U2G2B20	16,584.00 a	19.98	0.12	16,571.0	16,607.0	36.0		
U3G1B5	12,822.00 m	23.90	0.19	12,801.0	12,848.0	47.0		
U3G1B10	13,159.00 jk	25.53	0.19	13,137.0	13,187.0	50.0		
U3G1B15	13,221.00 ij	27.73	0.21	13,204.0	13,253.0	49.0		
U3G1B20	13,502.00	25.71	0.19	13,482.0	13,531.0	49.0		
U3G2B5	12,645.00 n	22.65	0.18	12,624,0	12,669,0	45.0		
U3G2B10	12,927.00 l	22.11	0.17	12,910.0	12,952.0	42.0		
U3G2B15	12,863.00 lm	20.88	0.16	12,849.0	12,887.0	38.0		
U3G2B20	13,249.00 i	26.29	0.20	13,230.0	13,279.0	49.0		

Note: *Different letters within a column denote statistically significant differences at the 95% confidence level*

In Table 3, the mean calorific values of willow biomass and coal mixtures amounted from 13,113 kJ/kg for coal sample U1 and 5% *Salix viminalis* biomass to 16,584 kJ/kg for coal sample U2 and 20% biomass *S. alba.* The obtained calorific values of mixtures of coal and biomass samples for both types, in different percentage ratios, are characterized by low values of the coefficient of variation (0.17-1.4%). The results of the analysis of variance (ANOVA) show that the mean calorific values of biomass mixtures for two willow species in different proportions and coal samples are statistically significantly different from each other (p = 0.0000), forming 18 homogeneous groups. Based on the above, it can be said that the calorific value of the mixture depends on the species from which the biomass is obtained, the amount of added biomass and the coal sample, which is consistent with Urošević et al. (2023). The lowest mean heat value was obtained by co-firing of 5% white willow biomass and coal sample U3 (12,645 kJ/kg). The highest mean heat value obtained by co-firing of 20% of white willow biomass and coal sample U2 (16,584 kJ/kg), whereby the addition of 15% of basket willow biomass to coal sample U2 results in a similar improvement in the calorific value of coal (see homogeneous group *ab*). Also, by adding only 10% of white willow biomass to coal sample U2, a solid improvement in calorific value is obtained (see homogeneous group *c*), because by adding half as much biomass of this species to coal sample U2, only 1.3% less improvement in calorific value of coal is obtained compared to the aforementioned mixture.

Based on the differences in the calorific value of coal and biomass mixtures, added in different percentage ratios, as well as the coal samples themselves, it can be stated that the greatest increase in calorific value is achieved by adding 20% of biomass to coal. It can also be stated that the percentage of added biomass does not increase the calorific values of the examined mixtures linearly. Hence, it can be pointed out that it is more favourable, more energy efficient and more economically profitable to use a mixture of coal with lower percentage shares of biomass (5-10%). The results presented in this paper, which indicate the economic using a lower percentage of biomass in co-firing with coal, are consistent with the findings in the literature. Thus, Savolainen (2003) points out that the concept of co-firing of biomass and coal represents the possibility of replacing smaller percentages of coal with biomass - RES. Also, in accordance with Dzikuć and Piwowar (2016), the application of biomass in lower percentages (5%, 6% and 7%) in the process of co-firing with coal in thermal power plants in Poland indicates that certain countries on their path to decarbonization have started to use biomass as a substitute for a smaller portions of coal in energy production processes.

4. CONCLUSION

Based on the results of this paper, the following conclusions can be drawn:
- Biomass obtained from contaminated soils can be used for energy production;
- White willow (*Salix alba*) has a greater potential in the processes of improving the calorific value of coal compared to basket willow (*S. viminalis*).
- the Sample U2 represents coal with the highest calorific value, and the coal sample U3 is the one with the lowest calorific value.
- the calorific value of the mixture of coal and biomass depends on the type of coal and the amount of added biomass, and less on the willow species or genotype, whereby the highest calorific increase in the mixture of biomass and lignite is achieved by adding 20% of white willow biomass;
- although the differences in calorific values between the coal sample and the mixture of coal and biomass grow with the increase in the percentage of biomass in the mixture, the use of lower amounts of biomass (5–10%) is more economically justified.

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CO-FIRING OF CONTAMINATED WILLOW BIOMASS (*SALIX* L.) WITH LIGNITE IN THE ENERGY PRODUCTION PROCESS

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Summary

One of the renewable energy sources is the biomass of fast-growing deciduous trees. Willows (*Salix* L.) can be grown both on uncontaminated soil and on soil loaded with heavy metals, where the level of contamination does not affect their calorific value, but the biomass yield, which depends on the species or clone of the plants and the contamination. A significant amount of certain heavy metals, in the process of phytoremediation, is stabilized in the willow roots, so that during the burning of biomass, it is not emitted into the atmosphere. The aim of this paper is to determine the energy potential of willow biomass grown on contaminated soil in co-firing processes with lignite in different percentage ratios.

The calorific values of three lignite samples, biomass from two willow species, and lignite-biomass mixtures with varying biomass proportions (5%, 10%, 15%, and 20%) were measured. The examined species include: *Salix viminalis* L. and *S. alba* L. (clone B-44), were grown for three years on soil contaminated with aqueous solutions of heavy metals (Cd, Cu, Cr, Ni, Pb and As). Two lignite samples (U1 and U2) were sampled at two localities in the eastern part of Kolubara Mining Basin (mixed coal from field B/C and field E). The third sample (U3) is a sample from the western part of the Kolubara Basin (mixed coal from the area of Tamnava western field and field G). Calorific values of coal samples, willow species, as well as their mixtures, were measured without correction using the IKA C 5003 calorimeter. The results were processed using descriptive statistics and analysis of variance (ANOVA).

The research results show that the species *S. viminalis* is characterized by lower calorific values (18,201 kJ/kg) compared to the species *S. alba* (18,219 kJ/kg). Also, the calorific value of coal depends on the sample, whereby the sample U2 shows the highest calorific value, and the sample U3 the lowest. Finally, the calorific value of the mixture of coal and biomass depends on the species from which the biomass is obtained, the amount of added biomass and the coal sample. The highest mean heat value obtained by co-firing of 20% of white willow biomass and coal sample U2 (16,584 kJ/kg), whereby the addition of 15% of basket willow biomass to coal sample U2 results in a similar improvement in the calorific value of coal. Also, by adding only 10% of white willow biomass to the coal sample U2, a solid improvement in calorific value is obtained, because by adding half as much biomass of this species to the coal sample U2, only 1.3% less improvement in calorific value of coal is obtained. Therefore, although the differences in calorific values between the coal sample and the mixture of coal and biomass grow with the increase in the percentage of biomass in the mixture, the use of lower amounts of biomass (5–10%) is more economically justified.

