ISSN 1821-1046
UDK 630

INSTITUTE OF FORESTRY BELGRADE | **INSTITUT ZA ŠUMARSTVO BEOGRAD**

SUSTAINABLE FORESTRY | ODRŽIVO ŠUMARSTVO

COLLECTION
Vol. 92

ZBORNIK RADOVA
Vol. 92

BELGRADE BEOGRAD
2025.

ISSN 1821-1046

ISSN 1821-1046
UDK 630

INSTITUTE OF FORESTRY
BELGRADE

INSTITUT ZA ŠUMARSTVO
BEOGRAD

SUSTAINABLE FORESTRY

COLLECTION
Vol. 92

ODRŽIVO ŠUMARSTVO

ZBORNIK RADOVA
Vol. 92

BELGRADE BEOGRAD
2025.

INSTITUTE OF FORESTRY BELGRADE — INSTITUT ZA ŠUMARSTVO BEOGRAD

COLLECTION OF PAPERS — ZBORNIK RADOVA

Publisher	**Izdavač**
Institute of Forestry Belgrade, Serbia	Institut za šumarstvo Beograd, Srbija
For Publisher	**Za izdavača**
Ljubinko Rakonjac, Ph.D.	Dr Ljubinko Rakonjac
Editor-in-Chief	**Glavni i odgovorni urednik**
Tatjana Ćirković-Mitrović, Ph.D.	Dr Tatjana Ćirković-Mitrović

Technical Editor and Layout	**Tehnički urednik i prelom teksta**
Ljiljana Brašanac-Bosanac, Ph.D.	Dr Ljiljana Brašanac-Bosanac
Secretary	**Sekretar Zbornika**
M.Sc. Jelena Božović	Mst. Jelena Božović
Printed in	**Tiraž**
100 copies	100 primeraka
Printed by	**Štampa**
Black and White Belgrade	Black and White Beograd

Belgrade, 2025

Beograd, 2025

Cover Page: River Vučjanka, Author of the Photo B.Sc. Nenad Šurjanac

Naslovna strana: Reka Vučjanka, autor fotografije Nenad Šurjanac, dipl. inž.

CONTENT SADRŽAJ

Vol. 92

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD
SUSTAINABLE FORESTRY COLLECTION 92, 2025
ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592001S
UDK: 630*188:633.88(497.11Kosmaj)=111
Original scientific paper

BEECH FORESTS OF KOSMAJ AS A NATURAL RESOURCE OF MEDICINAL PLANTS

Snežana STAJIĆ[1], Vlado ČOKEŠA[1], Violeta BABIĆ[2], Suzana MITROVIĆ[1], Marija MILOSAVLJEVIĆ[3], Saša EREMIJA[1], Jelena BOŽOVIĆ[1]*

Abstract: *This paper presents the results of research on wild-growing medicinal plants in the beech forests of the protected area of Kosmaj. Beech forests in this region are widely distributed and occur either as pure stands (Helleboro odori–Fagetum moesiacae Soo & Borhidi 1960) or as mixed stands with sessile oak (Querco petraeae–Fagetum moesiacae Glišić 1971). The floristic composition of these forests was analyzed using 22 phytosociological relevés. Out of a total of 100 recorded plant taxa, 60 medicinal species belonging to 50 genera and 36 families were identified. The taxonomic analysis showed that the most represented medicinal plants belong to the families Rosaceae (15%) and Lamiaceae (13%), followed by Fagaceae (7%) and Liliaceae (5%). Species of the Central European distribution type were the most common (36%), while the analysis of life forms indicated a predominance of phanerophytes (48.4%) and hemicryptophytes (23.3%), with a notable share of geophytes (18%).*

Keywords: beech forests, medicinal plants, taxonomic analysis, phytogeographical analysis, biological spectrum.

BUKOVE ŠUME KOSMAJA KAO PRIRODNI RESURS LEKOVITIH BILJAKA

Sažetak: *U radu su prikazani rezultati istraživanja samoniklih lekovitih biljaka u bukovim šumama zaštićenog područja Kosmaja. Bukove šume na ovom području su široko rasprostranjene i javljaju se kao čiste (Helleboro odori-Fagetum moesiacae Soo &Borhidi 1960.) ili mešovite sa kitnjakom (Querco petraeae-Fagetum moesiacae Glišić 1971.). Za analizu florističkog sastava bukovih šuma korišćeno je 22 fitocenološka snimka. Od ukupnog broja registrovanih biljaka (100) zabeleženo je 60 lekovitih vrsta iz 50 rodova i 36 familije. Taksonomska analiza pokazala je da su najzastupljenije lekovite biljke iz familije Rosaceae (15%) i Lamiacae (13%), dok su nešto manje prisutne lekovite biljke iz familija Fagaceae sa 7% i Liliaceae sa 5%. Najzastupljenije su lekovite biljke srednjeevropskog areal tipa sa 36%, dok je analiza životnih formi pokazala da su najviše zastupljene fanerofita sa 48,4% i hemikriptofite (23,3%), uz visoko učešće geofita (18%).*

[1]Institute of Forestry, Kneza Viseslava 3, 11030 Belgrade, Serbia
[2] Faculty of Forestry, University of Belgrade, Kneza Viseslava 1, 11030 Belgrade, Serbia
[3] Institute of Entomology, Branisovska 31, 37005 Ceske Budejovice, Czech Republic
*Corresponding author. E-mail: snezanastajic@yahoo.com

Ključne reči: Bukove šume, lekovite biljke, taksonomska analiza, fitogeografska anliza, biološki spektar.

1. INTRODUCTION

Medicinal plants and fungi have been used for centuries in folk and traditional medicine. However, global demand for these resources has threatened certain species, contributing to biodiversity loss and the depletion of natural resources essential for human health (Howes et al., 2020). Serbia is characterized by exceptional floristic diversity, which includes a substantial number of medicinal plant species. The highest alpha diversity is found in deciduous forests of the class *Querco–Fagetea* which accounts for 52.49% of the total diversity of all analyzed ecosystem types (Lakušić, 2005). However, the natural potential of medicinal plants within forest ecosystems remains largely unexplored, often resulting in unsustainable use of this resource. Populations of medicinal plants are declining primarily due to overharvesting, habitat degradation, and the spread of invasive species (Chen et al., 2016). For this reason, it is essential to protect natural habitats containing valuable medicinal species. Identifying suitable areas and climatic parameters associated with the current distribution of medicinal plants can facilitate predictions of their future distribution and help estimate their level of endangerment.

According to data from the Second National Forest Inventory of the Republic of Serbia (2023), beech forests are the most widespread forest type in the country, covering an area of 733,042 ha, or 25.68% of the total forested land. In Serbia, beech forests thrive under a wide range of ecological conditions, occurring from the submontane to the subalpine belt. In addition to their broad climatic, beech forests also exhibit a wide edaphic amplitude. They occur on acidic silicate, basic, ultrabasic, and carbonate bedrocks. In Serbia, beech grows on ten different soil types (Knežević, 2003). The vascular plant species composition and richness of beech forests are highly variable among European regions and habitats; however, European beech forests are generally regarded as species-poor. Compared to Central European shady forests, beech forests in Serbia are more complex and more diverse (Karadžić, 2018).

Submontane beech forests in Serbia are largely shaped by orographic conditions. They typically occur at lower elevations within the climatic oak forest belt, on cold exposures or in sheltered, shaded valleys with specific microclimatic conditions (Tomić & Rakonjac, 2013). Floristically, submontane beech forests differ considerably from montane beech forests: they contain a larger share of mesophilous species characteristic of lower elevations, as well as admixed elements typical of adjacent oak forests. The present-day stands of submontane beech forests, which fall within the belt of oak-dominated vegetation, may be regarded as remnants of a once much broader range of this forest type, which existed before the onset of the current, more arid climate (Jovanović, 1980).

A large part of the study area on Mount Kosmaj is covered by forest vegetation belonging syntaxonomically to the deciduous oak and beech forests of the class *Querco–Fagetea*. In this region, submontane beech forests are widely distributed, occurring either as pure stands (*Helleboro odori–Fagetum moesiacae* Soo & Borhidi 1960) or as mixed stands with sessile oak (*Querco petraeae–Fagetum* *moesiacae* Glišić 1971). The aim of this study was to determine the representation of medicinal plants within the flora of these beech forests, accompanied by a detailed taxonomic and phytogeographical assessment, as well as an analysis of their biological spectrum.

2. MATERIAL AND METHODS

Kosmaj is a low mountain massif (626 m) belonging to the Šumadija mountain system. Its terrain has a distinctive geological structure, which has resulted in considerable pedological diversity across the area. From a phytogeographical perspective, this region belongs to the Balkan floristic province within the Central European region.

To analyze the floristic composition, 22 phytosociological relevés were collected in beech forests within the study area. The floristic composition of the investigated stands was assessed using the Braun-Blanquet floristic–ecological method (Braun-Blanquet, 1964). Plant species were identified based on the following botanical literature: *Flora of Serbia* I–X (Josifović et al., 1972–1977; Sarić et al., 1986, 1992; Stevanović et al., 2012), and nomenclature was harmonized with the Euro+Med PlantBase database (Euro+Med, 2006 -). The identification of medicinal plants followed Sarić (1989). The spectra of floristic elements were prepared according to Gajić's (1980) classification of phytogeographical elements, while life-form spectra were derived following the method of Kojić et al. (1997).

3. RESULTS AND DISCUSSION

In the Kosmaj area, submontane beech forests are widely distributed, occurring either as pure stands (*Helleboro odori–Fagetum moesiacae* Soo & Borhidi 1960) or as mixed stands with sessile oak (*Querco petraeae–Fagetum moesiacae* Glišić 1971). They are mainly found at elevations between 370 and 580 m.a.s.l., on colder exposures (northern, northwestern, northeastern) and on slopes of 15–28° (Stajić et al., 2021).

The floristic structure of these beech forests comprises 46 families, 73 genera, and 100 plant species. Of the total 100 recorded taxa, as many as 60 medicinal plant species belonging to 36 families and 50 genera were identified (Table 1).

An essential prerequirement for the sustainable use of wild-growing medicinal plants is the preservation of forest or meadow ecosystems, as well as the key parameters such as abundance–cover and constancy (Obratov & Đukić, 2002). Species with the highest constancy (III–IV) in the investigated beech forests included *Lamium galeobdolon* (L.) Crantz, *Stachys silvatica* L., *Circaea lutetiana* L., *Helleborus odorus* Willd., *Hedera helix* L., *Dioscorea communis* (L.) Caddick & Wilkin, *Geranium robertianum* L. Considering that the abundance and cover of medicinal plants (as well as plant species in general) depend on habitat type—and despite the overall species-poor character of beech forests—this study recorded a somewhat higher number of medicinal plants compared to certain oak forests in the area (Stajić et al., 2025).

Table 1. *List of wild medicinal plants in the beech forests of Kosmaj*

Species	Family	Florisic element	Life form
Acer platanoides L.	*Aceraceae*	Subse.	p
Arum maculatum L.	*Araceae*	Se.	g
Hedera helix L.	*Araliaceae*	Subatl-subm.	pl
Asarum europaeum L.	*Aristolochiaceae*	Evr.	g
Ruscus aculeatus L.	*Asparagaceae*	Subatl-subm.	np
Ruscus hypoglossum L.	*Asparagaceae*	Subm.	np
*Alliaria petiolata (*M.Bieb.) Cavara&Grande	*Brassicaceae*	Subse.	h
Cardamine impatiens L.	*Brassicaceae*	Evr.	th
Campanula trachelium L.	*Campanulacae*	Subevr.	h
Lonicera caprifolium L.	*Caprifoliaceae*	Is.subm.	np
Stellaria media (L.) Vill.	*Caryophyllaceae*	Kosm.	th
Euonymus europaeus L.	*Celastraceae*	Subse.	np
Cornus mas L.	*Cornaceae*	Pont.subm.	np
Corylus avellana L.	*Corylaceae*	Subse.	p
Dioscorea communis (L.) Caddick & Wilkin	*Dioscoreaceae*	Subatl-subm.	g
Euphorbia amygdaloides L.	*Euphorbiaceae*	Subatl-subm.	zc
Fagus sylvatica L.	*Fagaceae*	Mez.	p
Quercus cerris L.	*Fagaceae*	Is.subm.	p
Quercus frainetto Ten.	*Fagaceae*	Is.subm.	p
Quercus petraea (Matt.) Liebl.	*Fagaceae*	Se.	p
Geranium robertianum L.	*Geraniaceae*	Subcirk.	th
Juglans regia L.	*Juglandaceae*	Subiran.-is.subm.	p
Ajuga reptans L.	*Lamiaceae*	Subse.	h
Clinopodium vulgare L.	*Lamiaceae*	Subm.	h
Glechoma hirsuta Waldst. & Kit.	*Lamiaceae*	Pont.-is.subm.	h
Lamium galeobdolon (L.) Crantz.	*Lamiaceae*	Subse.	zc
Melittis melissophyllum L.	*Lamiaceae*	Se.	g
Scrophularia nodosa L.	*Lamiaceae*	Evr.	h
Stachys alpina L.	*Lamiaceae*	Se.	g
Stachys silvatica L.	*Lamiaceae*	Subse.	g
Allium ursinum L.	*Liliaceae*	Se	g
Lilium martagon L.	*Liliaceae*	Evr.	g
Polygonatum odoratum (Mill.) Druce	*Liliaceae*	Subj.sib.	g
Circaea lutetiana L.	*Oenotheraceae*	Cirk.	g
Fraxinus excelsior L.	*Oleaceae*	Subse.	p
Fraxinus ornus L.	*Oleaceae*	Subm.	p
Chelidonium majus L.	*Papaveraceae*	Evr.	h
Dryopteris filix-mas (L.) Schott	*Polypodiaceae*	Kosm.	h
Lysimachia nummularia L.	*Primulaceae*	Subse.	zc
Lysimachia vulgaris L.	*Primulaceae*	Evr.	h
Clematis vitalba L.	*Ranunculaceae*	Subatl-subm.	p
Helleborus odorus Willd.	*Ranunculaceae*	Srbalk.	h
Crataegus monogyna Jack.	*Rosaceae*	Subse.	p
Crataegus nigra Waldst. & Kit.	*Rosaceae*	Subpan.	p
Fragaria vesca L.	*Rosaceae*	Evr.	h
Malus sylvestris (L.) Mill.	*Rosaceae*	Evr.	p
Prunus avium L.	*Rosaceae*	Subse.	p
Prunus spinosa L.	*Rosaceae*	Subpont.	np
Pyrus pyraster (L.) Burgsd.	*Rosaceae*	Subse.	p
Rosa canina L.	*Rosaceae*	Subse.	np
Rubus hirtus Waldst. & Kit.	*Rosaceae*	Se.	np
Galium odoratum (L.) Scop.	*Rubiaceae*	Subevr.	g
Populus tremula L.	*Salicaceae*	Subevr.	p
Sambucus nigra L.	*Sambucaceae*	Subse.	np
Atropa bella-donna L.	*Solanaceae*	Subse.	h
Tilia cordata Mill.	*Tiliaceae*	Se.	p
Tilia tomentosa Moench	*Tiliaceae*	Subbalk.	p
Ulmus minor Mill.	*Ulmaceae*	Subm.	p
Urtica dioica L.	*Urticaceae*	Evr.	h

Species	Family	Florisic element	Life form
Viola odorata L.	*Violaceae*	Subatl-subm.	h

Legend:p-phanerophytes;np-nanophanerophytes;pl-phanerophytic lianas;zc-herbaceous chamaephytes;h-hemicryptophytes; g- geophytes; th-therophytes/chamaephytes.

The taxonomic analysis showed that the most represented medicinal plants belong to the families *Rosaceae* (15%) and *Lamiaceae* (13%), while medicinal species from *Fagaceae* (7%) and *Liliaceae* (5%) were less common. The two most species-rich families were also the richest in terms of genera: *Rosaceae* (*Crataegus, Rubus, Prunus, Rosa, Fragaria, Malus*) and *Lamiaceae* (*Calamintha, Scrophularia, Glechoma, Lamium, Ajuga, Melittis, Stachys*). The results of the taxonomic analysis of medicinal plants in the Nature Monument "Košutnjak Forests" likewise indicate a dominance of the families *Lamiaceae* and *Rosaceae* (Jokanović et al., 2021).

Figure 1. *Circaea lutetiana* L.

Figure 2. *Stachys silvatica* L.

Figure 3. *Atropa bella-donna* L.

Figure 4. *Helleborus odorus* Willd.

A total of seven wild fruit tree species were also recorded in the floristic composition of these beech forests: *Prunus avium* L., *Prunus spinosa* L., *Pyrus pyraster* (L.) Burgsd., *Malus sylvestris* (L.) Mill., *Juglans regia* L., *Cornus mas* L., and *Rosa canina* L. In recent years, both in Europe and in Serbia, increasing attention has been devoted to forest fruit trees, as the collection of their seeds, the production of planting material, and their introduction into existing forests or into afforestation of bare areas contribute to the preservation of biological diversity.

In the spectrum of floristic elements, plants of the Central European range type were the most prevalent, accounting for 36.7% of the total (Table 2). Plant species of Eurasian range type had a somewhat smaller representation (21,7%), followed by plants of Sub-Mediterranean (11,7%), Sub-Atlantic (10%), Pontic (6,7%), and Balkan (5%) elements. Cosmopolitan and Circumpolar elements each represented 3.3% of the medicinal flora, while the desert floristic element was the least represented, with a share of 1.7%.

Overall, mesophilous plants were the most prevalent, accounting for as much as 46.7% of the flora. These included mainly Central European and Sub-Atlantic floristic elements, which are indicative of the mesophilous character of beech forests. They were followed by species with a broad ecological amplitude (25%), represented by Eurasian and Cosmopolitan range types, and xerothermophilous plants (23.3%), which included Pontic, Sub-Mediterranean, and Balkan elements. The somewhat higher proportion of Mediterranean and Pontic elements can be explained by the fact that beech in this area occurs at relatively low elevations, allowing a considerable number of thermophilous species from the oak forest zone to enter the community.

Table 2. *Spectrum of floristic elements*

Cumulative range types	Number	Share (%)	
Pontic	4	6.7	23.3
Sub-Mediterranean	7	11.7	
Balkan	3	5.0	
Central European	22	36.7	46.7
Subatlantic	6	10.0	
Desert	1	1.7	1.7
Eurasian	13	21.7	
Cosmopolitan	2	3.3	25.0
Circumpolar	2	3.3	3.3

The analysis of life-form spectra among medicinal plants revealed a dominance of phanerophytes, which accounted for 48.4%, followed by hemicryptophytes with 23.3% (Table 3). Geophytes were also well represented (18.3%), indicating favorable edaphic conditions (soil moisture, structure, and depth). This was to be expected, given that geophytes are typically associated with more mesophilous communities of a denser canopy structure.

Table 3. *Spectrum of life forms*

Life forms	Broj	Učešće (%)	
Phanerophytes	19	31.7	48.4
Nanophanerophytes	9	15.0	
Phanerophytic lianas	1	1.7	
Herbaceous chamaephytes	3	5.0	5.0
Hemicryptophytes	14	23.3	23.3
Geophytes	11	18.3	18.3
Therophytes /Chamaephytes	3	5.0	5.0

5. CONCLUSIONS

Of the total 100 plant species recorded in the beech forests of the Kosmaj area, as many as 60 medicinal plants were identified, belonging to 36 families and 50 genera. The most represented medicinal species belonged to the families *Rosaceae* (15%) and *Lamiaceae* (13%), while species from *Fagaceae* (7%) and *Liliaceae* (5%) were less common. Regarding the distribution of floristic elements, the Central European element was dominant, accounting for 36% of the occurring flora, followed by Eurasian (22%), Sub-Mediterranean (11%), and Sub-Atlantic (10%) elements. The analysis of life forms revealed a predominance of phanerophytes (48.4%), followed by hemicryptophytes (23.3%), with geophytes also well represented (18%).

The fact that approximately 60% of the entire flora of these beech forests consists of medicinal plants highlights the potential for harvesting this increasingly important natural resource. For this reason, future research should prioritize the assessment of the abundance and biotic potential of individual medicinal species. Identifying the areas and climatic parameters that currently determine the distribution of specific medicinal plants, as well as forest fruit trees, can contribute to predicting their future ranges and evaluating their level of threat, which is all fully aligned with the broader goal of preserving biodiversity in Serbia.

Acknowledgement: *This research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-136/2025-03/ 200027).*

REFERENCES

Braun-Blanquet, J. (1964). Pflanzensoziologie. *Grundzüge Der Vegetationskunde (3rd ed, 1-865)*. Springer Verlag, Vienna.

Chen SL, Yu H, Luo HM, Wu Q, Li CF, Steinmetz A. (2016). Conservation and sustainable use of medicinal plants: problems, progress, and prospects. *Chin Med*. 11:37. DOI: 10.1186/s13020-016-0108-7.

Howes M. J. R., Quave C. L., Collemare J., Tatsis E. C., Twilley D., Lulekal E., et al. (2020). Molecules from nature: Reconciling biodiversity conservation and global healthcare imperatives for sustainable use of medicinal plants and fungi. *Plants People Planet* 2, 463–481.

Josifović, M. (ed.) (1970-1977): *Flora of Serbia II-IX*. Serbian Academy of Sciences and Arts, Department of Natural and Mathematical Sciences, Belgrade. [Josifović, M. (ed.) (1970-1977): *Flora Srbije II-IX*. Srpska akademija nauka i umetnosti, Odeljenje prirodno-matematičkih nauka, Beograd.]

Jokanović, D., Petrović, J., Inđić, P., Stanković, D., Trivan, G., Urošević, J., Marić, M. (2021). Pharmacodynamic properties of medicinal plants within eight departments of NM „Šuma Košutnjak“. *Ecologica 101(28)*, 11-15. [Jokanović, D., Petrović, J., Inđić, P., Stanković, D., Trivan, G., Urošević, J., Marić, M. (2021). Farmakodinamska svojstva lekovitih vrsta u okviru osam odeljenja SP "Šuma Košutnjak". *Ecologica 101(28),* 11-15.]

Jovanović, B. (1980). Forest phytocoenoses and habitats of mt. Suva planina. *Bulletin of the Faculty of Forestry, series A*, Belgrade. [Jovanović, B. (1980). Šumske fitocenoze i staništa Suve planine. *Glasnik Šumarskog fakultet*a*, serija A.*, Beograd]

Karadžić, B. (2018). Beech forests (order *Fagetalia sylvaticae* Pawlowski 1928) in Serbia. *Botanica Serbica 42 (1),* 91-107.

Knežević M. (2003). Soils in beech forests of Serbia (in Serbian). *Forestry*, 1–2, pp. 97–106. [Knežević M. (2003). Zemljišta u bukovim šumama Srbije. *Šumarstvo* 1-2, Beograd, str. 97-106]

Kojić M., Popović R., Karadžić B. (1997). *Vascular plants of Serbia*. Institute for Agricultural Research "Serbia" and Institute for Biological Research "Sinisa Stankovć", Belgrade.

Lakušić D. (2005). Relation between species and ecosystem diversity. In: V. Stevanović (ed.), *Biodiversity at the onset of the new millennium*. Serbian Academy of Science and Art, Belgrade, pp. 75–102. [Lakušić D. (2005). Odnos specijskog i ekosistemskog diverziteta. U: V. Stevanović (ed.), *Biodiverzitet na početku novog milenijuma*. Srpska akademija i nauka i umetnosti pp. 75–102.]

Obratov-Petković, D., Đukić, M. (2000). Possibilities of exploitation of medical plants in the aim of forest functions improvement. *Bulletin of the Faculty of Forestry 82*, pp. 127-135. [Obratov-Petković D., Đukić M. (2000). Mogućnosti korišćenja lekovitog bilja u cilju unapređenja stanja i funkcija šuma. *Glasnik Šumarskog fakulteta 82*, str. 127-135.]

Sarić, M, Diklić, N. (Eds) (1986). *Flora of Serbia X*. Serbian Academy of Sciences and Arts, Department of Natural and Mathematical Sciences, Belgrade. [Sarić M, Diklić, N. (eds) (1986). *Flora Srbije X*. Srpska akademija nauka i umetnosti, Odeljenje prirodno-matematičkih nauka, Beograd.]

Sarić M. (Ed.) (1989). *Medicinal plants of SR Serbia*. Serbian. Academy of Sciences and Arts, Belgrade. [Sarić M. (1989). *Lekovite biljke SR Srbije*. Srpska akademija nauka i umetnosti, Beograd]

Sarić, M. (Ed.) (1992). *Flora of Serbia I*. Serbian Academy of Sciences and Arts, Department of Natural and Mathematical Sciences, Belgrade. [Sarić M. (ed.) (1992): *Flora Srbije I*. Srpska akademija nauka i umetnosti, Odeljenje prirodno-matematičkih nauka, Beograd]

Stajić S., Cvjetićanin R., Čokeša V., Miletić Z., Novaković-Vuković M., Eremija S., Rakonjac Lj. (2021). Plant species richness and diversity in natural beech and oak-dominated forests of Kosmaj protected area (Serbia). *Applied Ecology and Environmental Research 19(4),* 2617-2628. DOI 10.15666/aeer/1904_26172628

Stajić S., Čokeša V., Rakonjac Lj., Eremija S. (2025). *Distribution of medicinal plants and forest frut trees in oak-dominated forests in the area of Kosmaj (Serbia)*. Third conference on medicinal and wild-growing edible plants, Pirot, Serbia, June 26 – 28. 2025. Book of abstracts pp. 7–10. Research Association "Babin Nos", Temska, Pirot, Serbia; Institute of Forestry, Belgrade, Serbia

Stevanović, V. (Ed.) (2012). *Flora of Serbia II*. Serbian Academy of Sciences and Arts, Department of Natural and Mathematical Sciences, Belgrade. [Stevanović, V. (ed.) (2012): *Flora Srbije II*. Srpska akademija nauka i umetnosti, Odeljenje prirodno-matematičkih nauka, Beograd.]

Tomić, Z., Rakonjac, Lj. (2013). *Forest phytocoenoses of Serbia,* Institute of Forestry Belgrade, University Singidunum-Faculty for Applied Ecology Futura, Belgrade. [Tomić Z., Rakonjac Lj. (2013). *Šumske fitocenoze Srbije*. Institut za šumarstvo Beograd, Univerzitet Singidunum-Fakultet za primenjenu ekologiju Futura, Beograd]

Euro+Med (2006-): Euro+Med PlantBase – the information resource for Euro-Mediterranean plant diversity. Published at https://www.europlusmed.org/ [accessed 21 Oct 2025].

*(2023). *The Results of the Second National Forest Inventory of the Republic of Serbia*. Ministry of Agriculture, Forestry, and Water Management – Directorate for Forests.
[(2023). *Rezultati Druge nacionalne inventure šuma Republike Srbije*. Ministarstvo poljoprivrede, šumarstva i vodoprivrede-Uprava za šume]

BEECH FORESTS OF KOSMAJ AS A NATURAL RESOURCE OF MEDICINAL PLANTS

Snežana STAJIĆ, Vlado ČOKEŠA, Violeta BABIĆ, Suzana MITROVIĆ, Marija Milosavljević, Saša EREMIJA, Jelena BOŽOVIĆ

Summary

The aim of this study was to determine the representation of medicinal plants within the flora of beech forests in the study area, accompanied by a detailed taxonomic, phytogeographical, and biological-spectrum analysis.

In the Kosmaj region, submontane beech forests are widely distributed, occurring either as pure stands (*Helleboro odori–Fagetum moesiacae* Soó & Borhidi 1960) or as mixed stands with sessile oak (*Querco petraeae–Fagetum moesiacae* Glišić 1971). These forests are generally found at elevations between 370 and 580 m, on colder exposures (northern, northwestern, northeastern) and slopes ranging from 15° to 28°. A total of 22 phytosociological relevés were used in the analysis of floristic composition.

Out of 100 recorded plant species, 60 medicinal species were identified, belonging to 36 families and 50 genera. The most represented families were *Rosaceae* (15%) and *Lamiaceae* (13%), followed by *Fagaceae* (7%) and *Liliaceae* (5%).

Within the spectrum of floristic elements, medicinal plants of the Central European range type were predominant (36.7%). They were followed by species of the Eurasian type (21.7%), sub-Mediterranean (11.7%), sub-Atlantic (10%), Pontic (6.7%), Balkan (5%), Circumpolar (3.3%), and Cosmopolitan types (3.3%), while species of the Desert range type were the least represented (1.7%).

The analysis of life forms revealed that phanerophytes were dominant (48.4%), followed by hemicryptophytes (23.3%).

The floristic composition of these beech forests also includes seven species of wild fruit trees: *Prunus avium* L., *Prunus spinosa* L., *Pyrus pyraster* (L.) Burgsd., *Malus sylvestris* (L.) Mill., *Juglans regia* L., *Cornus mas* L., and *Rosa canina* L.

Identifying the current distribution areas of medicinal plant species provides a basis for predicting their future range of distribution and assessing their level of endangerment.

Therefore, future research in these forests should prioritize evaluating the abundance and biotic potential of some medicinal species.

BUKOVE ŠUME KOSMAJA KAO PRIRODNI RESURS LEKOVITIH BILJAKA

Snežana STAJIĆ, Vlado ČOKEŠA, Violeta BABIĆ, Suzana MITROVIĆ, Marija Milosavljević, Saša EREMIJA, Jelena BOŽOVIĆ

Rezime

Cilj ovog rada bio je da se utvrdi zastupljenost lekovitih biljaka u flori bukovih šuma ovog područja, sa detaljnom taskonomskom i fitogeografskom, kao i analizom biološkog spektra.

Na području Kosmaja brdske bukove šume imaju široko rasprostranjenje, bilo da se javljaju kao čiste (*Helleboro odori-Fagetum moesiacae* Soo &Borhidi 1960.) ili mešovite sa kitnjakom (*Querco petraeae-Fagetum moesiacae* Glišić 1971.). Prisutne su uglavnom na terenima 370 to 580 m nadmorske visine, hladnijim eskpozicijama (sever, severozapad, severoistok) i nagibima 15-28° U analizi florističkog sastava korišćeno je 22 fitocenološka snimka.

Od ukupnog broja biljnih vrsta (100), registrovano je 60 lekovitih vrsta biljaka iz 36 familije i 50 rodova. Najzastupljenije su lekovite biljke iz familije *Rosaceae* (15%) i *Lamiaceae* (13%), a nešto manje su prisutne lekovite biljke iz familija *Fagaceae* (7%) i *Liliaceae* (5%).

U spektru flornih elemenata, najzastupljenije su lekovite biljke srednjeevropskog areal tipa sa 36,7%. Nešto manju zastupljenost imaju biljne vrste evroazijskog areal tipa (21,7%), dok za njima slede biljke submediteranskog (11,7%), subatalanskog (10%), pontskog (6,7%), balkanskog (5%), cirkumpolarnog (3,3%), kosmopolitskog tipa (3,3%) i najmanje florni element pustinjskih predela (1,7%).

Analiza životnih formi lekovitih biljaka pokazuje da dominiraju fanerofite sa 48,4%, a zatim slede hemikriptofite sa 23,3%.

U florističkom sasatvu bukovih šuma ovog područja registrovano je i 7 vrsta divljih voćkarica: *Prunus avium* L., *Prunus spinosa* L., *Pyrus pyraster* (L.) Burgsd., *Malus sylvestris* (L.) Mill., *Juglans regia* L., *Cornus mas* L,, *Rosa canina* L.

Identifikacija područja gde se danas nalaze pojedine lekovite biljke može pomoći u definisanju njihove buduće rasprostranjenosti i proceni nivoa ugroženosti, zbog čega bi u daljem istraživanju ovih šuma prioritet bio na utvrđivanju brojnosti i biotičkog potencijala pojedinih lekovitih vrsta.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY COLLECTION 92, 2025
ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592011P
UDK: 630*232.3:582.632.2=111
Original scientific paper

SELECTION OF SESSILE OAK (*Quercus petraea* (Matt.) Liebl.) PLUS TREES FOR SEED ORCHARD ESTABLISHMENT

Vladan POPOVIĆ[1], Sanja LAZIĆ[1], Aleksandar LUČIĆ[1], Ljubinko RAKONJAC[1], Radojica PIŽURICA[1], Boris IVANOVIĆ[2], Aleksandra PETROVIĆ[2]

Abstract: *The results of selection of plus trees of sessile oak (Quercus petraea (Matt.) Liebl.) as a base for establishing a seed orchard are presented in this paper. The research included 86 trees of phenotypically highest quality, selected based on morphological and physiological criteria, in order to preserve and improve the genetic diversity of the species. Morphological characteristics of leaves and acorns were analysed, including dimensions, mass and the ratio of certain parameters. The results of one-way analysis of variance showed that there are statistically significant differences among the trees for all observed characteristics (p < 0.01), which indicates a high level of genetic and morphological variability. The obtained results confirm that selected plus trees represent a suitable source of reproductive material for establishment of seed orchard of sessile oak. This way a basis for long-term conservation of genetic potential and adaptive capacity of the species is created.*

Keywords: *Quercus petraea*, plus trees, morphological variability, acorn, leaf, seed orchard, genetic diversity.

SELEKCIJA PLUS STABALA HRASTA KITNJAKA (*Quercus petraea* (Matt.) Liebl.) ZA POTREBE OSNIVANJA SEMENSKE PLANTAŽE

Sažetak: *U ovom radu prikazani su rezultati selekcije plus stabala hrasta kitnjaka (Quercus petraea (Matt.) Liebl.) kao osnova za podizanja semenske plantaže. Istraživanja su obuhvatila 86 fenotipski najkvalitetnijih stabala, izdvojenih na osnovu morfoloških i fizioloških kriterijuma, u cilju očuvanja i unapređenja genetičke raznovrsnosti vrste. Analizirane su morfološke karakteristike listova i žira, uključujući dimenzije, masu i odnos pojedinih parametara. Rezultati jednofaktorijalne analize varijanse pokazali su postojanje statistički značajnih razlika među stablima za sva posmatrana svojstva (p < 0,01), što ukazuje na visok nivo genetičke i morfološke varijabilnosti. Dobijeni rezultati potvrđuju da izdvojena plus stabla predstavljaju pogodan izvor reproduktivnog materijala za osnivanje semenske plantaže hrasta kitnjaka, čime se stvara osnova za dugoročno očuvanje genetičkog potencijala i adaptivnog kapaciteta vrste.*

Ključne reči: *Quercus petraea*, plus stabla, morfološka varijabilnost, žir, list, semenska plantaža, genetička raznovrsnost.

[1] Institute of Forestry, Belgrade, Serbia
[2] PE Srbijašume, Belgrade
*Corresponding author. E-mail: vladanpop79@gmail.com

1. INTRODUCTION

Sessile oak (*Quercus petraea* (Matt.) Liebl.) is an autochthonous European species from the most significant group of broadleaved trees. In addition to pedunculate oak and cork oak it represents economically the most significant species of the genus, known for high-quality technical wood of high endurance. In an environmental sense, sessile oak increases forest biodiversity; it is an edifier of numerous types of forests, providing habitat and food for various species of insects, birds and mammals, mosses, as well as microorganisms. Given that the habitats of sessile oak are characterised by somewhat drier conditions, it is considered that its range will expand in the future (Girard et al., 2022), as well as that it is a species of choice in afforestation, in altered climatic conditions of the environment (Lindner et al., 2014; Schelhaas et al., 2015). In this regard it should also be noted that mixed forests of sessile oak are more resistant to fires, and sessile oak itself is considered a species relatively resistant to storms (lightnings and thunders), drought and heat (Kohler et al., 2020; Perkins et al., 2018; Kunz et al., 2018; Modrow et al., 2020).

Due to its importance, sessile oak is one of the two oak species most commonly produced in nurseries in Serbia (Popović et al., 2019). Sessile oak forests occupy 7.84 % of total forest area in the Republic of Serbia (Cuchietti et al., 2023). Since the mid-20th century there has been the trend of die-back of sessile oak, as a consequence of action of multiple factors (monograph on sessile oak). Therefore, restoration of sessile oak forests and their transformation from sprout forests to high forests is one of the most important tasks and goals of forestry in Serbia. However, considering that sessile oak is a species with irregular seed yield, it is necessary to provide sufficient quantities of high-quality seed also during the years without a rich yield.

For these purposes, a necessary prerequisite is the existence of seed orchards which will provide the necessary starting point – high-quality reproductive material of adequate genetic, physiological and morphological characteristics. When establishing seed orchards, superior, plus trees which possess the desired morphological characteristics are selected, while taking care to preserve genetic variability, and use provenances of the given/target region. The existence of genetic diversity, as evidenced by the variability of morphological characteristics, represents the imperative, for the stability and survival of a population, as well as the possibility for adaptation in different environmental conditions, thereby increasing evolutive potential (Alfaro et al., 2014). Selection of plus trees is carried out based on the phenotypic characteristics, which develop through the co-interaction of genotype and environmental conditions (EUFORGEN, 2023). Some of the desired characteristics are physiological vitality, correct tree shape, proportionate crown, fullness of bole, good health, and satisfactory seed production. Some of the listed traits are heritable and, therefore, important for the technical application of wood and its use in various types of industry and production. Also, correlations are shown in some morphological characteristics of trees. For example, Dobrosavljević et al. (2022) showed that the diameter of a sessile oak tree is positively correlated with the number of acorns per m2. This is a consequence of the increase in crown area which increases with the increase of tree diameter (Bechtold 2003). The same study also established the link between larger tree diameter and with larger acorn length and diameter, which in some studies has been associated with larger seedlings (Roth et al., 2009).

Continuing with the above, the link between morphological parameters of acorns and later development of seedlings is known in science. Various studies have shown a positive impact of the acorn size on their germination, rate of aboveground part development, survival success, biomass and overall seedling quality (Roth et al., 2009; Ivankovic et al., 2011). Acorn dimensions also affect the manipulation of this reproductive material in forest nurseries during seedling production, determining the density and depth of planting. (Major 2002).

The leaf, as the main photosynthetic organ is very important for the development and progress of sessile oak and it shows great variability in morphological parameters. They are also used for taxonomic purposes, in distinguishing species, like sessile oak and pedunculate oak, which are prone to mutual hybridization. The basic division of leaves is into heliomorphic (sun leaves) and sciomorphic (shade leaves) which are clearly, morphologically, anatomically and functionally different. The variability of leaf morphological parameters is influenced by genetics, origin, available sunlight, water availability, temperature, phases of polycyclic growth of shoot and leaves. Oaks are characterised by great plasticity and according to Arab et al. (2020) the environmental conditions take precedence over genetic traits and origin when varying morphological parameters, indicating great potential in adapting to current and future environmental conditions, especially in the context of climate change (Arab et al., 2021).

The object of this research was to identify and rate sessile oak plus trees based on the phenotypic traits and morphological characteristics of leaves and seeds, with the aim of selecting the most suitable individuals for establishing a seed orchard.