KOSAGOREVANJE KONTAMINIRANE BIOMASE VRBA (*SALIX* L.) SA LIGNITOM U PROCESU PROIZVODNJE ENERGIJE

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Rezime

Jedan od obnovljivih izvora energije predstavlja biomasa brzorastućih lišćara. Vrbe (*Salix* L.) je moguće gajiti kako na nekontaminiranom zemljištu, tako i na zemljištu opterećenom teškim metalima, pri čemu nivo kontaminacije ne utiče na njihovu kalorijsku vrednost, već na prinos biomase koji zavisi od vrste ili klona biljaka i kontaminacije. Značajna količina određenih teških metala, u procesu fitoremedijacije, stabilizovana je u korenu vrba, tako da se prilikom sagorevanja biomase ne emituje u atmosferu. Cilj rada je utvrđivanje energetskog potencijala biomase vrba gajenih na kontaminiranom zemljištu u procesima kosagorevanja sa lignitom u različitim procentualnim odnosima.

Utvrđene su kalorijske vrednosti tri uzorka lignita, biomase dve vrste vrba i smeše biomase i lignita u različitim procentualnim odnosima (5, 10, 15 i 20% biomase). Ispitivane vrste, *Salix viminalis* L. i *S. alba* L. (klon B-44), gajene su tri godine na zemljištu koje je kontaminirano vodenim rastvorima teških metala (Cd, Cu, Cr, Ni, Pb i As). Dva uzorka lignita (U1 i U2) uzorkovana su na dva lokaliteta istočnog dela RB Kolubara (mešani ugalj sa polja B/C i polja E). Treći uzorak (U3) je uzorak sa zapadnog dela Kolubarskog basena (mešani ugalj sa Tamnave zapadno polje i polja G). Kalorijske vrednosti uzoraka uglja, vrsta vrba, kao i njihovih smeša, određivane su bez korekcije kalorimetrom IKA C 5003. Rezultati su obrađeni primenom deskriptivne statistike i analize varijanse (ANOVA).

Rezultati istraživanja pokazuju da vrstu *S. viminalis* karakterišu niže kalorijske vrednosti (18201 kJ/kg) u poređenju sa vrstom *S. alba* (18219 kJ/kg). Takođe, kalorijska vrednost uglja zavisi od uzorka, pri čemu uzorak U2 karakteriše najveća kalorijska vrednost, a uzorak U3 najmanja. Najzad, kalorijska vrednost smeše uglja i biomase zavisi od vrste od koje se dobija biomasa, količine dodate biomase i uzorka uglja. Najveća srednja toplotna vrednost dobijena kosagorevanjem 20% biomase bele vrbe i uzorka uglja U2 (16584 kJ/kg), pri čemu se dodatkom 15% biomase košaračke vrbe uzorku uglja U2 dobija slično poboljšanje kalorijske vrednosti uglja. Takođe, dodatkom samo 10% biomase bele vrbe uzorku uglja U2 dobija se solidno poboljšanje kalorijske vrednosti, jer se dodatkom upola manje biomase ove vrste uzorku uglja U2 dobija samo 1,3% manje poboljšanje

kalorijske vrednosti uglja. Dakle, iako razlike u kalorijskim vrednostima između uzorka uglja i smeše uglja i biomase rastu sa povećanjem procentualnog sadržaja biomase u smeši, ekonomski je opravdanija upotreba manjih količina biomase (5–10%).

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THE IMPORTANCE OF APPLYING THE CIRCULAR BIOECONOMY CONCEPT IN FORESTRY

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Abstract: *Over the past few years, EU countries have been intensively adopting strategic documents and policies that guide and promote processes towards a circular bioeconomy. One of them is the European Green Deal, which was presented in December 2019. It is a package of policy initiatives, which aims to transform the EU into a fair and prosperous society with a modern, competitive economy based on efficient resource consumption and the protection of the environment and human health. The ultimate goal is to reach climate neutrality by 2050.*

The concept of circular bioeconomy has been recognized as an important strategic concept for the green transition. In this context, the forest-based sector plays a key role in ensuring sustainable and balanced environmental, economic, and social development using bio-based resources. Application of the circular bioeconomy concept requires innovation in forestry. The end result will be healthier ecosystems that consume and waste fewer resources.

However, integrating the concept of circular bioeconomy into forestry is a challenge due to the numerous conflicts and interests in space. In the coming period, innovative methods in the use of forestry biomass should be more actively promoted in Serbia, including circular business models, by increasing the efficiency of scientific, technical and financial support for innovations in this area. The key solution is in the knowledge transfer.

Keywords: circularity, forest-based sector, sustainable development, environmental protection.

ZNAČAJ PRIMENE KONCEPTA CIRKULARNE BIOEKONOMIJE U ŠUMARSTVU

Apstrakt: *Poslednjih godina, zemlje Evropske Unije intenzivno usvajaju strateške dokumente i direktive koje usmeravaju i podstiču procese ka cirkularnoj bioekonomiji. Jedan od njih je i Evropski zeleni dogovor, koji je predstavljen u decembru 2019. godine. Podrazumeva paket političkih inicijativa, sa ciljem transformacije EU u pravedno i prosperitetno društvo sa modernom, konkurentnom ekonomijom zasnovanom na efikasnoj potrošnji resursa i zaštiti životne sredine i zdravlja ljudi. Krajnji cilj je postizanje klimatske neutralnosti do 2050. godine.*

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Koncept cirkularne bioekonomije prepoznat je kao važan strateški koncept za zelenu tranziciju. U ovom kontekstu, sektor šumarstva ima ključnu ulogu u obezbeđivanju održivog i uravnoteženog ekološkog, ekonomskog i društvenog razvoja, korišćenjem bioloških resursa. Primena ovakvog koncepta zahteva inovacije u šumarstvu. Krajnji rezultat biće zdraviji ekosistemi sa niskim nivoom potrošnje resursa i rasipanja.

Treba naglasiti da je zbog mnogih sukoba i interesa u prostoru, uključivanje koncepta cirkularne bioekonomije u šumarstvo izazov. U narednom periodu u Srbiji bi trebalo aktivnije promovisati inovativne metode u korišćenju biomase iz šumarstva, uključujući i korišćenje cirkularnih poslovnih modela, povećanjem efikasnosti naučne, tehničke i finansijske podrške inovacijama u ovoj oblasti. Ključno rešenje je u transferu znanja.

Ključne reči: cirkularnost, sektor šumarstva, održivi razvoj, zaštita životne sredine.

1. INTRODUCTION

The bioeconomy is part of the green economy and can be defined in many ways, with different interpretations of the concept. Some countries around the world have a dedicated bioeconomy strategy or action plan. On the other hand, many countries do not have their strategy but have strategies or action plans that relate to the bioeconomy. Many of them relate to innovation and biotechnology in order to develop new products with added value or improve the productivity of biological resources and bioenergy. The role of forests and the forest sector is not always clearly recognized in the bioeconomy strategies or related strategies and action plans. However, forests and the forestry sector are important components of a sustainable circular bioeconomy. The production and consumption of wood-based materials and wood-based products is increasing. New products and technologies are emerging that aim to increase the added value of wood products, reduce the carbon and water footprint of products and processes, reduce pollution and waste generation and improve the circular economy.

While forest products can provide benefits compared to the use of non-renewable, greenhouse gas-intensive materials, there are also potential risks associated with the increased production and consumption of forest products. The production and extraction of raw materials needed to manufacture products has economic, social and environmental impacts.

Considering that the circular bioeconomy is focused on reducing the consumption of natural resources and the reuse of waste generated during the production cycle, this concept can provide an important guide for the development of a policy framework to promote innovation and investment in new technologies that reconcile the role of forests as a carbon sink. The increasing use of forest products raises concerns about increasing pressure on forests and forest-dependent populations, which could lead to forest degradation and ultimately to biodiversity loss and a reduction in carbon stocks and storage if unsustainable practices are adopted.

Sustainable, climate-smart forest management is needed to support biodiversity and other ecosystem services.

2. MATERIAL AND METHODS

The problem-oriented approach to the importance of the circular bioeconomy concept for sustainable development and the quality of the environment involved the use of numerous analytical tools to clearly identify opportunities, limitations and possible conflicts and to define measures to resolve them.

It is clear that we are facing strong negative impacts of climate change, which bring a new set of challenges. These challenges cannot be tackled independently in one area or sector (e.g. economy, industry, forestry, agriculture, environmental protection, etc.). The study was performed using the analysis method with descriptive, integral and participatory approaches. The importance of a circular bioeconomy, legislation, and approach to this problem is related to identifying the set of indicators suitable to monitor the performance of the forest-based sector by applying the analysis method with a descriptive approach.

The application of an integral approach meant the analyses of current laws, regulations, guidelines and recommendations on sustainable development and climate change adaptation as defined by various international, EU and national institutions. The introduction of new indicators and harmonization with European frameworks, policies and planning practices at all levels of decision-making was also applied.

Complex conditions and a multitude of conflicting interests and factors characterize forestry. To gain a deeper insight and assess the feasibility of the planned solutions, we therefore had to apply a participatory approach. This approach was achieved by analysing the legal and planning provisions on different aspects and sectors of forestry at the national level.

Different scientific methods were applied in the study following the needs and objectives of the research. Concerning specific scientific methods, the analytical method was used (Miljević, 2007) to study strategic and legislative frameworks of circular bioeconomy. To study the content of documents, content analysis was applied as a kind of partial analysis (Milosavljević & Radosavljević, 2008). Some authors (Bulmer, 1977; Neumann, 2014) classify content analysis into a group of nonreactive methods since it does not involve direct collection of data from the research subjects. This research also included review analysis (Wunder et al., 2008; Keča & Marković, 2019) of the elements in the field of circular bioeconomy.

The results and discussion presented in the paper are based on different international declarations, legal regulations and acts. The conclusions were based on collected literature data and knowledge transfer of researchers engaged in the CEE2ACT project.

3. RESULTS AND DISCUSSION

3.1. Meaning of the circular bioeconomy concept

The 2030 Agenda for Sustainable Development (UN, 2015), which includes a set of 17 Sustainable Development Goals supported by 169 targets, ranging from 5 to 12 targets per goal, was adopted by the international political community in September 2015. According to Miola and Schiltz (2019), the Goals emphasize the integration of the three pillars of sustainability - environmental, economic, social and the harmonious relationship between humanity and nature.

Developed countries of the European Union understand the circular bioeconomy as the economy that uses renewable biological resources to sustainably produce food, bio-based materials, feed, products, fuels and bioenergy, and in which waste products are kept within the system. Their policies of development and Strategies of Bioeconomy are focused on the sustainable conversion of biomass and bio-based resources into marketable products and place biomass production and processing in a single system while underscoring the role of technology in biological resources to create added value and encourage new business models. The legislative of EU countries recognized the importance of circular bioeconomy as a new techno-socio-economic paradigm of production and consumption. In Figure 1, a concept of circular bioeconomy is shown.

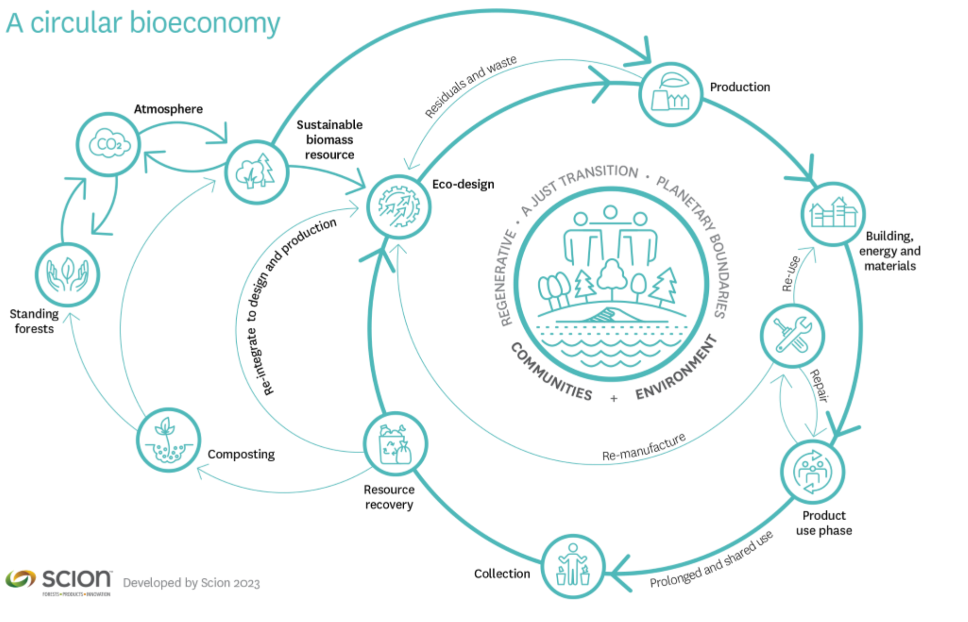

Figure 1. *A circular bioeconomy concept*
Source: SCION (https://www.scionresearch.com/about-us/the-forest-industry-and-bioeconomy/the-circular-bioeconomy)

According to D'Amato et al. (2019), the bioeconomy concept emphasizes the importance of technological innovations to complement or substitute non-renewable resources with bio-based alternatives. The circular bioeconomy is characterized by shifting from a fossil fuel-based economy to one based on renewable resources and then improving resource use efficiency and recovering/recycling waste generated in the production cycle.

The literature review concludes that the key principle of the circular bioeconomy is the 4Rs framework (Reduce, Reuse, Recycle, Recover), in which the hierarchy between the Rs is a fundamental aspect. The first R (Reduce) is considered to take precedence over the second R (Reuse) and so on. This hierarchical relationship is closely linked to the "cascade" principle", which envisages the use of raw materials according to a priority based on potential added value (Ciccarese et al., 2014; Proskurina et al., 2016; Paletto et al., 2019).