2. MATERIAL AND METHODS

Site and selection of plus trees

The research was carried out within several forest management units in the territory of natural stands of sessile oak (*Quercus petraea* (Matt.) Liebl.). A total of 86 plus trees were selected and rated as phenotypically of the highest quality. The selection criteria included: good physiological vitality, regular form of the tree, high-quality and proportionate crown, fullness of bole, health condition without the symptoms of disease, and satisfactory seed production. Attention is also paid to spatial arrangement, so that the trees were positioned at least 50 m apart to avoid close relatedness. All selected trees were evaluated according to the following mensurational indicators: diameter at breast height (cm), main stem height (m) and length (m), as well as according to the criteria of the stem form quality and crown form quality, fullness of bole, twisting of the main stem and health condition.

Geographical positioning

All selected plus trees were recorded in space by reading of geographical coordinates and altitude. The obtained data were used for cartographic representation of tree distribution and they form the basis for further monitoring and management of selected genetic resources.

Mensurational parameters and quality assessment

The following basic mensurational indicators were measured for all selected plus trees: diameter at breast height, total height and main stem length. In addition, the method of quality assessment of plus trees in the field was applied, which includes assessing the stem form quality (5 Excellent. Straight stem, apical domination, without strong competitive branches in the top; 4 Good. Weaker apical domination and/or single curved stem; 3 Less good. Bad apical domination and/or more then one stem curve. Fork in upper 2/3 of the tree height; 2 Bad. Very weak apical domination, more then two curves. Low fork (below 2/3 of the tree height) or multiple forks), crown form quality (5 Excellent. Relatively thin branches with flat insertion angle (>60°). Fairly symetrical crown; 4 Good. No more then one thich branch and/or smaller insertion angle (45-60°); Less fairly symmetrical; 3 Less good. More then one thich branches. Acute insertion angle (<45°). Asymetrical and/or not properly developed; 2 Bad. Multiple forks, acute branch insertion angle. Weakly developed and/or extremly asymmetrical), fullness of bole (5 Excellent. Very low degree of taper, very small decrease of diameter as a function of stem height, 3 Good. Moderate degree of taper, 1 Bad. High degree of taper), twisting of main stem (5 no bark twisting, 1 visible bark twisting) and health condition (5 Completely healthy tree without any visible symptoms, 1 Unhealthy. Visible sypmtoms such as cankers, many epicormics, stem cracks, less foliage etc). The data were recorded in standardized forms and used for further selection.

Collection of biological material

From all selected plus trees leaves and acorns were collected. The leaves were collected in the stage of full development, from short fertile shoots of the outer part of the crown, and exclusively from the southeast side in order to ensure comparability of the samples. Between 60 and 70 fully developed, undamaged leaves were collected from each tree, which were herbarized after collection. About 5 kg of ocularly healthy acorns were collected from each plus tree, and a random sample of 50 acorns per plus tree was taken for the purposes of morphometric analyses.

Morphometric measurement

Scanned leaves were measured by LAMINA software tool (Bylesjö et al., 2008). The following parameters were measured on the leaves: leaflet area, circumference, maximum width, width at 25%, 50% and 75% of leaflet length, total leaflet length, length at 25%, 50% and 75% of leaflet width, length-to-width ratio, and petiole length.

The following measurements were made on acorns: length, diameter (width) and mass. Length and diameter were determined by vernier caliper with a precision of 0.01 mm, while mass was measured by analytical scale with a precision of 0.01g.

Statistical processing of data

Basic indicators of descriptive statistics (mean value, minimum, maximum, standard deviation and coefficient of variation) were calculated for all measured parameters. In order to determine the existence of statistically significant differences among plus trees, a one-way analysis of variance (ANOVA) was applied, where a tree was treated as a factor of variability. The level of significance was set on $p<0.01$.

3. RESULTS

Selection and quality assessment of plus trees

All parameters showed that the selected trees meet the criteria of plus trees, which makes them suitable sources of production of reproductive material of the highest quality (Table 1).

Table 1. *Mensurational and quality assessment data of plus trees*

Plus tree ordinal number	Diameter at breast height (cm)	Height (m)	Main stem length (m)	Stem form quality	Crown form quality	Fullness of bole	Twisting of main stem	Health condition
1	40	20.3	8.1	5	4	5	5	5
2	44.5	19.6	7.3	5	5	5	5	5
3	49	19.7	7.8	5	4	5	5	5
4	45.5	22.2	9.7	5	4	5	5	5
5	50	21.4	8.4	5	5	5	5	5
6	41	21.2	10.7	5	5	5	5	5
7	43	22.8	9.2	5	5	5	5	5
8	49	27.5	10.9	5	5	5	5	5
9	42.5	19.7	9.7	5	5	5	5	5
10	40.5	23.3	9.9	5	4	5	5	5
11	45	21.1	8.3	5	4	5	5	5
12	51	24.3	11.5	5	4	5	5	5
13	54.5	20.6	10.4	5	5	5	5	5
14	50	20.7	9.2	5	5	5	5	5
15	44	20.8	10.7	5	4	5	5	5
16	46	19.6	7.2	5	4	5	5	5
17	39	19.6	9.6	5	5	5	5	5
18	48	21.1	8.4	5	5	5	5	5
19	52	20.4	10.4	5	5	5	5	5
20	54.5	24.5	11.9	5	5	5	5	5
21	45.5	22.4	9.6	5	5	5	5	5
22	52	24.9	14.2	5	5	5	5	5
23	57	23.1	11.1	5	5	5	5	5
24	52	24.2	9.6	5	5	5	5	5
25	52.5	24.6	9.9	5	5	5	5	5
26	46	24.4	12	5	4	5	5	5
27	46	25.8	14.1	5	5	5	5	5
28	54	22.5	12.3	5	5	5	5	5
29	56.5	19.9	10.8	5	4	5	5	5

Plus tree ordinal number	Diameter at breast height (cm)	Height (m)	Main stem length (m)	Stem form quality	Crown form quality	Fullness of bole	Twisting of main stem	Health condition
30	50.5	23.7	12.7	5	5	5	5	5
31	43	24.8	14.5	5	5	5	5	5
32	43.5	24.9	13.3	5	5	5	5	5
33	42.5	18.5	6.2	4	5	5	5	5
34	61	26.9	13.4	5	5	5	5	5
35	49.5	24.1	9.7	5	5	5	5	5
36	34.5	21.8	10.1	5	5	5	5	5
37	36.5	25.5	10.1	5	5	5	5	5
38	66	29.5	8.5	5	5	5	5	5
39	49.5	23.9	7.8	5	5	5	5	5
40	46	19.9	8.2	5	5	5	5	5
41	52	21.7	11.2	5	5	5	5	5
42	50	25.7	10.7	5	5	5	5	5
43	57	21.7	6.5	5	5	5	5	5
44	39	21.6	9.8	5	5	5	5	5
45	53	20.6	7.3	5	5	5	5	5
46	46	24.3	9.6	5	5	5	5	5
47	42	18.9	5.1	5	5	5	5	5
48	41	21.9	9.4	5	5	5	5	5
49	36	20.6	9	5	5	5	5	5
50	37	19.8	8.5	5	5	5	5	5
51	54	25	11	5	5	5	5	5
52	34	19	5.5	5	5	5	5	5
53	54	26.7	14.5	5	5	5	5	5
54	50	24.6	12.1	5	5	5	5	5
55	44	22.7	11.6	5	5	5	5	5
56	46	26.8	12.3	5	5	5	5	5
57	53	25.4	14.1	5	5	5	5	5
58	52	23.9	9.3	5	5	5	5	5
59	55	26.5	12.1	5	5	5	5	5
60	52	24.4	12.4	5	5	5	5	5
61	59	24.8	12.3	5	5	5	5	5
62	48.5	24.7	9.5	5	5	5	5	5
63	45	26.3	15.5	5	5	5	5	5
64	54	31.8	15.5	5	5	5	5	5
65	45	23	12.6	5	5	5	5	5
66	43	22.6	11.8	5	5	5	5	5
67	53	24	12.3	4	5	5	5	5
68	50.5	26.1	13.6	5	5	5	5	5
69	55	27.5	14.7	5	5	5	5	5
70	50	24.8	15.2	4	5	5	5	5
71	46.5	23.9	12.8	5	5	5	5	5
72	46	25.7	11.5	5	5	5	5	5
73	50.5	26.7	16.2	5	5	5	5	5
74	48	28	13.5	5	5	5	5	5
75	58	23	9	4	5	5	5	5
76	54	22	8.5	5	4	5	5	5
77	68	24.9	10.9	5	5	5	5	5
78	55	26.5	12.8	5	5	5	5	5
79	54	29.7	14.4	5	5	5	5	5
80	37	23.4	12.2	5	4	5	5	5
81	50.5	25.6	10	5	5	5	5	5
82	93	22.8	10.8	4	5	5	5	5
83	45	24.5	11.9	5	5	5	5	5
84	60	24.5	7.7	4	5	5	5	5
85	51	24.8	10.6	5	5	5	5	5
86	74.5	21.6	8.9	5	5	5	5	5

Morphometric analysis of leaves

Morphometric characteristics of leaves indicate pronounced variability among plus trees. Average leaflet area at the level of population amounted to 41.28 cm², with a minimum of 7.60 cm² and a maximum of 145.73 cm². The mean value of the leaflet length amounted to 98.63 mm, while the average width amounted to 59.25 mm. Leaflet length-to-width ratio was relatively stable (mean value 1.52), which indicates lower variability of this indicator compared to leaflet area or circumference. Leaflet area was the most variable characteristic (CV = 45.39%), while leaflet length-to-width ratio showed the lowest coefficient of variation (CV = 13.24%) (Table 2).

Table 2. *Basic indicators of descriptive statistics of morphometric parameters of the leaves*

Characteristic	Mean value	Minimum	Maximum	Standard deviation	Coefficient of variance
LA (cm^2)	41.28	7.60	145.73	18.38	45.39
LC (cm)	31.56	11.21	76.88	9.51	24.11
LW (mm)	59.25	19.03	156.77	15.89	23.56
LW25 (mm)	47.10	13.52	145.51	14.71	29.71
LW50 (mm)	53.45	16.55	137.79	15.31	28.28
LW75 (mm)	41.59	7.42	124.56	13.82	31.14
LL (mm)	98.63	38.85	185.35	22.18	21.16
LL25 (mm)	73.44	23.90	143.33	17.51	21.06
LL50 (mm)	97.36	7.05	181.36	22.81	20.42
LL75 (mm)	74.54	25.84	138.24	17.48	23.19
LL/LW	1.52	0.69	2.81	0.22	13.24
PL (cm)	2.14	1.02	4.42	0.47	21.18

Abbreviations: LA – leaflet area (cm^2); LC – leaflet circumference (cm); LW – leaflet width at the widest part of the leaflet (mm); LW25- leaflet width at 25% of leaflet length (mm); LW50- leaflet width at 50% of the leaflet length (mm); LW75- leaflet width at 75% of the leaflet length (mm); LL – leaflet length (mm); LL25 – leaflet length at 25% of the leaflet width (mm); LL50 – leaflet length at 50% of leaflet width (mm); LL75- leaflet length at 75% of leaflet width (mm); LL/LW-ratio of leaflet length and width; PL- petiole length (mm).

Table 3. *One-way analysis of variance for measured morphometric characteristics of leaves*

	F	p
LA		
Intercept	14350.91	0.0000
Tree	16.72	0.0000
LC		
Intercept	36344.16	0.0000
Tree	13.45	0.0000
LW		
Intercept	40261.50	0.0000
Tree	14.45	0.0000
LW25		
Intercept	29783.20	0.0000
Tree	10.93	0.0000
LW50		
Intercept	34295.40	0.0000
Tree	13.21	0.0000
LW75		
Intercept	30221.00	0.0000
Tree	18.34	0.0000

	F	p
LL		
Intercept	58325.42	0.0000
Tree	14.15	0.0000
LL25		
Intercept	47814.69	0.0000
Tree	11.33	0.0000
LL50		
Intercept	53357.70	0.0000
Tree	13.61	0.0000
LL75		
Intercept	48913.69	0.0000
Tree	12.15	0.0000
LL/LW		
Intercept	165798.9	0.0000
Tree	27.5	0.0000
PL		
Intercept	26259.69	0.0000
Tree	19.11	0.0000

The results of one-way analysis of variance (ANOVA) showed that there are statistically significant differences among plus trees ($p < 0.01$) for all observed morphometric characteristics of leaves. This confirms a high level of intraspecific variability and indicates the possibility of selection of trees with the favourable morphometric characteristics (Table 3).

Morphometric analysis of the acorn

Mean length of acorn amounted to 26.14 mm (min 20.54 – max 39.78 mm), thickness 15.44 mm (min 6.08 – max 23.84 mm), while mean mass was 3.85 g, with an extremely high range (0.82 – 30.35 g). Coefficient of variation was highest for the acorn mass (CV = 39.74%), while acorn length showed moderate variability (CV = 14.80%), and thickness was somewhat lower (CV = 13.08%) (Table 4).

Table 4. *Basic indicators of descriptive statistics of morphometric parameters of acorns*

Characteristic	Mean value	Minimum	Maximum	Standard deviation	Coefficient of variation
Acorn length (mm)	26.14	20.54	39.78	3.87	14.80
Acorn thickness (mm)	15.44	6.08	23.84	2.02	13.08
Acorn mass (g)	3.85	0.82	30.35	1.53	39.74

Table 5. *One-way analysis of variance for measured morphometric characteristics of acorns*

	F	p
Acorn length		
Intercept	353082.8	0.0000
Tree	41.8	0.0000
Acorn thickness		
Intercept	400243.5	0.0000
Tree	31.6	0.0000
Acorn mass		
Intercept	39909.89	0.0000
Tree	24.90	0.0000

The analysis of variance confirmed the existence of statistically significant differences among trees for all three observed characteristics ($p < 0,01$). These results show that the trees possess a significant level of genetic and morphological diversity, which is the basis for their further use in selection (Table 5).

By combining the results of morphometric analyses of leaves and acorns, a satisfactory level of genetic diversity is observed among the selected plus trees. This diversity enables the selection of individuals with the most favourable combinations of characteristics, while minimizing the risk of genetic closeness and inbreeding in future seed orchard.

Geographic characteristics of plus trees

All plus trees are geographically positioned and recorded with read off coordinates and altitude. The altitude ranged from about 285 m to 647 m of altitude, which indicates a wide ecological amplitude of selected trees. These data represent the basis for the preparation of the plus trees distribution map, which enables precise monitoring and management of genetic resources (Table 6, Figure 1).

In summary, the results show a high level of morphological and genetic variability among plus trees of sessile oak, with clearly identified candidates for a source of high-quality reproductive material. That provides a firm basis for forming a seed orchard with significant potential for conservation and improvement of the species gene pool.

Table 6. *Basic geographical data*

Plus tree ordinal number	Geographical coordinates		Altitude
	X	Y	
1	4919937	7578945	578
2	4919992	7578906	581
3	4920024	7778929	582
4	4920082	7878920	584
5	4920101	7978872	578
6	4920232	8078833	567
7	4920364	8178759	562
8	4920441	8278599	556
9	4920494	8378571	563
10	4920490	8478493	586
11	4920519	7578328	595
12	4920477	7578279	606
13	4920499	7578148	638
14	4920636	7578081	647
15	4920534	7578380	582
16	4921829	7578406	631
17	4921775	7578416	614
18	4921715	7578429	591
19	4921667	7578508	591
20	4921607	7578584	582
21	4921547	7578761	580
22	4921456	7578838	567
23	4921351	7578996	577
24	4921308	7578954	575
25	4921195	7578926	572
26	4921101	7578909	554
27	4921039	7578882	530
28	4921721	7578235	572

Plus tree ordinal number	Geographical coordinates		Altitude
	X	Y	
29	4921621	7578112	556
30	4921396	7578142	592
31	4921268	7578082	592
32	4920935	7578284	587
33	4917005	7580571	521
34	4916905	7580519	499
35	4916826	7580542	502
36	4916800	7580608	493
37	4916759	7580691	473
38	4916766	7580510	515
39	4916735	7580411	509
40	4916679	7580447	519
41	4916640	7580518	497
42	4916678	7580580	476
43	4916569	7580536	492
44	4916537	7580583	477
45	4916481	7580574	470
46	4916485	7580621	472
47	4916435	7580644	471
48	4916365	7580618	444
49	4916371	7580661	456
50	4916 691	7580348	486
51	4916814	7580365	482
52	4916788	7580180	441
53	4918066	7569606	506
54	4918043	7569658	490
55	4918007	7569735	493
56	4917890	7569789	460
57	4917884	7569775	455
58	4917767	7569821	458
59	4917583	7569914	452
60	4917493	7569972	466
61	4917480	7570075	471
62	4917352	7570143	456
63	4917250	7570238	442
64	4917268	7570350	431
65	4917160	7570414	433
66	4917154	7570483	420
67	4917156	7570544	415
68	4917096	7570674	395
69	4917073	7570738	393
70	4917021	7570784	384
71	4916994	7570844	351
72	4916950	7570923	368
73	4916899	7570964	349
74	4916768	7571017	325
75	4916825	7570905	323
76	4916950	7570680	285
77	4921793	7578166	587
78	4921838	7578277	594
79	4922048	7578248	624
80	4922060	7578193	618
81	4922067	7578267	604
82	4922270	7578321	639
83	4922363	7578211	628
84	4922704	7578532	630
85	4922959	7578423	644
86	4923173	7578680	612

4. DISCUSSION

Previous research showed that seed orchards with 30 to 50 unrelated clones keep the degree of genetic variability like the ones in natural populations (Ruņģis et al., 2019; Cortés et al., 2020; Pakull et al., 2021; Sang et al., 2022). In our case 86 plus trees were selected, representing a good starting genetic base for a future seed orchard.

Genetic diversity is manifested at the phenotypic level, in interaction with environmental conditions. It was shown that functional diversity, as well as diversity of various morphological characteristics of trees increases forest productivity and long-term resistance to climatic stressors (Sakschewski et al., 2016; Hisano et al., 2024), and that is one of the long-term goals when establishing seed orchard.

Dobrosavljević et al. (2022) showed that the diameter of sessile oak tree is positively correlated with the number of acorns per m^2. This is a consequence of the increase of crown area which increases with the increase of tree diameter (Bechtold 2003). The same study also established a link between larger tree diameter with larger acorn length and diameter.

The coordinates of selected plus trees confirm their mutual distance, which is significant for the prevention of inbreeding. Sessile oak has a very wide altitudinal range of spreading and it grows on altitudes from 0 to 2200 m (Nicolescu et al., 2025). Considering the topography of the area and the original stands in which the selection of plus trees was carried out, a relatively wide ecological amplitude of the species in the given area is covered. In this way, it is ensured that the genetic and morphological variability of the future seed orchard is increased, because each of the trees is specifically adapted to the conditions of its immediate microenvironment. Consequently, the probability of success of future afforestation, which will derive from the seeds of selected plus trees, increases.

In our research, the morphological parameters of acorns were also examined. The effect of population and maternal effect determine acorn dimensions (Gonzalez-Rodriguez et al., 2011). The largest part of the acorn mass consists of cotyledons (Giertych et al., 2019). Larger acorns are associated with later more robust and higher quality seedlings with greater survival success (Roth et al., 2009; Dobrosavljević et al., 2018), due to greater nutrient supplies. Germination percent was more than double for the group of larger acorns. Large acorns produced seedlings with greater dry weight of roots and lower shoot to root ratios (Devetaković et al., 2019). Also, the research of Sánchez-Montes de Oca et al. (2018) showed that heavier seeds germinate earlier. However, some authors also link the size of acorns with the method of seed dispersal (Perea et al., 2012; Wrobel and Zwolak 2017). Also, the largest acorns are often the most interesting to predators such as wild boars and mice (Gomez 2004).

It is important to note that the quality of seedlings, in accordance with the concept of targeted seedling production, is assessed also based on both the needs and final planting location (Grossnickle MacDonald, 2018), so the acorns of more modest dimensions must not be rejected a priori as future less successful seedlings. In addition to their role in preserving population variability and stability, it should be borne in mind that smaller seedlings are a competitive advantage in certain environmental conditions.

The characteristics of acorns are also important in the context of pathogen attack. Dobrosavljević et al. (2022) reported a significantly negative effect of acorn length on the rate of infection by harmful insects of the genera *Curculio* and *Cydia*, and confirmed a significant positive effect on the germination rate, while acorn diameter did not have a significant influence on the mentioned characteristics. The same study determined that the size of an acorn affects the rate of attack of the pest *Curculio glandium* (Marsham 1802) and the germination rate of damaged and healthy acorns.

Like acorns, sessile oak leaves show great variability in morphological parameters. The differences in length, width, circumference and leaflet area are also reflected in its productivity (Marron Ceulemans 2006). Kissling et al. (1980) indicate narrower base, shallower lobes, less hairiness and shorter petiole of oak leaves in secondary seasonal growth compared to the primary. Variability of morphological parameters of sessile oak leaves can also be the consequence of stressful environmental conditions, so in the conditions of drought and nitrogen deficiency smaller and thicker leaves develop, while in favourable environmental conditions they are larger and thinner (Arab et al., 2020; Arab et al., 2021; Thomas et al., 2024). Larger leaves enable faster plant growth, supplying it with larger quantities of photosynthetic products.

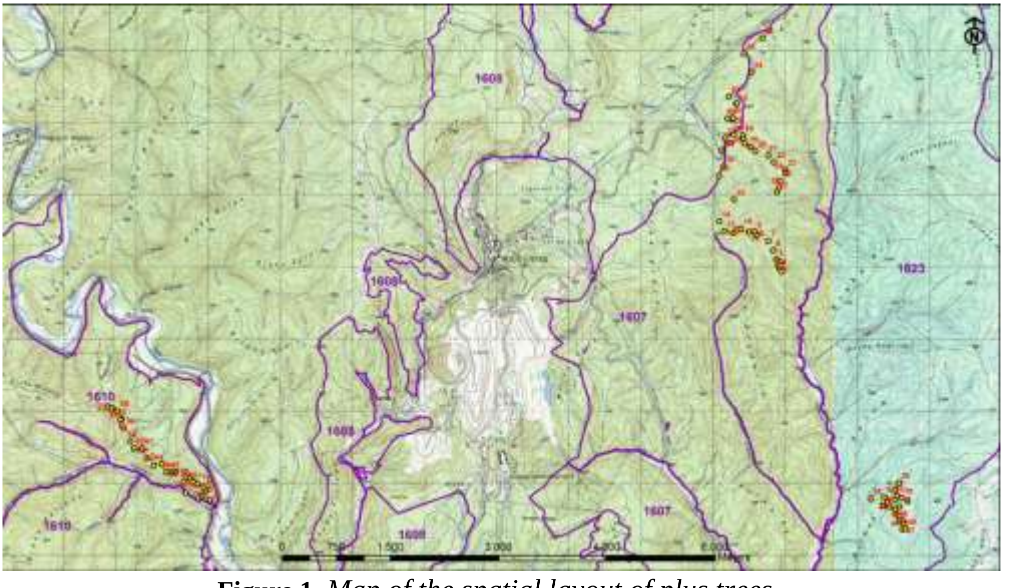


Figure 1. *Map of the spatial layout of plus trees*

5. CONCLUSION

Results of this research show that the selected plus trees of sessile oak exhibit a high degree of morphological and genetic variability, which is of crucial importance for their future application in seed production and programs of conservation of genetic resources. Significant differences in morphological parameters of leaves and acorns indicate the existence of trees with desirable combinations of characteristics that can be used as sources of reproductive material in establishing seed orchard.

Selection material includes trees of different geographical origins and altitude range, which additionally provides a wide adaptive basis for future plantations. The data on morphometric characteristics of acorns show that selected plus trees produce larger acorns, which indicates greater potential for germination and development of more vital seedlings.

This research represents an important step toward establishing a genetically valuable and productive source of sessile oak reproductive material, which will contribute to more efficient restoration and conservation of this economically and ecologically significant species.

Acknowledgements: *This study was carried out under the Agreement on the Realization and Funding of Scientific Research Activity of Scientific Research Organizations in 2025, funded by the Ministry of Education, Science, and Technological Development of the Republic of Serbia, No. 451-03-136/2025-03/200027 from February 04, 2025 the project "Establishing a Generative Seed Orchard of Sessile Oak [Quercus petraea (Matt.) Lieblein] – Stage I" funded by PE "Srbijašume" Belgrade, FMU "Severni Kučaj" Kučevo.*

REFERENCES

Arab, L., Seegmueller, S., Dannenmann, M., Eiblmeier, M., Albasher, G., Alfarraj, S., Rennenberg, H. (2020): Foliar traits of sessile oak (*Quercus petraea* Liebl) seedlings are largely determined by site properties rather than seed origin. Tree physiology. https://doi.org/10.1093/treephys/tpaa094.

Arab, L., Seegmueller, S., Kreuzwieser, J., Eiblmeier, M., Dannenmann, M., Rennenberg, H. (2021): Significance of current weather conditions for foliar traits of old-growth sessile oak (*Quercus petraea* Liebl) trees. Trees, 36, 777-791. https://doi.org/10.1007/s00468-021-02249-x.

Alfaro, R., Fady, B., Vendramin, G., Dawson, I., Fleming, R., Sáenz-Romero, C., Lindig-Cisneros, R., Murdock, T., Vinceti, B., Navarro, C., Skrøppa, T., Baldinelli, G., El-Kassaby, Y., Loo, J. (2014): The role of forest genetic resources in responding to biotic and abiotic factors in the context of anthropogenic climate change. Forest Ecology and Management, 333, 76-87. https://doi.org/10.1016/J.FORECO.2014.04.006.

Bechtold, W.A. (2003): Crown-diameter prediction models for 87 species of stand-grown trees in the eastern United States. South J Appl For 27: 269-278.

Bylesjö, M., Segura, V., Soolanayakanahally, R.Y. et al. (2008): LAMINA: a tool for rapid quantification of leaf size and shape parameters. BMC Plant Biol 8, 82 https://doi.org/10.1186/1471-2229-8-82

Cortés, A., Restrepo-Montoya, M., Bedoya-Canas, L. (2020): Modern Strategies to Assess and Breed Forest Tree Adaptation to Changing Climate. Frontiers in Plant Science, 11. https://doi.org/10.3389/fpls.2020.583323.

Cuchietti, A., Morales-Hidalgo, D., García, J. (2023): Annex 3: Complementary document to the results of the Serbian Second National Forest Inventory - Recalculation of the NFI2 report using the Two-phase Sampling design. Belgrade: Food and Agriculture Organization of the United Nations, Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia and Global Environment Facility.

Devetaković, J., Nonić, M., Prokić, B., Šijačić-Nikolić, M., Popović, V. (2019): Acorn Size Influence on the Quality of Pedunculate Oak (*Quercus robur* L.) One-Year Old Seedlings. REFORESTA, 8: 17–24.

Dobrosavljević, J., Marković, C., Milanović, S., Vujičić, P., Srbulović, B., Bojić, S. (2018): Influence of *Curculio glandium* (Marsham, 1802) (*Coleoptera, Curculionidae*) on Turkey oak (*Quercus cerris* L., 1753) (*Fagales, Fagaceae*) acorn germination. Proceedings of the IX International Agricultural Symposium “Agrosym 2018” pp. 1014-1018.

Dobrosavljević, J., Devetaković, J., Kanjevac, B. (2022): The bigger the tree the better the seed - effect of Sessile oak tree diameter on acorn size, insect predation, and germination. Reforesta 14: 36-45. https://dx.doi.org/10.21750/REFOR.14.04.99

EUFORGEN (2023): Seed harvesting, processing, storage, and nursery practices: How management practices can affect or influence genetic diversity of forest reproductive materials. Focus on Forest Genetic Diversity, Theme 5. European Forest Institute.

Giertych, M.J., Chmielarz, P. (2019): Size variability in embryonic axes, cotyledons, acorns and seedlings in fifteen species of the genus *Quercus*. Trees, 34:593-601. https://doi.org/10.1007/s00468-019-01941-3

Gomez, J.M. (2004): Bigger is not always better: conflicting selective pressures on seed size in *Quercus ilex*. Evolution 58:71–80

Gonzalez-Rodriguez, V., Villar, R., Navarro-Cerrillo, R.M. (2011): Maternal influences on seed mass effect and initial seedling growth in four *Quercus* species. Acta Oecol 37:1–9

Girard, Q., Ducousso, A., de Gramont, C.B., Louvet, J.M., Reynet, P., Musch, B., Kremer, A. (2022): Provenance variation and seed sourcing for sessile oak (*Quercus petraea* (Matt.) Liebl.) in France. Annals of Forest Science. 79, 27. https://doi.org/10.1186/s13595-022-01140-0.

Grossnickle, S.C., MacDonald, J.E. (2018): Seedling Quality: History, Application, and Plant Attributes. Forests, 9(5), 283. https://doi.org/10.3390/f9050283

Hisano, M., Ghazoul, J., Chen, X., Chen, H. (2024): Functional diversity enhances dryland forest productivity under long-term climate change. Science Advances, 10. https://doi.org/10.1126/sciadv.adn4152.

Ivanković, M., Popović, M., Bogdan, S. (2011): Acorn Morphometric Traits and Seedling Heights Variation of Pedunculate Oak (*Quercus robur* L.) from the Seed Stands in Croatia. Šumarski list 135(13): 46- 57.

Kissling, P. (1980): Clef de détermination des chênes médioeuropéens (*Quercus* L.). Ber. Schweiz. Bot. Ges. 90 29–44.

Kohler, M., Pyttel, P., Kuehne, C., Modrow, T., Bauhus, J. (2020): On the knowns and unknowns of natural regeneration of silviculturally managed sessile oak (*Quercus petraea* (Matt.) Liebl.) forests—a literature review. Annals of Forest Science 77, 101. https://doi.org/10.1007/s13595-020-00998-2

Lindner, M., Fitzgerald, J.B., Zimmermann, N.E., et al. (2014): Climate change and European forests: What do we know, what are the uncertainties, and what are the implications for forest management? J. Environ. Manag. 146, 69–83. https://doi.org/10.1016/j.jenvman.2014.07.030

Marron, N., Ceulemans, R. (2006): Genetic variation of leaf traits related to productivity in a *Populus deltoides* × *Populus nigra* family. Can. J. For. Res. 200636:390–400. https://doi.org/10.1139/x05-245

Major, S. (2002): Variability of *Quercus robur* L. and *Quercus petraea* (Matt.) Liebl. acorn size in the region of the Pomeranian plains. Dendrobiology, 47: 25-31.

Pakull, B., Eusemann, P., Wojacki, J., Ahnert, D., Liesebach, H. (2021): Genetic diversity of seeds from four German Douglas fir (*Pseudotsuga menziesii*) seed orchards. European Journal of Forest Research, 140, 1543 - 1557. https://doi.org/10.1007/s10342-021-01419-3.

Perea, R., San Miguel, A., Martínez-Jauregui, M., Valbuena-Carabaña, M., Gil, L. (2012): Effects of seed quality and seed location on the removal of acorns and beechnuts. Eur J For Res 131:623–631

Popović, V., Lučić, A., Rakonjac, Lj., Kerkez-Janković, I. (2019): Analysis of morphological quality parameters of one-year old bare root sessile oak (*Quercus petraea* (Matt.) Liebl) seedlings. Sustainable forestry, 79-80, pp.23-31.

Roth, V., Dubravac, T., Pilaš, I., Dekanić, S., Brekalo, Z. (2009): Krupnoća žira hrasta lužnjaka (*Quercus robur* L.) i kitnjaka (*Quercus petraea* Liebl.), kao čimbenik rasta i razvoja sadnica. Šumarski list (5–6): 257–266.

Ruņģis, D., Luguza, S., Bāders, E., Šķipars, V., Jansons, Ā. (2019): Comparison of Genetic Diversity in Naturally Regenerated Norway Spruce Stands and Seed Orchard Progeny Trials. Forests. https://doi.org/10.3390/f10100926.

Sánchez-Montes de Oca, E.J., Badano, E.I., Silva-Alvarado, L.E., Flores, J., Barragán-Torres, F., Flores-Cano, J.A. (2018): Acorn weight as determinant of germination in red and white oaks: evidences from a common-garden greenhouse experiment. Ann For Sci 75:12

Sang, Y., Long, Z., Dan, X., Feng, J., Shi, T., Jia, C., Zhang, X., Lai, Q., Yang, G., Zhang, H., Xu, X., Liu, H., Jiang, Y., Ingvarsson, P., Liu, J., Mao, K., Wang, J. (2022): Genomic insights into local adaptation and future climate-induced vulnerability of a keystone forest tree in East Asia. Nature Communications, 13. https://doi.org/10.1038/s41467-022-34206-8.

Sakschewski, B., Bloh, W., Boit, A., Poorter, L., Peña-Claros, M., Heinke, J., Joshi, J., Thonicke, K. (2016): Resilience of Amazon forests emerges from plant trait diversity. Nature Climate Change, 6, 1032-1036. https://doi.org/10.1038/NCLIMATE3109.

Schelhaas, M.J., Nabuurs, G.J., Hengeveld, G., et al. (2015): Alternative forest management strategies to account for climate change-induced productivity and species suitability changes in Europe. Reg. Environ. Change, 15, 1581–1594.
https://doi.org/10.1007/s10113-015-0788-z

Thomas, F., Preusser, S., Backes, B., Werner, W. (2024): Leaf traits of Central-European beech (*Fagus sylvatica*) and oaks (*Quercus petraea/robur*): Effects of severe drought and long-term dynamics. Forest Ecology and Management.
https://doi.org/10.1016/j.foreco.2024.121823.

Wrobel, A., Zwolak, R. (2017): Deciphering the effects of disperser assemblages and seed mass on patterns of seed dispersal in a rodent community. Integr Zool 12:457–467.

SELECTION OF SESSILE OAK (*Quercus petraea* (Matt.) Liebl.) PLUS TREES FOR SEED ORCHARD ESTABLISHMENT

Vladan POPOVIĆ, Sanja LAZIĆ, Aleksandar LUČIĆ, Ljubinko RAKONJAC, Radojica PIŽURICA, Boris IVANOVIĆ, Aleksandra PETROVIĆ

Summary

The research represents a part of the program of selection and conservation of genetic resources of sessile oak (*Quercus petraea* (Matt.) Liebl.) in Serbia, with the aim of identifying and selecting plus trees as a basis for establishing a seed orchard. This paper analysed the total of 86 trees of phenotypically highest quality, selected based on the criteria of morphological regularity, physiological vitality, proportionality of the crown, fullness of the bole, and satisfactory seed production.

Samples of leaves and acorns were collected from each tree and detailed morphometric measurements were carried out on them. The leaves were analysed using LAMINA software, while the dimensions and mass of the acorns were measured by precise laboratory instruments. The results showed a high degree of variability in the morphological characteristics of both leaves and acorns. Analysis of variance (ANOVA) confirmed statistically significant differences among trees for all observed characteristics ($p < 0.01$), which indicates pronounced intraspecific genetic and morphological variability.

By combining the results of morphometric analyses of acorns and leaves, it can be concluded that the selected trees represent a genetically valuable basis for the seed orchard establishment. High variability ensures sufficient genetic distance between individuals and reduces the risk of inbreeding, which is crucial for preserving the vitality of future generations. At the same time, the selected trees come from different habitats and altitudes (285-647 m), which expands ecological amplitude and increases the adaptive potential of future reproductive material.

The obtained results have a practical significance in planning and organization of production of high-quality forest reproductive material, as well as in defining the program of conservation of autochthonous genetic resources of sessile oak. Establishing a seed orchard based on plus trees selected in this way represents a key step in the long-term strategy of conservation, adaptation and improvement of populations of this economically and ecologically significant tree species in Serbia.

SELEKCIJA PLUS STABALA HRASTA KITNJAKA (*Quercus petraea* (Matt.) Liebl.) ZA POTREBE OSNIVANJA SEMENSKE PLANTAŽE

Vladan POPOVIĆ, Sanja LAZIĆ, Aleksandar LUČIĆ, Ljubinko RAKONJAC, Radojica PIŽURICA, Boris IVANOVIĆ, Aleksandra PETROVIĆ

Rezime

Istraživanje predstavlja deo programa selekcije i očuvanja genetičkih resursa hrasta kitnjaka (*Quercus petraea* (Matt.) Liebl.) u Srbiji, sa ciljem identifikacije i odabira plus stabala kao osnove za osnivanje semenske plantaže. U radu su analizirana ukupno 86 fenotipski najkvalitetnija stabala, izdvojena na osnovu kriterijuma morfološke pravilnosti, fiziološke vitalnosti, proporcionalnosti krošnje, punodrvnosti i zadovoljavajuće semenske produkcije.

Sa svakog stabla sakupljeni su uzorci listova i žireva, na kojima su sprovedena detaljna morfometrijska merenja. Listovi su analizirani korišćenjem LAMINA softvera, dok su dimenzije i masa žireva merene preciznim laboratorijskim instrumentima. Rezultati su pokazali visok stepen varijabilnosti morfoloških svojstava i listova i semena. Analiza varijanse (ANOVA) potvrdila je statistički značajne razlike među stablima za sva posmatrana svojstva ($p < 0,01$), što ukazuje na izraženu intraspecifičnu genetičku i morfološku varijabilnost.

Kombinacijom rezultata morfometrijskih analiza žira i lista može se zaključiti da odabrana stabla predstavljaju genetički vrednu osnovu za formiranje semenske plantaže. Velika varijabilnost obezbeđuje dovoljnu genetičku distancu između jedinki i smanjuje rizik od srodničkog ukrštanja, što je ključno za očuvanje vitalnosti budućih generacija. Istovremeno, izdvojena stabla potiču sa različitih staništa i nadmorskih visina (285-647 m), što proširuje ekološku amplitudu i povećava adaptivni potencijal budućeg reproduktivnog materijala.

Dobijeni rezultati imaju praktičan značaj u planiranju i organizaciji proizvodnje šumskog reproduktivnog materijala visokog kvaliteta, kao i u definisanju programa konzervacije autohtonih genetičkih resursa hrasta kitnjaka. Uspostavljanje semenske plantaže na osnovu ovako selekcionisanih plus stabala predstavlja ključni korak u dugoročnoj strategiji očuvanja, adaptacije i unapređenja populacija ove ekonomski i ekološki značajne vrste drveća u Srbiji.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 92, 2025 ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592029M
UDK: 630*232.425:630*164.5=111
Original scientific paper

EFFECT OF FERTILIZATION ON LEAF MORPHOMETRIC CHARACTERISTICS OF *Paulownia elongata* S. Y. Hu AND *Paulownia fortunei* Seem. Hemsl. IN THE SECOND YEAR OF GROWTH

Suzana MITROVIĆ[1], Milorad VESELINOVIĆ[1], Snežana STAJIĆ[1], Zoran PODUŠKA[1], Vanja STOJANOVIĆ[1], Natalija MOMIROVIĆ[1], Marija MILOSAVLJEVIĆ[2]*

Abstract: *This paper presents the results of an analysis of the effect of fertilization in the second year after planting on the morphological characteristics of Paulownia leaves. The results are continuation of the research and possibility of introduction and adaptation of paulownia to different habitats in Serbia. Obtaining of the results regarding quality of the plant leaves in the second year in relation to different fertilization treatments is significant for the technology of cultivation of this species on determined soil types. The research is carried out on two sites. Experimental fields on sites in Obrenovac and Pambukovica have been established with species Paulownia elongata S. Y. Hu. and Paulownia fortunei Seem. Hemsl.. Collecting of leaf material for the analysis in laboratory conditions was carried out within the experimental fields. Measuring of the following morphometric characteristics of leaves were carried out: leaf area, leaf circumference, leaf blade length, central veine length, leaf width on the widest part of leaf blade, leaf width at 1 cm from the leaf base, petiole length, distance between 3rd and 4th nerve, number of nerves on the left side of the central veine, and number of nerves on the right side of the central veine. The obtained results of morphometric measurings of leaves are statistically processed in the program Statgraphics. Morphometric analysis of leaves shows structural-functional connections, i.e. more detailed indicators of the adaptability of the species. Based on these measuring results it was determined that fertilization in the second year of plant development after planting has a positive effect on the size of leaves of analysed species of paulownia.*

Keywords: fast-growing species, adaptability of species, plant growth and development, introduction of woody species, soil type.