3.2. The intersection of the circular bioeconomy with forestry

Forests are a renewable resource, providing wood, non-timber products and many ecosystem goods and services (Deng et al., 2024). Beyond timber, forests provide various ecosystem services such as biodiversity conservation, climate regulation, water regulation and flood protection, soil protection and nutrient supply, pest control and pollination, etc. (Figure 2).

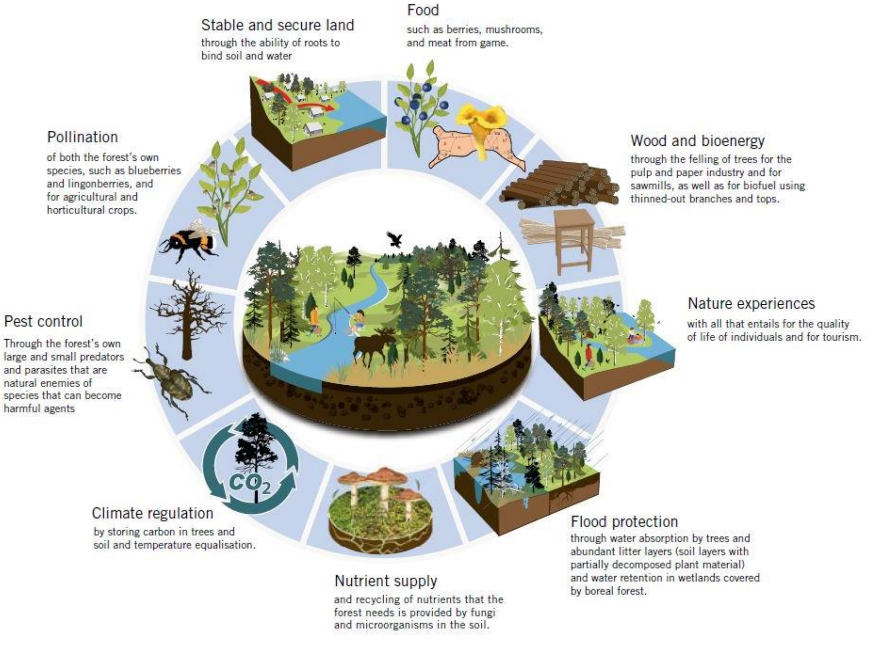

Figure 2. *Examples of ecosystem goods and services provided by forests*
Source: https://forestbiofacts.com/introduction-to-forest-based-bioeconomy/the-forest-sector-and-the-idea-of-circular-bioeconomy/

The **forest-based sector** is one of the most important sectors for developing a bioeconomy. It has a fundamental role in the pursuit of the following choices and objectives (Bracco et al., 2019; Linser & Leier, 2020):

- ✓ the sustainable management of natural resources and the supply of ecosystem goods and services useful for human well-being;
- ✓ enables sustainable patterns of production and consumption because wood is a renewable resource, a versatile raw material used to produce high added value products;
- ✓ improving the efficient use of resources;
- ✓ reduce waste production and promote secondary raw material market;
- ✓ boost sustainable farming and forestry throughout the production and supply chain.

The circular bioeconomy and forestry intersect through their shared sustainability goals, resource efficiency, and climate action. If we look back and analyse the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), we can see that even then, the importance of a sustainable forest management strategy for mitigating CO_2 emissions was highlighted, and the IPCC strategy aims to conserve forest carbon stocks while achieving a sustainable annual yield of fibre for energy and material extraction. Circular bioeconomy strategies promote the same goal - „Sustainable forest management practices that maintain forests' ecological, economic, and social functions" (Toppinen et al., 2020). This includes selective logging, afforestation, reforestation and revegetation, and promoting biodiversity to ensure forests serve as carbon sinks and habitats while supplying raw materials. The circular bioeconomy emphasizes protecting and enhancing these services by adopting practices that maintain or restore natural ecosystems, ensuring long-term sustainability. Also, it promotes forest practices that prioritise biodiversity, such as mixed species planting and reducing monocultures (Piplani & Smith-Hall, 2021). This makes forests more resilient to pests, diseases, and climate change and enhances their ecological function.

Biomass helps diversify Europe's energy supply, create growth and jobs, and lower GHG emissions (Jarre et al., 2020). For example, high-quality wood can be used for construction, and lower-grade materials can be used for paper, bioenergy, or bio-based products. Maximising the value extracted from each part of the tree reduces waste and improves resource efficiency. Residues, such as branches, bark, and sawdust, are transformed into valuable products like bioenergy (e.g., pellets), biochemicals, or bioplastics, contributing to a closed-loop system that minimises environmental impact (Arâmburu et al., 2022).

Forests are also crucial to achieving carbon neutrality as they can sequester carbon from the atmosphere (Nunes et al., 2020). They store carbon and support the circular economy by being renewable, recyclable and energy efficient, but they also contribute to climate change mitigation by reducing CO_2 levels in the atmosphere. In addition, forests provide raw materials for innovative bioproducts such as bioplastics, biofuels and biochemicals that replace fossil materials.

Figure 3. *The intersection of the circular bioeconomy with forestry*

According to the latest available data from the European Commission (Joint Research Centre, Biomass flows), the total biomass supply in 2022 in EU27 added up to 1 billion tons of dry matter. The forestry sector is a producer of 31% biomass. Around 60% of the biomass in the EU is used for food and feed, with 24% of identified biomass used for energy and 16% for biomaterials (Gurria et al., 2022).

The wood industry in Serbia, which relies heavily on forestry, presents substantial potential for circular bioeconomy practices. By maximising the efficient use of raw materials throughout all processing stages, waste can be reduced and value increased across the supply chain. The forest-based sector is recognised in Serbia's Industrial Policy Strategy for 2021-2030 (Official Gazette, 2022) as having great potential for circular economy integration.

4. CONCLUSION

The circular bioeconomy helps transform forestry into a key contributor to a more sustainable and resilient economy by promoting sustainable forest management, waste minimization, closed-loop systems, and bio-based innovation. The circular bioeconomy concept is developed on the principle: „We borrow from nature and give new products back by creating a closed-loop system in which there is no waste". Promotes the cascading use of forest biomass, where wood and its by-products are used through multiple stages of value creation.

Applying the circular bioeconomy principles to forestry aims to create circular value chains where materials are reduced, reused, recycled and recovered at the end of their life cycles. This reduces pressure on forests by minimising the need for continuous extraction of raw materials, thus creating more sustainable forestry-based industries. Additionally, by promoting the local processing of forest products, the circular bioeconomy strengthens regional economies, reduces transportation emissions, and fosters more sustainable use of local forest resources. Local communities also benefit through job creation and the development of sustainable forestry practices.

By integrating circular bioeconomy practices such as recycling, renewable energy use, and forest regeneration, forestry can play a key role in mitigating climate change. Sustainable forest management can enhance the carbon sink capacity of forests, while bio-based products offer alternatives to fossil-based ones, reducing overall greenhouse gas emissions. Biomass from forestry belongs to solid biomass, which includes firewood, plant mass of fast-growing plants, branches, wood waste from forests, sawdust, bark, and wood residue from the wood-processing industry.