UTICAJ ĐUBRENJA NA MORFOMETRIJSKE KARAKTERISTIKE LISTOVA VRSTA *Paulownia elongata* S. Y. Hu. I *Paulownia fortunei* Seem. Hemsl. U DRUGOJ GODINI RASTA

Sažetak: *U radu su prikazani rezultati analize uticaja prihranjivanja biljaka u drugoj godini nakon sadnje, na morfološke karakteristike listova. Ovde su prikazani rezultati*

[1] Institute of forestry, Kneza Višeslava 3, 11000 Belgrade, Serbia
[2] Institute of Entomology, Branisovska 31, 37005 Ceske Budejovice, Czech Republic
*Corresponding author. E-mail: suzana.mitrovic@forest.org.rs

koji su nastavak istraživanja u okviru istraživanja mogućnosti introdukcije i adaptacije paulovnija na različita staništa u Srbiji. Dobijeni rezultati o kvalitetu listova biljaka u drugoj godini razvoja biljaka nakon sadnje u odnosu na na različite tretmane prihranjivanja su značajni za tehnologiju gajenja ove vrste na određenim tipovima zemljišta. Istraživanja su sprovedena na dva lokaliteta. Ogledna polja na lokalitetima u Obrenovcu i Pambukovici su osnovana sa vrstama Paulownia elongata S. Y. Hu. i Paulownia fortunei Seem. Hemsl.. U okviru oglednih polja vršeno je prikupljanje lisnog materijala za analizu u laboratorijskim uslovima. Izvršena su merenja morfometrijskih karakteristika listova: površina lista, obim lista, dužina lisne ploče, dužina centralnog nerva, širina lista na najširem delu lisne ploče, širina lista na 1 cm od osnove lista, dužina peteljke, razmak između 3. i 4. nerva, broj nerava na levoj strani od centralnog nerva, i broj nerava na desnoj strani od centralnog nerva. Dobijeni rezultati morfometrijskih merenja listova statistički su obrađeni u programu Statgraphics. Morfometrijska analiza listova pokazuje strukturno – funkcionalne veze, odnosno detaljnije pokazatelje adaptibilnost vrste. Na osnovu ovih rezultata merenja utvrđeno je da prihranjivanje u drugoj godini razvoja biljaka nakon sadnje ima pozitivan uticaj na veličinu listova analiziranih vrsta paulovnije.

Ključne reči: brzorstuće vrste, adaptabilnost vrsta, rast i razvoj biljaka, introdukcija drvenastih vrsta, tip zemljišta.

1. INTRODUCTION

Anthropogenic influences and the speed of change in the environmental conditions of habitat influence that not all autochthonous plant species can adapt to the new conditions (Aragao et al., 2008; Betts et al., 2008; Innes et al., 2009; Lavadinović et al., 2010). That leads to changes in their growth and development, their vitality, and in some cases to the loss of species in certain area. The efforts to preserve autochthonous species are object of many studies, but most often their survival in certain area does not guarantee that they still have the same characteristics and provide the same ecosystem services. That is why the selection of adequate species for some area represents the greatest challenge, since it is necessary to preserve the areas covered with forests, and also to carry out reforestation where they are lost. In this sense, many studies are carried out which deal with examining the possibility of introduction of different species and their adaptation to new environmental and climate changes. The confirmation of choice of certain species through different research processes is essential for success in trying to find the right solutions for reduction of negative effects caused by anthropogenic and climate changes.

Plantation forestry and energy plantations of fast-growing woody species are the response of today's society to the growing need for wood as a raw material and wood biomass as an energy source. This study aims to harness the potential of fast-growing species as a means of mitigating excessive forest exploitation through the introduction of new species for plantation establishment in non-forested or long-deforested areas. Also, the recultivation of areas degraded by various surface extractions of mineral and other raw materials may provide suitable sites for establishing such plantations, whose utilization can have both ecological and economic benefits.

Species of the genus *Paulownia* Sieb. & Zucc. represent a great potential in the area of their range for obtaining of biomass and biofuel due to their sprout power and rapid growth (Ivetić & Vilotić, 2014; Mishra et al., 2010; Lucas-Borja et al., 2011; Yadav et al., 2013). Leaves of young paulownia trees (in juvenile stage of development) have a wavy rim with pronounced lobes, they are extremely large and can reach a length of up to 90 cm. The fact that the size of the leaf is important for photosynthetic processes and production of nutrients is in direct correlation with production of entire biomass of plants. Leaf litter of this species has a pronounced meliorating role in improving quality of the soil around the tree thanks to the large leaf mass rich in nitrites. Because of these properties, the leaves are made into green manure which is used in some areas in China to improve soil-ecological properties of the soil. Dense hairs that cover both sides of leaves, as well as their size, contribute to the important role of crown in purification of air.

That is why this species was the subject of our research. The soils on which the afforestation is carried out are in most cases poor in nutrients, so it is necessary to add different fertilizers. Providing plants with the availability of necessary assimilatives should ensure formation of biologically healthy material, resistant to new environmental conditions (Jacobs et al., 2005; Mitrović et al., 2012; García-Morote et al. 2014). First of all, the choice of type, quantity and time of use of fertilizers depends on pedological condition, but also on biological properties (Óskarsson and Brynleyfsdóttir, 2009; Tucović and Simić, 2002; Güsewell et al., 2003; Hawkins et al., 2005). The aim of this paper was to determine how different fertilization treatments affect ten key leaf morphometric characteristics in the second year of development of the studied *Paulownia* species, using a modified protocol based on the Assessment of oak leaf morphology (Kremera et al., 2022).

2. MATERIAL AND METHODS

Experimental fields on the site in the village Veliko Polje near Obrenovac (site I) and in village Pambukovica near Ub (site II) – which have different orographic traits, climate conditions and physical-chemical characteristics of soil, were established by planting seedlings of two species of paulownia: *Paulownia elongata* and *Paulownia fortunei*.

The experimental field on site 1 is located in the village Veliko Polje, municipality Obrenovac on the left bank of the Kolubara River at an altitude of 74 m. The plot on which the experimental field is located is flat and has no slope. The rows of plants are oriented in the northwest-southeast direction. The experimental field on site II is located in the village Pambukovica near Ub and it belongs to Kolubara District in Tamnava microregion. The experimental area is located on the hill Jastrebovac, municipality Ub. The plot on which the experiment is located is undulating, whereby the lowest point is at 162.60 m, and the highest at 176.11 m above sea level. The relief of this area is flat and hilly with small differences in altitude. The plot has south-eastern exposure for the most part and north-western exposure on one smaller part. It is surrounded by beech and oak forests. The rows with plants are oriented in the direction north-south.

The seedlings were produced from the seeds which had been collected from well adapted genotypes of two species of paulownia, from the experimental field in

Bela Crkva. The seedlings were produced in containers and used as a starting material in establishing experimental plantations.

The seedlings were planted in rows, at the distance of 4x4 m. In each row, 25 plants were planted, out of which in 12 rows seedlings of the species *Paulownia elongata* and in 12 rows of the species *Paulownia fortunei*. The seedlings were planted manually in dug pits 30x30 cm in 12 rows each.

Due to heavy mechanical composition and acidic reaction of the soil, chicken manure – Fertor (http://www.mrf-garden.com) produced from 100% chicken manure which decomposes well in contact with water was used on the site in Obrenovac (I) and in Pambukovica (II). Other organic matters of plant origin were added to it, in order to increase the nutritional value of the fertilizer. This is a type of slow-release fertilizer where one part of the macroelements and microelements is easily accessible and immediately available to plants, while the other part is gradually released.

During planting, each of the sample plots was divided in six treatments (for each of the treatments 4 rows of 25 plants), which differ by the quantity of added fertilizer (Fertor) and control without fertilization. Fertilizer was added to plants in quantities of 240 gr per plant (T1) and 120 gr per plant (T2). On control areas (T3) fertilization of plants was not carried out.

Collection of the leaf material in the field was carried out using the sample method at the end of the second growing season, whereby the leaves were collected from the same part of the crown, i.e. from the same nodes. The collected leaf material was herbarized and scanned (Figures 1 and 2). Measurements were conducted using AutoCAD (Autodesk, version 2020). Morphometric characteristics were measured with the precision of 1 mm. On the site in Obrenovac (I) and in Pambukovica (II) the size of the sample was 150 plants per site. From each of the plants whose morphometric characteristics were measured 5 leaves were taken for morphometric analysis, which amounts to 750 leaves per site, i.e. 1500 leaves in total for both sites according to the previously determined terminology (Mitrovic et al., 2022).

Ten basic characteristics of the leaves were measured: total area of the leaf without petiole in cm^2 (AREA); total circumference of the leaf without petiole in cm (PERI); leaf blade length, from the base of the leaf to the tip of the leaf in cm (LL); the length of a central veine (CN); maximum width of the leaf in cm (MWL); leaf width at 1 cm from the leaf base in cm (LW); petiole length, from the leaf base to the petiole tip in cm (PL); the distance between 3^{rd} and 4^{th} nerve in cm (HL); number of nerves on the left side of the leaf (NLL); and number of nerves on the right side of the leaf (NLR) (Mitrovic et al., 2022) (Figure 3).

The data of morphometric measurements of the leaves were statistically processed in the program STATGRAPHICS (Statistical Graphics Corporation, USA). The design of the experiment factor A (site) with two levels: site I (Obrenovac) and site II (Pambukovica), factor B (species) with two levels: species 1 (*P. elongata*) and species 2 (*P. fortunei*) and factor C (treatment) with three levels: treatment 1, treatment 2 and treatment 3 corresponds to three-factor and two-factor analysis of variance: ANOVA III.

3. RESULTS

The soil that represents the profile on the site in Obrenovac (I) is well permeable to both water and air and has sufficiently high capacity to retain accessible water. According to its textural composition it belongs to sandy loams. The surface layer of soil on this site belongs to class of sandy loams, and deeper analysed layer belongs to the loam class. Although they belong to different texture classes, physical properties of both analysed layers are similar, i.e. there is no strong differentiation of profiles by textural composition. The content of individual textural fractions in both layers are close to the limit values between sandy loam and loam. This soil is well permeable to water and well aerated throughout the depth of the solum.

Table 1. *Physical properties of soil*

Site	Depth of profile (cm)	Coarse sand	Fine sand	Powder	Clay	Total Sand	Total Clay	Textural class
		%						
I	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
II	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

The surface layer of the soil on the site in Pambukovica (II) belongs to class of loam and it is well permeable to water and air. With the depth of soil solum the content of clay and fine sand increases in textural composition and textural class changes to sandy clay loam, which is somewhat less permeable to water and air (Table 1).

Table 2. *Chemical properties of the soil*

Site	Depth of profile (cm)	pH H_2O	pH KCl	Adsorption complex T	S	T-S	V	Y1	Total humus	Total N	C/N	Accessible P_2O_5	Accessible K_2O
				equ.m.mol/100g			%	cm^3	%	%		mg/100g	
1	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
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

On the site I in Obrenovac the reaction of the soil solution is moderate. The total capacity of adsorption is quite high, due to the high proportion of clay in textural composition. According to the content of total humus both analysed layers belong to soils with low content of humus. A narrow C/N ratio is favourable for mineralization of the organic matter. The provision of easily accessible forms of phosphorus is good throughout the depth of the solum, and the provision of easily accessible forms of potassium is medium. The reaction of soil solution on site II is very acidic throughout the depth of the solum. Total adsorption capacity is high. According to the content of total humus surface layer belongs to the soils of low humus content, while deeper analysed layer is on the limit between soils with low and very low content of humus. The content of total nitrogen is low and the ratio of carbon to nitrogen is narrow. In both analysed layers the amount of phosphorus accessible to plants is below the limit of detection for Al–method, which means that this soil is extremely poorly provided by forms of phosphorus easily accessible to plants. The amounts of forms of potassium easily accessible to plants are within the limits of poor provision throughout the depth of the profile (Table 2).

Figure 1. *Leaves of paulownia seedlings from the experimental field in Obrenovac at the end of second growing season*

Figure 2. *Leaves of paulownia seedlings from the experimental field in Pambukovica at the end of second growing season*

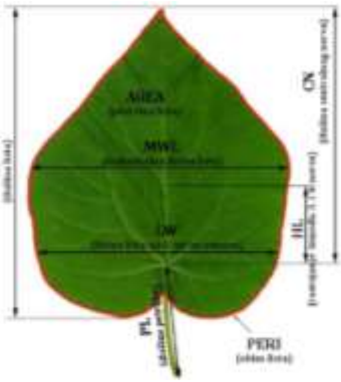


Figure 3. *Schematic representation of analysed measurement parameters of paulownia leaves (Mitrovic et al., 2022)*

The results of the statistical analysis of ten selected parameters of leaf are presented in tables 3 and 4. For the characteristic leaf area in the second growing season (Table 3), as well as in the first, there is a difference in mean values of the groups (measurements) depending on the factors site, species and treatment. The seedlings on the site in Obrenovac (I) have significantly higher mean leaf area values (75.36 cm^2) then mean values of seedlings from the site in Pambukovica (II) (43.98 cm^2). There is statistically significant difference between species. The seedlings of the species *Paulownia elongata* have higher mean values of leaf area (64.69 cm^2) than seedlings of the species *Paulownia fortunei* (54.66 cm^2). Statistically significant difference exists among all three treatments, whereby the seedlings from the treatment which was fertilized with larger quantity of fertilizer have higher mean values of the characteristic leaf area (80,61 cm^2). They are followed by the seedlings from the treatment fertilized by smaller quantity of fertilizer (54.05 cm^2), and the seedlings from the control treatment had the lowest mean values (44.36 cm^2). All interactions are statistically significant.

For the characteristic leaf circumference in the second growing season (Table 3), there is a difference in mean values of the groups depending on the factors site, species and treatment. The seedlings from the site in Obrenovac (I) show significantly higher values of leaf circumference (33.54 cm) compared to the mean values of seedlings at the site in Pambukovica (II) (25.99 cm). There is statistically significant difference in mean values of circumference between species, whereby the seedlings of the species *Paulownia elongata* show significantly higher mean values (31.33 cm) then the seedlings of the species *Paulownia fortunei* (28.19 cm). The difference in mean values of circumference among seedlings within different treatments is statistically significant. The seedlings from the treatment which was fertilized with the larger quantity of fertilizer showed the highest mean values (34.20 cm), and the lowest were in the control treatment (25.90 cm). For the characteristic leaf circumference in the second growing season, all interactions are significant.

For the characteristic leaf blade length in the second growing season (Table 3) there is a difference in the mean values of the groups depending on the factors site, species and treatment. The mean values of the leaf blade length of the seedlings on the site in Obrenovac (I) differ significantly compared to the seedlings on the site in Pambukovica (II), whereby the seedlings on the site (I) have higher mean values of the leaf length (33.54 cm) then the seedlings on the site (II) (25.99 cm). The seedlings of the species *Paulownia elongata* have significantly higher mean values of the leaf length (31.33 cm) compared to the seedlings of the species *Paulownia fortunei* (28.19 cm). The difference between mean values of the leaf blade length of seedlings within different treatments is also significant, whereby the seedlings from the treatment which was fertilized with larger amount of fertilizer have the highest mean value of the length (10.39 cm), and the lowest was from the control treatment (7.91 cm). The interaction between species and treatments is not statistically significant. For the characteristic leaf blade length in second growing season, the interactions between factor site and factor species (AxB) and between factor site and factor treatment (AxC) were statistically significant.

For the characteristic the central veine length in the second growing season (Table 3) there is a difference in mean values of the groups depending on the factors site, species and treatment. The seedlings on the site in Obrenovac (I) have significantly higher mean values of the central veine length (8.23 cm), compared to the seedlings on the site in Pambukovica (II) (6.67 cm). The seedlings of the species *Paulownia elongata* have statistically significantly higher mean value (7.82 cm) compared to the seedlings of the species *Paulownia fortunei* (7.08 cm). The seedlings within the treatment fertilized by larger quantity of fertilizer have significantly higher (8.57 cm) mean values than the seedlings from the treatment fertilized by smaller amount of fertilizer (7.28 cm) and from the control treatment (6.50 cm). For the characteristic the central veine length in the second growing season, the interactions between factors site and species (AxB) and factors site and treatment (AxC) were statistically significant.

For the characteristic leaf width in the second growing season (Table 3) there is a difference in mean values of groups depending on the factors site, species and treatment. There is a significant difference in mean values of leaf width of the seedlings on the site in Obrenovac (I) and in Pambukovica (II), whereby it is larger in seedlings on the site (I) (9.42 cm) then in seedlings on the site (II) (7.07 cm). The seedlings of the species *Paulownia elongata* have significantly higher mean values of the characteristic (8.76 cm) than seedlings of the species *Paulownia fortunei* (7.74 cm). Mean values of leaf width are significantly different in seedlings within treatments, whereby the seedlings from the treatment which is fertilized with larger amount of fertilizer have the highest (9.70 cm) mean value of the characteristic leaf width, and seedlings from the control treatment have the lowest mean value (6.94 cm). All interactions are statistically significant.

Table 3. *Basic parameters of descriptive statistics and three-way ANOVA for the leaf characteristics: leaf width at 1 cm from the base (cm), petiole length (cm), the distance between the 3rd and the 4th nerve, the number of nerves on the left side and number of nerves on the right side; for seedlings on sites in Obrenovac (I) and in Pambukovica (II), at the end of the second growing season*

Factor	Level	Leaf width at 1 cm from the leaf base	Petiole length	Distance between the 3rd and the 4th nerve	Number of nerves - left	Number of nerves - right
Site (A)	Site I	8.76(3.64)[b]	6.37(2.53)[b]	2.09(1.03)[b]	7.82(1.00)[a]	7.86(0.98)[a]
	Site II	6.71(2.81)[a]	4.87(2.17)[a]	1.76(1.29)[a]	8.029)[b]	7.99 (0.83)[b]
		$F_{1.1490}$=205.16*	$F_{1.1490}$=170.25*	$F_{1.1490}$=34.95*	$F_{1.1490}$=21.23*	$F_{1.1490}$=10.88*
Species (B)	*P. elongata*	8.22(3.39)[b]	5.82(2.44)[b]	2.06(1.41)[b]	7.67(0.95)[a]	7.68(0.95)[a]
	P. elongata	7.26(3.36)[a]	5.42(2.50)[a]	1.79(0.86)[a]	8.18(0.88)[b]	8.16(0.80)[b]
		$F_{1.1490}$=44.46*	$F_{1.1490}$=2.32*	$F_{1.1490}$=22.90*	$F_{1.1490}$=152.03*	$F_{1.1490}$=152.34*
Treatment (C)	Treatment 1	9.26(3.82)[c]	6.06(2.55)[b]	2.30(1.02)[c]	7.56(0.93)[a]	7.53 (0.92)[a]
	Treatment 2	7.45(2,47)[b]	5.97(2.11)[b]	1.97(1.23)[b]	8.2(0.86)[b]	8.14(0.78)[b]
	Treatment 3	6.50(3.20)[a]	4.82(2.55)[a]	1.51(1.13)[a]	8.09(0.95)[b]	8.09(0.90)[b]
		$F_{2.1490}$=129.50*	$F_{2.1490}$=48.11*	$F_{2.1490}$=67.90*	$F_{2.1490}$=78.01*	$F_{2.1490}$=98.32*
***Interactions* (AXB)**		$F_{1.1490}$=15.12*	$F_{1.1490}$=8.93*	ns	c	ns
***Interactions* (AXC)**		$F_{2.1490}$=103.25*	$F_{2.1490}$=23.30*	$F_{2.1490}$=55.65*	$F_{2.1490}$=108.73*	$F_{2.1490}$=111.85*
***Interactions* (BXC)**		$F_{2.1490}$=29.97*	$F_{2.1490}$=14.79*	$F_{2.1490}$=5.76*	$F_{2.1490}$=51.41*	$F_{2.1490}$=43.46*

A three-factor 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 (larger amount of fertilizer), treatment 2 (smaller amount of fertilizer), and treatment 3 (control), and their interactions. The size of the pooled sample (number of elements of the pooled sample), n=1500 (2 sites x 2 species x 3 treatments x 125 = 1500). A = mean value (standard deviation); B= F-test indicator with the number of degrees of freedom; ns = non-significant difference between mean values of populations (P□ 0.05); * = statistically significant difference (P□ 0.05).

For the characteristic leaf width at 1 cm from the base in the second growing season (Table 4) there is a difference in mean values of groups depending on the factors site, species and treatment. The seedlings on the site in Obrenovac (I) have statistically significantly higher mean values of the leaf width (8.76 cm) compared to the seedlings on the site in Pambukovica (II) (6.71 cm). The seedlings of the species *Paulownia elongata* have significantly higher (8.22 cm) mean values of leaf width than the seedlings of the species *Paulownia fortunei* (7.26 cm). Among the treatments there is a significant difference whereby the seedlings within the treatment fertilized with larger amount of fertilizer have statistically significantly higher (9.26 cm) mean values of the characteristic compared to the seedlings from the treatment that was fertilized with less fertilizer (7.45 cm) and control treatment (6.50 cm). All interactions of factors are statistically significant.

For the characteristic petiole length in second growing season (Table 4) there is a difference in mean values of the groups depending on the factors site, species and treatment. The seedlings on the site in Obrenovac (I) have significantly higher mean values of petiole length (6.37 cm) than mean values of the characteristic in seedlings at the site in Pambukovica (II) (4.87 cm). The seedlings of the species *Paulownia elongate* have statistically significantly higher (5.82 cm) mean values of petiole length than the seedlings of the species *Paulownia fortunei* (5.42 cm). The mean value of the characteristic petiole length differs significantly in seedlings within different treatments that were fertilized (no statistically significant difference between them) compared to the seedlings from the control treatment. The seedlings from the treatment fertilized with the larger amount of fertilizer have the highest mean value of petiole length (6.06 cm), and the seedlings from the control treatment have the smallest (4.82 cm). All interactions are statistically significant.

For the characteristic the distance between the 3rd and the 4th leaf nerve in the second growing season (Table 4) there is a difference in mean values of the groups depending on the factors site, species and treatment. The seedlings on the site in Obrenovac (I) show significantly higher mean values of the distance between the 3rd and the 4th leaf nerve (2.09 cm) compared to the mean values in seedlings on the site in Pambukovica (II) (1.76 cm). The seedlings of the species *Paulownia elongata* have significantly higher mean values of the characteristic (2.06 cm) compared to the seedlings of the species *Paulownia fortunei* (1.79 cm). The difference in mean values of the distance between the 3rd and the 4th leaf nerve in seedlings within different treatments is statistically significant. The highest mean value of this characteristic is in the seedlings from the treatment which was fertilized by the larger amount of fertilizer (2.30 cm), and the smallest is in seedlings from the control treatment (1.51 cm). For the characteristic the distance between the 3rd and the 4th leaf nerve in the second growing season, the interactions of the factors site and treatment (AxC) and factors species and treatment (BxC) are statistically significant.

For the characteristic number of nerves on the left side of the leaf in the second growing season (Table 4) there is a difference in the mean values of the groups depending on the factors site, species and treatment. The seedlings on the site in Pambukovica (II) have significantly higher mean values of the number of nerves on the left side of the leaf (8.02) than the mean values of the characteristic in seedlings on the site in Obrenovac (II) (7.82). The seedlings of the species *Paulownia fortune* have statistically significantly higher (8.18) mean values of the number of nerves on the left side of the leaf than the seedlings of the species *Paulownia elongata* (7.67). In seedlings within different treatments there is no statistically significant difference in the mean value of number of nerves. The highest mean values of the number of nerves on the left side of the leaf appears in seedlings from the treatment which is fertilized by smaller amount of fertilizer (8.12), then from the control treatment (8.09) and the lowest mean values from the treatment fertilized by larger quantity of fertilizer (7.56). For the characteristic number of nerves on the left side of the leaf in the second growing season, the interactions of factors site and treatment (AxC) and factors species and treatment (BxC) are statistically significant. Interaction of factors site and species has no statistical significance.

Table 4. *Basic parameters of descriptive statistics and three-way ANOVA for the leaf characteristics: leaf width at 1 cm from the base (cm), petiole length (cm), distance between the 3rd and the 4th nerve, number of nerves on the left side and number of nerves on the right side; for the seedlings on sites in Obrenovac (I) and in Pambukovica (II), at the end of the second growing season*

Factor	Level	Leaf width at 1 cm from the leaf base	Petiole length	The distance between the 3rd and the 4th nerve	Number of nerves – left	Number of nerves - right
Site (A)	Site I	8.76(3.64)[b]	6.37(2.53)[b]	2.09(1.03)[b]	7.82(1.00)[a]	7.86(0.98)[a]
	Site II	6.71(2.81)[a]	4,87(2.17)[a]	1.76(1.29)[a]	8.02(0.89)[b]	7.99(0.83)[b]
		$F_{1.1490}$=205.16*	$F_{1.1490}$=170.25*	$F_{1.1490}$=34.95*	$F_{1.1490}$=21.23*	$F_{1.1490}$=10.88*
Species (B)	*P. elongata*	8.22(3.39)[b]	5.82(2.44)[b]	2.06(1.41)[b]	7.67(0.95)[a]	7.68(0.95)[a]
	P. elongata	7.26(3.36)[a]	5.42(2.50)[a]	1.79(0.86)[a]	8.18(0.88)[b]	8.16(0.80)[b]
		$F_{1.1490}$=44.46*	$F_{1.1490}$=12.32*	$F_{1.1490}$=22.90*	$F_{1.1490}$=152.03*	$F_{1.1490}$=152.34*
Treatment (C)	Treatment 1	9.26(3.82)[c]	6.06(2.55)[b]	2.30(1.02)[c]	7.56(0.93)[a]	7.53 (0.92)[a]
	Treatment 2	7.45(2.47)[b]	5.97(2.11)[b]	1.97(1.23)[b]	8.12(0.86)[b]	8.14(0.78)[b]
	Treatment 3	6.50(3.20)[a]	4.82(2.55)[a]	1.51(1.13)[a]	8.09(0.95)[b]	8.09(0.90)[b]
		$F_{2.1490}$=129.50*	$F_{2.1490}$=48.11*	$F_{2.1490}$=67.90*	$F_{2.1490}$=78.01*	$F_{2.1490}$=98.32*
***Interactions* (AXB)**		$F_{1.1490}$=15.12*	$F_{1.1490}$=8.93*	ns	C	ns
***Interactions* (AXC)**		$F_{2.1490}$=103.25*	$F_{2.1490}$=23.30*	$F_{2.1490}$=55.65*	$F_{2.1490}$=108.73*	$F_{2.1490}$=111.85*
***Interactions* (BXC)**		$F_{2.1490}$=29.97*	$F_{2.1490}$=14.79*	$F_{2.1490}$=5.76*	$F_{2.1490}$=51.41*	$F_{2.1490}$=43.46*

A three-factor 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 (larger amount of fertilizer), treatment 2 (smaller amount of fertilizer), and treatment 3 (control), and their interactions'. The size of pooled sample (number of elements of the pooled sample), n=1500 (2 sites x 2 species x 3 treatments x 125 = 1500). A = mean value (standard deviation); B= F-test indicator with the numbers of degrees of freedom; ns = non-significant difference between mean values of populations (P□ 0.05); * = statistically significant difference (P□ 0.05).

For the characteristic number of nerves on the right side of the leaf in the second growing season (Table 4) there is a difference in mean values of groups depending on the factors site, species and treatment. The seedlings on the site in Pambukovica (II) have significantly higher mean values of the number of nerves on the right side of the leaf (7.99) than the mean values of the characteristic in seedlings on the site in Obrenovac (I) (7.86). The seedlings of the species *Paulownia fortunei* have statistically significantly higher (8.16) mean values of the number of nerves on the right side of the leaf than the seedlings of other species (7.68). The seedlings from the treatment that was fertilized by smaller amount of fertilizer have higher mean values of the characteristic (8.14) than the seedlings from the control treatment (8.09), and statistically they do not differ significantly. Significant difference exists in the mean value of the characteristic in seedlings from these two treatments compared to the seedlings from the treatment fertilized by larger amount of fertilizer, which has the lowest mean value (7.53). For the characteristic number of nerves on the right side of the leaf in the second growing season, interaction of factors site and treatment (AxC) and interaction of factors species and treatment (BxC) are statistically significant. Interaction of site and species is not statistically significant.

4. DISCUSSION

The analysis of the results in the second growing season shows that mean values of all morphometric parameters of the leaf are higher (Table 3; Table 4) compared to the first growing season (Mitrovic et al., 2022). The differences between morphometric characteristics of the leaf between the seedlings on the site in Obrenovac (I) and in Pambukovica (II), and between the seedlings within different species, as well as between the seedlings within the treatments in the second growing season followed the trends of morphometric characteristics of the leaf same as in the first year of the research.

The differences have statistical significance for all analysed parameters of the leaf. Mean values of the length (33.54 cm) and the width of the leaf (9.42 cm) and petiole (6.37 cm) of the seedlings on the site in Obrenovac (I) in the second year of the research are far below average values for these species (Graves, 1989; Šijačić-Nikolić et al., 2009). In seedlings on the site in Pambukovica (II) mean values of these parameters of the leaf are even lower and amount to 25.99 cm, 7.07 cm and 4.87 cm.

Environmental conditions on experimental fields are unfavourable for the genus *Paulownia*. The shape and the structure of the leaves of *Paulownia elongata* compared to *Paulownia fortunei* significantly depend on numerous factors (Zhu et al., 1986; Bergmann, 1998; Popović 2005; Fender et al., 2011; Stojnić, 2013). The results of morphometric characteristics of leaves of seedlings on the sites are the consequence of adaptation to the unfavourable environmental conditions in which they grew (Yong-Hua et al., 2012; Mitrovic et al., 2022; Mitrovic et al., 2024). On the site in Pambukovica (II) the content of nitrogen, phosphorus and potassium in the soil (Table 2) was lower than on the site in Obrenovac (I), which is why the conditions for plant growth were less favourable, which also affected leaf growth.

The seedlings on the site in Pambukovica (II) showed greater lack of moisture in the soil although the average value of precipitation in the growing season on this site is higher than for the site in Obrenovac (1). The reason for this is that the site is located on a slope, so the atmospheric precipitation quickly ran off the plot. Accordingly, the leaves on this site had smaller dimensions. Climatic factors significantly influence the size of the leaves, whereby as a rule the leaves are smaller in drier environmental conditions which is pointed out by numerous authors in their research (Pedrol et al., 2000; Otieno et al., 2005; Niinemets, 2001; Ozturk et al. 2014; Wright et al., 2001).

In accordance with the findings of other authors which indicate the variability of morphologic characteristics within the genus *Paulownia* (Zhu et al., 1986; Šilić, 1990; Bergmann, 1998; Cvjetićanin i Perović, 2009) the differences in morphometric characteristics of the leaf between the seedlings of analysed species are clearly confirmed. The seedlings of the species *Paulownia elongata* had higher mean values of all analysed parameters compared to the seedlings of *Paulownia fortunei* on both sites – in Obrenovac (I) and in Pambukovica (II), except for the characteristic number of nerves on left and right side of the leaf blade, where the differences were not significantly pronounced (Niinemets 2001; Wright et al., 2001).

The differences in morphometric parameters of leaves are clearly expressed through correlation with the results of fertilization of seedlings. The seedlings fertilized with a larger amount of fertilizer had the highest mean values of the majority of measured parameters, which indicates a direct relation between the availability of fertilizer and growth intensity. These findings are in accordance with the research of Adejobi et al. (2014), which showed that fertilization affects positively the increase of leaf area and dimensions. The exception is the number of nerves on the left and right side of the leaf blade, where the highest values were recorded in the treatment with the smaller amount of fertilizer and in the control variant, while the lowest values were recorded in seedlings fertilized with the larger amount of fertilizer.

5. CONCLUSION

Species *Paulownia elongata* S. Y. Hu. and *Paulownia fortunei* Seem. Hemsl., which were planted on different habitats and treated with different amounts of fertilizer, based on the analyses of the results of measurement of morphological parameters of leaves indicate that fertilization affects positively the leaf parameters and size in the second year after the planting. Also, the type of habitat affects morphological parameters of the leaf.

On the site in Obrenovac (I) the results of all measured parameters are statistically significantly higher than the values measured on the site in Pambukovica (II) which is in correlation with the physical properties of the soil which are better on the site in Obrenovac (I). Also, the soil on this site has greater content of humus and a more favourable ratio of carbon and nitrogen (C/N).

The size of the leaves of the plants in experimental fields is in direct correlation with the amount of fertilizer by which the plants are fertilized. In plants which were fertilized with the larger amount of fertilizer (240 g per plant) all analysed parameters of the leaf had statistically significantly higher values than the leaves of the seedlings which were fertilized with the smaller amount of fertilizer (120 g per plant) and leaves of the plants on the control plot where fertilization was not carried out. Compared to the leaves from the control plot and all analysed parameters of the leaves of plants that were fertilized with the smaller amount of fertilizer were statistically significantly higher, except for the parameters number of nerves on the right side of the leaf and number of nerves on the left side of the leaf where fertilization did not have any effect.

The analysis of morphological parameters of the leaf between the researched species shows that in *Paulownia elongata* mean values are higher and they are statistically significant for the characteristics leaf area, leaf circumference, leaf blade length, the length of the central veine, leaf width, leaf width at 1 cm from the base, petiole length, the distance between the 3rd and the 4th nerve of the leaf, number of nerves on the left side of the leaf. For the characteristic number of nerves on the right side of the leaf in *Paulownia fortunei* mean values are higher and they are statistically significant.

Based on the obtained results, it can be concluded that particular attention should be paid to soil structure when introducing these species. The soil should be loose, well-aerated, and capable of supporting rapid early root development, as compact or poorly aerated soils may limit their growth potential. Given that paulownia is a fast-growing genus with high nutrient demands, fertilization practices must be carefully harmonized with the physical and chemical properties of the soil in order to ensure optimal nutrient availability and prevent physiological imbalance. The results also highlight a significant potential of these species for use in energy plantations, where fast biomass accumulation is a key requirement.

To fully evaluate and utilize their production capacity in such systems, further research is needed in later stages of plant development, including measurements up to harvest and across repeated post-harvest cycles typical of energy plantations. Continuous monitoring over multiple rotations will enable a complete valorisation of their biomass yield, resilience, and long-term suitability for sustainable energy production. These recommendations provide a practical framework for growers and land managers aiming to optimize cultivation, fertilization, and site selection for maximizing the performance of paulownia in energy-oriented plantations.

Acknowledgement: *The work of S.M., S.S., Z.P., V.S. and N.M. was supported by Ministry of Science, Technological Development and Innovation of the Republic of Serbia (No. 451-03-136/2025-03/200027. The work of M.M. was supported by the grant by the European Community's Program Interreg Czech-Austria BIPC, reg. no. ATCZ00189.*

REFERENCES

Adejobi, K.B., Akanbi, O.S., Ugioro, O., Adeosun, S. A., Mohammed, I., Nduka, B.A., Adeniyi, D.O., 2014. Comparative effects of NPK fertilizer, cowpea pod husk and some tree crops wastes on soil, leaf chemical properties and growth performance of cocoa (*Theobroma cacao* L.). *African Journal of Plant Science 8(2)*, 103-107.

Aragao, L.E.O.C., Malhi, Y., Barbier, N., Lima, A., Shimabukuro, Y., Anderson, L., Saatchi, S., 2008. Interactions between rainfall, deforestation and fires during recent years in the Brazilian Amazonia. *Philosophical Transactions of the Royal Society of London Series B Biological Sciences 363*, 1779–1785

Bergmann, B.A., 1988. Propagation method influences first year field survival and growth of Paulownia. *New Forests*, *16*, 251-264.

Betts, R.A., Malhi, Y., Ro berts, J.T., 2008. The future of the Amazon: new perspectives from climate, ecosystem and social sciences. *Philosophical Transactions of the Royal Society of London Series B, Biological Sciences 363*, 1729–1735.

Cvjetićanin, R., Perović, M., 2009. Pregled vrsta roda Paulovnija (*Paulownia* Sieb. et Zucc.) i njihove bioekološke karakteristike. *Šumarstvo (2009) 3-4,* 111-121.

Fender, A.-C., Mantilla-Contreras, J., Leuschner, C., 2011. Multiple environmental control of leaf area and its significance for productivity in beech saplings. *Trees 25,* 847–857.

García-Morote, F.A., López-Serrano, F.R., Martínez-García, E., Andrés-Abellán, M., Dadi, T., Candel, D., Rubio, E., Lucas-Borja, M.E., 2014. Stem Biomass Production of Paulownia elongata × P. Fortunei under Low Irrigation in a Semi-Arid Environment. *Forests 5(10),* 2505-2520.

Güsewell, S., Koerselman, W., Verhoeven, J.T.A., 2003. Biomass N:P ratios as indicators of nutrient limitation for plant populations in wetlands. *Ecol. Appl. 13*, 372-38.

Hawkins, B.J., Burgess, D., Mitchell, A.K., 2005. Growth and nutrient dynamics of western hemlock with conventional or exponential greenhouse fertilization and planting in different fertility conditions. *Canadian Journal of Forest Research 35,* 1002–1016.

Innes, J., Joyce, L.A., Kellomaki, S., Louman, B., Ogden, A., Parrotta, J., Thompson, I. 2009. Management for Adaptation. Adaptation of Forests and People to Climate Change - A Global Assessment Report. *IUFRO World Series 22*, 135-185.

Ivetić, V., Vilotić, D., 2014. The role of plantation forestry in sustainable development. *Bulletin of the Faculty of Forestry*, 157-180.

Jacobs, D.F., Salifu, F.F., Seifert, J.R. (2005): Growth and nutritional response of hardwood seedlings to controlled-release fertilization at outplanting. *Forest Ecology and Management 214*, 28–39.

Kremera A., Dupoueyb J.L., Deansc J.D., Cottrelld J., Csaikle U., Finkeldeyf R., Espinelg S., Jensenh J., Kleinschmiti J., Dama B. Van, Ducoussoa A., Forrestd I., Lopez de Heredia U., Lowec A.J., Tutkovae M., Munroc R.C., Steinhoffi S., Badea V. (2022): Leaf morphological differentiation between *Quercus robur* and *Quercus petraea* is stable across western European mixed oak stands. Annals of Forest Science, Volume 59 (7): 777 – 787, https://doi.org/10.1051/forest:2002065.