The forest-based bioeconomy contributes to climate change mitigation in different ways: through the carbon stored in forests and the carbon stored in products made from wood and by using wood to substitute fossil fuels and other, more carbon-intensive materials. Forests and harvested wood products currently sequester the equivalent of circa 10% of the EU's greenhouse gas emissions. However, the carbon sink of forests is declining due to many factors. Reversing this trend requires sustainable forest management practices and afforestation. A shift towards greater use of wood products with longer service lives and substitution benefits can also increase the benefit of climate change mitigation. A "system-perspective" analysis helps to understand the trade-offs and synergies amongst the different options and optimise the contribution of the forest-based bioeconomy to Europe's climate goals.

To apply the circular bioeconomy concept in forestry, it is necessary to:

- ✓ rethinking forestry development orientations;
- ✓ taking advantage of innovative technological solutions;
- ✓ economic support;
- ✓ strengthening political and institutional support;
- ✓ ensuring policy coherence across objectives, instruments and practices and
- ✓ involving relevant stakeholders in forest policy design processes.

Circular bioeconomy principles align with forestry in promoting practices that reduce emissions across the entire value chain, from sustainable harvesting to producing low-carbon bio-based products. Applying the principles of the circular bioeconomy in forestry promotes competitiveness, innovation, and protection of the environment and space while contributing to economic growth. It has the potential to create many new jobs while conserving valuable and increasingly scarce natural resources and adding new value to waste materials.

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THE IMPORTANCE OF APPLYING THE CIRCULAR BIOECONOMY CONCEPT IN FORESTRY

Ljiljana BRAŠANAC-BOSANAC, Nevena ČULE, Ilija ĐORĐEVIĆ, Goran ČEŠLJAR, Aleksandar LUČIĆ, Predrag ŠUMARAC, Tatjana ĆIRKOVIĆ-MITROVIĆ

Summary

The circular bioeconomy is a complex and dynamic system which requires new strategies and tools to steer and govern this complex system towards the desired outcomes. The importance of applying a circular bioeconomy concept is in the potential to contribute to climate change mitigation, socio-economic development and environmental protection by maintaining the value of bio-based products, materials and resources in the economy for as long as possible. Applying the principles of the circular bioeconomy in the economy prioritizes the use of renewable biological resources in bio-based materials, feed, products, fuels and bioenergy, keeping waste products in the system and transforming them into value-added products. Dissemination of examples of good practices from EU countries, profitable business successes and innovative business models can be a valuable tool for attracting the attention of small and medium-sized enterprises and entrepreneurs in Serbia to the circular bioeconomy, especially in the forestry sector.

ZNAČAJ PRIMENE KONCEPTA CIRKULARNE BIOEKONOMIJE U ŠUMARSTVU

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Rezime

Cirkularna bioekonomija je složen i dinamičan sistem koji zahteva nove strategije, mape puta i alate za usmeravanje i upravljanje ovim složenim sistemom ka željenim ishodima. Važnost primene koncepta cirkularne biokonomije je u potencijalu da doprinese ublažavanju klimatskih promena, društveno-ekonomskom razvoju i zaštiti životne sredine, održavanjem vrednosti proizvoda, materijala i resursa na bazi biomase u privredi dugo vremena. Primena principa cirkularne biekonomije u privredi daje prioritet korišćenju obnovljivih bioloških resursa u bio-materijalima, stočnoj hrani, proizvodima, gorivima i bioenergiji, zadržavanju otpadnih proizvoda u sistemu i pretvaranju u proizvode sa dodatom vrednošću. Širenje primera dobre prakse iz zemalja EU, profitabilnih poslovnih uspeha i inovativnih poslovnih modela može biti koristan alat za privlačenje pažnje malih i srednjih preduzeća i preduzetnika u Srbiji na cirkularnu bioekonomiju, posebno u sektoru šumarstva.

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FOREST FIRES AS A FACTOR OF ECOLOGICAL SAFETY AND THEIR IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT

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Abstract: *Ecological safety represents an important segment of every country, with each nation striving to strengthen it by reducing risks that can compromise it. Forest fires are a significant factor of ecological safety due to their capacity to disrupt ecosystems by generating a range of harmful by-products. By reducing the frequency of forest fires and the resulting damage – both material and environmental – ecological safety can be enhanced. Ecological safety, in turn, contributes significantly to the sustainable development of regions, given the broad impacts of forest fires on natural and human systems.*

Keywords: ecological safety, forest fires, sustainable development.

ŠUMSKI POŽARI KAO FAKTOR EKOLOŠKE BEZBEDNOSTI I UTICAJ NA ODRŽIVI RAZVOJ

Izvod: *Ekološka bezbednost je važan segment svake države, i svaka država se trudi da ekološka bezbednost bude što bolja i rizike koje dovode do narušavanja ekološke bezbednosti smanji na što manju meru. Šumski požari su važan faktor ekološke bezbednosti, jer njihovim nastankom remeti se i ekološka ravnoteža, pojavom niza negativnih produkata. Smanjenjem broja šumskih požara i smanjenjem šteta nastalih šumskim požarima, kako materijalnih, tako i ekoloških, utiče se da ekološka bezbednost bude bolja. Ekološka bezbednost utiče na održivi razvoj svakog regiona, kao i pojava i ispoljavanje šumskih požara u svim segmentima svog ispoljavanja.*

Ključne reči: ekološka bezbednost, šumski požari, održivi razvoj.

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1. INTRODUCTION

Unregulated and uncontrolled exploitation of natural resources, including forests, and their endangerment through various harmful influences and processes lead to severe disruptions in fundamental ecological processes, endangering the quality and survival of essential natural substrates, including plant and animal life.

Forests play a crucial ecological role, providing health benefits, recreational opportunities, aesthetic value, material goods and a food supply. Consequently, any threat to forest resources can be considered a threat to ecological safety.

In general terms, an ecologically safe state can be defined as one where no environmental threats are present or active, nor is there any risk of their development. Based on these environmental characteristics and factors, ecological safety signifies the absence of elements that might disturb balanced and harmonious natural processes and relationships. However, this is often unattainable in practice, as the primary threats today stem from human activities (anthropogenic factors), influenced by work practices, and daily activities and habits. The anthropogenic impact on forests and the broader environment disrupts natural processes, depletes natural resources, and diminishes environmental quality, issues in which forests play a significant role.

1.1. The Concepts of Safety, Ecological Safety, and Environmental Crime

Unregulated and uncontrolled exploitation of natural resources, along with their endangerment through harmful processes and activities, disrupts fundamental natural processes and jeopardises essential ecological principles. This degradation endangers the quality and survival of specific natural entities, ultimately threatening the broader environment.

A lack of awareness and concern for the surrounding environment, along with deliberate harm to it, are primary causes of environmental violations. These offenses include prohibited and punishable actions by individuals or groups that aim to derive benefits or engage in practices harmful to the environment, endangering both public health and safety.

An ecologically safe state, in its broadest sense, can be defined as one in which there are no active environmental threats or risks of their development.

Most factors that jeopardise the environment, including forest resources, originate from human activities, both occupational and lifestyle-related.

These harmful effects give rise to further disruptions that, directly or indirectly, impact the quality of life and public health, while also degrading the environment. Such impacts include loss of arable land, reduction of forested areas, damage to the recreational and health-supporting roles of forests, air and water pollution, habitat destruction, and decline of plant and animal species. These environmental degradations lead to critical issues such as reduced drinking water supplies, lower food availability, the effects of global warming, increased frequency of extreme weather events, and rising disease rates.

The complexity and severity of these issues significantly impact economic and social stability and, consequently, overall safety.

When safety is viewed as a core responsibility of the state toward its citizens, primary tasks for achieving and maintaining ecological safety include identifying, understanding, and addressing the causes and manifestations of environmental threats. Preventive measures— enforced through legal instruments, education, monitoring, and repressive measures, such as detecting and penalizing ecological offenders, enable the state to safeguard citizens' rights to a healthy and sustainable environment.

The various unlawful acts committed by individuals, social groups, or business entities that endanger the environment, threaten human health and safety, and destroy material assets are collectively called **environmental offenses**.

Environmental crime is a relatively new concept, encompassing a category of offenses that has grown significantly in recent years. This type of crime involves a wide range of actions and consequences that impose serious harm on both the environment and public well-being, thereby threatening the ecological safety of both the state and society. The drivers of environmental crime vary and may involve actions by individuals, groups, or organisations, with harmful activities conducted either out of ignorance or deliberately. In essence, the various forms of environmental crime can generally be understood as stemming from either negligence or purposeful, intentional actions.

The primary challenges in identifying, preventing, and combating environmental offenses and environmental crime include:

– clear definition of environmental offenses: A precise and comprehensive definition of environmental offenses is essential to establish which behaviours are considered undesirable and dangerous.
– legal regulation of environmental crime: This requires formal integration of environmental offenses into environmental and criminal law frameworks.
– inadequate and lenient penalties for environmental offenders.
– limited personnel and technical resources: Insufficient resources impede the thorough investigation of environmental offenses, identification of offenders, and analysis of causes and consequences.

Key data regarding the characteristics, state and quality of environmental conditions – both before and after an offense occurs—can be obtained through an effective monitoring system. Tracking the frequency and patterns of certain occurrences enables the monitoring system to capture the dynamic characteristics of particular areas and processes.

A system essential for improving ecological safety is risk management, which should aim to reduce incidents that endanger ecological stability, address risks leading to environmental harm, and enable prompt and effective responses to hazardous events that negatively impact the environment. Data that reflect both the character of natural processes and the consequences of harmful actions toward nature can significantly aid in risk assessment and forecasting potential outcomes. Ultimately, this supports more effective environmental protection and stronger ecological safety, which can be achieved through an efficient risk management system.

Ecological safety can be understood not only as the sustainable use and protection of nature but also as the minimisation of risks or the likelihood of experiencing adverse effects from ecological changes and threats. It represents the absence or minimal presence of endangering factors, which must be achieved through effective risk management.

1.2. Ecological Safety Factors

Ecological safety factors can be broadly categorised into two types: those that enhance safety and those that pose threats. Both types are interconnected to varying degrees, collectively shaping a particular state of ecological safety that ultimately impacts the environment itself. Depending on their characteristics and behaviours, certain factors may serve as stabilising elements that improve ecological safety or as destabilising forces that jeopardise it. For example, human actions can positively contribute to ecological safety through responsible behaviour; however, irresponsible or careless actions can disrupt ecological safety and pose risks to the environment.

When it comes to forest fires as a key aspect of ecological safety, climate serves as a prime example. Rainy periods within a climate cycle reduce the likelihood of forest fires, strengthening ecological safety. Conversely, droughts and high temperatures create conditions conducive to fires, thereby weakening ecological safety.

Factors that support ecological safety include:

- policy instruments for environmental protection,
- public awareness,
- relevant government authorities,
- social groups and organisations,
- international and other organisations.

Factors that may pose risks to ecological safety include:

- natural environmental hazards,
- states,
- economic and other entities,
- technical and technological factors,
- human activities.

1.3. Forest Fires and Ecological Safety

Forests have always been regarded as a national treasure, contributing not only to the preservation of vital ecological cycles but also providing economic, tourism, recreational, and health benefits. Due to their essential role in sustaining life, humans have historically sought to protect, nurture, and restore forests. In the past, forests covered a much larger portion of the Earth than they do today. In the Republic of Serbia, forest cover currently spans around 27% of the land, or about 2.3 million hectares, with roughly 50% in private ownership. Serbia’s forest and forestland consist of 50% high forests, 28% coppice forests, and 22% barren land suitable for afforestation.

Forests face a variety of adverse factors, from tree diseases and forest pests, over weather extremes, droughts, floods and erosion to human-induced damage.

However, none of these factors can be as destructive as forest fires. The rising frequency and severity of forest fires, which often reach catastrophic proportions, not only devastate forests but also damage agricultural crops, threaten settlements, and endanger human lives. This growing threat underscores the need for organised, strategic monitoring of fire-risk factors and the establishment of preventive and suppressive protection measures.

Frequent fires and large burned areas result in substantial material losses and numerous other adverse effects, both direct and indirect. In Serbia and worldwide, both the number of forest fires and the total burned area have risen annually. Over the past decade in Serbia, hundreds of significant fires have affected large forested areas. Between 1997 and 2009, 1,442 forest fires were recorded in Serbia, burning a total of 57,884 hectares.

Countries aiming to effectively protect their forests face the challenge of organising and preparing for fire prevention, ensuring better coordination and functioning of activities and measures to prevent forest fires, and implementing meaningful short- and long-term measures to benefit nature and preserve forest wealth. To develop an effective forest fire management system, it is crucial to implement proactive measures addressing fire risk factors and establish a coordinated structure that ensures optimal functioning of forest protection—even in case of a fire. Such a system can be achieved through systematic forest fire risk management, which significantly enhances ecological safety.

Ecological safety concerning forest resources and fire occurrence entails the absence or minimisation of fire hazards, preventing forest fires or ensuring rapid containment and recovery. Given that forests are complex systems vulnerable to both biological and human-induced threats, the methods for protecting them are diverse and essential for safeguarding these valuable resources.

The main factors influencing forest fire risk, and therefore ecological safety, include:

– vegetation and available combustible material,
– natural phenomena,
– human influence (anthropogenic factors),
– climate and climatic factors,
– bedrock and soil type,
– orography,
– forest management,
– fire history.

Monitoring of forest fires in the Braničevo District from 1998 to 2008 revealed that the most common fires involved fine combustible materials, such as grass and small shrubs (Table 1).