Lavadinović, V., Isajev, V., Miletić, Z., 2010. *Ecological adaptability of Douglas - Fir provenances in Serbia*. First Serbian Forestry Congress - Future with forests. University of Belgrade Faculty of Forestry, 312-319.

Lucas-Borja, M.E., Wic-Baena, C., Moreno, J.L., Dadi, T., García, C., Andrés-Abellán, M., 2011. Microbial activity in soils under fast-growing *Paulownia* (*Paulownia elongata* x *fortunei*) plantations in Mediterranean areas. Applied Soil Ecology 51, 42– 51.

Mishra, A., Swamy, S.L., Bargali, S.S., Singh, A.K., 2010. Tree growth, biomass and productivity of wheat under five promising clones of *Populus deltoids*. *Int J Ecol Environ Sci 36(2/3),* 167–174.

Mitrović, S., Veselinović, M., Vilotić, D., Bojović, S., Šijačić-Nikolić, M., Čule, N., 2012. *The Influence of Fertilizing on Growth of Seedlings Paulownia spp*. International Scientific Conference "Forests in Future - Sustainable Use, Risks and Challenges", Belgrade, Serbia, 1001-1009.

Niinemets, Ü., 2001. Global-scale climatic controls of leaf dry mass per area, density, and thickness in trees and shrubs. *Ecology, 82(2),* 453–469.

Óskarsson, H., Brynleyfsdóttir, S.J., 2009. The interaction of fertilization in nursery and field on survival, growth and the frost heaving of birch and spruce. *Icel. Agric. Sci. 22*, 59-68.
Otieno, D.O., Schmidt, M.W.T., Adiku, S., Tenhunen, J., 2005. Physiological and morphological responses to water stress in two *Acacia* species from contrasting habitats. *Tree Physiology 25,* 361–371.

Ozturk, A., Serdar, U., Gürgör, N., Korkmaz, A., 2014. The effect of different nursery conditions on some of the leaf and stomata characteristics in Chestnuts. *Journal of Applied Botany and Food Quality 87*, 190 – 195.

Pedrol, N., Ramos, P., Reigosa, M.J., 2000. Phenotypic plasticity and acclimation to water deficits in velvet-grass: a long-term greenhouse experiment. Changes in leaf morphology, photosynthesis and stress-induced metabolites. *Journal of Plant Physiology 157*, 383–393.
Popović, M.T., 2005. *Biohemija biljaka*. Poljoprivredni fakultet, Novi Sad, 2005, 565. ISBN 86-7520-052-8 COBISS.SR-ID 199233543.

Stojnić, S., 2013. *Varijabilnost anatomskih, fizioloških i morfoloških karakteristika različitih provenijencija bukve u Srbiji.* Doktorska disertacija. Univerzitet u Beogradu, Šumarski Fakultet, Beograd. 256-287.

Mitrović, S., Veselinović, M., Čule, N., Češljar, G., Eremija, S., Gagić-Serdar, R., Stajić, S., 2022. Morphometric characteristics of *Paulownia elongata* S. Y. Hu. and *Paulownia fortunei* Seem. Hemsl. leaves and fertilisation in different sites. *Sustainable forestry, Collection 85-86*, 35-52.

Mitrović, S., Veselinović, M., Stajić, S., Gagić-Serdar, R., Marković, M., Bjedov, I., Milosavljević, M., 2024. Effects of fertilisation on survival and morphological growth characteristics of one-yearold seedlings of Paulownia elongata S. Y. Hu. and *Paulownia fortunei* Seem. Hemsl. in two different sites in Serbia. *Sustainable forestry, Collection 89-90*, 87-108.

Šilić, Č., 1990. *Ukrasno drveće i grmlje*. IP „SVJETLOST", Zavod za udžbenike i nastavna sredstva, Sarajevo, Zavod za udžbenike i nastavna sredstva, Beograd. 166.
Tucović, A., Simić, Z., 2002. *Ishrana bilja*. Zavod za udžbenike i nastavna sredsta, Beograd. 1-122.

Wright, I. J., Reich, P. B., Westoby, M., 2001. Strategy shifts in leaf physiology, structure and nutrient content between species of high- and low-rainfall and high- and low-nutrient habitats. *Funct. Ecol. 15*, 423–434. doi: 10.1046/j.0269-8463.2001.00542.x

Yadav, N.K., Vaidya, B.N., Henderson, K., Frost Lee, J., Stewart, W.M., Dhekney, S.A., Joshee, N., 2013. A Review of Paulownia Biotechnology: A Short Rotation, Fast Growing Multipurpose Bioenergy Tree. *American Journal of Plant Sciences 4*, 2070-2082.

Yong-Hua, LiQi, Wu Bo, Zhu Yajuan, Liu Dianjun, Zhang Jinxin, Zhan-Hu Jin, 2012. A review of leaf morphology plasticity linked to plant response and adaptation characteristics in arid ecosystems. *Chinese Journal of Plant Ecology 36(1)*, 88-98 DOI: 10.3724/SP.J.1258.2012.00088.

Zhu, Z.-H., Chao, C.-J., Lu, X.-Y., Xiong, Y.G., 1986. Paulownia in China: Cultivation and Utilization. *Asian Network for Biological Sciences and International Development Research Centre*, 1-64.

EFFECT OF FERTILIZATION ON LEAF MORPHOMETRIC CHARACTERISTICS OF *Paulownia elongata* S. Y. Hu AND *Paulownia fortunei* Seem. Hemsl. IN THE SECOND YEAR OF GROWTH

Suzana MITROVIĆ, Milorad VESELINOVIĆ, Snežana STAJIĆ, Zoran PODUŠKA, Vanja STOJANOVIĆ, Natalija MOMIROVIĆ, Marija MILOSAVLJEVIĆ

Summary

Starting material for the production of seedlings of species *Paulownia elongata* and *Paulownia fortunei* of *Paulownia* Sieb. & Zucc. from the family *Paulowniaceae* was collected on plantation established in 1993 near Bela Crkva in Vojvodina. The species used within these studies should show whether the introduction of these species of paulownia is possible and justified within the research of adaptability of these species to environmental conditions of two different sites in Serbia. The introduction of new species in the territory of Serbia is significant if we have in mind the climate change which is evident, where many species are lost from their natural habitats, and the need for production of biomass is increasingly pronounced. The size and characteristics of leaves which are significant for photosynthetic processes and production of nutrients are in direct correlation with the production of total biomass of plants. Starting from the above-mentioned facts, a comparative analysis of ten basic morphological characteristics of leaf was carried out. Morphological analysis was carried out according to the modified protocol Assessments of Oak Leaf Morphology, with adjustments to the specificities of the species of the genus *Paulownia*. Morphological characteristics of the leaf were analysed depending on the pedological conditions and the regime of plant fertilization during the second year of growth, whereby different quantities of fertilizer were applied. The results of the analysis of the measurement data of leaf morphological parameters of species *Paulownia elongata* S. Y. Hu. and *Paulownia fortunei* Seem. Hemsl., planted on different habitats and treated by different amounts of fertilizers, indicate that the type of habitat has a significant effect on leaf morphological characteristics. Fertilization proved itself to be a factor which has a positive effect on the development of morphological parameters, as well as on overall size of the leaves in the first year after the planting. The obtained results indicate significant potential of the examined species of *Paulownia* genus, whereby greater adaptive and morphogenetic potential was pronounced in the species *Paulownia elongata* compared to *Paulownia fortunei*. During the introduction and establishing of plantation of the species *P. elongata* it is necessary to take care of adjusting the quantity of nutrients introduced by fertilization to the chemical properties of the soil, in order to provide optimal values for growth and development of plants. Since it is a fast-growing species with high requirements in terms of aeration and permeability of the substrate, it is advisable to form plantations on loose, well-aerated soils rich in humus, which enables intensive vegetative growth and maximum use of species potential.

UTICAJ ĐUBRENJA NA MORFOMETRIJSKE KARAKTERISTIKE LISTOVA VRSTA *Paulownia elongata* S. Y. Hu I *Paulownia fortunei* Seem. Hemsl. U DRUGOJ GODINI RASTA

Suzana MITROVIĆ, Milorad VESELINOVIĆ, Snežana STAJIĆ, Zoran PODUŠKA, Vanja STOJANOVIĆ, Natalija MOMIROVIĆ, Marija MILOSAVLJEVIĆ

Rezime

Polazni materijal za proizvodnju sadnica vrsta *Paulownia elongata* i *Paulownia fortunei* roda *Paulownia* Sieb. & Zucc. iz familije *Paulowniaceae* je sakupljen na plantaži koja je osnovana 1993. godine kod Bele Crkve u Vojvodini. Korišćene vrste u okviru ovih istraživanja treba da pokažu da li je introdukcija ovih vrsta paulovnija moguća i opravdana u sklopu istraživanja adaptibilnosti ovih vrsta na uslove sredine dva različita lokaliteta u Srbiji. Introdukcija novih vrsta na području Srbije je od značaja ako imamao u vidu klimatske promene koje su evidentne, gde se mnoge vrste gube sa svojih prirodnih staništa, a potreba za produkcijom biomase je sve izraženija. U dirktnoj korelaciji sa produkcijom celokupne biomase biljaka su veličina i karakteristike lista koje su od značaja za fotosintetičke procese i produkciju hranljivih materija. Polazeći od navedenih činjenica, izvršena je komparativna analiza deset osnovnih morfoloških obeležja lista. Morfološka analiza sprovedena je prema modifikovanom protokolu Assessments of Oak Leaf Morphology uz prilagođavanja specifičnostima vrsta roda *Paulownia*. Analizirana su morfološka svojstva lista u zavisnosti od pedoloških uslova i režima prihranjivanja biljaka tokom druge godine razvoja, pri čemu su primenjene različite količine đubriva. Rezultati analize merenih podataka morfoloških parametara listova vrsta *Paulownia elongata* S. Y. Hu. i *Paulownia fortunei* Seem. Hemsl., posađenih na različitim staništima i tretiranih različitim količinama đubriva, ukazuju da tip staništa ima značajan uticaj na morfološke karakteristike lista. Prihranjivanje se pokazalo kao faktor koji pozitivno utiče na razvoj morfoloških parametara, kao i na ukupnu veličinu listova u prvoj godini. Dobijeni rezultati ukazuju na značajan potencijal ispitivanih vrsta roda *Paulownia*, pri čemu je kod vrste *Paulownia elongata* S. Y. Hu. izražen veći adaptivni i morfogenetski potencijal u odnosu na *Paulownia fortunei* Seem. Hemsl. Prilikom introdukcije i podizanja zasada vrste *P. elongata* neophodno je voditi računa o usklađivanju količine hranljivih materija unetih đubrenjem sa hemijskim osobinama zemljišta, kako bi se obezbedile optimalne vrednosti za rast i razvoj biljaka. S obzirom na to da je reč o brzo rastućoj vrsti sa visokim zahtevima u pogledu aeracije i propustljivosti supstrata, plantaže je preporučljivo formirati na rastresitim, dobro aerisanim i humusom bogatim zemljištima, što omogućava intenzivan vegetativni porast i maksimalno iskorišćenje potencijala vrste.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 92, 2025 ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592047C
UDK: 630*232.322.4:582.713=111
Original scientific paper

EFFECTS OF A CONTROLLED-RELEAS FERTILISER ON HEIGHT GROWTH OF TWO-YEAR-OLD TRANSPLANTED (1+1) WILD CHERRY (*Prunus avium* L.) SEEDLINGS

Tatjana ĆIRKOVIĆ-MITROVIĆ[1], Dragica VILOTIĆ[2], Milan REBIĆ[3], Ljiljana BRAŠANAC-BOSANAC[1]*

Abstract: *Previous research has shown that, besides an appropriate species selection, the characteristics of planting material play a key role in the success of reforestation efforts. The application of fertilisation products in modern nursery production represents an important factor in producing high-quality seedlings. This study aimed to examine the effect of a controlled-release fertiliser, marketed under the commercial name Osmocote® Exact Standard 5–6 M, on the height growth and survival of two-year-old wild cherry (Prunus avium L.) transplants (1+1). Shoot height was measured at the beginning of the growing season, during the season, and at its end. Based on these measurements, the height increment and the survival rate of two-year-old transplanted seedlings were calculated. The results indicate a positive influence of the fertiliser on all examined parameters. The mean height at the end of the growing season was 68.8 cm in unfertilised seedlings compared with 80.4 cm in fertilised ones. The relative height increment in the second year amounted to 69.6% in unfertilised seedlings and 101.6% in fertilised seedlings. Thus, the application of controlled-release fertiliser can enhance height growth and improve the survival of wild cherry seedlings.*

Keywords: transplanted seedlings, seedling growth, reforestation techniques, nursery production, Osmocote.

UTICAJ ĐUBRIVA SA KONTROLISANIM OSLOBAĐANJEM NA VISINSKI PRIRAST DVOGODIŠNJIH ŠKOLOVANIH (1+1) SADNICA DIVLJE TREŠNJE (*Prunus avium* L.)

Sažetak: *Dosadašnja iskustva pokazala su da se pri pošumljavanju, osim pravilnog izbora vrste, mora voditi računa i o karakteristikama sadnog materijala koje su od značaja za uspeh pošumljavanja. Primena preparata ishrane u savremenoj rasadničkoj proizvodnji je značajan faktor u proizvodnji visokokvalitetnog sadnog materijala. Cilj ovog rada bio je da istraži uticaj đubriva sa kontrolisanim oslobađanjem komercijalnog naziva Osmocote® Exact Standard 5-6 M na visinski prirast i preživljavanje dvogodišnjih presađenih sadnica*

[1] Institute of Forestry, 3 Kneza Višeslava, 11000 Belgrade, Serbia
[2] Faculty of Forestry, 1 Kneza Višeslava, 11000 Belgrade, Serbia
[3] Provincial Secretariat for Agriculture, Water Management and Forestry, 25 Mihajla Pupina Boulevard, 3/II, 21000 Novi Sad, Serbia
*Corresponding author. E-mail: tanjacirk@yahoo.com

divlje trešnje (Prunus avium L.) tipa 1+1. Izmerene su visina izbojka na početku vegetacionog perioda, u toku i na kraju vegetacionog perioda. Na osnovu izmerenih visina izračunat je visinski prirast i utvrđen procenat preživljavanjea dvogodišnjih školovanih sadnica. Dobijeni rezultati pokazuju pozitivan uticaj preparata ishrane na sve ispitivane parametre. Prosečna visina na kraju vegetacionog perioda netretiranih sadnica bila je 68,8 cm, a tretiranih 80,4 cm. Relativna vrednost visinskog prirasta netretiranih školovanih dvogodišnjih sadnica u drugoj godini je bila 69,6%, a tretiranih 101,6%. Dakle, primena đubriva đubriva sa kontrolisanim oslobađanjem može poboljšati visinski prirast i preživljavanje sadnica trešnje (Prunus avium).

Ključne reči: školovana sadnica, rast sadnica, tehnike pošumljavanja, rasadnik, Osmocote.

1. INTRODUCTION

Improving the production of tree and shrub planting material is one of the strategic priorities in forestry. This requires a well-organised nursery system capable of producing the planting stock intended for afforestation and reforestation programmes.

Wild cherry (*Prunus avium* L.) is a native broadleaved tree species growing in the mixed European forests. It has a wide elevation range, from lowland areas up to the submontane belts. On larger mountain massifs, it can be found up to 2000 m a.s.l. (Russell, 2003). According to Tomić (2004) and Tomić, Rakonjac (2012), in Serbia it is an autochthonous species occurring as scattered individuals within mixed secondary stands of the oak belt forests *Querco-Castanetum sativae* (Ht. 38) Glišić 1975., *Carpino betuli-Quercetum roboris* (Anić 59) Rauš 1971.s.l., *Carpino betuli-Quercetum roboris* (Anić 59) Rauš 1971. var. geograph. *Tilia cordata+Tilia argentea* B. Jovanović 1979., and mesophilic beech forests *Aceri-Fraxinetum illyricum* Ht. 1938., *Fagetum submontanum moesiacum* (Rudski 49) B. Jovanović 1976., *Fago moesiacae-Castanetum sativae* (Glišić 1975) Matović 1986.

Globally, up to half of plant and animal species inhabiting the world's most biodiverse regions (such as the Amazon, the Arctic and the Galapagos, and in Europe, the Mediterranean and the Black Sea Basin) could face local extinction by the turn of the century due to climate change if carbon emissions continue to rise unchecked (WWF, 2014). According to Holz et al. (2022), 7% to 9% of European vascular plant diversity is threatened in its entire range, the majority of which are single-country endemics. Of these globally threatened species, 84% currently have no assessment in the global Red List. The high demand and increasing use of wild cherry wood are putting constant pressure on existing populations of this species (Pilipović et al., 2011). Therefore, it is necessary to preserve the cherry gene pool.

Seed collection, nursery production of wild cherry seedlings, and their introduction into existing forests and afforestation of unstocked areas contribute to improving biodiversity status and enhancing the natural biological richness. This species is significant not only for the conservation of plant diversity but also for wildlife, as it provides a valuable food source for many animal species.

Previous experience has shown that in afforestation, in addition to proper species selection, it is necessary to consider characteristics of the planting material that are crucial for successful establishment (root system development, tolerance to temperature extremes, etc.). Several studies dealing with nursery production, growth, development and morphological traits of wild cherry seedlings were conducted by Mikić (2007), Jarni et al. (2012), Stjepanović (2012), Drvodelić et al. (2012), Stjepanović & Ivetić (2013), Ćirković-Mitrović (2014), Pérez-Jiménez et al. (2017), Stanković-Neđić et al. (2018), Popović et al. (2021), Shayesteh Pahangeh et al. (2022), Stojnić et al. (2022), EFSA Panel on Plant Health (PLH) (2024), Kerkez-Janković et al. (2024), etc.

Planted broadleaved tree species, including wild cherry, frequently experience transplant stress, reducing their survival (Hemery et al., 2008; Savill et al., 2009; Eşen et al., 2012). Research results indicate that nursery-grown seedlings have higher survival rates when outplanted in sites with more demanding environmental conditions (Eşen et al., 2012).

Fertilisation is the most common method used to enhance the soil's nutritional status. In modern nursery production, the application of nutritional preparations is not only a supplementary source of nutrients but also a powerful means and an important factor in producing high-quality planting material.

The aim of this study was to investigate the effect of a controlled-release fertiliser, commercially known as Osmocote® Exact Standard 5–6 M, on the height growth and survival of two-year-old transplanted (1+1) wild cherry seedlings (*Prunus avium* L.). A simple method of applying the nutritional preparation by incorporating it into the substrate would certainly justify its use in mass production of high-quality planting material (Ćirković-Mitrović et al., 2012).

2. MATERIAL AND METHODS

2.1. Field Characteristics and Nursery Experiment

For the purposes of this study, 1+0 wild cherry (*Prunus avium* L.) seedlings produced from selected seed were used. The seed originated from the Fruit and Ornamental Plant Research Institute (NARIC), Cegléd Research Station (Cegléd, Hungary – 47.175063N, 19.820214E). In early autumn 2023, the seed was sown in nursery beds at the "Grower" Nursery (Ada, Vojvodina, Serbia – 45.769559N, 20.129032E). Prior to sowing (late summer 2023), the seed was placed in moist sand for stratification in a climate chamber for a period of two months at 2°C. The experiment was established in the "Eco-Nimi" Nursery (Zrenjanin, Vojvodina, Serbia – 45.399263N, 20.395358E).

According to data from the Republic Hydrometeorological Service of Serbia, the territory of the Zrenjanin municipality is characterised by a temperate continental climate, specifically the steppe-continental subtype. A common feature of all climatic elements in this region is the pronounced annual amplitude and considerable intra-annual variability in their values.

To assess the climatic characteristics of the area, the meteorological data used for analysis were taken from the Meteorological yearbooks of the Republic Hydrometeorological Service of Serbia, covering the period 1990 to 2024.

The climatic characteristics of the area in which the nursery is located, for the year in which the experiment was conducted, are presented in Table 1.

Table 1. *Monthly temperature and precipitation in Zrenjanin in 2024, annual averages (AA) and growing season (GS) values, and their deviations from the 1990-2020 reference period*

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	AA	GS
Temperature [°C]	2.5	**9.5**	10.9	15.0	18.7	24.1	**26.4**	**26.8**	19.1	13.2	4.4	2.7	14.4	21.7
Deviation (Reference value)	↑1.8	**↑7.1**	↑3.9	↑2.4	↑1.2	↑2.9	↑3.5	↑4.1	↑1.6	↑1.0	↑2.6	↑1.0	↑2.3	↑2.6
	0,7	2,4	7,0	12,6	17,5	21,2	22,9	22,7	17,5	12,2	7,0	1,7	12,1	19,1
Precipitation [mm]	39.5	6.6	27.2	30.7	89.8	42.4	53.5	**2.4**	**109.8**	33.6	52.1	47.7	535.3	328.6
Deviation (Reference value)	↑0.8	↓27.1	↓8.9	↓9.8	↑27.8	↓38.7	↓5.0	**↓47.2**	**↑55.4**	↓17.2	↓5.9	↑1.1	↓62.9	↓17.5
	38.7	33.7	36.1	40.5	62.0	81.1	58.5	49.6	54.4	50.8	46.2	46.6	598.2	346.1

Analysis of climatic parameters for 2024 indicates that this year was the warmest on record in Serbia, including the Zrenjanin area (the record highest values and deviations are marked in red). The winter, spring, and summer of 2024 were the warmest seasons recorded since the beginning of temperature measurements in the country.

The mean annual air temperature in Zrenjanin in 2024 was 14.4°C, which was 2.3°C higher than the normal value for the 1991-2020 period. All twelve months recorded higher mean monthly temperatures relative to the reference period, with anomalies ranging from +1.0°C (October and December) to +7.1°C (February). In February, July, and August, record values of both mean monthly and mean maximum air temperatures were observed. The mean air temperature during the growing season in 2024 was 21.7°C, exceeding the reference value by 2.6°C.

Total annual precipitation amounted to 535.5 mm, which was 62.9 mm below the 1991-2020 normal. Precipitation was distributed relatively evenly across seasons, although some deviations were recorded. January, May, September, and December had precipitation totals above the reference values (from +0.8 mm in January to +55.4 mm in September), while all other months showed deficits (from -5.0 mm in July to -47.2 mm in August). During the growing season, precipitation was 17.5 mm lower than the long-term average.

One-year-old bare-root seedlings were grown in this nursery. They were transplanted into 1.4-L containers filled with a substrate composed of a mixture of topsoil and peat (30:70). The peat consisted of a 50:50 mixture of light and dark peat originating from Lithuania, marketed under the commercial name REKYVA (https://rekyva.eu/en/). In 50 containers, no fertiliser was incorporated into the substrate prior to planting, while in the remaining 50 containers Osmocote was applied at a rate of 400 g per 100 L (4 kg/m³) of substrate (Figure 1).

Osmocote® Exact Standard 5–6 M is labelled 15+9+12+2MgO+TE, indicating the percentage content of nitrogen, phosphorus, potassium, magnesium, and essential micronutrients required for plant growth and development. The N–P–K ratio (15–9–12) corresponds to 15% nitrogen (N), 9% phosphorus (P), and 12% potassium (K), followed by 2% MgO and TE (trace elements). The essential micronutrients include iron (Fe) 0.47%, manganese (Mn) 0.065%, zinc (Zn) 0.028%, copper (Cu) 0.06%, molybdenum (Mo) 0.024%, and boron (B) 0.024%. The release of nutrients is unaffected by soil salinity, pH, microbial activity, or water quality (including rainfall); it depends solely on temperature, which makes Osmocote® Exact highly reliable in use.

Figure 1. *Nursery experiment –Eco-Nimi Nursery in Zrenjanin*
(Photos by Milan Rebić)

During the growing season, the seedlings were irrigated with water. Based on the climatic characteristics recorded for 2024, it can be concluded that the combination of record-high mean monthly temperatures and reduced precipitation could have negatively affected the growth and development of the seedlings if controlled irrigation had not been applied.

2.2. Seedlings measurement

Initial shoot height (h_0) was measured in April 2024, followed by a mid-growing season measurement (h_1) on 10 July 2024, and a final measurement at the end of the growing season (h_2) in October 2024 (all units of measures are in cm). Based on these measurements, height increment of the two-year-old seedlings was calculated. Seedling survival (S) of the two-year-old transplanted plants was estimated by comparing the number of one-year-old seedlings initially planted with the number of surviving seedlings at the end of the second growing season. The effect of the fertiliser treatment on the measured and calculated seedling parameters was assessed using analysis of variance (ANOVA). Statistical analyses were performed in Statgraphics Centurion XVI.I.

3. RESULTS AND DISCUSSION

The basic descriptive statistics of the measured heights are presented in Table 2.

Table 2. *Descriptive statistics for height and height increment of wild cherry seedlings in the second year*

Treatment	Measurement time	N	h (cm)	Sd	Cv	Min	Max
UT	April	50	40.4	6.4	15.8	28.2	50.7
	July	48	52.2	6.5	12.5	39.7	72.2
	October	41	68.6	8.6	12.5	52.5	89.2
T	April	50	39.9	6.3	15.8	26.3	49.3
	July	48	58.3	6.3	10.9	45.2	70.5
	October	45	80.4	5.6	7.0	68.8	93.0

Abbreviations: N – number of seedlings; h – mean height; Sd – standard deviation; Cv – coefficient of variation; Min – minimum measured height; Max – maximum measured height; UT – untreated seedlings; T – seedlings treated with fertiliser.

The initial height measurements of one-year-old seedlings indicate that there was no statistically significant difference at the beginning of the growing season (in April). During the second measurement, conducted in July, divergence between the treatments became evident in favour of the seedlings treated with slow-release fertiliser. The mean height of the untreated seedlings was 52.2 cm, whereas the treated seedlings reached 58.3 cm. This difference continued to increase, and by the end of the growing season the untreated seedlings reached an average height of 68.6 cm, while the treated seedlings attained 80.4 cm.

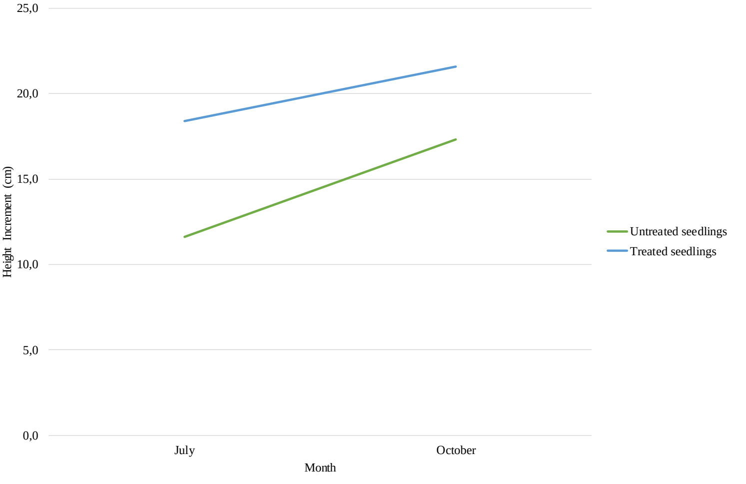
Table 3. *Differences in height increment of wild cherry seedlings in the second year during the 2024 growing season*

Treatment	Count	Mean (cm)	F-Ratio	P-Value
h				
h_0				
UT	50	40.4^a	0.21	0.6490
T	50	39.9^a		
h_1				
UT	48	52.2^a	21.48	0.0000
T	48	58.3^b		
h_2				
UT	41	68.6^a	57.89	0.0000
T	45	80.4^b		
ih				
ih_{0-1}				
NT	48	11.6^a	56.51	0.0000
T	48	18.4^b		
ih_{1-2}				
NT	41	16.3^a	24.35	0.0000
T	45	21.6^b		
ih				
UT	41	27.3^a	81.35	0.0000
T	45	40.1^b		

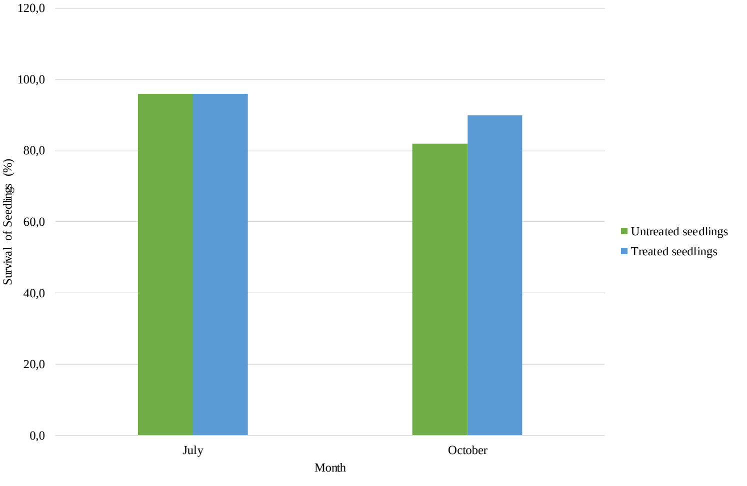
Abbreviations: h_0 – initial shoot height; h_1 – shoot height during the growing season (10 July 2024); h_2 – shoot height at the end of the growing season; ih_{0-1} – height increment during the first part of the growing season (April–July); ih_{1-2} – height increment during the second part of the growing season (July–October); ih – total height increment; NT – untreated seedlings; T – seedlings treated with fertiliser.

*Mean values in the same column followed by different letters are statistically different at $p <0.05$

Height increment also shows a statistically significant difference in favour of the treated seedlings – calculated for the first half of the growing season, the second half of the growing season, and for the total height increment (Table 3, Graph 1).



Graph 1. *Height increment of two-year-old seedlings in the second year, untreated and treated with fertiliser*



Graph 2. *Survival of seedlings during the second growing season, untreated and treated with fertiliser*

The percentage of height increment in untreated seedlings in the second year was 29.1% during the first half of the growing season (April–July), 31.4% during the second half (July–October), and 69.6% for the entire growing season. In treated seedlings, the relative height increment was 46.2% for the April–July period, 37.9% for the July–October period, and 101.6% for the whole growing season.

Seedling survival after transplanting, when they experience considerable stress, was higher at the end of the growing season in the fertilised seedlings, with a survival rate of 90%. In contrast, the survival rate of the untreated seedlings was 82% (Graph 2).

In studies investigating the effects of the controlled slow-release fertiliser Osmocote on the growth and survival of hardwood seedlings of black walnut (*Juglans nigra L.*), white ash (*Fraxinus americana* L.), and yellow-poplar (*Liriodendron tulipifera* L.), Jacobs et al. (2005) reported a positive influence of the fertiliser regardless of species. Nacheva et al. (2015) also documented a positive effect of Osmocote on the growth and development of *Ginkgo biloba* L. seedlings, while Tatun Ya and Nosnikov (2025) reported similar effects on silver birch (*Betula pubescens* Ehrh.) seedlings. Eşen et al. (2012) examined the early effects of a controlled-release fertiliser on the survival and growth of wild cherry (*Prunus avium* L.) seedlings in the western Black Sea Region of Turkey. Fertilised seedlings had significantly greater heights than untreated seedlings both in the first and the second year. Pérez-Jiménez et al. (2017) similarly reported that fertilisation can improve the quality, growth, and survival of cherry seedlings.

The positive impact of fertilisation on the development and nutrient uptake of black locust (*Robinia pseudoacacia* L.) seedlings was confirmed by Ombódi et al. (2020). Jasik et al. (2025) and Rotowa et al. (2025, 2025a) investigated the growth of European beech (*Fagus sylvatica* L.) and pedunculate oak (*Quercus robur* L.) seedlings on an innovative peat-free organic substrate treated with Osmocote. Their results showed strong correlations between soil nutrient content and seedling growth parameters. The importance of seedling cultivation for afforestation success, including its positive effect on survival rate and height increment in the wild pear (*Pyrus pyraster* Burgsd.), was demonstrated by Drvodelić et al. (2012).

4. CONCLUSIONS

One-year-old wild cherry seedlings responded to the application of slow-release fertiliser during the second year after transplanting. The effect of the fertiliser was reflected in significantly greater seedling height, height increment, and survival rate after planting and nursery cultivation. At the end of the growing season, the mean height of untreated seedlings was 68.8 cm, whereas fertilised seedlings reached 80.4 cm. The relative height increment of untreated two-year-old nursery grown plants in the second year was 69.6%, while in the treated seedlings, it reached 101.6%.

Slow-release fertilisers can improve seedling performance in nursery production. The findings of this study may support further improvements in the cultivation of wild cherry seedlings through the use of controlled-release fertilisers during the nursery stage. This approach could contribute to better planning of afforestation and the restoration of natural forest ecosystems on harsh sites, where post-planting survival of seedlings is generally lower.

Acknowledgement: *This study was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract No. 451-03-136/2025-03/200027.*

REFERENCES

Ćirković-Mitrović, T. (2014): *Uticaj različitih preparata ishrane na morfoanatomske karakteristike sadnica šumskih voćkarica.* Doktorska disertacija, Šumarski fakultet Univerziteta u Beogradu, 0-315.

Ćirković-Mitrović, T., Brašanac-Bosanac, Lj., Popović, V. (2012): Effect of fertiliser application on morphological characteristics of walnut (Juglans regia L.) juvenile seedlings, International Conference on BioScience: Biotechnology and Biodiversity – Step in the Future, The Fourth Joint UNS–PSU Conference, Novi Sad, June 18-20, 2012. Book of the Proceedings, p. 149-164.
https://semenarska.rs/UNS-PSU/radovi/1/13%20CIRKOVIC%20149-164.pdf

Drvodelić, D., Oršanić, M., & Zeman, Z. (2012). *Field performance after reforestation with one year old non-transplanted (1+ 0) and transplanted (1+ 1) seedlings of wild pear (Pyrus pyraster Burgsd.).* Šumarski list, 136(7-8), 355-366. https://hrcak.srce.hr/86972

EFSA Panel on Plant Health (PLH), Bragard, C., Baptista, P., Chatzivassiliou, E., Gonthier, P., Jaques Miret, J. A., ... & Yuen, J. (2024). *Commodity risk assessment of Prunus avium plants from United Kingdom.* EFSA Journal, 22(7), e8836. https://doi.org/10.2903/j.efsa.2024.8836

Eşen, D., Ediş, S., Esen, U., Çetintaş, C., and Yıldız, O. (2012). *Early effects of a control-release fertilizer on the survival and growth of wild cherry (Prunus avium L.) seedlings in Düzce*. Journal of Bartin Faculty of Forestry 14:77-83

Holz, H., Segar, J., Valdez, J., & Staude, I. R. (2022). *Assessing extinction risk across the geographic ranges of plant species in Europe.* Plants, People, Planet, 4(3), 303-311. https://doi.org/10.1002/ppp3.10251

Jacobs, D.F., Salifu, K.F. and Seifert, J.R. (2005). Growth and Nutritional Response of Hardwood Seedlings to Controlled-Release Fertilisation at Outplanting. For. Ecol. Manage. 214(1-3), 28-39. https://doi.org/10.1016/j.foreco.2005.03.053

Jasik, M., Staszel-Szlachta, K. & Małek, S. *Leaf stoichiometry of European beech (Fagus sylvatica L.) and pedunculate oak (Quercus robur L.) seedlings grown on an innovative peat-free organic substrate.* Sci Rep 15, 39674 (2025). https://doi.org/10.1038/s41598-025-23221-6

Kerkez-Janković, I., Popović, V., Nonić, M., & Šijačić-Nikolić, M. (2024). *Divlja trešnja (Prunus avium L.) – od rasadnika do predela Velikog ratnog ostrva.* Simpozijum sa međunarodnim učešćem Pejzažna hortikultura 2024 "Sadni materijal kao resurs–od rasadnika do predela ", 9. https://omorika.sfb.bg.ac.rs/handle/123456789/1586

Meteorological yearbooks of the Republic Hydrometeorological Service of Serbia (1990-2024)
https://www.hidmet.gov.rs/latin/meteorologija/klimatologija_godisnjaci.php

Nacheva, L., Gercheva, P., & Ivanova, V. (2015). *Effect of the controlled-release fertiliser osmocote on the growth and development of Ginkgo biloba L. seedlings*. Agricultural University – Plovdiv, Scientific Works, vol. LIX, book 4, 2015 Jubilee Scientific Conference with International Participation Traditions and Challenges of Agricultural Education, Science and Business, 143-147.

Ombódi, A., Csorbai Gógán, A., Papp, B., & Posta, K. (2020). *Effects of fertilisation on development and nutrient uptake of black locust saplings grown in pots.* COLUMELLA: JOURNAL OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES, 7(2), 43-52. https://doi.org/10.18380/SZIE.COLUM.2020.7.2.43

Pérez-Jiménez, M., Bayo-Canha, A., López-Ortega, G., & del Amor, F. M. (2017). *Growth, Plant Quality, and Survival of Sweet Cherry (Prunus avium L.) Seedlings are Enhanced by CO2 Enrichment.* HortScience, 52(12), 1650–1654. https://doi.org/10.21273/HORTSCI12337-17

Pérez-Jiménez, M., Bayo-Canha, A., López-Ortega, G., & del Amor, F. M. (2017). Growth, Plant Quality, and Survival of Sweet Cherry (Prunus avium L.) Seedlings are Enhanced by CO2 Enrichment. HortScience, 52(12), 1650–1654. https://doi.org/10.21273/HORTSCI12337-17

Pilipović, A., Orlović, S., Stojnić, S., Galović, V., Marković, M. (2011): *Inventarizacija genofonda divlje trešnje (Prunus avium) u Srbiji u cilju usmerenog korišćenja genetičkog potencijala.* Topola 187/188: 53-63.

Popović, V., Rakonjac, L., Lazarević, I., & Lučić, A. (2021): *Morphological characteristics and variability of the seedlings of wild cherry (Prunus avium L.) in Serbia*. Proceedings of the XII International Scientific Agricultural Symposium "Agrosym 2021", 1405-1414.

Rotowa, O. J., Małek, S., Jasik, M., & Staszel-Szlachta, K. (2025). *Effect of innovative peat-free organic growing media and fertiliser on nutrient allocation in pedunculate oak (Quercus robur L.) and European beech (Fagus sylvatica L.) seedlings*. New Forests, 56(1),17. https://doi.org/10.1007/s11056-024-10079-1

Rotowa, O. J., Małek, S., Kupka, D., Pach, M., & Banach, J. (2025). *Innovative Peat-Free Organic Substrates and Fertilisers Influence Growth Dynamics and Root Morphology of Fagus sylvatica L. and Quercus robur L. Seedlings One Year After Planting*. Forests, 16(5),800. https://doi.org/10.3390/f16050800

Russell, K. (2003): EUFORGEN *Technical Guidelines for Genetic Conservation and Use for Wild Cherry (Prunus avium).* International Plant Genetic Resources Institute, Rome, Italy. www.bioversityinternational.org/fileadmin/bioversity/publications/.../859.pdf

Shayesteh Pahangeh, E., Aliarab, A., Sadati, S. E., Espahbodi, K., & Karimian, Z. (2022). *Effect of soil moisture content on survival, growth, and physiological characteristics of wild cherry (Prunus avium L.) seedlings*. Iranian journal of Forest 13(5), 57-69.