Table 1. *Total Number of Fires by Vegetation Type in Braničevo District (1998-2008)*

Number of fires	Deciduous forest	Coniferous forest	Mixed forest	Grass and low vegetation
2220	124	45	24	2027
% 100	5.59	2.02	1.09	91.30

Table 1 shows that, in addition to grass and low vegetation (91.3%), the most frequent fires occurred in deciduous forests (5.59%), followed by coniferous forests (2.02%) and mixed forests (1.09%). From an ecological safety perspective, this data is crucial for implementing preventive measures focused on vegetation types most susceptible to ignition.

Forest fires are classified into the following types:

- underground fires
- low or surface fires
- high or crown fires

Table 2 shows the number of fires by type in the Braničevo District from 1998 to 2008.

Table 2. *Fires by Type in Braničevo District (1998-2008)*

Total number of fires	High (Crown) fires	Low (Surface) fires	Underground fires
2220	193	2027	0
% 100	8.7	91.3	0

From the perspective of vulnerability and ecological safety, high or crown fires are particularly significant, as they are generally the most challenging to extinguish and can cause substantial material and ecological damage.

Table 3. *Number of Crown Fires and Area Affected by Fires in Braničevo District (1998-2008)*

Vegetation type affected by fire (crown fires)	Number of fires	Average area affected (ha)	Average duration of fire (h)
Deciduoud forest	124	9.8	2.5
Coniferous forest	45	13.6	3.1
Mixed forest	24	5.2	1.2

Table 3 illustrates that, relative to the number of fires, the average area affected is largest in coniferous forests, followed by deciduous forests—both characterised by a uniform composition (single-species stands). In contrast, mixed forests have the smallest average affected area due to their diverse composition and varying tree flammability. Fires also tend to last longer in coniferous forests, owing to the chemical composition of these trees and the greater difficulty of extinguishing them, while mixed forests have the shortest fire duration due to slower fire spread and easier containment.

From an ecological safety standpoint, these findings are essential as they highlight the areas where forest fire prevention efforts should be concentrated to enhance ecological safety.

The main causes of fires are typically:

– natural phenomena
– anthropogenic factors (human activity)

Table 4 provides an overview of the frequency and percentage of fires caused by natural events in the Braničevo District from 1998 to 2008.

Table 4. *Number of Fires Caused by Natural Phenomena in Braničevo District (1998-2008)*

Total number of fires	Number of fires caused by natural phenomena	Number of fires caused by atmospheric discharge	Number of fires caused by solar heat
2220	28	24	4
100%	1.26%	1.08%	0.18%

Table 4 shows that fires resulting from natural phenomena in the Braničevo District accounted for 1.26% of all fires from 1998 to 2008. Lightning strikes and atmospheric discharges were responsible for the majority of these, at approximately 1.08%. However, this figure may be underestimated, as some fires with unknown causes likely stem from natural phenomena as well.

Human activities have a substantial impact on forest fire occurrence. Statistical data indicate that approximately 98% of forest fires are either directly or indirectly linked to human activity.

Table 5 provides the number of fires attributed to human causes in the Braničevo District during the 1998-2008 period.

Table 5. *Number of Fires Caused by Human Activity in Braničevo District (1998-2008)*

Total number of forest fires	Number of forest fires caused by human activity	Number of forest fires caused by human activity with open flames	Number of forest fires caused by other human activities	Number of fires with undetermined cause
2220	2087	2066	21	89
100%	94.01	93.06	0.95	4.01

Table 5 clearly indicates that over 94% of all fires occurring during the observed period can be attributed to human activity. Furthermore, the number of unidentified causes of forest fires can also be linked to human actions, raising this percentage to over 98%. The majority of forest fires caused by humans (93.06%) originate from open flames, while 0.95% result from other activities, such as work on electrical lines, operations at outdoor shooting ranges, and welding or cutting tasks conducted in open areas. The threat to forests from human activity increases significantly when these activities involve fire, such as burning stubble and other organic waste or using fire for various purposes.

From the perspective of ecological safety, this information is vital, as measures to prevent forest fires must primarily target human behaviour, which is the most common driver forcause of these incidents.

Table 6 illustrates the number of fires and their percentage contribution resulting from human activity via open flames, categorised by activity and location in the Braničevo District for the period from 1998 to 2008.

Table 6. *Number of Fires and Percentage Contribution Attributed to Human Activity by Type in Braničevo District (1998-2008)*

Number of forest fires caused by human open flames	Near settlements	Near recreational areas	In tourist areas	During agricultural activities	While gathering forest products	Hunters and fishers	Intentional
2066	212	28	9	1748	16	22	31
100%	10.26%	1.35%	0.43%	84.62%	0.77%	1.06%	1.51%

Table 6 shows that the highest number of forest fires was caused by open flames during agricultural activities, primarily due to the burning of organic material during field clearing, accounting for 84.62%. This is followed by fires near settlements at 10.26% and intentionally set fires at 1.51%.

The occurrence of human-caused fires, which represents the majority of cases, is influenced by several key factors, including:

The proximity of rural and urban settlements and tourist facilities, as well as the network of roads through or near forests increases public access to these areas. As more people frequent forests, the risk of fire incidents rises significantly.

Stationary tourism, drawn by the favourable forest and mountain environmental conditions, is steadily increasing. Tourist facilities are occupied throughout the fire season, with visitors often spending entire days in forested areas, where even a small lapse, like a poorly extinguished cigarette or match, can start a fire.

Picnic tourism with a great number of picnic areas and extensive road networks through forests presents an added fire hazard. Such locations attract large crowds, and these visitors, who often venture deeper into the forest, increase the risk by lighting fires for cooking and using cigarettes or matches, all of which contribute to the potential for wildfires.

Agricultural and field workers represent one of the leading causes of forest fires, often working on land adjacent to or within forest boundaries. Clearing fields by burning organic waste and weed is one of the primary sources of these fires.

Forest fruit harvesters visiting the forest during fire season can be a potential cause of fires. The large number of people in the forest during this time may accidentally or carelessly ignite a forest fire by lighting fires or discarding cigarette butts.

Hunters and fishermen, too, are known fire risks, often using open flames for heating and food preparation and sometimes discarding cigarette butts or matches carelessly.

Intentional fires in forests or grasslands represent a significant portion of human-caused fires. Reasons for setting such fires include the destruction of forested areas for later logging, revenge, or burning grass to promote greener growth for grazing. This type of fire incident has been on the rise year after year. They are usually set at dusk or during the night, when there are few or no people in the forest, and in secluded areas, delaying discovery and intervention efforts. These fires are often started in areas with abundant fuel, which accelerates the rate of spread.

From an ecological safety standpoint, these data are essential for organisations responsible for forest protection and safety, providing guidance on preventative measures to mitigate fire risks effectively.

2. CONCLUSION

While environmental security implies protection against ecological degradation, ecological safety involves creating conditions in which the physical environment supports community needs without depleting natural resources. Sustainable development is central to promoting ecological safety, as it enables current generations to meet the needs of the present without undermining resources for future generations. Forest resources are a vital component of sustainable development due to their numerous benefits, making their protection essential. Effective fire management systems greatly enhance ecological safety, and if the state fulfills its responsibilities within this system, both ecological and other forms of safety will be elevated.

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Bošković, M. (2010). *Nove tehnologije i ekološka bezbednost [New technologies and environmental security],* Faculty of Security Studies.

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Đorđević, G. (2012). *Upravljanje rizikom u zaštiti šuma od požara [Risk Management in Forest Fire Protection]*, Doctoral dissertation, Faculty of Security Studies, University of Belgrade.

A GUIDE FOR WRITING RESEARCH PAPER

SUSTAINABLE FORESTRY is a scientific journal which is published original scientific papers, review papers and short communications of Forestry scientific disciplines, Environmental protection, Wood processing, Landscape architecture and horticulture and Environmental engineering (Erosion Control) at least once a year.

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Categorization of papers (suggested by the author – determined by Editorial board taking into account the opinion of the reviewer):

Scientific Articles

1. Review paper (paper that contains original, detailed and critical review of the research issue or field in which the author contributed, visible on the basis of auto-citations);
2. Original scientific paper (paper which presents previously unpublished results of author's researches by scientific method);
3. Preliminary communication (Original scientific paper of full format, but small-scale or preliminary character).
4. Other known forms: scientific review, case study and others, if Editorial board finds that such paper contributes to the improvement of scientific thought.

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Papers (in the Template form) should be sent to the e-mail of Secretary of the Journal "Sustainable Forestry": jelena.bozovic@forest.org.rs.

- **The paper** should be written in English, **Abstract** should be written both in English and Serbian, whereas **Summary** should be written only in Serbian.
- **The paper length** should not exceed 12 typewritten pages, with normal line spacing (Single Space).
- **Paper format:** width 16,5 cm, height: 24 cm.
- **Margins:** Top 1.5cm, Left 1.5cm, Bottom 1.5cm, Right 1.5cm, Gutter 0.5 cm, mirror margins.
- The paper should be typed in Word, using the Times New Roman Font, Justify, First Line 1.27.
- **Layout:** header 0.5 cm, footer 0.5 cm.

If special signs (symbols) are used in the text, use the Symbol Font.

The paper structure is as follows:

PAPER TITLE IN ENGLISH

(capital letters, Font Size 11pt, bold, centered)

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Name and SURNAME[1] (capital letters, Font Size 11pt, italic, centered) with footnotes which indicate affiliations and addresses of each author and mark * which indicate the corresponding author.

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Abstract: The abstract is written in English with three spaces below the name of the paper author. In abstract are given basic aim of research, materials and methods, more important results and conclusion (maximum 700 characters (no spaces)) (Font Size 10pt, italic).

Keywords: in English, 3-6 words (Font Size 10pt, normal).

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PAPER TITLE IN SERBIAN IN LATIN ALPHABET (capital letters, 11 points, bold, centered)

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Sažetak: Text of the abstract in Serbian in Latin alphabet (Font Size 10pt, italic)

Ključne reči: in Serbian (Font Size 10pt, normal).

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1. INTRODUCTION (Font Size 11pt, bold, align left)

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The introduction should be a short review of explanation about reasons that led to the research of specific scientific issue. The introduction contains reference data of published papers that are relevant for the analyzed issue (Text Normal, Font Size 11pt, Justify, First Line 1.27).

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[1] Affiliation, address (9pt, normal)

*Corresponding author. E-mail: (9pt, normal)

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2. MATERIAL AND METHODS (Font Size 11pt, bold, align left)

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Within this chapter there can be subtitles of first and second line. In the description of material, it should be given enough information to allow other researchers to repeat the experiment at a different location. It is necessary to provide information on the material, subject of the study that precisely defines its origin, physical characteristics etc. If a device or instrument is used to obtain experimental results should be specified: name of the device or instrument, model, manufacturer's name and country of origin. If a scientifically recognized method is used it has to be cited in the References, without the explanation of the steps of the used method. If changes were made in a scientifically recognized method should be provided the original literature references that will support – justify those changes.

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3. RESULTS (Font Size 11pt, bold, align left)

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Within this chapter there can be subtitles of first and second line. The paper results should be presented in the form of text, tables and figures. From the results should be clear whether the hypotheses have been confirmed or disproved and whether the aim and tasks have been achieved. It should not be avoided the presentation of the negative results or disproving the hypotheses.

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3.1. Subchapter title (Font Size 11pt, bold, align left)

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Subchapter text (Font Size 11pt, normal, justify, first line 1.27)

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Table 1. (bold, 11pt), Table title (11pt, italic, centered)

Column name (8pt, bold)		
Table content (8pt, normal)		

Note (Font Size 8pt, bold)**:** Text (Font Size 8pt, italic)

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Figure 1. 11pt, bold Figure title, (11pt, italic, centered)

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In text (Figure 1); Continuation of the text, 11pt, justify, first line 1.27.

More than one figure and table in text separated with semicolon (Figure 1; Table 1) (Figure 1; Figure 2).

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4. DISCUSSION (Font Size 11pt, bold, align left)

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Discussion should not be the simple repeating of obtained results. The results should be discussed by comparing them with the results of other authors with compulsory citing of literature sources. It is very important to give discussion of the results and the opinion of the authors. Interpretation of perceived ambiguities and illogicalities should be correctly stated (11pt, justify, first line 1.27).

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5. CONCLUSION (Font Size 11pt, bold, align left)

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Conclusions of the paper should be carefully carried out and shown clearly to the reader. Conclusions can be significantly connected with the result discussion, but in them should be given freer and wider interpretation of the paper subject and results. The special quality is the defining of suggestions for future work and identifying the issues need to be resolved (11 points, justify, first line 1.27).

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Acknowledgement (10pt, bold): If the paper is a part of a research within a project in acknowledgement are indicated: name of the project, registration number and the full name of the institution that finances the project (10pt, justify, italic).

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References should be listed in alphabetical order in the reference list.
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Dragićević, S., Kostadinov, S., Novković, I., Momirović, N., Langović, M., Stefanović, T., Radović, M., & Tošić, R. (2022). Assessment of soil erosion and torrential flood susceptibility: Case study—Timok river basin, Serbia. In A. Negm, L. Zaharia, & G. Ioana-Toroimac (Eds.), The Lower Danube River (pp. 357–380). Springer International Publishing. https://doi.org/10.1007/978-3-031-03865-5_12

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Parenthetical citation in text: (Republički hidrometeorološki Zavod Republike Srbije, 2022)

*When citing two or more works together, arrange the in-text citations alphabetically in the same order in which they appear in the reference list separated with semicolon
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(e.g., Bergstrom et al., 2006; Clément, 2010; Harris & Corriveau, 2011; Harris & Koenig, 2006; Heyman, 2008; Heyman & Legare, in press; Koenig & Harris, 2005).

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