Stanković-Neđić, M., Stojnić, S., Orlović, S., Čolić, H., Petrović, D., Isajev, V. (2018). *Varijabilnost klijavosti sjemena i morfoloških osobina sadnica divlje trešnje porijeklom iz Republike Srpske (BiH).* Topola 201-202, 213-225.

Stojnić, S., Kovačević, B., Kebert, M., Vasić, V., Vuksanović, V., Trudić, B., & Orlović, S. (2022*). Genetic differentiation in functional traits among wild cherry (Prunus avium L.) half-sib lines.* Journal of Forestry Research, 33(3), 991-1003.

Tatun Ya. U., Nosnikov V. V. (2025). *Use of slow-release fertilisers in growing containerized silver birch seedlings.* Proceedings of BSTU, issue 1, Forestry. Nature Management. Processing of Renewable Resources, no. 2 (294), pp. 69-77 (In Russian). https://doi.org/10.52065/2519-402X-2025-294-8

Tomić, Z. (2004): *Šumarska fitocenologija, Šumarski fakultet Univerziteta u Beogradu, Beograd, (133-174).* [Tomić, Z. (2004): Forest Phytocoenology, Faculty of Forestry, University of Belgrade, Belgrade, (133-174).]

World Wildlife Fund (WWF) 2014 https://www.wwf.mg/?324571/Half-of-plant-and-animal-species-at-risk-from-climate-change

https://www.statgraphics.com/centurion-xvi

https://www.hidmet.gov.rs/eng/meteorologija/klimatologija.php

REKYVA https://rekyva.eu/en/

EFFECTS OF A CONTROLLED-RELEASE FERTILISER ON HEIGHT GROWTH OF TWO-YEAR-OLD TRANSPLANTED (1+1) WILD CHERRY (*Prunus avium* L.) SEEDLINGS

Tatjana ĆIRKOVIĆ-MITROVIĆ, Dragica VILOTIĆ, Milan REBIĆ, Ljiljana BRAŠANAC-BOSANAC

Summary

Wild cherry (*Prunus avium* L.) is a native broadleaved tree species growing in mixed European forests. It has a wide elevation range, from lowland sites up to submontane belts, and on larger mountain massifs it may be found at elevations up to 2000 m (Russell, 2003).

Seed collection, nursery production of wild cherry seedlings, and their introduction into existing forests and afforestation of unstocked areas contribute to improving biodiversity status and enhancing the natural biological richness of Serbia. This species is significant not only for the conservation of plant diversity but also for wildlife, as it provides a valuable food source for many animal species. Previoius experience has shown that in afforestation, in addition to proper species selection, it is necessary to consider characteristics of the planting material that are crucial for successful establishment (root system development, tolerance to temperature extremes, etc.). Planted broadleaved seedlings, including wild cherry, frequently experience transplant stress, which reduces their survival (Hemery et al., 2008; Savill et al., 2009; Eşen et al., 2012).

Fertilisation is one of the most common methods used to improve soil nutrient status. In modern nursery production, the application of nutritional preparations is not only a supplementary source of nutrients but also a powerful means and an important factor in producing high-quality planting stock.

The aim of this study was to examine the effect of a controlled-release fertiliser, marketed as Osmocote® Exact Standard 5-6 M, on height growth and survival of two-year-old transplanted (1+1) wild cherry seedlings (*Prunus avium* L.). Shoot height was measured at the beginning of the growing season, during the season, and at its end. Based on these measurements, height increment was calculated, and the survival percentage of the two-year-old nursery-grown seedlings was determined. The results showed a positive effect of the fertiliser on all assessed parameters. At the end of the growing season, the mean height of untreated seedlings was 68.8 cm, whereas treated seedlings reached 80.4 cm. The relative height increment of untreated two-year-old nursery-grown seedlings in the second year was 69.6%, while that of treated seedlings was 101.6%. Thus, control-release fertiliser application can enhance height growth and survival of wild cherry seedlings.

Slow-release fertilisers can improve seedling performance in nursery production. The findings of this study may support further improvements in the cultivation of wild cherry seedlings through the use of controlled-release fertilisers during the nursery stage. This approach could contribute to better planning of afforestation and the restoration of natural forest ecosystems on harsh sites, where post-planting survival of seedlings is generally lower.

UTICAJ ĐUBRIVA SA KONTROLISANIM OSLOBAĐANJEM NA VISINSKI PRIRAST DVOGODIŠNJIH ŠKOLOVANIH (1+1) SADNICA DIVLJE TREŠNJE (*Prunus avium* L.)

Tatjana ĆIRKOVIĆ-MITROVIĆ, Dragica VILOTIĆ, Milan REBIĆ, Ljiljana BRAŠANAC-BOSANAC

Rezime

Divlja trešnja (*Prunus avium* L.) je autohtona lišćarska vrsta koja raste u mešovitim šumama Evrope. Ima širok raspon nadmorske visine, od nizijskih područja do submontanih pojaseva. Na većim planinskim masivima može se naći i do 2.000 metara nadmorske visine (Russell, 2003).

Sakupljanje semena, proizvodnja sadnica divlje trešnje i njihovo unošenje u postojeće šume i pri pošumljavanju neobraslih površina doprinosi poboljšavanju stanja biodiverziteta i unapređenju prirodnog biološkog bogatstva Srbije. Ova biljna vrsta nije značajna samo za očuvanje biodiverziteta flore, već i za faunu, jer mnogim životinjskim vrstama služi kao hrana. Dosadašnja iskustva pokazala su da se pri pošumljavanju, osim pravilnog izbora vrste, mora voditi računa i o karakteristikama sadnog materijala koje su od značaja za uspeh pošumljavanja (razvijenost korenovog sistema, otpornost na temperaturne ekstreme i dr.). Sadnice lišćara (uključujući i divlju trešnju) često dožive stres prilikom presadnje, što smanjuje njihovo preživljavanje na terenu (Hemery et al., 2008, Savill et al., 2009, Eşen et al. 2012).

Đubrenje je najčešći način za poboljšanje hranljivog statusa zemljišta. Primena preparata ishrane u savremenoj rasadničkoj proizvodnji ne predstavlja samo dopunski izvor hranljivih materija, već i moćno sredstvo i značajan faktor u proizvodnji visokokvalitetnog sadnog materijala. Cilj ovog rada bio je da istraži uticaj đubriva sa kontrolisanim oslobađanjem komercijalnog naziva Osmocote® Exact Standard 5-6 M na visinski rast i preživljavanje dvogodišnjih školovanih (1+1) sadnica divlje trešnje (*Prunus avium* L.). Izmerene su visina izdanka na početku vegetacionog perioda, u toku i na kraju vegetacionog perioda. Na osnovu izmerenih visina izračunat je visinski prirast i utvrđen procenat preživljavanjea dvogodišnjih školovanih sadnica. Dobijeni rezultati pokazuju pozitivan uticaj preparata ishrane na sve ispitivane parametre. Prosečna visina na kraju vegetacionog perioda netretiranih sadnica bila je 68,8 cm, a tretiranih 80,4 cm. Relativna vrednost visinskog prirasta netretiranih školovanih dvogodišnjih sadnica u drugoj godini je bila 69,6%, a tretiranih 101,6%. Dakle, primena đubriva đubriva sa kontrolisanim oslobađanjem može poboljšati visinski prirast i preživljavanje sadnica divlje trešnje.

Spororazlagajuće đubrivo može poboljšati performanse sadnica u rasadniku. Istraživanja će omogućiti dalje unaptređenje i poboljšanje rasadničke proizvodnje sadnica divlje trešnje kroz upotrebu đubriva sa kontrolisanim oslobađanjem kod školovanja sadnica. Ovaj pristup mogao bi doprineti planiranju pošumljavanja i obnovi prirodnih šumskih ekosistema na ekstremnim staništima školovanim sadnicama, jer je preživljavanje nakon sadnje na ovakvim staništima manje.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 92, 2025 ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592061V
UDK: 581.5:582.284=111
Original scientific paper

THE EFFECT OF TEMPERATURE AND NUTRIENT MEDIUM ON GROWTH OF *Fistulina hepatica*

Aleksandar VEMIĆ[1], Sanja LAZIĆ[1], Katarina MLADENOVIĆ[1], Jelena BOŽOVIĆ[1], Danilo FURTULA[1], Bojan KONATAR[1], Radojica PIŽURICA[1]*

Abstract: *Fungus Fistulina hepatica represents one of the especially important fungi in forestry. Due to better knowledge of Fistulina hepatica bioecology as well as the possibility of usage, effect of temperature and nutrient media on pure cultures was investigated. Temperature of 25 °C was optimal for mycelium growth, while the biggest growth of cultures was recorded on MEA nutrient medium. Somewhat slower growth was recorded on SMA and PDA nutrient medium while the slowest growth was on CMA nutrient medium. On all nutrient media mycelium was white, while there were differences in shape of cultures. Obtained results indicate better possibility of stimulating and growing certain strains of Fistulina hepatica. Medicinal properties and usage of obtained results were discussed.*

Keywords: ecological conditions, heart rot, brown oak, usage

UTICAJ TEMPERATURE I HRANLJIVE PODLOGE NA RAZVOJ *Fistulina hepatica*

Sažetak: *Gljiva Fistulina hepatica predstavlja jednu od posebno značajnih gljiva u šumarstvu. Zbog boljeg poznavanja bioekologije Fistulina hepatica, kao i mogućnosti njenog intenzivnijeg korišćenja, ispitan je uticaj temperature i hranljive podloge na razvoj čistih kultura. Temperatura 25 °C je bila optimalna za razvoj micelije, dok je najveći rast kultura zabeležen na MEA hranljivoj podlozi. Nešto sporiji rast je zabeležen na SMA i PDA hranljivoj podlozi dok je najsporiji rast bio na CMA hranljivoj podlozi. Na svim hranljivim podlogama micelija je bila bele boje, dok su postojale razlike u izgledu kultura. Dobijeni rezultati ukazuju na bolju mogućnost stimulisanja i gajenja pojedinih sojeva Fistulina hepatica. Lekovita svojstva gljive i upotreba dobijenih rezultata su diskutivani.*

Ključne reči: ekološke karakteristike, centralna trulež, smeđi hrast, korišćenje

[1] Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
*Corresponding author. E-mail: aleksandar.vemic2@gmail.com

1. INTRODUCTION

The genus *Fistulina* consists of poroid fungi including edible species (González et al., 2021). *Fistulina hepatica* (Schaeff.) With. causes brown heart rot, most often in oaks (*Quercus* spp.), that in the initial phase leads to change in colour of the wood, and that is why this type of wood is especially valued in industry (Schwarze et al., 2000; Karadžić 2010). In addition to oaks, the occurrence of *F. hepatica* has also been confirmed on sweet chestnut (*Castanea sativa* Mill.) on which it causes similar damages (Piętka & Ciurzycki 2018).

In the case of sweet chestnut (*Castanea sativa*), a correlation was established between certain environmental factors such as altitude, stand density, average annual temperature, or exposure, and increase in rot intensity (Regué et al., 2019). The time of ripening of *F. hepatica* fruiting bodies has a greater significance then the temperature for spreading of spores of this fungus (Marčiulynas & Menkis 2023). Therefore, the objective of the research was to examine the influence of temperature and nutrient medium on the development of tested isolate of *F. hepatica*. The obtained results will have simultaneous importance in the protection of forests as well as in better production, i.e. the use of this fungus.

2. MATERIAL AND METHOD

2.1 The examining of the effect of temperature on the growth of cultures

The isolate of *F. hepatica*, strain HF1 was taken from mycological collection of the Institute of Forestry, Belgrade. Fragments measuring 5×5 mm were placed in the centre of petri dish on 3% MEA (malt extract - Biolab, Hungary; agar - Torlak, Serbia) nutrient medium.

The petri dishes were exposed to temperatures of 12 °C, 17 °C, 25 °C and 30 °C. The experiment was completed after 34 days when the first culture filled the petri dish, and all cultures showed clear growth. Each of the temperatures contained 3 repetitions. The diameter of the cultures was measured in 2 directions at right angles from the centre of the petri dish. The average diameter value was used for comparing the growth.

2.2 The examining of the effect of nutrient medium on the growth of cultures

For examining of the effect of nutrient medium on the growth of cultures, the isolate of *F. hepatica*, identical as in the experiment of examining the effect of temperature was used. Four types of nutrient media were selected: sabouraud maltose agar (SMA; Torlak, Serbia), malt extract agar (MEA; Lab M, UK), corn meal agar (CMA; Himedia, India) and potato dextrose agar (PDA; Lab M, UK). Each of the nutrient media contained 9 to 10 repetitions. Cultures were stored in an incubator at 25 °C in dark regime. The experiment was completed after 25 days when the first culture filled petri dish. The diameter of the cultures was measured in the same way as when examining the effect of temperature.

2.3 Statistical methods

The dimensions of cultures in experiments were tested for normality and homogeneity of variances, as well as normality of residuals. Depending on the statistical significance of the result, parametric or non-parametric tests were used. General linear model (GLM) was used for examining the effect of temperature on the growth of cultures. Tukey's post hoc test was used for determining the differences in growth of cultures between different pairs of temperatures.

Kruskal-Wallis test was used for testing of differences in dimensions of cultures on different nutrient media. Dunn's post hoc test was used for comparison of different pairs of cultures between tested nutrient media.

All statistical analyses were carried out using software packages SPSS 27 (IBM Corp.) and Microsoft Office Excel 2021 (Microsoft Corp.).

3. RESULTS AND DISCUSSION

There was statistically significant difference in the growth of *F. hepatica* cultures at different temperatures ($F = 662.938$; $p < 0.001$). Cultures at 12 °C showed the slowest growth, with an average diameter of cultures of 8.00 mm (Figure 1). Larger dimensions of cultures, with an average value of 51.17 ± 3.75 were at 17 °C (Figure 1). The largest diameter of cultures was recorded at 25 °C, and it amounted to 80.17 ± 1.53 mm (Figure 1). At 30 °C the growth of the cultures was also good, with an average value of 65.17 ± 1.04 mm, slightly smaller then at 25 °C (Figure 1).

The colour of the mycelia was the same at all temperatures. The cultures were white, cottony and raised around inoculum.

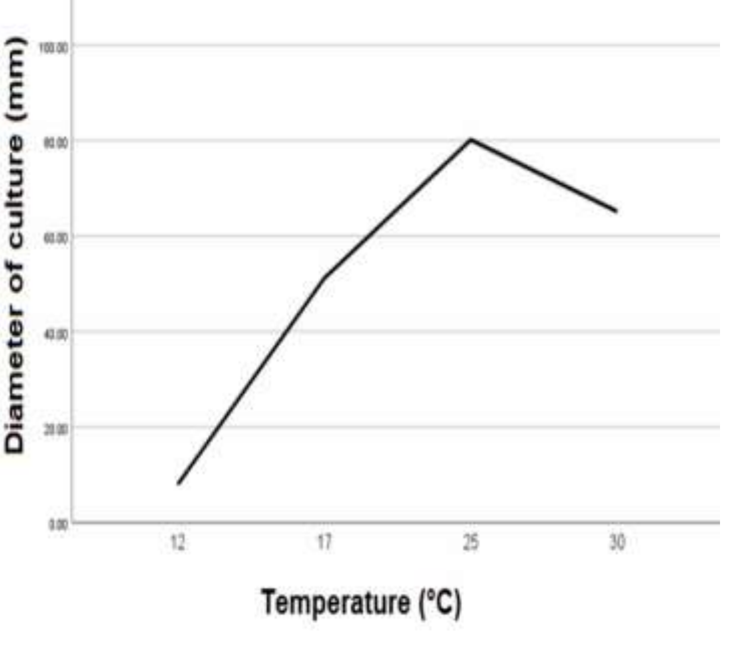


Figure 1. *Growth of Fistulina hepatica cultures at different temperatures*

Nutrient medium showed great influence on growth and appearance of the cultures (Figure 2, Figure 3). There was statistically significant difference in growth of cultures on different nutrient media ($H = 27.737$; $p < 0.001$).

The largest growth of cultures was on MEA nutrient medium (81.22 ± 2.25 mm), and somewhat slower on PDA nutrient medium (78.05 ± 1.99 mm). Nutrient medium SMA showed the same growth as MEA and PDA, i.e. it was on the transition between these two nutrient media (80.80 ± 0.86 mm). The slowest growth of the cultures was on CMA nutrient medium (69.75 ± 2.62 mm).

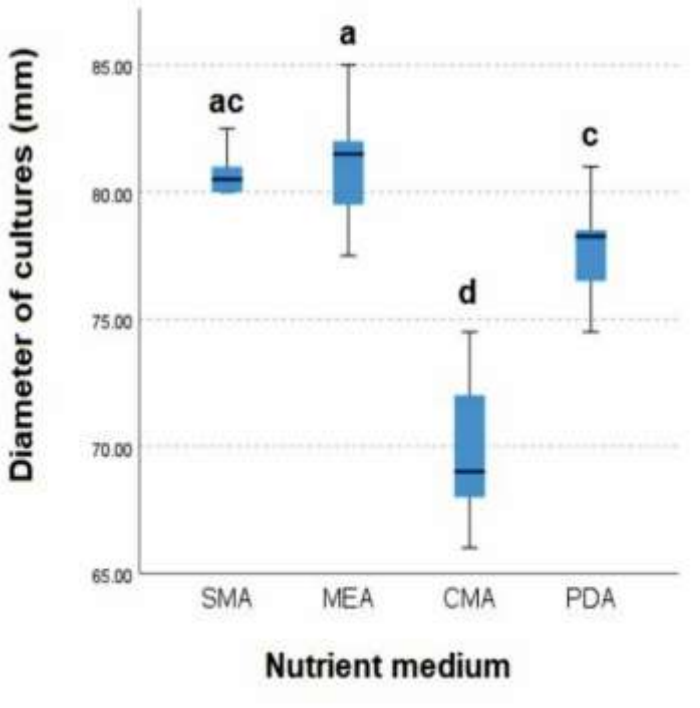


Figure 2. *Growth of Fistulina hepatica cultures on different nutrient media*

The appearance of cultures differed depending on the nutrient medium used (Figure 3). On SMA nutrient medium, the mycelia were white, solid, compact, occasionally grey in central part (Figure 3). On MEA and PDA nutrient media it was white, velvety, cottony, raised around inoculum (Figure 3). On CMA nutrient medium the mycelia were white, raised around inoculum, slightly concentric (Figure 3).

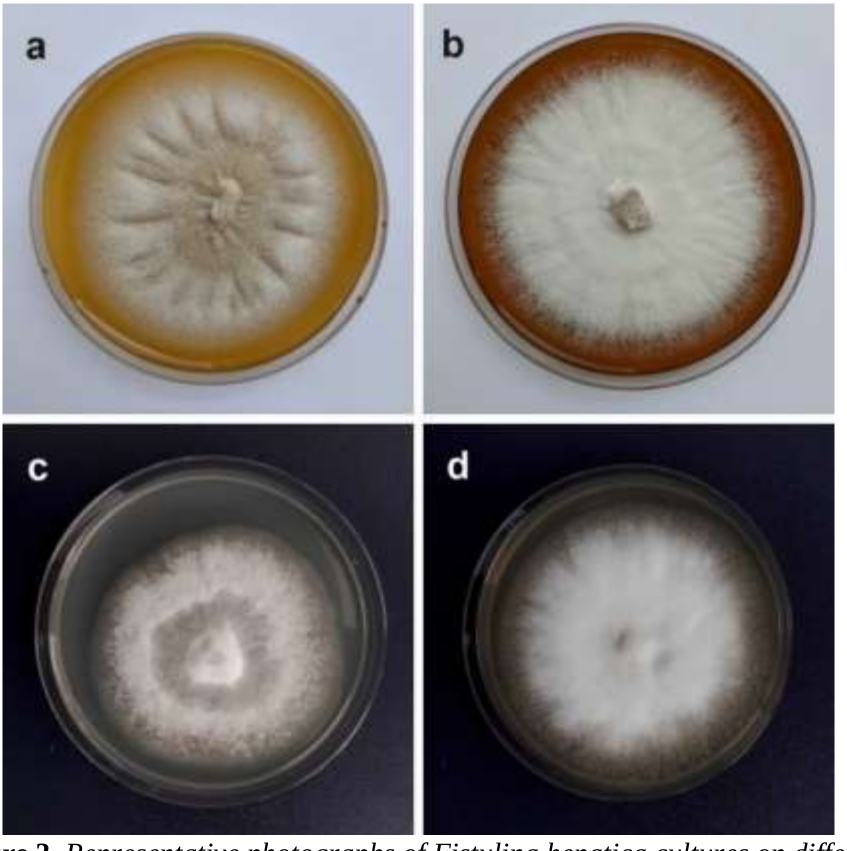


Figure 3. *Representative photographs of Fistulina hepatica cultures on different nutrient media: a) SMA, b) MEA, c) CMA, d) PDA*

The most important medicinal properties of *F. hepatica* are presented below, based on literature review (Table 1). Several categories of the most important medicinal properties were singled out regarding literature sources (Table 1).

Table 1. *Medicinal properties of Fistulina hepatica*

Use value	Component	Reference
Antibacterial properties	Methanolic extracts, polyacetylenic fatty acid derivatives, octadeca-8,11-dienoic acid methylester	Karaman et al. (2009) Aleem et al. (2012) Ivanova et al. (2013) Dubljanin et al. (2018) Whaley et al. (2023)
Antifungal properties	Feldin	Lee et al. (2020)
Antioxidant properties	Alkali extracts	Oke & Aslim (2011) Savino et al. (2016) Dubljanin et al. (2018) Rašeta et al. (2025)
Bioactive components	Proteins, phenols	Yıldız et al. (2017), Fedotov (2020)
Other properties (diabetes treatment, etc.)	Volatile components	Wu et al. (2005) Rašeta et al. (2025)
Traditional use	-	Jorjadze et al. (2023)

Efficient use of *F. hepatica*, as well as preventing damages which occur in woods depend on timely detection of this fungus. In the case of sweet chestnut (*Castanea sativa*) wood loses its value even in the initial stage of rotting due to the change of colour of wood (Meijer et al., 2025). It has been determined that higher temperatures have a more favourable effect on the development of this fungus than lower temperatures. In this sense, an increase of temperature as a consequence of climate change can have a negative effect on the trees, increasing damages. Heart rot has a long period of development, while infection is present on young trees (Vasaitis 2013). Therefore, earlier thinning of the stands significantly reduces occurrence of this fungus (Meijer et al., 2024). Hence, more frequent monitoring of the health and vitality of the trees is recommended.

On the other hand, occurrence of *F. hepatica* fruiting bodies can be positive for easier isolation and use of this fungus. Determined optimal temperature and nutrient medium can significantly accelerate the growth of certain isolates of *F. hepatica*. Cultivation of *F. hepatica* has several advantages. First of all, there are examples that the content of metals, including heavy metals, is higher in wild than in cultivated specimens of *F. hepatica* (Yildiz et al., 2019; Thachunglura et al., 2025).

Taxonomy of the species *F. hepatica* is insufficiently studied. The imperfect stage of *F. hepatica* belongs to the genus *Confistulina* (Stalpers & Vlug 1983). Intensive cultivation of *F. hepatica*, comparing of different isolates, and inoculation of trees can significantly contribute to better knowledge of morphology of this fungus.

5. CONCLUSION

This paper presents the effect of temperature and nutrient medium on the growth of cultures of the tested isolate of *F. hepatica*. The obtained results have a great significance for understanding the intensity of the rot in natural conditions, as well as the possibility of cultivation of the fungus *F. hepatica*. In accordance with the obtained results the stated conclusions can be presented as follows:

- The optimal temperature for growth of the tested isolate was 25 °C. The smallest growth was recorded at 12 °C. Somewhat larger growth was at 17 °C and 30 °C.
- The average growth rate at 25 °C amounted to 2.36 mm/day, while at 12 °C it amounted to 0.24 mm/day. At 17 °C and 30 °C the average growth rate was 1.50 mm/day and 1.92 mm/day.
- The best nutrient medium for growth of *F. hepatica* cultures was malt extract agar (MEA). Similar growth occurred on potato dextrose agar (PDA), while the growth was somewhat smaller on corn meal agar (CMA). The smallest growth was on sabouraud maltose agar (SMA) nutrient medium.
- The cultures of *F. hepatica* were white on all nutrient media. However, the appearance of the mycelia differed depending on the nutrient medium.
- The most important medicinal properties of *F. hepatica* were divided in several groups: antibacterial properties, antifungal properties, antioxidant

properties and other properties such as the treatment of diabetes. In addition, *F. hepatica* has many bioactive components which can be used in different ways.

Acknowledgement: *This research was carried out under the Agreement on funding by the Ministry of Science, Technological Development and Innovation for the year 2025 451-03-136/2025-03/200027.*

REFERENCE

Aleem, A., Anjum, N.F., & Kavitha, A.N. (2012). Comparative In Vitro Antimicrobial Activity of Three different Macro Fungus Extracts Against Clinical Isolates of Gram-Negative Pathogens. *Research Journal of Pharmacognosy and Phytochemistry, 4(1),* 29-32.

Dubljanin, T., Petrović, M., Kozarski, M., Vunduk, J., Nikšić, M. & Klaus, A. (2018). *Antioxidant and antimicrobial activity of mushrooms Daedalea quercina and Fistulina hepatica*. In M. Pojić (Ed.), IV International congress Food technology, quality and safety (pp.110-116). https://fiver.ifvcns.rs/bitstream/id/6766/bitstream_6766.pdf

Fedotov, O.V. (2020). Phenolic substances as regulators of the intensity of lipid peroxidation processes of the strains *Pleurotus eryngii*, *Fistulina hepatica* and *Agrocybe cylindracea*. *Regulatory Mechanisms in Biosystems, 11(2),* 232-236. https://doi.org/10.15421/022034

González, G.C., Barroetaveña, C., Visnovsky, S.B., Rajchenberg, M., & Pildain, M.B. (2021). A new species, phylogeny, and a worldwide key of the edible wood decay *Fistulina* (Agaricales). *Mycological Progress, 20,* 733-746. https://doi.org/10.1007/s11557-021-01696-7

Ivanova, V., Kolarova, M., Aleksieva, K., Schlegel, R., Schumann, P., & Graefe, U. (2013). Octadeca-8,11-dienoic Acid Methylester, a New Fatty Acid Metabolite from *Fistulina hepatica*. *Journal of Modern Medicinal Chemistry, 1(1),* 43-48. https://doi.org/10.12970/2308-8044.2013.01.01.4

Jorjadze, A., Bussmann, R.W., Paniagua Zambrana, N.Y., Batsatsashvili, K., & Svanidze, E. (2023). Traditional use of Polypores in Georgia (the Caucasus). *Ethnobotany Research and Applications, 26,* 1-18. http://dx.doi.org/10.32859/era.26.5.1-18

Karadžić, D. (2010). Šumska fitopatologija, Univerzitet u Beogradu, Šumarski fakultet.

Karaman, M., Mimica-Dukic, N., Knezevic, P., Svircev, Z., & Matavuly, M. (2009). Antibacterial Properties of Selected Lignicolous Mushrooms and Fungi from Northern Serbia. *International Journal of Medicinal Mushrooms, 11(3),* 269-279. https://doi.org/10.1615/IntJMedMushr.v11.i3.60

Lee, J., Shi, Y.-M., Grün, P., Gube, M., Feldbrügge, M., Bode, H., & Hennicke, F. (2020). Identification of Feldin, an Antifungal Polyyne from the Beefsteak Fungus *Fistulina hepatica*. *Biomolecules, 10(11),* 1502. https://doi.org/10.3390/biom10111502

Marčiulynas A, & Menkis A. (2023). The Release and Spread of Basidiospores of Red-Listed Wood-Decay Fungus *Fistulina hepatica* in Oak Stands. *Diversity, 15(11),* 1110. https://doi.org/10.3390/d15111110

Meijer, A., Muñoz-Adalia, E. J., & Colinas, C. (2024). Early Thinning: A Promising Tool to Prevent *Fistulina hepatica* Heart Rot in *Castanea sativa* Coppice Stands. *Forests*, *15*(9), 1639. https://doi.org/10.3390/f15091639

Meijer, A., Muñoz-Adalia, E.J., Correal-Mòdol, E., & Colinas, C. (2025). Early detection of heartwood rot caused by *Fistulina hepatica* in *Castanea sativa* productive coppices through low-invasive resistance drilling. *Wood Science and Technology, 59,* 10. https://doi.org/10.1007/s00226-024-01616-4

Oke, F., & Aslim, B. (2011). Protective effect of two edible mushrooms against oxidative cell damage and their phenolic composition. *Food Chemistry, 128(3),* 613-619. https://doi.org/10.1016/j.foodchem.2011.03.036

Piętka, J., & Ciurzycki, W. (2018). The first record of *Fistulina hepatica* (Schaeff.) With. on *Castanea sativa* Mill. in Poland. *Acta Mycologica, 53(1),* 1108. https://doi.org/10.5586/am.1108

Rašeta, M., Mišković, J., Kebert, M., Berežni, S., Krstić, S., Gojgić-Cvijović, G., Pirker, T., Bauer, R., & Karaman, M. (2025). Mycochemical profiles and bioactivities of *Fistulina hepatica* and *Volvopluteus gloiocephalus* from Serbia: Antioxidant, enzyme inhibition, and cytotoxic potentials. *Food Bioscience, 66,* 106221. https://doi.org/10.1016/j.fbio.2025.106221

Regué, A., Bassié, L., de-Miguel, S., & Colinas, C. (2019). Environmental and stand conditions related to *Fistulina hepatica* heart rot attack on *Castanea sativa*. *Forest Pathology*, *49(3),* e12517. https://doi.org/10.1111/efp.12517

Savino, E., Girometta, C., Miteva-Staleva, J., Kostadinova, A., & Krumova, E. (2016). Wood decay macrofungi: strain collection and studies about antioxidant properties. *Comptes rendus de l'Académie bulgare des Sciences, 69(6)*, pp. 747+.

Schwarze, F.W.M.R., Baum, S., & Fink, S. (2000). Dual modes of degradation by *Fistulina hepatica* in xylem cell walls of *Quercus robur*. *Mycological Research, 104,* 846-852. https://doi.org/10.1017/S0953756299002063

Stalpers, J.A., & Vlug, I. (1983). *Confistulina*, the anamorph of *Fistulina hepatica*. *Canadian Journal of Botany, 61(6),* 1660-1666. https://doi.org/10.1139/b83-178

Thachunglura, V.L., Rai, P.K., Chawngthu, Z., Lalzarzovi, S.T., Zothanzama, J., & Vanlalhluna, P.C. (2025). Heavy metals bioaccumulation in wild edible mushrooms of an Indo Burma biodiversity hotspot: Suitability assessment for safe consumption and food safety/security implications. *International Journal of Environmental Quality, 70,* 66-75. https://doi.org/10.6092/issn.2281-4485/21806

Vasaitis, R. (2013). Hearth Rots, Sap Rots and Canker Rots, In P. Gontier., & G. Nicolotti (Eds.), *Infectious forest diseases,* (pp. 197-229). CAB International, UK. https://doi.org/10.1079/9781780640402.0197

Whaley, A.O., Whaley, A.K., Orlova, A.A., Volobuev, S.V., Shakhova, N.V, Smirnov, S.N., Pustovit, N.V., & Kraeva, L.A. (2023). Polyacetylene Derivatives from the Polypore Fungus

(*Fistulina hepatica,* Agaricomycetes) and Their Antimicrobial Activity. *International Journal of Medicinal Mushrooms, 25(12)*, 43-53. https://doi.org/10.1615/IntJMedMushrooms.2023050525

Wu, S., Krings, U., Zorn, H., & Berger, R.G. (2005). Volatile compounds from the fruiting bodies of beefsteak fungus *Fistulina hepatica* (Schaeffer: Fr.) Fr. *Food Chemistry, 92(2),* 221-226. https://doi.org/10.1016/j.foodchem.2004.07.013

Yildiz, S., Gürgen, A., & Çevik, U. (2019). Accumulation of metals in some wild and cultivated mushroom species. *Sigma Journal of Engineering and Natural Sciences, 37(4),* 1375-1384.

Yıldız, S., Yılmaz, A., Can, Z., Adel Tabbouche, S., Kılıç, A.O., & Sesli, E. (2017). Some bioactive properties of wild and comertial mushroom species. *Journal of Food and Health Science, 3(4)*, 161-169. https://doi.org/10.3153/JFHS17019

THE EFFECT OF TEMPERATURE AND NUTRIENT MEDIUM ON GROWTH OF *Fistulina hepatica*

Aleksandar VEMIĆ, *Sanja LAZIĆ*, *Katarina MLADENOVIĆ*, *Jelena BOŽOVIĆ*, *Danilo FURTULA*, Bojan *KONATAR*, *Radojica PIŽURICA*

Summary

Knowledge of bioecological characteristics of different fungi has great importance for various aspects in forestry. Importance of fungus *Fistulina hepatica* is reflected in specific influence on wood colour in initial decay stage. Moreover, *F. hepatica* possesses great medicinal properties. In this study, the effect of temperature and nutrient medium on the development of *F. hepatica* cultures were examined.

Results showed effect of temperature and nutrient medium on growth rate and characteristics of cultures. The fastest growth was recorded at 25°C, followed with 30°C, something smaller growth at 17°C while the smallest growth was at 12°C. The best nutrient medium for *F. hepatica* growth was malt extract agar (MEA). Nutrient media sabouraud maltose agar (SMA) and potato dextrose agar (PDA) showed similar and somewhat weaker effect on growth of *F. hepatica* mycelium. Cultures of *F. hepatica* had the slowest growth on corn meal agar (CMA) nutrient medium.

Appearance of cultures was different according to nutrient medium. On SMA nutrient medium mycelium was compact with expressed stretches, while aerial on edges. On MEA and PDA nutrient media mycelia was fallen, cottony, velvety, on place of inoculum raised. On CMA nutrient medium mycelium was concentric, on place of inoculum also raised.

Prevention of greater damages of trees and medicinal properties of *F. hepatica* were discussed.

UTICAJ TEMPERATURE I HRANLJIVE PODLOGE NA RAZVOJ *Fistulina hepatica*

Aleksandar VEMIĆ, *Sanja LAZIĆ*, *Katarina MLADENOVIĆ*, *Jelena BOŽOVIĆ*, *Danilo FURTULA*, Bojan *KONATAR*, *Radojica PIŽURICA*

Rezime

Poznavanje bioekoloških karakteristika različitih gljiva ima veliki značaj za različite aspekte šumarstva. Značaj gljive *Fistulina hepatica* se ogleda u specifičnom uticaju na boju drveta u početnoj fazi truleži. Osim toga, *F. hepatica* poseduje velika medicinska svojstva. U ovoj studiji je ispitan uticaj temperature i hranljive podloge na rast kultura *F. hepatica*.

Rezultati su pokazali uticaj temperature i hranljive podloge na brzinu i karakteristike kultura *F. hepatica*. Najbrži rast kultura je zabeležen na 25°C, potom na 30°C, nešto manji rast na 17°C dok je najmanji rast bio na 12°C. Najbolja hranljiva podloga za razvoj *F. hepatica* je bila malc ekstakt agar (MEA). Hranljive podloge sabouraud maltoza agar (SMA) i krompir dekstroza agar (PDA) su pokazale sličan i nešto slabiji efekat na rast micelije *F. hepatica*. Kulture *F. hepatica* na hranljivoj podlozi kukuruzna kaša agar (CMA) su imale najsporiji rast.

Izgled kultura se razlikovao na različitim hranljivim podlogama. Na SMA hranljivoj podlozi micelija je bila kompaktna sa izraženim linijama i po ivicama vazdušna. Na MEA i PDA hranljivoj podlozi micelija je bila polegla, pamučna, baršunasta, na mestu inokuluma podignuta. Na CMA hranljivoj podlozi micelija je bila koncentrična, na mestu inokuluma takođe podignuta.

Sprečavanje većih šteta na stablima i medicinska svojstva *F. hepatica* su diskutovani.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY COLLECTION 92, 2025
ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592071R
UDK: 630*53:582.632.2=111
Original scientific paper

LIVE CROWN RATIO AND SLENDERNESS COEFFICIENT AS INDICATORS OF BEECH TREE STABILITY

Miloš RAČIĆ[1], Nenad PETROVIĆ[2], Nikola MARTAĆ[1], Jovan DOBROSAVLJEVIĆ[2], Janko LJUBIČIĆ[2], Ivana RAČIĆ[1], Branko KANJEVAC[2]*

Abstract: *This study investigates the applicability of the live crown ratio (LCR) and the slenderness coefficient (SC) as indicators of tree and stand stability of European beech (Fagus sylvatica L.). The research was conducted within the Forest Management Unit (FMU) "Lomnička Reka", managed by the Public Enterprise "Srbijašume". Data were obtained from the stand inventory of the analyzed FMU, conducted on a network of permanent sample plots. The analysis focused on five structurally uneven-aged stands, encompassing 103 beech trees belonging to the middle-aged silvicultural group across eight sample plots. For each measured tree, both the live crown ratio and the slenderness coefficient were determined. Logistic regression and Conditional Inference Tree (CIT) analyses were used to identify critical LCR thresholds distinguishing slender from non-slender trees, with bootstrap procedures employed to assess the stability of the results. The findings revealed a significant negative relationship between LCR and SC (p < 0.001), with a critical LCR threshold of approximately 0.36–0.40 identified as necessary to maintain tree stability. Both statistical approaches yielded consistent results, supporting the robustness of LCR as a reliable predictor of slenderness. The obtained results emphasize the importance of analyzing these parameters during the process of planning silvicultural measures, particularly thinning, aiming to enhance tree stability, and improve the overall resilience of beech stands.*

Keywords: beech, live crown ratio, slenderness coefficient, stand stability.

RELATIVNA DUŽINA ŽIVE KRUNE I KOEFICIJENT VITKOSTI KAO INDIKATORI STABILNOSTI STABALA BUKVE

Sažetak: *Ova studija istražuje primenljivost relativne dužine žive krune (LCR) i koeficijenta vitkosti (SC) kao pokazatelja stabilnosti stabala i sastojina evropske bukve (Fagus sylvatica L.). Istraživanje je sprovedeno u okviru gazdinske jedinice (FMU) „Lomnička Reka“, kojom upravlja Javno preduzeće „Srbijašume“. Podaci korišćeni u ovoj studiji dobijeni su iz sastojinske inventure analizirane gazdinske jedinice, sprovedene na mreži permanentnih primernih površina. Analiza je obuhvatila pet sastojina, strukturno raznodobnih, sa ukupno 103 stabla bukve na 8 primernih površina koje pripadaju*

[1] Institute of Forestry, Belgrade, Serbia
[2] Faculty of Forestry University of Belgrade, Belgrade, Serbia
*Corresponding author. E-mail: milos.racic@forest.org.rs

srednjedobnoj uzgojnoj grupi. Za svako izmereno stablo određeni su relativna dužina žive krune i koeficijent vitkosti. Za identifikaciju kritičnih vrednosti LCR koje razdvajaju vitka od nevitkih stabala korišćene su logistička regresija i analiza uslovnog stabla zaključivanja (CIT), dok su bootstrap postupci primenjeni za procenu stabilnosti dobijenih rezultata. Rezultati ukazuju na značajnu negativnu vezu između LCR i SC (p < 0.001), pri čemu je utvrđen kritični prag LCR od približno 0.36–0.40 kao neophodan za održavanje stabilnosti stabala. Obe statističke metode dale su konzistentne rezultate, potvrđujući pouzdanost LCR kao prediktora vitkosti. Dobijeni rezultati ukazuju na potrebu da se ovi parametri analiziraju u postupku planiranja uzgojnih mera, posebno proreda, sa ciljem povećanja stabilnosti stabala i poboljšanja ukupne otpornosti sastojina bukve.

Ključne reči: bukva, relativna dužina žive krune, koefiicijent vitkosti, stabilnost sastojine.

1. INTRODUCTION

Climate change has been identified as one of the greatest global challenges (Psistaki et al, 2024). Forest ecosystems, which cover an area of 4.06 billion hectares globally (FAO, 2020), are recognized as a fundamental component of the Earth`s climate system (Brack, 2019) while being significantly affected by climate change impacts (Kirilenko et al, 2007; Aaheim et al, 2011; Tian et al, 2016; Marković et al, 2019). These impacts are manifested through the generation of various biotic and abiotic risks (Venäläinen et al, 2020). Due to climate change, the frequency of extreme events is expected to rise (Lidskog and Sjödin, 2016; Campbell et al, 2020). The resilience of forest ecosystems, defined as their capacity to recover from such adverse effects (Ibáñez et al, 2019), has declined in tropical, arid, and temperate forests (Forzieri et al, 2022). Adequate forest management can enhance the resilience of forest stands, thereby ensuring the preservation of ecosystem services and biodiversity (Triviño et al, 2023).

Tree crowns represent a fundamental structural feature of both individual trees and entire forest stands, owing to the multitude of ecological and functional roles they fulfill (Zhu et al, 2021; Jucker et al, 2025). A significant role of tree crowns is reflected in biomass production and the process of photosynthesis (He et al, 2023). By hosting nearly 50% of terrestrial biodiversity (Lowman, 2021), tree crowns constitute a key structural component essential for sustaining and protecting biological diversity within forest ecosystems (Matsumoto et al, 2017). Proper crown formation, achieved through adequate and timely implementation of silvicultural treatments, greatly enhances the stability of individual trees and forest stands (Kaźmierczak and Jędraszak, 2014; Pretzsch, 2014). In the context of climate change, tree crowns may play a critical role in the adaptation and response of forest ecosystems (McNeil et al, 2023).

The study of crown structural elements is of great practical importance for the forestry profession (Stajić et al, 2017). One of the key indicators of crown structure is the live crown ratio (LCR), defined as the proportion of the total tree height that has live foliage (Zarnoch et al, 2004). LCR is used as an indicator of tree vigor, as higher values of LCR generally indicate greater vitality and favorable physiological condition (Schomaker et al, 2007). Trees with low LCR are generally less structurally stable and more susceptible to mechanical damage, which underscores the significance of LCR as an indicator of both tree vitality and stand stability (Karamzadeh et al, 2023). In addition to being an indicator of tree vigor and stand stability, LCR also serves as an indicator of tree and stand growth, with research showing that trees with higher LCR values generally exhibit greater growth rates (Patton et al, 2019), which is of considerable practical importance for forestry, particularly in the implementation of silvicultural treatments.

Besides crown characteristics, several other parameters have been identified as important indicators of tree stability, among which the slenderness coefficient (SC) is particularly significant. Defined as the ratio of total tree height to diameter at breast height, SC has been widely acknowledged in silvicultural research as a robust and practical measure of tree resistance to mechanical stresses caused by external factors such as wind, snow, and ice (Wang et al, 1998; Kanjevac et al, 2023). Previous studies have shown that SC is negatively correlated with diameter at breast height, basal area, and tree volume, while exhibiting a positive relationship with total tree height (Shamaki, 2022).

European beech (*Fagus sylvatica*) forests are the most widespread forest type in Serbia, covering 660,400 ha (29.3% of the total forested area) and occurring across altitudes from 100 to 1,700 m (Banković et al, 2009). Given their ecological significance, economic value, and role in maintaining biodiversity and forest stability, the study of beech forests is of paramount importance for sustainable forest management.

Based on the ecological and silvicultural importance of beech forests and the critical role of crown structure, this study aims to evaluate the applicability of the live crown ratio as a tool for guiding tending interventions to promote and maintain vigorous European beech stands.

2. MATERIAL AND METHODS

The research was conducted within the Forest Management Unit (FMU) "Lomnička Reka", which is managed by the Public Enterprise "Srbijašume" (Figure 1). The FMU is located in the municipality of Kruševac, Central Serbia (between 18°59′ and 19°05′ E, and 43°24′ and 43°28′ N), at elevations ranging from 300 to 1394 m above sea level. The total area of the management unit is 3,399.96 ha. The mean annual temperature is 12.5 °C, while the total annual precipitation amounts to 1025.7 mm. The predominant forest management type is mixed beech high forest, covering an area of 2,300.48 ha, of which 432.11 ha (18.8%) belong to the middle-aged silvicultural group that constitute the primary focus of this research (Forest Management Plan "Lomnička Reka" 2026 – 2035).

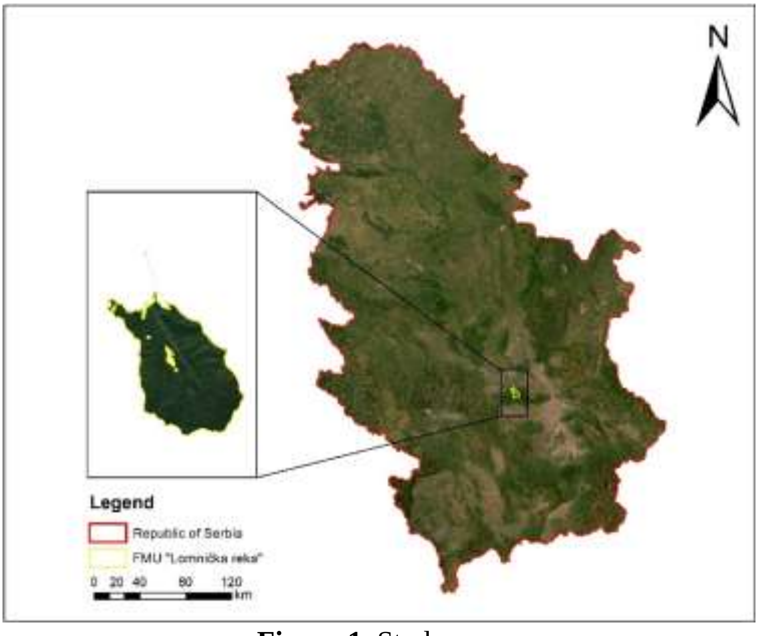


Figure 1. Study area

The data used in this study were obtained from the stand inventory of the analyzed FMU, conducted on a network of permanent sample plots spaced 200 × 200 m apart. Sampling was performed using a system of concentric circular plots with areas of 0.02 and 0.05 ha, followed by field verification to ensure data accuracy. The analysis focused on five structurally uneven-aged stands, encompassing 103 beech trees across eight sample plots belonging to the middle-aged silvicultural group.

For each measured tree, both the live crown ratio and the slenderness coefficient were determined. The live crown ratio (LCR) is defined as the ratio of the length of the live crown to the total tree height:

$$LCR=CL/H$$

where CL represents the crown length (m) and H is the total tree height (m).

The slenderness coefficient (SC) is defined as the ratio of the total tree height to the diameter at breast height, with both measurements expressed in centimeters:

$$SC=H/DBH$$

where H is the total tree height and DBH is the diameter at breast height measured at 1.3 m above ground. Based on SC values, trees were classified into two categories: slender (above 80) and non-slender (below 80) (Pach et al, 2022; Wonn and O`hara, 2001; Skrzyszewski and Pach, 2020).

To identify the critical LCR threshold distinguishing slender from non-slender trees, two statistical approaches were applied. The first was logistic regression, in which the probability of a tree being slender was estimated as a function of LCR. The threshold was defined as the inflection point of the model, corresponding to a 50% probability of slenderness. Logistic regression was used to analyze the effect of the LCR on the probability of a tree being slender. The model is defined by the formula:

$$\ln(P/(1-P)) = \beta 0 + \beta 1 x LCR$$

P represents the probability that a tree is slender, β0 is the intercept, and β1is the coefficient for LCR.

The stability of this threshold was assessed using a bootstrap procedure with confidence interval estimation. The predictive performance of the model was evaluated using the Receiver Operating Characteristic (ROC) curve and the Area Under the Curve (AUC). The ROC illustrates the relationship between sensitivity and the false positive rate, and the AUC quantifies the overall ability of the model to discriminate between slender and non-slender trees.

The second approach applied was the Conditional Inference Tree (CIT), which partitions trees into groups based on LCR and assesses the statistical significance of the splits. Bootstrap analysis was also employed to the CIT threshold to evaluate the reliability of the obtained values.

This combined approach allows both statistical and visual assessment of the relationship between LCR and tree slenderness, with identification of critical thresholds relevant for silvicultural practice. A similar methodological approach has been used for determining the LCR threshold for stability in Turkey oak (*Quercus cerris*) stands (Stancioiu et al, 2021) and to establish habitat thresholds for deadwood, which serve as a basis for management recommendations in European forests (Müller and Bütler, 2010). All data processing and statistical analyses were conducted using R (R core Team, 2025).

3. RESULTS AND DISCUSSION

The descriptive statistics (Table 1) revealed that the mean slenderness coefficient (SC) was 77.81, with values ranging from 34.74 to 143.64. The relatively high standard deviation (24.40) indicates notable variability in tree slenderness within the stand. The average LCR was 0.397, with a range from 0.125 to 0.812, showing a moderate variation among trees (SD = 0.131).

Table 1. *Descriptive statistics of SC and LCR*

Variable	N	Mean	SD	SE	Min	Max
SC	103	77.81	24.40	2.40	34.74	143.64
LCR	103	0.397	0.131	0.013	0.125	0.812

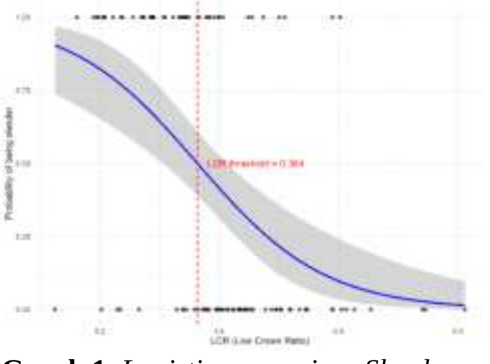
Trees with a high SC are more vulnerable (Šēnhofa et al, 2020), as their stems are not adapted to withstand high mechanical disturbances (Valinger and Fridman, 1997). Studies conducted in beech stands indicate that thinning regimes have a significant effect on the slenderness coefficient, with the lowest values observed in stands managed using the crown thinning method (Stefančík et al., 2018). Research conducted in stands of other tree species likewise underscores the significance of timely and appropriately implemented silvicultural interventions in enhancing stand stability and resilience. The study of the effects of stocking and thinning on wind damage in *Pinus radiata* plantations indicated that the SC is a significant indicator of tree stability. Lower stocking density and appropriate thinning reduce slenderness, increase stem diameter, and promote the development of crowns and roots, which significantly reduce the risk of stem breakage and wind damage (Cremer et al, 1982). Similar results were obtained in the studies of Douglas-fir plantations, where the importance of timely thinning was highlighted, and early interventions were shown to reduce SC and increase tree stability (Wilson and Oliver, 2000). Therefore, the SC can be used as a practical indicator in the planning of silvicultural management measures.

The estimated coefficients show that the intercept was 3.4218, while the coefficient for LCR was -9.4111, which was statistically significant ($p < 0.001$). The positive intercept indicates that when LCR = 0, the probability of a tree being slender is high, whereas the negative LCR coefficient indicates increasing LCR decreases the probability of slenderness (Table 2).

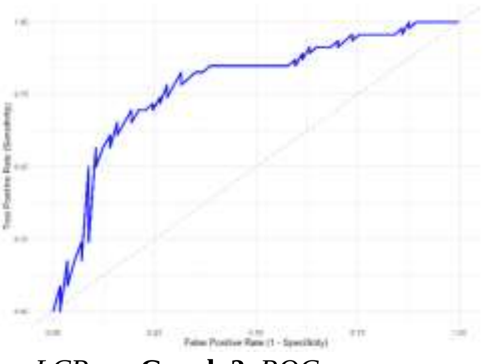
Table 2. *Results of Logistic regression*

Predictor	Estimate	Std. Error	Z value	p value	Inflection point (LCR)	AUC
Intercept	3.4218	0.8903	3.843	0.0001	0.364	0.785
LCR	-9.4111	2.2792	-4.129	0.000036		

This result confirms the inverse relationship between LCR and tree slenderness, which is consistent with expectations and previous studies. Based on the estimated coefficients, the model's inflection point– the LCR threshold at which the probability of slenderness is 50%– was calculated as 0.364 (Graph 1). This threshold represents a practical boundary for distinguishing between slender and non-slender trees and may serve as a guideline in silvicultural practice, for instance, in planning thinning treatments or selecting trees for removal. The predictive performance of the model was evaluated using the ROC curve (Graph 2), with an AUC of 0.785 (Table 2), indicating a good ability of the model to discriminate between slender and non-slender trees and confirming that LCR can be a reliable predictor of tree slenderness in the analyzed sample.

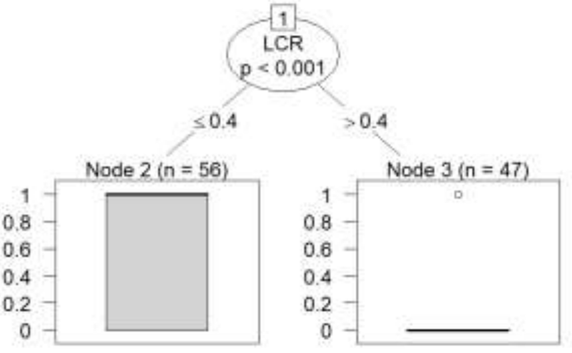


Graph 1. *Logistic regression: Slenderness ~ LCR*



Graph 2. *ROC curve*

The analysis using the CIT model divided the trees into two statistically significant groups based on LCR values: trees with LCR ≤ 0.4 were predominantly slender, whereas trees with LCR > 0.4 largely belonged to the non-slender category (Graph 3). Similar results from previous studies, based on the regression model, indicate that in order for European beech trees (*Fagus sylvatica* L.) to maintain a SC below 100, the LCR should be at least 0.4 (Turtoi et al., 2019).



Graph 3. *Conditional Inference Tree (CIT)*

Table 3. *Bootstrap estimation of the LCR threshold derived from logistic regression and CIT models*

Method	Mean LCR Threshold	95% Confidence Interval
Logistic Regression	0.3637	0.3113 – 0.4095
CIT	0.3688	0.3227 – 0.4062

Bootstrap analysis was applied to assess the stability of the LCR threshold estimated from both the logistic regression and the CIT models (Table 3). For the logistic regression, the mean LCR threshold was 0.3637, with a 95% confidence interval ranging from 0.3113 to 0.4095. This value represents the inflection point at which the probability of a tree being slender equals 50%, thus providing a practical boundary between slender and non-slender trees. For the CIT model, the mean bootstrap threshold was 0.3688 (95% CI: 0.3227–0.4062), clearly separating trees into two groups according to LCR, where lower LCR values indicate predominantly slender trees and higher values correspond to non-slender trees. The close agreement between the thresholds obtained from both statistical approaches indicates the robustness of the estimated critical LCR value and supports the reliability of LCR as a predictor of tree slenderness within the studied stand. Results from previous studies indicate similar LCR threshold values, around 0.36–0.39, highlighting their importance for ensuring tree stability and suggesting that this range can serve as a practical guideline for determining the optimal timing of thinning interventions in young Turkey oak stands (Stancioiu et al, 2021).

4. CONCLUSION

The analysis revealed a clear negative relationship between the live crown ratio (LCR) and the slenderness coefficient (SC), confirming that trees with a higher LCR—i.e., longer live crowns—are less likely to be slender and therefore more stable. The identified LCR threshold range of 0.36–0.40 provides a practical criterion for distinguishing slender and stable trees and can guide the timing and intensity of thinning and other silvicultural interventions. Both species-specific traits and stand and site conditions influence LCR and SC, indicating that thresholds may vary under different ecological circumstances. Future research should explore additional factors such as soil conditions, slope, exposure, and competition dynamics, particularly in the context of climate change, to refine these thresholds.

Due to the limited spatial coverage and specific site conditions, the identified live crown ratio (LCR) threshold should be regarded as an indicative value applicable to the studied stands. Nevertheless, these results can serve as a basis for future research that, through a larger and more diverse sample, could verify and confirm this threshold, as well as explore its potential applicability in a broader ecological context. Incorporating LCR assessments into forest inventories allows for more informed management decisions, helping to reduce the risk of mechanical damage, promote proper stem and crown development, and enhance the structural stability of beech stands.

Acknowledgement: *This study was carried out under the Agreement on realization and funding of scientific research activity of scientific research organizations in 2025, funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, no. 451-03-136/2025-03/200027 of February 4, 2025 and 451-03-137/2025-03/ 200027 of February 4, 2025. I am deeply grateful to my colleagues at the public enterprise "Srbijašume" for their valuable support and collaboration throughout the course of this research.*

REFERENCES

Aaheim, A., Chaturvedi, R. K.,Sagadevan, A.A. (2011). Integrated modelling approaches to analysis of climate change impacts on forests and forest management. *Mitig Adapt Strateg Glob Change* 16, 247–266. https://doi.org/10.1007/s11027-010-9254-x

Banković, S., Medarević, M., Pantić, D., Petrović, N. (2009). Nacionalna inventura šuma Republike Srbije - Šumski fond Republike Srbije, *Ministarstvo poljoprivrede šumarstva i vodoprivrede Republike Srbije -Uprava za šume*, Beograd, 1-244.

Brack, D. (2019). Forests and climate change. *Proceedings of background study prepared for the fourteenth session of the United Nations forum on forests*. New York, NY, USA: United Nations Forum on Forests.

Campbell, J.L., Rustad, L.E., Driscoll, C.T., Halm, I., Fahey, T.J., Fakhraei, H., Groffman, P.M., Hawley, G.J., Leuenberger, W., Schaberg, P.G. (2020). Simulating Impacts of Ice Storms on Forest Ecosystems. *J. Vis. Exp*. (160), e61492, doi:10.3791/61492

Cremer, K.W., Borough, C.J., McKinnel, F.H., Carter, P.R. (1982). Effects of stocking and thinning on wind damage in plantations. *NZ J For Sci* 12, 244–268.

FAO. (2020). Global forest resources assessment 2020—Key findings. Rome.

Forzieri, G., Dakos, V., McDowell, N.G. et al. (2022). Emerging signals of declining forest resilience under climate change. *Nature* 608, 534–539. https://doi.org/10.1038/s41586-022-04959-9

Forest management plan for Forest Management Unit "Lomnička Reka" (2026–2035). *Public Enterprise "Srbijašume"*, 170.

He, L., Zhang, X., Wang, X., Ullah, H., Liu, Y., & Duan, J. (2023). Tree crown affects biomass allocation and its response to site conditions and the density of *Platycladus orientalis* Linnaeus plantation. *Forests*, 14(12), 2433. https://doi.org/10.3390/f14122433

Ibáñez, I., Acharya, K., Juno, E., Karounos, C., Lee, B.R., McCollum, C., et al. (2019). Forest resilience under global environmental change: Do we have the information we need? A systematic review. *PLoS ONE* 14(9): e0222207. https://doi.org/10.1371/journal.pone.0222207

Jucker, T., Fischer, F.J., Chave, J. et al. (2025). The global spectrum of tree crown architecture. *Nat Commun* 16, 4876. https://doi.org/10.1038/s41467-025-60262-x

Kanjevac, B., Račić, M., Dobrosavljević, J., Martać, N. (2023). Responses at the stand and tree level to ice storm injuries in beech forests in Eastern Serbia. *Reforesta* 16:16-26. https://dx.doi.org/10.21750/REFOR.16.02.107

Karamzadeh, S., Nikooy, M., Abkenari, K. T., Tavankar, F., Lo Monaco, A., & Picchio, R. (2023). The Relationship between Stand Structure and Tree Growth Form—Investigating the Effects of Selection Cuttings in Mountainous Mixed Beech Forests. *Forests*, 14(9), 1861. https://doi.org/10.3390/f14091861

Kaźmierczak, K., Jędraszak, A. (2014). The influence of crown length on tree stability. *Žmogaus Ir Gamt. Sauga*, 42-44.

Kirilenko, A. P., Sedjo, R. A. (2007). Climate change impacts on forestry. *Proceedings of the National Academy of Sciences*, 104(50), 19697-19702.

Lidskog, L., Sjödin, D. (2016). Extreme events and climate change: the post-disaster dynamics of forest fires and forest storms in Sweden. *Scandinavian Journal of Forest Research*, 31:2, 148-155, https://doi.org/10.1080/02827581.2015.1113308

Lowman, M. (2021). Life in the Treetops—An Overview of Forest Canopy Science and Its Future Directions. *Plants, People, Planet* 3:16–21.

Marković, M., Rajković, S., Marković, N. (2019). The crown condition of beech trees after the disastrous ice storm on Mt. Crni Vrh. *Sustainable Forestry: Collection*, 78-79, 65-78.

Matsumoto, H., Ohtani, M., Washitani, I. (2017). Tree Crown Size Estimated Using Image Processing: A Biodiversity Index for Sloping Subtropical Broad-Leaved Forests. *Tropical Conservation Science*. 10. https://doi.org/10.1177/1940082917721787

McNeil, B.E., Fahey, R.T., King, C.J., Erazo, D.A., Heimerl, T.Z., Elmore, A.J. (2023). Tree crown economics. *Front. Ecol. Environ*., 21, 40–48.

Müller, J., Bütler, R. (2010). A review of habitat thresholds for dead wood: A baseline for management recommendations in European forests. *Eur. J. For. Res*., 129, 981–992.

Pach, M., et al. (2022). Climate-Smart Silviculture in Mountain Regions. In: Tognetti, R., Smith, M., Panzacchi, P. (eds) Climate-Smart Forestry in Mountain Regions. Managing Forest Ecosystems, vol 40. *Springer, Cham*. https://doi.org/10.1007/978-3-030-80767-2_8

Patton, S.R., Russell, M.B., Windmuller-Campione, M.A., Edgar, C.B. (2019). Modeled diameter growth response to intermediate treatments of planted white spruce (Picea glauca) affected by eastern spruce budworm (*Choristoneura fumiferana*) in Minnesota, USA. *Can. J. For. Res*., 49, 1633–1637.

Pretzsch, H. (2014). Canopy space filling and tree crown morphology in mixed-species stands compared with monocultures, *Forest Ecology and Management*, Volume 327, 251-264, ISSN 0378-1127, https://doi.org/10.1016/j.foreco.2014.04.027

Psistaki, K., Tsantopoulos, G., & Paschalidou, A. K. (2024). An overview of the role of forests in climate change mitigation. *Sustainability*, 16(14), 6089.

R Core Team. (2025). R: A Language and Environment for Statistical Computing; R Foundation for Statistical Computing: Vienna, Austria.

Schomaker, M. E., S. J. Zarnoch, W. A. Bechtold, D. J. Latelle, W. G. Burkman, and S. M. Cox. (2007). Crown-classification: A guide to data collection and analysis. USDA Forest Service General Technical Report SRS-102. USDA Forest Service, Southern Research Station, Raleigh, North Carolina.

Shamaki, S. (2022). Relationships between tree slenderness coefficients and stand characteristics for major plantation-grown species in North-western Nigeria. *Journal of Agriculture and Environment*, 18(2), 125-134.

Skrzyszewski, J., Pach, M. (2020). The use of the slenderness coefficient in diagnosing wind damage risks. *Acta Silvestria*, 57, 7-24.

Stajić, B., Vukić, K., Janjatović, Ž., Kazimirović, M. (2017). Efikasnost korišćenja prostora za rast belog jasena (Fraxinus excelsior L.) sa područja Majdanpečke domene. *Glasnik Šumarskog fakulteta*, 115, 99-126. https://doi.org/10.2298/GSF1715099S

Stancioiu, P.T., Serbescu,A.A., Dutcˇa, I. (2021). Live Crown Ratio as an Indicator for Tree Vigor and Stability of Turkey Oak (*Quercus cerris* L.): A Case Study. *Forests*, 12, 1763. https://doi.org/10.3390/f12121763

Stefančík, I., Vacek, Z., Sharma, R.P., Vacek, S., Rösslová, M. (2018). Effect of thinning regimes ongrowth and development of crop trees in Fagus sylvatica stands of Central Europe over fifty years. *Dendrobiology*, 79, 141-155.
http://dx.doi.org/10.12657/denbio.079.013

Šēnhofa, S., Katrevičs, J., Adamovičs, A., Bičkovskis, K., Bāders, E., Donis, J., Jansons, Ā. (2020). Tree Damage by Ice Accumulation in Norway Spruce (Picea abies (L.) Karst.) Stands Regarding Stand Characteristics. *Forests*, 11(6), 679.
https://doi.org/10.3390/f11060679

Tian, X., Sohngen, B., Kim, J. B., Ohrel, S., & Cole, J. (2016). Global climate change impacts on forests and markets. *Environmental Research Letters*, 11(3), 035011.

Triviño, M., Potterf, M., Tijerín, J. et al. (2023). Enhancing Resilience of Boreal Forests Through Management Under Global Change: a Review. Curr Landscape Ecol Rep 8, 103–118. https://doi.org/10.1007/s40823-023-00088-9

Turtoi, A. V., Stancioiu, P. T., Dutcă, I. (2019). The live crown ratio-an indicator for growth vigor of European beech trees (Fagus sylvatica L.). *Romania Revista Padurilor*, Vol. 134, No. 4, 29-40.

Valinger, E., Fridman, J. (1997). Modelling probability of snow and wind damage in Scots pine stands using tree characteristics. *For. Ecol. Manag*., 97, 215–222.

Venäläinen, A., Lehtonen, I., Laapas, M., Ruosteenoja, K., Tikkanen, O. P., Viiri, H., ... & Peltola, H. (2020). Climate change induces multiple risks to boreal forests and forestry in Finland: A literature review. Global Change Biology, 26(8), 4178-4196.

Wang, Y., Titus, S.J., LeMay, V.M. (1998). Relationships between tree slenderness coefficients and tree or stand characteristics for major species in boreal mixedwood forests. *Canadian Journal of Forest Research*. 28(8): 1171-1183. https://doi.org/10.1139/x98-092

Wilson, J. S., Oliver, C. D. (2000). Stability and density management in Douglas-fir plantations. *Canadian Journal of Forest Research*, 30(6), 910-920.

Wonn, H.T., O'Hara, K.L. (2001). Height: Diameter ratios and stability relationships for four northern Rocky Mountain tree species. *Western Journal of Applied Forestry*, Volume 16, Issue 2, 87–94. https://doi.org/10.1093/wjaf/16.2.87

Zarnoch, S.J., Bechtold, W.A.; Stolte, K.W. (2004). Using crown condition variables as indicators of forest health. *Can. J. For. Res*. 34: 1057-1070.

Zhu, Z., Kleinn, K., Nölke, N. (2021). Assessing tree crown volume—a review, Forestry: An International Journal of Forest Research, Volume 94, Issue 1, 18–35.
https://doi.org/10.1093/forestry/cpaa037

LIVE CROWN RATIO AND SLENDERNESS COEFFICIENT AS INDICATORS OF BEECH TREE STABILITY

Miloš RAČIĆ, Nenad PETROVIĆ, Nikola MARTAĆ, Jovan DOBROSAVLJEVIĆ, Janko LJUBIČIĆ, Ivana RAČIĆ, Branko KANJEVAC

Summary

Forest stability is increasingly challenged by the effects of climate change, which can exacerbate the occurrence of extreme events such as storms, ice accumulation, and droughts, posing significant risks to both individual trees and forest ecosystems. Understanding the factors that influence tree and stand stability is therefore essential for sustainable forest management. The live crown ratio (LCR) and slenderness coefficient (SC) have been widely recognized as practical measures of tree stability and vigor. The LCR is defined as the ratio of the length of the live crown to the total tree height, while SC is calculated as the ratio of tree height to diameter at breast height. This study aimed to evaluate the applicability of LCR and SC as indicators of European beech tree stability and to determine critical LCR thresholds that could guide silvicultural interventions.

Research was conducted in the Forest Management Unit (FMU) "Lomnička Reka" in Central Serbia, managed by the Public Enterprise "Srbijašume". The area covers 3,399.96 ha, with elevations ranging from 300 to 1,394 m. The analysis focused on five structurally

uneven-aged stands, encompassing 103 beech trees across eight sample plots belonging to the middle-aged silvicultural group. Data were collected through stand inventories conducted on a network of permanent sample plots (200 × 200 m), using concentric circular plots with areas of 0.02 and 0.05 ha. Field verification ensured the accuracy and reliability of recorded measurements.

For each tree, LCR and SC were determined. Trees were classified as slender or non-slender based on an SC threshold of 80. Two complementary statistical approaches were applied to identify critical LCR thresholds associated with tree slenderness. Logistic regression modeled the probability of a tree being slender as a function of LCR, with the inflection point representing the LCR value at which the probability of slenderness equals 50%. The Conditional Inference Tree (CIT) method partitioned trees into statistically significant groups based on LCR values. Bootstrap procedures were employed for both methods to assess the stability and reliability of estimated thresholds.

Descriptive statistics revealed a mean SC of 77.81, with values ranging from 34.74 to 143.64. The average LCR was 0.397, ranging from 0.125 to 0.812. Logistic regression analysis identified a statistically significant inverse relationship between LCR and SC ($p < 0.001$), with an estimated LCR threshold (inflection point) of 0.364. CIT analysis indicated a similar threshold, with trees having LCR ≤ 0.4 predominantly classified as slender, and those with LCR > 0.4 as non-slender. Bootstrap analysis confirmed the robustness of these thresholds.

The findings highlight the practical importance of crown structure for forest management. Trees with higher LCR values show lower slenderness and greater stability. Maintaining optimal LCR through timely thinning and other interventions can reduce slenderness, support stem and crown development, and lower susceptibility to wind or snow damage. LCR and SC are influenced by species traits, stand density, site conditions, and ecological factors, suggesting that future research should explore additional drivers such as soil, slope, exposure, and competition, especially under climate change.

RELATIVNA DUŽINA ŽIVE KRUNE I KOEFICIJENT VITKOSTI KAO INDIKATORI STABILNOSTI STABALA BUKVE

Miloš RAČIĆ, Nenad PETROVIĆ, Nikola MARTAĆ, Jovan DOBROSAVLJEVIĆ, Janko LJUBIČIĆ, Ivana RAČIĆ, Branko KANJEVAC

Rezime

Stabilnost šuma je sve više ugrožena posledicama klimatskih promena, koje mogu pojačati učestalost ekstremnih događaja kao što su oluje, nakupljanje leda i suše, predstavljajući značajne rizike kako za pojedinačna stabla, tako i za šumske ekosisteme. Razumevanje faktora koji utiču na stabilnost stabala i sastojina stoga je od suštinskog značaja za održivo upravljanje šumama. Relativna dužina žive krune (LCR) i koeficijent vitkosti (SC) su široko prepoznati kao praktične mere stabilnosti i vitalnosti stabala. LCR se definiše kao odnos dužine žive krune I ukupne visine stabla, dok je SC izračunat kao odnos visine stabla i prečnika stabla na prsnoj visini. Ova studija je imala za cilj da proceni primenljivost LCR i SC kao indikatora stabilnosti stabala evropske bukve i da odredi kritične LCR pragove koji bi mogli da usmere šumarsko-uzgojne intervencije.

Istraživanje je sprovedeno u gazdinskoj jedinici (FMU) „Lomnička Reka“ u Centralnoj Srbiji, kojom upravlja Javno preduzeće „Srbijašume“, a koja pokriva ukupnu površinu od 3.399,96 ha i nadmorske visine u rasponu od 300 do 1.394 m. Analiza je bila fokusirana na pet strukturno raznodobnih sastojina, obuhvatajući 103 stabla bukve na 8

primernih površina u srednjedobnoj uzgojnoj grupi. Podaci su prikupljeni putem sastojinske inventure sprovedene na mreži permanentnih primernih povrsina (200 × 200 m), koristeći koncentrične kružne uzorke površine 0,02 i 0,05 ha. Terenska verifikacija je obezbedila tačnost i pouzdanost zabeleženih merenja.

Za svako stablo određeni su LCR i SC. Stabla su klasifikovana kao vitka ili ne-vitka na osnovu SC praga od 80. Primijenjene su dve komplementarne statističke metode kako bi se identifikovali kritični LCR pragovi povezani sa vitkošću stabala. Logistička regresija je modelirala verovatnoću da je stablo vitko u zavisnosti od LCR-a, pri čemu infleksiona tačka predstavlja LCR vrednost pri kojoj je verovatnoća vitkosti 50%. Metoda uslovnog stabla zaključivanja (CIT) je podelila stabla u statistički značajne grupe na osnovu LCR vrednosti. Bootstrap procedure su primenjene za obe metode radi procene stabilnosti i pouzdanosti procenjenih pragova.

Deskriptivna statistika je pokazala prosečan SC od 77,81, sa vrednostima u rasponu od 34,74 do 143,64. Prosečan LCR iznosio je 0,397, sa rasponom od 0,125 do 0,812. Analiza logističke regresije pokazala je statistički značajnu obrnutu vezu između LCR i SC ($p < 0{,}001$), sa procenjenim LCR pragom (infleksionom tačkom) od 0,364. CIT analiza je pokazala sličan prag, pri čemu su stabla sa LCR ≤ 0,4 uglavnom klasifikovana kao vitka, dok su stabla sa LCR > 0,4 pripadala ne-vitkoj kategoriji. Bootstrap analiza je potvrdila pouzdanost ovih pragova.

Rezultati ističu praktičnu važnost strukture krune za gazdovanje šumama. Stabla sa većim LCR vrednostima pokazuju manju vitkost i veću stabilnost. Održavanje optimalnog LCR kroz pravovremeno proređivanje i druge mere može smanjiti vitkost, podržati razvoj stabla i krune, i smanjiti podložnost oštećenjima od vetra ili snega. LCR i SC zavise od svojstava vrste, gustine sastojine, uslova staništa i ekoloških faktora, što sugeriše da bi buduća istraživanja trebalo da ispituju dodatne faktore kao što su zemljište, nagib, izloženost i konkurencija, posebno u kontekstu klimatskih promena.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY COLLECTION 92, 2025
ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592085M
UDK: 630*232:633.872=111
Original scientific paper

COMPARATIVE ANALYSIS OF SILVICULTURAL TREATMENTS IN EVEN-AGED HUNGARIAN OAK STANDS

Nikola MARTAĆ[1], Nemanja LAZAREVIĆ[1], Miloš RAČIĆ[1], Nenad PETROVIĆ[2], Ivana RAČIĆ[1], Natalija MOMIROVIĆ[1], Branko KANJEVAC[2]*

Abstract: *The research was conducted in Hungarian oak (Quercus frainetto Ten.) coppice stands located on Mt. Cer in western Serbia. Data collection and processing on the experimental fields were carried out using standard dendrometric methods. The aim was to identify the most appropriate silvicultural treatments for converting these stands into a high forest structure, based on an analysis of their initial condition. The paper also presents the state of the stands before and after the applied treatments, allowing for a comparative evaluation. The investigated stands exhibited higher values of volume and volume increment compared to the average for Hungarian oak coppice forests in Serbia. Based on the analysis of site conditions, total volume, number of trees per unit area, and the dominant tree height, it was concluded that the stands could be converted into high forest through indirect conversion. The statistical significance of differences in mean tree volume and mean tree height between the experimental fields (EF) was tested using an independent t-test. The obtained values of stand parameters, together with the statistically confirmed differences in mean tree volume and height, indicate that the stand on EF I has higher productivity compared to the stand on EF II, which consequently required the application of different silvicultural treatments. In the stand on EF I, selective thinning was conducted due to the sufficient number of high-quality trees per unit area and the larger diameters and heights of dominant trees. Conversely, the condition of the stand on EF II suggested that postponing its conversion to a high forest form would be unjustified; therefore, the process of indirect conversion was initiated immediately through the application of a preparatory–regeneration felling. The conducted research highlights the importance of a detailed analysis of forest stand parameters as a basis for making appropriate decisions when selecting suitable silvicultural treatments for converting Hungarian oak coppice stands into a high forest.*

Keywords: Hungarian oak, coppice stands, conversion, silvicultural treatment.

UPOREDNI PRIKAZ RAZLIČITIH GAZDINSKIH TRETMANA U SASTOJINAMA SLADUNA ISTE STAROSTI

Sažetak: *Istraživanje je sprovedeno u izdanačkim sastojinama sladuna, na planini Cer u Zapadnoj Srbiji. Prikupljanje i obrada podataka sa oglednih polja izvršena je*

[1] Institute of Forestry, Kneza Višeslava 3, 11030 Beograd, Serbia
[2] Faculty of Forestry University of Belgrade, Kneza Višeslava 1, 11030 Beograd, Serbia
*Corresponding author. E-mail: martac.nikola94@gmail.com

standardnim dendrometrijskim metodama. Cilj istraživanja je da se na osnovu analize početnog stanja istraživanih sastojina definišu najprikladniji uzgojni tretmani za njihovo prevođenje u viši uzgojni ublik. Takođe, rad prikazuje stanje sastojina pre i nakon izvrešnih tretmana što omogućava analizu i evaluaciju istih. U istraživanim sastojinama zabeležene su više vrednosti zapremine i zaprmeinskog prirasta u odnosu na prosek za izdanacke šume sladuna u Srbiji. Na osnovu analize stanišnih uslova, ukupne zapremine, broja stabala po jedinici površine i gornje visine dominantnih stabala odlučeno je da se istraživane sastojine mogu prevesti u viši uzgujni oblik putem indirektne konverzije. Statistička značajnost razlika prosečne zapremine stabala, kao i prosečne visine stabala između oglednih polja ispitana je pomoću nezavisnog t -testa. Dobijeni taksacioni pokazatelji, kao i statistička verifikacija razlika prosečne zapremine i visine stabala, ukazuju na veću proizvodnost satojine na OP I u odnosu na sastojinu na OP II, što je za posledicu imalo izbor različitih uzgojih tretmana na oglednim poljima. U okviru sastojine na OP I sprovedena je selektivna proreda, s obzirom na dovoljan broj kvalitetnih stabala po jedinici površine, kao i više vrednosti prečnika i visine dominantnih stabala. Na osnovu zatečenog stanja sastajine na OP II, oodlučeno je da nema svrhe da se proces prevođenja u visoki uzgojni oblih odlaže, već da se u njoj odmah započne postupak indirektne konverzije primenom pripremno - oplodnog seka. Sprovedeno istraživanje ukazuje na značaj detaljne analize taksacionih pokazatelja kao osnove za pravilno donošenje odluka pri odabiru adekvatnih uzgojnih tretmana za prevođenje izdanačkih sastojina sladuna u viši uzgojni oblik.

Ključne reči: sladun, izdanačke sastojine, konverzija, uzgojni tretman.

1. INTRODUCTION

Hungarian oak (*Quercus frainetto* Ten.), as one of the edifying species of forest habitats, most commonly occurs in Serbia together with Turkey oak (*Quercus cerris* L.) within the climate-determined climax community *Quercetum frainetto-cerris* Rud. 1949. Besides the typical climate-determined zonal association *Quercetum frainetto-cerris* Rud. 1949, numerous subassociations have been described in Serbia, representing various ecological variants of this forest community (Stajić et al., 2008).

Hungarian oak forests occupy a significant area of the growing stock of Serbia—approximately 159,600 ha, 33.8% of which are in state ownership. The average wood volume in seed-origin stands amounts to 192 m³/ha, while it is 124 m³/ha in coppice stands. The mean annual increment for seed-origin stands is 4.2 m³/ha, while for coppice-origin stands it amounts to 3.2 m³/ha. Coppice stands dominate, covering about 141,600 ha, with most stands between 40 and 50 years old, while the area under young, regenerated stands remains very limited (Banković et al., 2006, Banković et al., 2009).

The fact that only 33.8% of Hungarian oak forests are state-owned, whereas 66.2% are in private ownership, indicates that these forests were subject to strong anthropogenic influence in the past. This human impact has largely had negative consequences for the distribution, origin, and preservation of these forests, as well as for their genetic diversity, as confirmed by previous research (Jovanović et al., 1997; Ratknić et al., 2010; Popović et al., 2021).

It is well known that coppice forests are considerably less productive and stable than seed-origin forests. Therefore, their gradual conversion into high forests is of great importance. Considering the current stand structure and developmental phase of these forests, the long-term silvicultural objective is directed toward the formation of stable and productive seed-origin stands. Consequently, the priority task is the implementation of silvicultural and ameliorative measures aimed at improving stand structure and, thereby, the ecological and productive functions of forest ecosystems. Such activities enable more efficient utilisation of site productivity potential, substantially enhance ecological stability, resilience to degradation processes, and the economic value of forests, while also contributing to the conservation of indigenous genetic diversity (Amorini et al., 1998; Burczyk et al., 2006; Notarangelo et al., 2018; Manetti, 2020).

The conversion of coppice forests into seed-origin forests is a complex and long-term process that requires careful planning and the application of appropriate silvicultural measures. In defining these measures, whose primary long-term goal is the transformation of coppice stands into stable and productive seed-origin stands, several key questions always arise: when to initiate this process, on which areas it should be implemented, and in what manner it should be carried out. Addressing this silvicultural challenge primarily depends on the degree of preservation and quality of stands and sites, their health status, tree age, and the frequency and abundance of seed production (Medarević et al., 2004; Krstić et al., 2006).

In this context, the study aims to determine, based on an analysis of the initial condition of two coppice stands of the same age and following the principles and criteria outlined above, the most suitable silvicultural treatments for their conversion into seed-origin stands. The study also aimed to document the condition of the stands before and after the implementation of these treatments. This approach allows for a clear evaluation of the applied measures and provides a solid foundation for planning and improving the process of converting coppice stands into stable, seed-origin forest stands.

2. MATERIAL AND METHODS

The study was conducted on two square experimental fields, each measuring 0.25 ha, established in 70-year-old Hungarian oak coppice stands on Mt. Cer in western Serbia. On each field, all trees above the minimum DBH threshold for coppice forests were inventoried. For each tree, diameter at breast height (DBH), total height, and crown base height were measured.

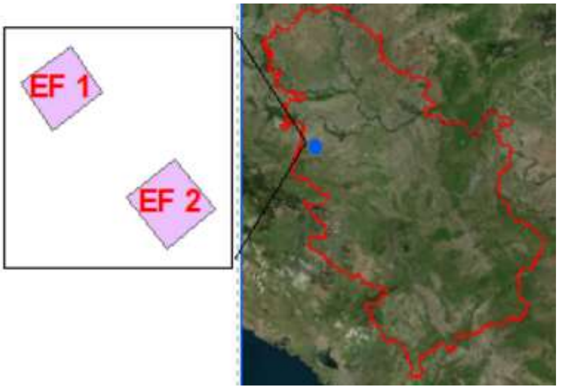


Figure 1. *Study site*

Experimental field (E:374 657, N:4 946 043) is located on a uniform slope of 6°–10°, at an average elevation of 230 m, with a northwest-facing aspect. The soil is either illimerised or loessified, moderately deep, developed over a granodiorite bedrock. The field contains a well-preserved, mixed, even-aged stand of Hungarian oak (*Quercus frainetto* Ten.) and small-leaved lime (*Tilia cordata* Mill.), with full canopy closure and good health. Other tree species, including Turkey oak (*Quercus cerris* L.), black ash (*Fraxinus nigra*), wild cherry (*Prunus avium*), and other hardwoods, are present but contribute less than 10% of the total stand volume.

Experimental field (E:374 769, N:4 945 901) is located on a slope of 11°–15°, at an average elevation of 225 m, with a southwest-facing aspect. The soil is similarly illimerised or loessified, moderately deep, developed over a granodiorite bedrock. The field contains a well-preserved, pure, even-aged Hungarian oak stand, with full canopy closure and good health, while other tree species contribute less than 10% of total volume.

Stand parameter data were processed using standard methods. Tree heights were corrected using the "Graph" program, stand volume was calculated with the Schumacher–Hal function, and volume increment was estimated based on the percentage of growth (Banković et all., 2000). Differences in mean tree volume and mean height between the two fields were assessed using an independent-samples t-test. Prior to testing, the assumptions of normality and sample independence were verified. Statistical analyses were conducted using *IBM SPSS Statistics* software.

Based on analyses of site conditions, stand parameter measurements, and the resulting statistical parameters, different silvicultural treatments were applied to the experimental fields. Selective thinning was conducted on EF1, whereas preparatory–regeneration felling was applied on EF2. Following the treatments, the same stand parameters were remeasured, providing a basis for assessing the effectiveness of the applied silvicultural interventions.

3. RESULTS AND DISCUSSION

Given the specific nature of the study and that the decision to apply different silvicultural treatments was preceded by an analysis of the initial stand conditions, the results are presented accordingly. In other words, the findings are shown both before and after the implementation of the silvicultural treatments.

The basic stand parameters of the investigated stands prior to treatment are summarised in Tables 1 and 2.

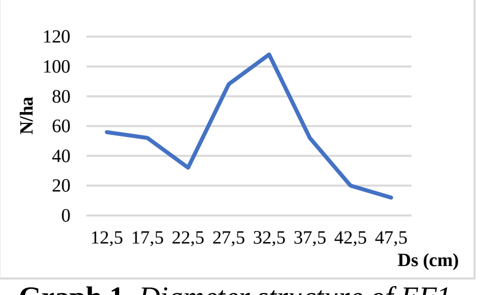
Table 1. *Basic stand parameters of the experimental fields prior to the implementation of silvicultural treatments*

Tree species	Experimental Field I						Experimental Field II					
	N/ha	G m^2/ha	hg (m)	dg (cm)	Iv (m^3/ha)	V (m^3/ha)	N/ha	G m^2/ha	hg (m)	dg (cm)	Iv (m^3/ha)	V (m^3/ha)
Hungarian oak	254	20.30	24.20	31.90	4.61	213.69	454	22.4	17.30	25.10	4.75	195.00
Turkey oak	6	0.92	29.00	44.20	0.18	9.33	12	1.41	23.50	38.70	0.25	12.56
Other hardwoods	24	0.50	15.70	16.30	0.22	5.35	4	0.05	13.50	12.50	0.03	0.57

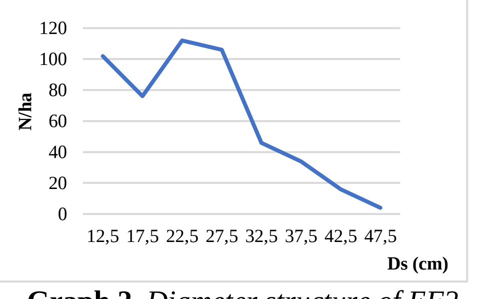
Tree species	Experimental Field I						Experimental Field II					
	N/ha	**G m^2/ha**	**hg (m)**	**dg (cm)**	**Iv (m^3/ha)**	**V (m^3/ha)**	**N/ha**	**G m^2/ha**	**hg (m)**	**dg (cm)**	**Iv (m^3/ha)**	**V (m^3/ha)**
Black ash	32	0.60	15.00	15.50	0.12	4.58	14	0.20	11.00	13.30	0.03	1.19
Small-leaved lime	94	5.59	23.50	27.50	1.31	53.2						
Wild cherry	10	0.17	11.90	14.70	0.05	1.08						
Rowan tree							2	0.02	14.10	12.50	0.01	0.20
Wild service tree							10	0.25	11.50	17.80	0.07	1.95
Total	**420**	**28.08**	**/**	**/**	**6.49**	**287.23**	**496**	**24.33**	**/**	**/**	**5.14**	**211.47**

The observed values of total stand volume and volume increment exceed the average for Hungarian oak forests in Serbia (Banković et al., 2009) and indicate higher productivity compared to data from previous studies (Krstić et al., 2006; Martać et al., 2024). The stand on EF1 has a lower number of trees per hectare but a higher total volume, volume increment, and basal area than the stand on EF2. Mean height and diameter of Hungarian oak trees are also greater on EF1.

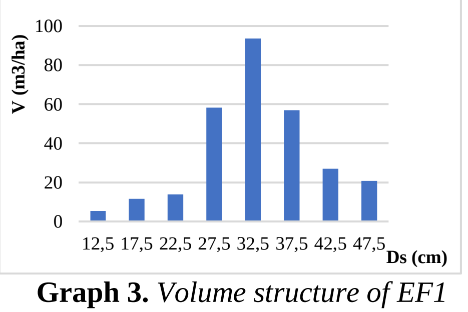
Graphs 1–4 illustrate the diameter and volume structure of the investigated stands.



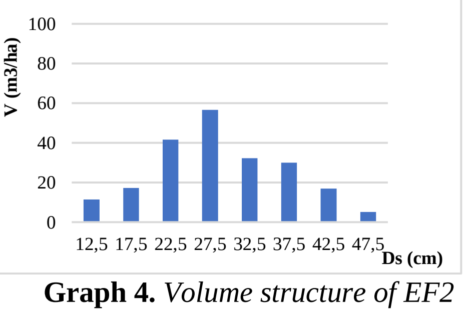
Graph 1. *Diameter structure of EF1 prior to the implementation of silvicultural treatment*



Graph 2. *Diameter structure of EF2 prior to the implementation of silvicultural treatment*



Graph 3. *Volume structure of EF1 prior to the implementation of silvicultural treatment*



Graph 4. *Volume structure of EF2 prior to the implementation of silvicultural treatment*

Table 2. *Diameter and height values of dominant trees by basal area*

Tree species	Experimental field I		Experimental field II	
	Dg max (m)	Hg max (m)	Dg max (m)	Hg max (m)
Hungarian oak	39,40	25,17	36,00	19,10

The values of dominant tree heights by basal area also indicate higher productivity of the stand on EF1. To ensure that the observed differences in productivity between the investigated stands were statistically significant, and to inform the final decision regarding the choice of appropriate silvicultural treatment, a statistical analysis of the data was conducted.

The results of this analysis are presented in Tables 3 and 4.

Table 3. *Results of the independent-samples t-test for mean tree volume*

EF	N	V(m^3)	SD	SEM	t	df	p
1	210	0.673	0.409	0.028	7.964	345.394	<0.001
2	248	0.412	0.263	0.017			

Prior to felling, the mean tree volume on EF1 was 0.673 m^3 (SD = 0.409; N = 210), whereas on EF2 it was 0.412 m^3 (SD = 0.263; N = 248). The results of the independent-samples t-test ($t_{(345.394)} = 7.964$; $p < 0.001$) indicated a statistically significant difference in mean tree volume between the experimental plots (Table 3), with a mean difference of 0.261 m^3.

Table 4. *Results of the independent-samples t-test for mean tree height*

EF	N	H (m)	SD	SEM	t	df	p
1	210	21.26	5.02	0.35	13.500	390.942	<0.001
2	248	15.51	3.90	0.25			

Before felling, the mean tree height on EF I was 21.26 m (SD = 5.02; N = 210), while on EF II, it was 15.51 m (SD = 3.90; N = 248). The results of the independent-samples t-test ($t_{(390.942)} = 13.500$; $p < 0.001$) indicated that the difference in mean tree height between the two experimental fields was statistically significant (Table 4). The difference between the mean values amounted to 5.75 m.

Taking into account the previously presented results obtained from the measurement of stand parameters, which point to higher stand productivity on EF I and the statistically confirmed significance of these differences, it was decided to apply different silvicultural treatments in the studied stands. Based on site conditions, total volume, number of trees per unit area, and the height of dominant trees, it was concluded that the stands have the potential to be converted, through indirect conversion, into high forest stands.

The timing of the initiation of indirect conversion was determined based on the number of trees, as well as the diameter and height of the dominant trees. Since the stand on EF I had a sufficient number of high-quality trees per unit area, along with significantly greater diameters and heights of dominant trees, it was decided to postpone the initiation of conversion into a high forest form. Accordingly, the production process in this stand was prolonged, and at that stage, a heavy selective thinning was carried out.

Based on the condition of the stand on EF II, it was concluded that there was no reason to delay the conversion process; therefore, the procedure of indirect conversion was initiated immediately by applying a preparatory seed cutting of the shelterwood system.

The presentation of the main stand parameters of the studied stands after the implementation of silvicultural treatments is given in Tables 5 and 6.

Table 5. *Basic stand parameters of the experimental fields after the implementation of silvicultural treatments*

Tree species	Experimental Field I						Experimental Field II					
	N/ha	G m^2/ha	hg (m)	dg (cm)	Iv (m^3/ha)	V (m^3/ha)	N/ha	G m^2/ha	hg (m)	dg (cm)	Iv (m^3/ha)	V (m^3/ha)
Hungarian oak	200	16.60	24.30	32.20	3.68	173.00	134	9.86	18.20	30.60	1.71	82.46
Turkey oak	2	0.28	25.10	42.50	0.05	2.62	4	0.57	23.80	42.50	0.09	4.99
Other hardwoods	22	0.45	15.70	16.10	0.20	4.83	/	/	/	/	/	/
Black ash	26	0.39	14.10	13.80	0.08	2.87	/	/	/	/	/	/
Small-leaved lime	58	2.34	21.20	22.70	0.64	21.70						
Wild cherry	8	0.15	12.10	15.20	0.04	0.93						
Rowan tree							2	0.02	14.10	12.50	0.01	0.20
Wild service tree							8	0.22	11.60	18.90	0.06	1.81
Total	**316**	**20.21**	/	/	**4.69**	**205.95**	**148**	**10.67**	/	/	**1.87**	**89.46**

The tree marking intensity on EF I amounted to 28.3% of the total volume and 126% of the ten-year volume increment. The number of selected “future trees” per hectare was 89, while an average of 1.06 trees were removed per each “future tree.” All 89 “future trees” were Hungarian oaks.

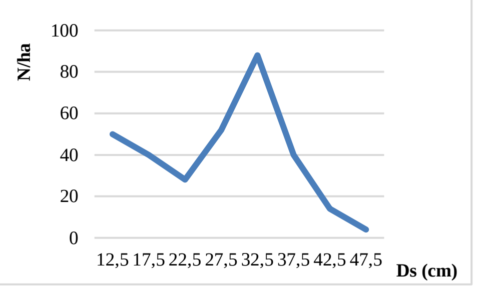
On EF II, the marking intensity amounted to 57.7% of the total volume and 237% of the ten-year volume increment. The number of trees remaining after felling was 138 per hectare. Of these, 134 were Hungarian oak, while the remaining four were Turkey oak trees. Rowan tree and wild service tree individuals were retained in the stand as fruit-bearing species.

Table 6. *Diameter and height values of dominant trees by basal area after the implementation of silvicultural treatments*

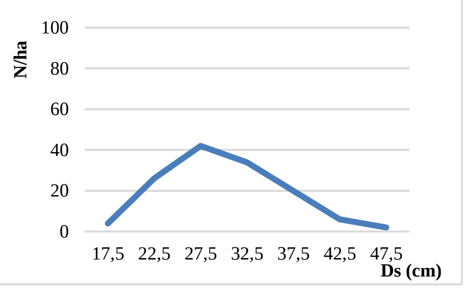
Tree species	Experimental field I		Experimental field II	
	Dg max (m)	Hg max (m)	Dg max (m)	Hg max (m)
Hungarian oak	39,80	25,20	39,50	19,30

Higher values of diameters and heights of dominant trees by basal area after the implementation of silvicultural treatments indicate that the highest-quality trees were retained in the stand.

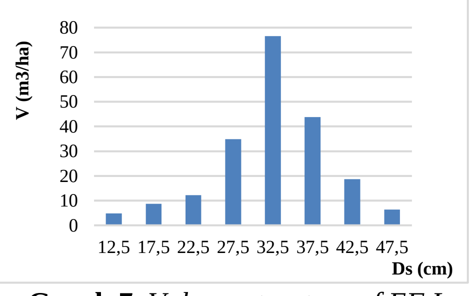
Graphs 5–8 present the diameter and volume structure of the studied stands after the implementation of silvicultural treatments.



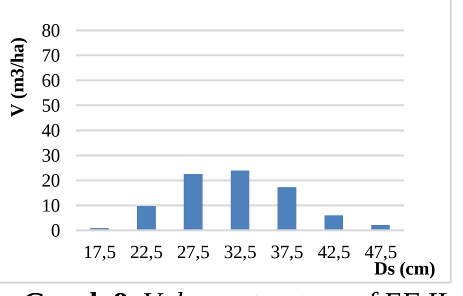
Graph 5. *Diameter structure of EF I after the implementation of the silvicultural treatment*



Graph 6. *Diameter structure of EF II after the implementation of the silvicultural treatment*



Graph 7. *Volume structure of EF I after the implementation of the silvicultural treatment*



Graph 8. *Volume structure of EF II after the implementation of the silvicultural treatment*

The diameter structure presented in Graph 5 indicates that a heavy selective thinning was carried out in the stand and that the highest-quality trees were selected as “future trees.” Conversely, trees in the smallest diameter classes were retained at this stage to prevent potential ground vegetation overgrowth.

Graph 6 shows that the application of the preparatory seed cutting removed accompanying species from the understory and lower-quality trees from the upper layer, leaving only the highest-quality trees and fruit-bearing trees in the stand. The remaining trees were predominantly concentrated in the 27.5 cm and 32.5 cm diameter classes.

The volume structure presented in Graph 7 confirms these findings, indicating that the selective thinning targeted the removal of trees competing with the “future trees,” thereby providing additional space for their unhindered growth and development.

4. CONCLUSIONS

The conducted research shows that a detailed analysis of stand parameters allows for a reliable assessment of the productivity and developmental potential of Hungarian oak coppice stands, providing a solid basis for informed decision-making in the management of these stands. The established values of volume and volume increment, as well as the diameters and heights of dominant trees, demonstrated that the stands on EF I and EF II differ despite being of the same age, which was confirmed by statistical analysis of the average volume and height of trees in the investigated experimental fields.

Based on these results, different silvicultural treatments were defined—intensive selective thinning in the more productive stand and the initiation of indirect conversion in the less productive one. This approach illustrates a rational, tailored method for planning silvicultural operations.

The findings underline the importance of such research in the planning and implementation of amelioration measures in coppice forests. At the same time, this study illustrates the necessity of a systematic approach in defining silvicultural treatments for each stand individually, which allows for the proper planning of measures aimed at preserving productivity, stability, and genetic diversity in these ecosystems. The results also confirm that such research plays a fundamental role in improving forest management practices and achieving the long-term objectives of sustainable forestry in Serbia.

Acknowledgement: *This study was conducted under the Agreement on the implementation and funding of scientific research activities of research organizations in 2025, financed by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, No. 451-03-136/2025-03/200027, dated February 4, 2025.*

REFERENCES

Amorini E., Bruschini S., Cutini A., Di Lorenzo MG., Fabbio G. (1998a). Treatment of Turkey oak (Quercus cerris L.) coppice. Structure, biomass and silvicultural options. *Annali Istituto Sperimentale Selvicoltura, Arezzo, Vol. 27, Special issue MedCop*, 121-129.

Banković S., Jović D., Medarević M., Pantić D. (2000). Regresioni modeli procenta zapremiskog prirasta u čistim i mešovitim sastojinama bukve i hrasta kitnjaka u Srbiji. *Glasnik Šumarskog fakulteta, Beograd*. 83, 21-31.

Banković S., Medarević M., Pantić D. (2006). Regresioni modeli procenta zapreminskog prirasta za sastojine krupnolisne, sitnolisne i srebrnaste lipe na Fruškoj Gori. *Časopis Šumarstvo*, 4, 37-46.

Banković S., Medarević M., Pantić D., Petrović N. (2009). Nacionalna inventura šuma Rešublike Srbije - Šumski fonda Republike Srbije, Ministarstvo poljoprivrede šumarstva i vodoprivrede Republike Srbje -Uprava za šume, Beograd, 1-244.

Burczyk, J., Adams, W.T., Birkes, D.S., Chybicki, I.J. (2006). Using genetic markers to directly estimate gene flow and reproductive success parameters in plants on the basis of naturally regenerated seedlings. *Genetics, Vol.173(1)* , 363-372. Doi: 10.1534/genetics.105.046805

Jovanović, B., Mišić, V., Dinić A., Jović, N., Vukićević, E. (1997). Vegetacija Srbije II1, *Srpska akademija nauke i umetnosti, Beograd*, vol. 2.

Krstić M., Stojanović Lj., Vorkapić D. (2006). Konzervacija izdanačkih šuma kitnjaka, saladuna i cera na području „Stolovi – Ribnica". *Časopis Šumarstvo*, 3, 125-140.

Manetti M., C., Becagli, C., Bertini, G., Cantiani P., Marchi M., Pelleri F., Sansone D., Fabbio G. (2020). The conversion into high forest of Turkey oak coppice stands: methods, silviculture and perspectives, *iForest Biogeosciences and Forestry, Vol. 13,* 309-317. Doi:10.3832/ifor3483-013

Martac N., Racic M., Kanjevac B., Pavlovic B., Jovic Đ., Čokeša V. (2024). The condition of the coppice stand of Hungarian and Turkey oak in private ownership in the Bukovik mountain area, *Book of abstracts*, XV International Scientific Agriculture Symposium ,,Agrosym 2024", Jahorina October 10-13, 2024, 884.

Medarević M., Banković S., Pantić D., Petrović N. (2004). Izdanačke šume bukve – stanje, problemi gazdovanja i mogućnosti njihovog rešavanja. *Časopis Šumarstvo,* 3, 37-47.

Notarangelo M., La Marca O., Moretti N. (2018). Long-term effects of experimental cutting to convert an abandoned oak coppice into transitional high forest in a protected area of the Italian Mediterranean region. *Forest Ecology and Management, Vol. 430,* 241-249. Dio: 10.1016/j.foreco.2018.08.012

Popović, V., Lučić A., Rakonjac Lj. (2021). Varijabilnost populacija sladuna (*Quercetum frainetto Ten*.) u Srbiji prema morfološkim svojstvima žira. *Časopis Šumarstvo,* 1-2, 49-58.

Ratknić M., Dražić M., Rakonjac Lj. (2010). Melioracija izdanačkih i degradiranih šuma i obnavljanje šumskih ekosistema, Institut za šumarstvo, Beograd.

Stajić, S., Rakonjac, Lj., Čokeša,V. (2008). Phytoceonological characteristics of Hungarian oak and Turkey oak with hornbeam forest (*Carpino betuli-Quercetum frainetto-cerris*) in the area of Bogovadja. *Sustainable Forestry*, 57-58, 104-114.

COMPARATIVE ANALYSIS OF SILVICULTURAL TREATMENTS IN EVEN-AGED HUNGARIAN OAK STANDS

Nikola MARTAĆ, Nemanja LAZAREVIĆ, Miloš RAČIĆ, Nenad PETROVIĆ, Ivana RAČIĆ, Natalija MOMIROVIĆ, Branko KANJEVAC

Summary

The research was conducted in *coppice stands* of Hungarian oak (*Quercus frainetto*) on Mount Cer, Western Serbia. The main objective of the study was to define optimal *silvicultural treatments* for converting coppice stands into a higher silvicultural form, based on an analysis of their initial condition. Additionally, the paper presents the stand condition before and after the applied treatments, enabling a reliable assessment of their effectiveness. Data collection and processing from the sample plots were carried out using *standard dendrometric methods*, while the statistical analysis was performed using an *independent t-test*.

The results showed that the studied stands achieved higher values of *standing volume* and *volume increment* compared to the average for Hungarian oak coppice forests in

Serbia. Statistical analysis confirmed significant differences in mean tree volume and height between the sample plots, with the stand on Plot I exhibiting higher productivity than the stand on Plot II. The analysis of *site conditions*, *stand structure*, and the height and diameter of dominant trees indicated that the studied stands meet the requirements for *conversion to a high forest* through *indirect conversion*. Based on the previous analyses, it was decided that the stand on Plot I should continue the production process with the application of *high selective thinning*, whereas in the stand on Plot II, the process of indirect conversion was initiated immediately through the application of *preparatory–seed cutting* as part of the *shelterwood system*.

The results obtained after the implementation of the silvicultural treatments indicate that in the stand on Plot I, the best-quality trees—those contributing most to total volume—were retained, as well as trees from the lower storey to prevent *weed encroachment*. In the stand on Plot II, the best-quality trees were preserved with the aim of *seeding the regeneration area*.

The findings represent an example of a systematic approach to the planning of silvicultural measures based on previously assessed stand conditions, forming the foundation for maintaining and enhancing the *productivity* and *stability* of coppice stands, as well as for their gradual *conversion into high forests*. Such an approach contributes to the implementation of modern principles of *sustainable forest management* and to the long-term conservation of the natural values of these ecosystems.

UPOREDNI PRIKAZ RAZLIČITIH GAZDINSKIH TRETMANA U SASTOJINAMA SLADUNA ISTE STAROSTI

Nikola MARTAĆ, Nemanja LAZAREVIĆ, Miloš RAČIĆ, Nenad PETROVIĆ, Ivana RAČIĆ, Natalija MOMIROVIĆ, Branko KANJEVAC

Rezime

Istraživanje je sprovedeno u izdanačkim sastojinama hrasta sladuna (Quercus frainetto) na planini Cer u Zapadnoj Srbiji. Cilj istraživanja je bio definisanje optimalnih uzgojnih tretmana za prevođenje izdanačkih sastojina u viši uzgojni oblik, na osnovu analize njihovog početnog stanja. Dodatno, rad obuhvata prikaz stanja sastojina pre i posle sprovođenja tretmana, čime se omogućava pouzdana analiza i procena njihove efikasnosti. Prikupljanje i obrada podataka sa oglednih polja izvršeni su primenom standardnih dendrometrijskih metoda, dok je statistička analiza sprovedena pomoću nezavisnog t-testa.

Rezultati su pokazali da istraživane sastojine ostvaruju veće vrednosti zapremine i zapreminskog prirasta u odnosu na prosek za izdanačke šume sladuna u Srbiji. Statistička analiza potvrdila je značajne razlike u prosečnoj zapremini i visini stabala između oglednih polja, pri čemu je sastojina na OP I pokazala višu proizvodnost od sastojine na OP II. Analiza stanišnih uslova, strukture sastojina, visine i prečnika dominantnih stabala, pokazala je da predmetne sastojine ispunjavaju uslove za prevođenje u viši uzgojni oblik putem indirektne konverzije. Na bazi prethodno sprovedenih analiza odlučeno je da se u sastojini na OP I produži proizvodni proces i sprovede visoka selektivna proreda, dok je u sastojini na OP II odmah započet proces indirektne konverzije primenom pripremno-oplodnog seka oplodne seče. Rezultati nakon sprovedenih uzgojnih tretmana ukazuju da su u satojini na OP I zadržana najkvalitetnija stabla koja su nosioci zapremine i stabla iz podstojnog sprata kako bi se sprečilo zakorovljavanje tla, dok su u sastojini na OP II zadržana najkvalitetnija stabla sa ciljem da osemene površinu predviđenu za obnovu.

Dobijeni rezultati predstavljaju primer sistematskog pristupa u planiranju uzgojnih mera u skladu sa prethodno utvrđenim stanjem šuma, što čini osnovu za očuvanje i unapređenje produktivnosti i stabilnosti izdanačkih sastojina, kao i za njihovo postupno prevođenje u visoki uzgojni oblik. Ovakav pristup doprinosi primeni savremenih principa održivog gazdovanja šumama i dugoročnom očuvanju prirodnih vrednosti ovih ekosistema.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD
SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 92, 2025 ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592097Z
UDK: 712.41+534.6:582.681.81=111
Original scientific paper

RELATIONSHIP BETWEEN THE VISUAL TREE RATINGS AND WOOD SOUND VELOCITY OF POPLAR TREES

Ivana ŽIVANOVIĆ[1], Aleksandar LUČIĆ[1], Nenad ŠURJANAC[1], Goran ČEŠLJAR[1], Ilija ĐORĐEVIĆ[1], Filip JOVANOVIĆ[1]

Abstract: *Fifty-six Populus spp. trees were examined in Belgrade, Serbia, with a focus on assessing vitality and decorativeness using the Visual Tree Assessment (VTA) method and measuring wood sound velocity. The study aimed to explore the connection between visual indicators of tree condition and internal structural properties based on sonic wave velocities. Vitality and decorativeness ratings ranged from 2 to 5 (out of 5), with mean values of 2.80 and 2.93, respectively; wood sound averaged 788,39 m/s. Statistically significant correlations (r = 0.52 for vitality, r = 0.53 for decorativeness) confirmed the possibility of integrating VTA and sonic measurements. Mathematical models were developed that successfully predict tree vitality and decorativeness based on sound velocity. It can be concluded that this combined approach improves tree health assessment accuracy, supports timely interventions, and contributes to sustainable urban greenery management.*

Keywords: decorativeness, vitality, sound velocity, Populus spp., mathematical models

KORELISANOST VIZUELNIH OCENA STABALA I BRZINE PROSTIRANJA ZVUKA U DRVETU TOPOLA

Sažetak: *Analizirano je 56 stabala topole (Populus L.) na području Beograda, sa fokusom na procenu vitalnosti i dekorativnosti metodom vizuelne procene stabala (VTA), uz merenje brzine zvučnih talasa u drvetu. Cilj istraživanja je da se prouči povezanost vizuelnih indikatora stanja stabala i unutrašnjih strukturalnih svojstava na osnovu brzine zvučnih talasa. Ocene vitalnosti i dekorativnosti su se kretale u rasponu od 2 do 5 od 5, s prosečnim vrednostima od 2,80 i 2,93, dok je brzina zvuka u drvetu pokazala prosečnu vrednost od 788,39 m/s. Statistički značajne korelacije utvrđene su između brzine zvuka u drvetu i vizuelnih parametara (r = 0,52 za vitalnost, r = 0,53 za dekorativnost), što ukazuje na mogućnost integracije VTA metode i zvučnih merenja. Razvijeni su matematički modeli kojima se pouzdano mogu predvideti vitalnost i dekorativnost drveta na osnovu brzuine zvuka. Zaključuje se da ovaj kombinovani pristup poboljšava preciznost procene zdravlja stabala, podržava pravovremene intervencije i doprinosi održivom upravljanju urbanim zelenilom.*

[1] Institute of Forestry, Kneza Viseslava 3, 11030 Belgrade, Serbia
*Corresponding author. E-mail: ivana.zivanovic@forest.org.rs

Ključne reči: dekorativnost, vitalnost, brzina zvuka, *Populus* spp., matematički modeli

1. INTRODUCTION

Belgrade, the capital of Serbia, located at 116.75 m elevation (44°49'14" N, 20°27'44" E), covers 359.92 m² of urbanized area (City of Belgrade, Secretariat for Information, 2022). The city has 2,907.37 ha of green spaces, including parks and squares (393.00 ha), residential greenery (1,077.67 ha), roadside green spaces (174.89 ha), urban forests (650.88 ha), coasts, shores, and Great War Island (225.83 ha), protective zones (35.77 ha), and other types of green areas (349.24 ha) (Milanović, 2006). Belgrade's rich ecological diversity and unique microclimatic conditions have resulted with varied plant communities throughout the area. Native deciduous species, such as lindens (*Tilia* spp.), maples (*Acer* spp.), ashes (*Fraxinus* spp.), poplars (*Populus* spp.), and hornbeams (*Carpinus* spp.) dominate in this area, whereas oaks (*Quercus* spp.) are less common. Introduced species include acacia (*Robinia pseudoacacia* L.), horse chestnut (*Aesculus hippocastanum* L.), catalpa (*Catalpa bignonioides* Walter), as well as conifers, such as cedar (*Cedrus* spp.) (Maksimović et al., 1979). Human influence has expanded the diversity of dendroflora species, enhancing the city's green spaces.

Poplars (*Populus* L. fam. *Salicaceae)* are fast-growing broadleaved tree species inhabiting river banks and sites with accessible water supplies (Keča et al., 2014). The genus comprises 25–30 species native to the Northern Hemisphere. According to the National Forest Inventory (NFI) poplar stands cover about 48,000 ha, or 2.1% of the total forest area in Serbia (Banković *et al*., 2009). Poplar trees have garnered attention in previous decades for their great potential to contribute significantly to the quality and quantity of urban greenery. Poplars are ideal for urban areas due to: (1) the rapid growth and production of large biomass; (2) the ability to improve the microclimate through shading and pollution filtration; and (3) a great potential for heavy metals phytoextraction(Łukaszkiewicz *et al*., 2024).

Assessing the health and mechanical condition of trees in urban environments has become increasingly important due to the need to maintain public safety as well as the aesthetic and ecological value of green spaces. Urban trees are exposed to various stress factors, limited rooting space, soil compaction, mechanical injuries, and environmental pollution, which can promote the development of internal and external defects that are not always detectable through visual observation.

Modern approaches to evaluating tree stability integrate visual indicators with biomechanical principles that describe how trees respond to loading and tissue degradation. Changes in stem form, crown architecture, or vitality provide essential information for identifying potential structural weaknesses. However, numerous studies have shown that substantial internal defects often develop before they become externally visible, which may lead to an underestimation of risk when assessments rely solely on outward symptoms (Goh *et al*., 2018; Mahon *et al*., 2007).

For this reason, contemporary urban arboriculture increasingly relies on combining visual assessment with non-destructive techniques that provide information on wood condition and its ability to transmit mechanical energy. These approaches enable a more accurate estimation of degradation extent, a better understanding of the relationship between internal wood quality and mechanical properties, and ultimately an improved evaluation of the residual load-bearing capacity of trees. Integrating qualitative visual observations with quantitative indicators contributes to more reliable decision-making in tree management, particularly in high-risk urban areas (Živanović *et al*., 2019; Živanović *et al*., 2022).

In this paper, the wood speed velocities measured in 56 poplar trees were compared with vitality and decorativeness visual ratings. The objective of this research is to establish a connection between the vitality and decorativeness of poplar trees, as evaluated through a detailed visual inspection, and the sound wave velocities obtained through measurements conducted on the same trees. By integrating these two factors, the study aims to provide deeper insights into how visual assessments correlate with the physical-mechanical properties of trees, as indicated by acoustic measurements. Understanding this relationship can contribute significantly to developing comprehensive methods for tree health evaluation, combining both subjective visual parameters and objective scientific data for a more holistic assessment approach.

2. MATERIAL AND METHODS

The sample consisted of 56 trees of *Populus* in the city of Belgrade (Figure 1).

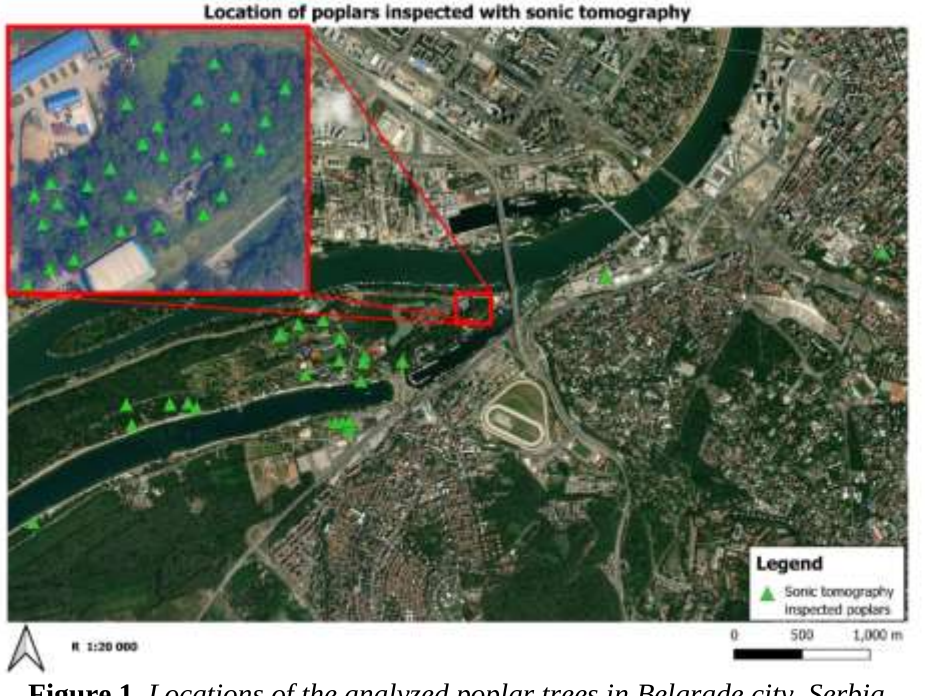


Figure 1. *Locations of the analyzed poplar trees in Belgrade city, Serbia*

The examined trees belonged to four poplar taxa [36 trees of *Populus alba* L., eleven trees of *P. nigra* L., four trees of *P. euroamericana* (Dode) Guinier, and five trees of *P. x canadiensis* Moench]. The vitality and decorativeness of the trees were evaluated using the Visual Tree Assessment (VTA) method (Mattheck and Breloer, 1994), according to the rating scales defined in Table 1.

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 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, phytopathological 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 sound propagation velocities were measured at breast height using the Arbotom 2D Impulse Tomograph, manufactured by the German company Rinntech. At the start of the measurements, a compass was used to locate the north side of each tree, where the first sensor was placed. Additional sensors were then positioned clockwise around the tree's circumference at intervals of at least 15 cm. Depending on the diameter of the tree, 3–12 sensors were used for analysis. Based on the measurements of sound propagation velocities, the average sound wave velocity was calculated for each analyzed tree.

The obtained numerical data were processed using descriptive and regression statistical methods. Raw data were used to calculate the mean values of all variables and to determine the standard deviation and coefficient of variation for every mean value. The relationship between the visual tree ratings and wood sound velocity was identified using the Pearson’s linear correlation test. Statistical analyses were performed using Statgraphics software, version XVI.I (2009; Statpoint Technologies, Inc., Warrenton, Virginia, US).

3. RESULTS

The vitality and decorativeness of the examined poplar trees ranged from grade 2 to grade 5, with mean values of 2.80 and 2.93, respectively. The descriptive statistics revealed a moderate variability of these visual tree condition ratings (coefficient of variation was 20.80% for the vitality and 22.17% for the decorativeness of trees). On the other hand, the wood sound velocity ranged from 375.00 m/s to 2090.00 m/s, with a mean value of 788.39 m/s. In comparison to the vitality and decorativeness, the wood sound velocity was more variable tree condition parameter (coefficient of variation 37.15%) (Table 2).

Table 2. *Descriptive statistics for visual ratings of tree condition and wood sound velocity of poplars*

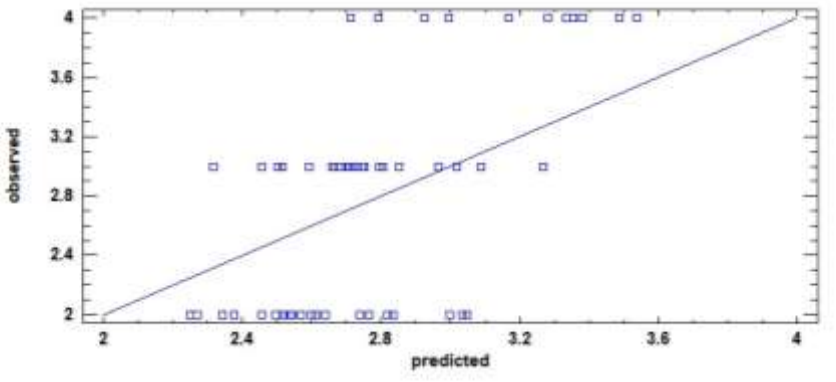
Tree condition parameters	Mean value	Standard deviation	Coeff. of variation (%)	Minimum value	Maximum value
Vitality (1–5)	2.80	0.75	26.71	2	4
Decorativeness (1–5)	2.93	0.74	25.10	2	5
Wood sound velocity (m/s)	788.39	292.90	37.15	375	2090

Table 3 and Figure 2 show linear models which describe the relationship between the visual ratings of vitality and decorativeness and wood sound velocity of poplar trees. According to the obtained results, almost the same as a correlation occurred between the ratings of tree decorativeness and the wood sound velocity (r = 0.534) than between the ratings of tree vitality and the wood sound velocity (r = 0.523). Both values are statistically significant ($p < 0.05$) with similar standard errors of estimate (0.523 for vitality and 0.534 for decorativeness). These results indicate that the visual ratings of trees are good indicators of tree condition and health of poplars, although some preference might be given to the decorativeness ratings. Using the obtained linear regression models, visual tree condition parameters can be calculated based on wood sound velocity.

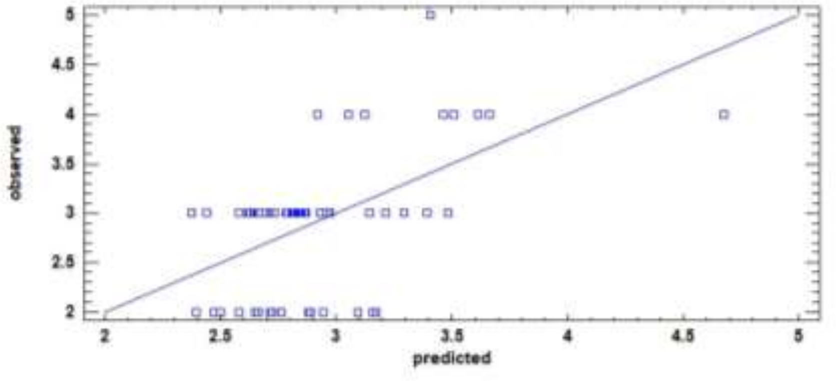
Table 3. *Linear regresion models of tree condition ratings based on average sound velocity in wood of poplars*

Tree condition parameters	Linear regression model	Correlation coefficient	Standard error of estimate
Vitality	1.74819 + 0.00133865*Avg sound velocity	**0.523**	0.249
Decorativeness	1.87164 + 0.00134061* * Avg sound velocity	**0.534**	0.242

Note: Bold values denote statistically significant correlation coefficients.



A)



B)

Figure 2. *Correlation between visual tree ratings (A. tree vitality, B. tree decorativeness) and average sound velocity in wood of poplars.*

4. DISCUSSION

Using Arbotom Sonic Tomograph, an investigation was conducted on 27 poplars to assess their internal condition and confirm the findings obtained through Visual-Tree Assesment (VTA). Visual Tree Assessment (VTA), developed in 1994 by Claus Mattheck and Helge Breloer, is a method for evaluating tree stability and detecting defects. It relies on the principle that trees reinforce weak areas in response to mechanical stress. Arborists use VTA to identify external signs of internal decay, such as bulges, dents, or cracks, indicating structural weaknesses. If defects are suspected, further testing like sonic wave velocity measurements or drilling may be used. Widely adopted in arboriculture, VTA is a non-invasive method that assesses tree safety and risks effectively. Initially, signs of potential problems were identified through VTA, evaluating the vitality and decorative value of the trees. To further validate these assessments, sound analysis was applied.

The results showed a significant correlation between the ratings obtained through VTA and the data collected using Arbotom tomography. The correlation coefficient was 0.52 for vitality and 0.53 for decorative value, confirming that the sound method can reliably complement and validate VTA assessments.

Studies conducted by Mattheck and Bethge (1994) demonstrated that tree safety can be assessed by measuring sound velocities, making it a reliable method for detecting internal defects. A successive approach was recommended, where visual assessments are performed first (VTA), followed by sound measurements to confirm initial concerns. Their research also showed that root decay can be detected if it extends into the base of the tree, further supporting the use of sound technology in tree diagnostics. However, it was noted that certain types of decay, such as embrittlement (a reduction in strength without loss of stiffness), cannot be detected in early stages.

Additionally, this connection between the two methods was also confirmed by the research of Saad (2023), where PiCUS Sonic Tomograph was used to detect internal decay, providing scientific confirmation for the suspicions raised by VTA. Their findings emphasized the importance of integrating sound analysis in tree health assessments, proving that VTA and sound methods are closely related and mutually supportive.

Moreover, iron-wood trees were visually inspected for seven main defects, including decay, cracks, root issues, and weak branch unions by Lin *et al*., 2015. Nondestructive testing revealed that decay-damaged trees had lower stress wave velocities compared to undamaged ones, with a threshold of 1636 m/s used for diagnosis. Tomograms showed a distinct pattern of high velocity in healthy areas and low velocity in decay-damaged areas of the stem.

Additional studies further support the combined use of visual assessments and nondestructive tools. Deflorio *et al*. (2008) demonstrated that stress-wave and ultrasonic velocities correlate strongly with wood stiffness and decay progression, making them valuable for early detection of internal defects. Nicolotti *et al*. (2003) showed that tomographic imaging significantly improves the identification of hidden cavities and fungal decay compared to visual inspection alone. Similarly, Rinn (2012) emphasized that integrating VTA with sonic and resistance-based methods increases diagnostic reliability and supports better management decisions in urban tree care. Research by Wang *et al*. (2007) further confirmed that wave-propagation tools are sensitive to density loss and changes in mechanical properties, validating their role in structural assessment.

The findings of these researchers align with the results of this study on poplars, reinforcing that the combination of VTA analysis and sound methods provides more precise data and allows timely interventions in tree maintenance. This approach contributes to the preservation of urban greenery and reduces the risk of tree failure, in accordance with the methods applied by mentioned authors in their studies.

5. CONCLUSION

Based on the results of the conducted research, the integrated application of Visual Tree Assessment (VTA) and sonic tomography represents a consistent approach for evaluating the physiological condition and structural stability of poplar trees. The combination of external visual indicators and internal sonic data provides a comprehensive understanding of tree health, allowing assessment not only of surface symptoms but also of the internal integrity of the wood. Variability observed among the analyzed trees indicates differences in vitality and mechanical condition that can be objectively quantified through sound velocity measurements.

The relationship between sound velocity and visual parameters of vitality and decorativeness confirms the correspondence between external appearance and internal wood quality. Trees with higher sound velocities generally exhibit better physiological condition and more favorable aesthetic attributes, reflecting their stability and vitality within the urban environment. The established regression relationships enable the estimation of visual parameters based on measurable sonic characteristics, thus extending the diagnostic value of the method.

The integration of VTA and sonic tomography contributes to a more precise, science-based evaluation of urban trees. Such an approach enhances the reliability of decision-making in arboricultural practice, supports preventive maintenance and risk management, and ultimately contributes to the preservation and sustainable development of urban green spaces.

REFERENCES

Banković, S., Medarević, M., Pantić, D., Petrović, N., Šljukić, B., & Obradović, S. (2009). The growing stock of the Republic of Serbia: State and problems. *Glasnik Sumarskog fakulteta*, (100), 7-29.

Deflorio, G., Fink, S., & Schwarze, F. W. M. R. (2008). Detection of incipient decay in tree stems with sonic tomography after wounding and fungal inoculation. *Wood Science and Technology*, 42(2), 117–132. https://doi.org/10.1007/s00226-007-0155-5

Goh, C. L., Rahim, R. A., Rahiman, M. H. F., Talib, M. T. M. and Tee, Z. C. (2018): Sensing wood decay in standing trees: *A review, Sensors and Actuators, A: Physical*, 269, 276–282

Gradska opština Savski venac, https://sr.wikipedia.org/sr-ec/Gradska_opština_Savski_venac (pristupljeno: 26. 3. 2022)

Keča, L. (2014). Determination of the optimal production cycle length from the financial aspect in poplar plantations on meadow semigley. *Glasnik Sumarskog fakulteta*, (110), 87-104.

Lin, C. J., & Yang, T. H. (2015). Detection of acoustic velocity and electrical resistance tomographies for evaluation of peripheral-inner wood demarcation in urban royal palms. *Urban Forestry & Urban Greening*, *14*(3), 583-589.

Łukaszkiewicz, J., Długoński, A., Fortuna-Antoszkiewicz, B., & Fialová, J. (2024). The ecological potential of poplars (Populus L.) for city tree planting and management: A preliminary study of Central Poland (Warsaw) and Silesia (Chorzów). *Land*, *13*(5), 593.

Mahon Jr, J. M. (2007). The use of acoustics for the wood quality assessment of standing P. taeda trees (*Doctoral dissertation*, uga).

Maksimović, B., Prošić, B., Krstić, A., Stanojević, S. (1979): Zelenilo Beograda. RO „Zelenilo-Beograd“, Kulturni centar Beograda, Beograd

Mattheck, C., & Breloer, H. (1994). Field guide for visual tree assessment (VTA). *Arboricultural Journal*, *18*(1), 1-23.

Nicolotti, G., Socco, L. V., Martinis, R., Godio, A., & Sambuelli, L. (2003). Application and comparison of three tomographic techniques for detection of decay in trees. *Journal of Arboriculture*, 29(2), 66–78.

Rinn, F. (2012). Integrated tree assessment: Combining VTA, resistance drilling, and sonic methods. *Arboriculture & Urban Forestry*, 38(6), 251–259.

Saad, A. H. M., Roseli, A. N. M., & Kamaruzaman, R. (2023). PiCUS Sonic Tomograph: A Case Study of Crimson Bottlebrush Tree (Melaleuca citrina (Curtis) Dum. Cours). *Journal of Tropical Plant Physiology*, *15*(1), 13-13.

Sambuelli, L., Socco, L. V., Godio, A., Nicolotti, G., & Martinis, R. (2003). Ultrasonic, electric and radar measurements for living trees assessment. *Bollettino di Geofisica Teorica ed Applicata (Bulletin of Theoretical and Applied Geophysicist*), 44, 3-4.

Wang, X., Allison, R. B., Wang, L., Simpson, W. T., Ross, R. J., & Green, D. W. (2007). Stress wave nondestructive evaluation of standing trees: A review. *General Technical Report FPL–GTR–168*. Madison, WI: U.S. Department of Agriculture, Forest Service.

Živanović, I., Jovanović, F., Šurjanac, N., Filipović, Đ., & Lučić, A. (2023). Condition of northern red oak trees in the urban environment of Belgrade (Serbia). *Sustainable Forestry*: Collection, (87-88), 89-98.

Živanović, I., Poduška, Z., Rakonjac, Lj. and Jovanović, F. (2019): Potentials of the evaluation of the wood quality in living trees by using semi- and non-destructive methods to reduce wood-processing costs, *Sustainable Forestry*, 78-79: 115–126

RELATIONSHIP BETWEEN THE VISUAL TREE RATINGS AND WOOD SOUND VELOCITY OF POPLAR TREES

Ivana ŽIVANOVIĆ, Aleksandar LUČIĆ, Nenad ŠURJANAC,
Goran ČEŠLJAR, Ilija ĐORĐEVIĆ, Filip JOVANOVIĆ

Summary

A total of 56 poplar trees (Populus sp.) in the Belgrade area were examined to assess vitality and decorativeness using the Visual Tree Assessment (VTA) method and by measuring the velocity of sound waves in wood. VTA, as a widely applied non-invasive method, enables the detection of external symptoms that indicate internal degradation processes in wood, while sound analysis complements this assessment by providing quantitative data on sound propagation velocity through the woody tissue. The mean vitality score was 2.6780, and the mean decorativeness score was 2.8993, both showing moderate variability (coefficients of variation 20.27% and 22.25%, respectively).

The velocity of sound waves exhibited greater variability, with an average value of 663.26 m/s. Statistically significant correlations were found between sound velocity and visual scores ($r = 0.52$ for vitality, $r = 0.60$ for decorativeness), indicating a relationship between external tree assessment and internal structural characteristics. Mathematical models

were developed that allow reliable prediction of tree vitality and decorativeness based on sound velocity.

The results demonstrate that combining visual assessment and sonic analysis improves the precision of tree condition diagnostics, enabling timely interventions and contributing to the preservation of urban greenery.

KORELISANOST VIZUELNIH OCENA STANJA STABALA I BRZINE PROSTIRANJA ZVUKA U DRVETU TOPOLA

Ivana ŽIVANOVIĆ, Aleksandar LUČIĆ, Nenad ŠURJANAC,
Goran ČEŠLJAR, Ilija ĐORĐEVIĆ, Filip JOVANOVIĆ

Rezime

Ispitano je 56 stabala topole (*Populus* sp.) na području Beograda radi procene vitalnosti i dekorativnosti korišćenjem metode vizuelne procene stabala (VTA) i merenjem brzine zvučnih talasa u drvetu. VTA, kao široko primenjena neinvazivna metoda, omogućava detekciju spoljašnjih simptoma koji ukazuju na unutrašnje degradacione procese u drvetu, dok zvučna analiza ovu procenu upotpunjuje kvantitativnim podacima o brzini prostiranja zvuka kroz drvno tkivo. Ocene vitalnosti su imale prosečnu vrednost od 2,80, dok je dekorativnost imala prosečnu vrednost od 2,93, pri čemu su obe pokazale umerenu varijabilnost (koeficijenti varijacije 26,71% i 25,10%).

Brzina zvučnih talasa pokazala je veću varijabilnost, s prosečnom vrednošću 788,39 m/s. Statistički značajne korelacije utvrđene su između brzine zvuka i vizuelnih ocena (r = 0,52 za vitalnost, r = 0,53 za dekorativnost), što ukazuje na povezanost između spoljašnje procene stabala i unutrašnjih strukturalnih osobina. Razvijeni su matematički modeli kojima se pouzdano mogu predvideti vitalnost i dekorativnost drveta na osnovu brzuine zvuka.

Rezultati rada potvrđuju da kombinovanje metoda vizuelne procene i zvučne analize poboljšava preciznost dijagnostike stanja stabala, omogućujući pravovremene intervencije, kao i očuvanje urbanog zelenila.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY
COLLECTION 92, 2025

ODRŽIVO ŠUMARSTVO
ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592107M
UDK: 712.253 (497.11Beograd)=111
Original scientific paper

VISUAL ASSESSMENT OF TREES IN THE URBAN FOREST IN BELGRADE: A CASE STUDY OF THE AREA PLANNED FOR THE CONSTRUCTION OF THE MULTIFUNCTIONAL HALL OF THE INSTITUTE FOR SPORT AND SPORTS MEDICINE OF THE REPUBLIC OF SERBIA

Suzana MITROVIĆ[1], Milorad VESELINOVIĆ, Snežana STAJIĆ, Nemanja LAZAREVIĆ, Katarina MARINKOVIĆ[2], Radmila ĐURAŠINOVIĆ[3], Marija MILOSAVLJEVIĆ[4]*

Abstract: *This paper aims to evaluate the vegetation in the area proposed for the construction of the Multifunctional Hall of the Institute for Sport and Sports Medicine of the Republic of Serbia. The assessment of the existing vegetation was based on the analysis of qualitative evaluation parameters – vitality and decorativeness – of selected trees. Vitality and decorativeness were assessed on a five-point scale (1–5) using the Visual Tree Assessment (VTA) method. A total of 509 trees were recorded in the surveyed area, including 11 dead individuals. More than 30 species were identified, comprising five coniferous and twenty-four deciduous species. Conifers predominated, with Pinus nigra J.F.Arnold as the most common, while Quercus sp., Acer platanoide L., and Betula pendula Roth were the most frequent deciduous species. The average vitality and decorativeness scores, assessed on a five-point scale, were 3.10 and 3.08, respectively. The Urban Project proposed that most new facilities be constructed on existing green spaces and meadows previously used as sports fields. Less than 5% of the analysed vegetation would need to be removed in areas designated for construction. During redevelopment, all felled trees should be replaced through appropriate greening measures. Timely visual assessment of trees and green areas is essential in the planning and development of such facilities to ensure the preservation of urban forests and the continuity of green infrastructure.*

Keywords: VTA method, urban forests, greenery, tree vitality, tree decorativeness.

[1] Institute of forestry, Kneza Višeslava 3, 11000 Belgrade, Serbia
[2] Rasadnik Žića Dragan Đurđević PR, 37204 Veliki Šiljegovac, Kruševac, Serbia
[3] Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia
[4] Institute of Entomology, Branisovska 31, 37005 České Budějovice, Czech Republic

*Corresponding author. E-mail: suzana.mitrovic@forest.org.rs

VIZUELNA PROCENA DRVEĆA U URBANOJ ŠUMI U BEOGRADU: STUDIJA SLUČAJA PODRUČJA PLANIRANOG ZA IZGRADNJU MULTIFUNKCIONALNE DVORANE ZAVODA ZA SPORT I MEDICINU SPORTA REPUBLIKE SRBIJE

Sažetak: *Cilj ovog rada je procena vegetacije na području predloženom za izgradnju Multifunkcionalne dvorane zavoda za sport i medicinu sporta Republike Srbije. Procena postojećeg stanja vegetacije zasnovana je na analizi kvalitativnih parametara procene (vitalnost i dekorativnost) odabranih stabala. Vitalnost i dekorativnost stabala procenjene su na petostepenoj skali (1–5) korišćenjem Metode vizuelne procene stabala (VTA). Na ispitivanom području zabeleženo je ukupno 509 stabala, uključujući 11 mrtvih jedinki. Identifikovano je više od 30 vrsta, od kojih pet četinarskih i dvadeset četiri listopadne vrste. Četinari su dominantni, Pinus nigra je bio najčešći, dok su Quercus sp., Acer platanoides i Betula penudla bile najčešće listopadne vrste. Prosečne ocene vitalnosti i dekorativnosti, procenjene na petostepenoj skali, bile su 3,10 i 3,08. Urbanističkim projektom je planirano da se većina novih objekata izgradi na postojećim zelenim površinama i livadama koje su se ranije koristile kao sportski tereni. Manje od 5% analizirane vegetacije bi trebalo ukloniti u područjima određenim za izgradnju. Tokom procesa rekonstrukcije, planirano je da sva posečena stabla budu zamenjena. Blagovremena vizuelna procena stabala i zelenih površina je neophodna u planiranju i razvoju ovakvih objekata jer se na taj način osigurava očuvanje gradskih šuma i zadržava kontinuitet zelene infrastrukture.*

Ključne reči: VTA metoda, urbane šume, zelenilo, vitalnost drveća, dekorativnost drveća.

1. INTRODUCTION

Urban greenery is affected by various adverse anthropogenic factors. Pollution, drought, soil compaction that restricts root growth, and mechanical damage are the most common stressors in urban environments (Burton, 2002; Haaften et al., 2021). These factors have a detrimental effect on plant health, vigour, and overall development (Smith et al., 2019). To evaluate the condition of the green space analysed, it is necessary to assess the health and characteristics of the individual plants and species present in the area. The greatest ecological and aesthetic potential of the site lies in the tree species that form the structure of the park vegetation (Tomićević-Dubljević et al., 2017). Trees in urban settings play an important ecological role, contributing to improved air quality, microclimate regulation, landscape stability, and overall quality of life. Therefore, understanding the current state of the tree population is essential for informed planning and sustainable management of urban green spaces.

The primary objective of the assessment was to provide a preliminary evaluation of the existing tree population to support the planned development of sports facilities, including a multifunctional hall and an indoor Olympic swimming pool, as well as to improve the accommodation capacity of the existing hotel. At the time of the assessment, the sports fields did not meet the standards required for elite athlete training and competition, highlighting the need for redevelopment while preserving valuable vegetation and ensuring environmental quality.

2. MATERIAL AND METHODS

The Visual Assessment of green areas was conducted in 2016 in the area of the Sports and Recreational Centre (SRC) Košutnjak, located within the Institute of Sport and Sports Medicine of the Republic of Serbia. This site is situated within the urban forest, which forms part of the green infrastructure of the city of Belgrade.

Figure 1. *Location of the analysed space, construction plan of the facilities*

The methodology used to assess and evaluate the existing greenery was based on analysing certain tree attributes using the VTA (Visual Tree Assessment) method (Mattheck & Breloer 1994; Stojanović et al. 2011; He et al., 2022). These attributes were determined from assessment data. The evaluated parameters are vitality and decorativeness, rated on a five-point scale (1–5). The vitality of individual trees was quantified using a comprehensive metric based on the ratio of measured tree height to diameter at breast height, combined with observations of specific characteristics, including the number of dry or broken branches in the crown, the presence of dry tips and dieback of lower branches, and the intensity of leaf and needle desiccation. The overall health of each tree, including the presence of mechanical damage, phytopathological infections, or insect infestations, also influenced the vitality rating. The decorativeness of trees refers to their aesthetic value. Assessment of this attribute primarily relies on the subjective judgement of researchers, considering criteria such as tree form, surface characteristics, crown mass, symmetry, coloration, and seasonal variability.

A five-level scale was applied to evaluate tree vitality and the decorativeness of individual trees.

Table 1. *Ranks given for tree vitality and decorativeness (Stojanović et al. 2011).*

Rank	Criteria for evaluating tree vitality	Criteria for evaluating tree decorativeness
1	A dead or dying tree; deformed, diseased, decaying, broken, or severely damaged, with no potential for recovery.	A visually unbalanced, asymmetrical tree that disrupts the overall spatial impression. Lacking distinct colour, variation, or dynamics, with poorly defined form and structure.
2	Still vital with any mechanical or health damage. Trees with missing a part of the crown. Extremely damaged tree that can survive.	A tree with an uneven, disproportionate silhouette and poorly defined form, showing signs of mechanical or health damage. Missing parts of the crown, with weak colour harmony and an unbalanced relationship between mass and volume.

Rank	Criteria for evaluating tree vitality	Criteria for evaluating tree decorativeness
3	A damaged tree that can be revitalized through proper maintenance. Tree with a distinctly shaped crown. Tree with a moderate level of disease or mechanical damage.	Tree with a clearly outlined crown visible in silhouette. Lacking colour variation and visual interest. Positioned in a way that appears disproportionate or poorly integrated within the surrounding space.
4	A healthy tree showing slight signs of disease or pest damage. Minor defects are present but can be easily corrected through proper maintenance.	Tree with a visually harmonious shape and only slight aesthetic imperfections. Displays a well-balanced interplay of colour, form and volume.
5	Completely healthy and undamaged tree. Tree of exceptional vitality and strong adaptation to surrounding environmental conditions.	A visually striking and highly ornamental tree that exhibits clear proportion and symmetry consistent with its species. Distinct in colour and form, it enhances the space through its elegant lines, structure, and overall appearance.

During the visual inspection, the health of each tree-including crown and leaf condition-was evaluated, with particular attention to phytopathological diseases, mechanical damage, and entomological infestations. Trees assigned scores of 1 or 2 for vitality and decorativeness, as well as species classified as invasive in Serbia, were considered unsuitable for preservation and potentially hazardous to site users. Descriptive statistical analyses included calculation of the mean ($\overline{X}$), standard deviation (±SD), and coefficient of variation (CV, %). Pearson correlation analysis was performed to examine relationships between variables, with statistical significance set at $p = 0.05$. All statistical analyses were conducted using the online program DATAtab (DATAtab e.U., Graz, Austria; https://datatab.net).

3. RESULTS

In this study, a total of 509 trees were assessed for vitality and decorativeness using a five-point scale, of which 11 were dead. Thirty tree species were recorded, comprising five coniferous and twenty-four deciduous species. Among the conifers, *Pinus nigra* was the most abundant (307 individuals). The most common deciduous species were *Quercus* sp., *Acer platanoides*, and *Betula penudla*. Species exhibiting the highest vitality included *Cornus* sp., *Prunus avium* L., *Picea abies* L. and *Aesculus hippocastanum* L., whereas *Ficus carica* L., *Pyrus pyraster* L. Burgsd., and *Morus* sp. showed the lowest vitality (Figure 2).

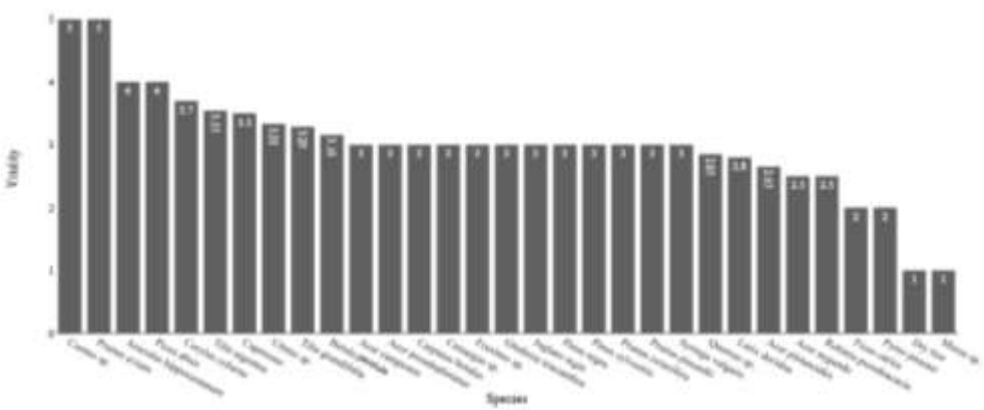


Figure 2. *Mean vitality by species*

Species of the genus *Cornus* sp., *Prunus avium*, *Picea abies*, and *Pinus nigra* exhibited the highest levels of decorativeness, whereas *Ficus carica*, *Pyrus* sp., and *Morus* sp. demonstrated the lowest aesthetic values (Figure 3).

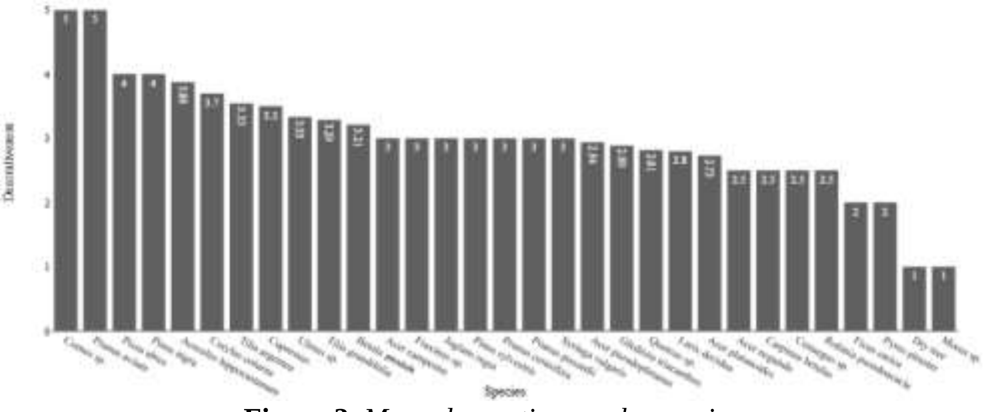


Figure 3. *Mean decorativeness by species*

Descriptive statistical analysis indicated that the mean vitality score across all assessed trees was 3.10, while the mean decorativeness score was 3.08. For coniferous species, the mean vitality was 3.02 ± 0.13 and the mean decorativeness was 3.98 ± 0.15. Deciduous species exhibited a comparable vitality score (3.01 ± 1.03) but a lower decorativeness score (2.99 ± 1.05). The higher standard deviation values observed for broadleaf species suggest greater variability in both vitality and aesthetic quality compared to coniferous species (Table 2).

Table 2. *The mean value of vitality and decorativeness in broadleaf and coniferous tree species*

		Frequency	Mean	Median	Sum	Std. Deviation	Variance	Min	Max	Range	Mean ± Std.
Vitality	conifer	307	3.02	3	926	0.13	0.02	3	4	1	3.02 ± 0.13
	broadleaf	202	3.01	3	609	1.03	1.07	1	5	4	3.01 ± 1.03
Decorativeness	conifer	307	3.98	4	1221	0.15	0.02	3	4	1	3.98 ± 0.15
	broadleaf	202	2.99	3	604	1.05	1.09	1	5	4	2.99 ± 1.05

The summarized results of the correlation analysis between vitality and decorativeness are presented in Table 3, including the correlation coefficient (*r*) and the corresponding significance level (*p*).

Table 3. *Correlation between decorativeness and vitality*

	Vitality	Decorativeness
Vitality	0.43	0.41
Decorativeness	0.41	0.68

Pearson correlation analysis revealed a statistically significant and strong positive relationship between vitality and decorativeness, with a correlation coefficient of $r = 0.76$ ($p < 0.001$). This finding indicates that trees exhibiting higher vitality scores also tend to possess greater aesthetic value, emphasizing the close association between physiological health and ornamental quality.

4. DISCUSSION

The general beneficial functions of urban vegetation, defined as ecosystem services, were also evident within the studied green space (Li et al., 2022; Mitrović et al., 2024). A decline in tree vitality reduces the capacity of species to improve environmental conditions, such as air quality and microclimate regulation, which in turn diminishes their ornamental value. This reduction in aesthetic quality further decreases their contribution to human well-being and overall environmental benefits (Chiesura, 2004; Lin & Lin, 2010). Maintaining tree vitality is therefore essential not only for ecological function but also for the aesthetic and recreational value of urban green spaces (Milosavljević et al., 2023; Mitrović et al., 2025).

In the context of the planned construction activities, 21 trees were designated for removal, while approximately 70% of the area was covered with invasive shrubs and undergrowth. The urban development plan proposed constructing most new facilities on existing grassy areas previously used as sports fields. However, the plan was not fully implemented; only part of the sports facilities and associated terrains were built, resulting in fewer tree removals than originally anticipated. Additionally, new green areas were established around the newly constructed buildings and on the roof of the sports hall. The integration of the building into the existing green infrastructure demonstrates a high level of environmental sustainability within the study area (Đurašinović et al., 2025). These measures, along with the expansion of the existing stadium and the addition of new amenities, helped minimise pressure on the remaining grass vegetation and surrounding greenery, thereby mitigating negative impacts on local biodiversity.

5. CONCLUSION

In this study, 30 tree species, comprising 509 individuals, were analysed. Using a five-point rating scale, the mean vitality of the trees was 3.10, and the mean decorativeness was 3.08. Less than 5% of the analysed green areas are planned for removal to accommodate the construction of new facilities. The selection of trees for removal has been carefully planned to minimise impacts on the overall structure and ecological functions of the urban forest. During the remodelling of the area, it is essential to replace removed trees with appropriate species, as outlined in the landscaping project. The initial visual assessment of trees and green areas plays a crucial role in ensuring the preservation and management of urban forests during the planning and execution of construction activities. Such proactive evaluation allows planners to maintain the balance between development and ecological sustainability while safeguarding aesthetic and recreational values.

By analysing the condition of tree vegetation across the site, it is possible to identify the potential impacts of construction on the green space. Biodiversity is not expected to be threatened by these interventions, as tree removals are focused on the most common species within the area. Furthermore, the strategic planting of new trees to replace those felled is expected to enhance both the average vitality and decorativeness of the urban forest, contributing to long-term ecological resilience and improved ecosystem services.

Acknowledgement: *This research was supported by: Ministry of Science, Technological Development and Innovation of the Republic of Serbia (No. 451-03-136/2025-03/200027); The Department of Architecture and Urban Planning, Faculty of Technical Sciences, University of Novi Sad through the project "The integration of contemporary practices, innovative approaches, and results of scientific research and artistic work in advancing the processes of dissemination and teaching through the application of the digital gallery in architecture, urbanism, and scene design", 2025; The grant by the European Community's Program Interreg Czech-Austria BIPC, reg. no. ATCZ00189.*

REFERENCES

Burton, E. (2002). Measuring Urban Compactness in Uk Towns and Cities. *Environment and Planning B: Planning and Design, 29(2),* 219-250. https://doi.org/10.1068/b2713

Chiesura, A. (2004). The Role of Urban Parks for the Sustainable City. *Landsc Urban Plan. 68(1),* 129–138. https://doi.org/10.1016/j.landurbplan.2003.08.003

Đurašinović, R., Zeković, M., Mitrović, S., Konstantinović, D., Pejić, S., Vemić, A. (2025). Indeterminacy as a Framework for Sustainable Architecture: Lessons from Spens, a Socialist Megastructure. *Sustainability 17,* 8527. https://doi.org/10.3390/su17198527

Haaften, V.M., Liu, Y., Wang, Y., Zhang, Y., Gardebroek, C., Heijman, W., Meuwissen, M. (2021). Understanding Tree Failure—A Systematic Review and Meta-Analysis. *PLoS ONE 16(2),* e0246805. https://doi.org/10.1371/journal.pone.0246805

He, K., Wei, L., Wang, B. (2022). How to Accurately Detect and Assess the Street Trees Risk in Mega Cities: A Tree Risk Assessment Method and Its Application. *Research Square,* 1- 21. DOI: https://doi.org/10.21203/rs.3.rs-1605348/v2

Li, H., Zhang, X., Li, Z., Wen, J., Tan, X. (2022). A Review of Research on Tree Risk Assessment Methods. *Forests. 13(10),* 1556. https://doi.org/10.3390/ f13101556.

Lin, B-S. & Lin, Y-J. (2010). Cooling Effect of Shade Trees with Different Characteristics in A Subtropical Urban Park. *HortScience. 45(1),* 83-86. https://doi.org/10.21273/hortsci.45.1.83

Mattheck, C. & Breloer, H. (1994). Field Guide for Visual Tree Assessment (VTA). *Arboricultural Journal, 18(1),* 1–23. https://doi.org/10.1080/03071375.1994.9746995

Milosavljević, M., Tabaković, T. M., Gavrilović, B., Mitrović, S., Milovac, Ž., Tomić, M., Eremija, S. (2023). Assessment of biotic threats to urban greenery: A case study in Stromovka Park, České Budejovice. *Sustainable Forestry: Collection 87-88,* 125-136. 10.5937/SustFor2388125M

Mitrović, S. Ž., Veselinović, M. M., Čule, N. M., Stajić, S. A., Češljar, G. D., Gagić-Serdar, R. P., Milosavljević, M. D. (2025). Visual Evaluation of Tree Health in Belgrade's Urban Forest: Čukarica Case Study. *HortScience, 60(1),* 54-55. https://doi.org/10.21273/HORTSCI18283-24

Mitrović, S., Veselinović, M., Poduška, Z., Stojanović, V., Marković, M., Opelka, J., Milosavljević, M. 2025. Vitality as an Indicator of Aesthetic Quality: An Initial Assessment of Urban Trees in Akademski Park, Belgrade. SEEFOR 11 (1): early view. DOI: https://doi.org/10.15177/seefor.20-XX

Smith, I. A., Dearborn, V. K., Hutyra, L. R. (2019). Live Fast, Die Young: Accelerated Growth, Mortality, And Turnover in Street Trees. *PLoS ONE 14(5),* e0215846. https://doi.org/10.1371/journal.pone.0215846

Stojanović N, Galečić N, Mešiček M (2011). *Functionality assesment of Sophora japonica L. trees used for urban land planting SC „Košutnjak"*, XIV International Eco-conference, Environmental protection of urban and suburban settlements, Novi Sad, Serbia, 379-388.

Tomićević-Dubljević, J., Živojinović, I., Tijanić, A. (2017). Urban Forests and the Needs of Visitors: A Case Study of Košutnjak Park Forest, Serbia. *Urban Forestry & Urban Greening 29*, 201-209. https://doi.org/10.1016/j.ufug.2018.07.004

VISUAL ASSESSMENT OF TREES IN THE URBAN FOREST IN BELGRADE: A CASE STUDY OF THE AREA PLANNED FOR THE CONSTRUCTION OF THE MULTIFUNCTIONAL HALL OF THE INSTITUTE FOR SPORT AND SPORTS MEDICINE OF THE REPUBLIC OF SERBIA

Suzana MITROVIĆ, Milorad VESELINOVIĆ, Snežana STAJIĆ, Nemanja LAZAREVIĆ, Katarina MARINKOVIĆ, Radmila ĐURAŠINOVIĆ, Marija MILOSAVLJEVIĆ

Summary

This study presents a comprehensive visual assessment of trees in the urban forest of Belgrade, focusing on the area proposed for the construction of a Multifunctional Hall at the Institute of Sport and Sports Medicine of the Republic of Serbia. The primary aim was to evaluate the existing tree vegetation in order to support sustainable planning and development of sports facilities while preserving urban green infrastructure. A total of 509 trees, representing 30 species-including five coniferous and twenty-four deciduous species-were assessed using the Visual Tree Assessment (VTA) method. The evaluation considered qualitative attributes (vitality and decorativeness), which were rated on a five-point scale.

Conifers were the dominant group, with *Pinus nigra* being the most frequent species, while the most common deciduous species were *Quercus* sp., *Acer platanoides*, and *Betula penudla*. Species exhibiting the highest vitality included *Cornus* sp., *Prunus avium*, *Picea abies*, and *Aesculus hippocastanum*, whereas *Ficus carica*, *Pyrus pyraster* Burgsd., and *Morus* sp. showed the lowest vitality. In terms of decorativeness, the highest scores were observed for *Cornus* sp., *Prunus avium*, *Picea abies*, and *Pinus nigra*, while *Ficus carica*, *Pyrus* sp., and *Morus* sp. were rated lowest. Descriptive statistical analysis revealed that the mean vitality and decorativeness scores across all trees were 3.10 and 3.08, respectively, with broadleaf species exhibiting greater variability in both attributes compared to conifers.

Pearson correlation analysis demonstrated a statistically significant and strong positive correlation between vitality and decorativeness ($r = 0.76$, $p < 0.001$), highlighting the close association between tree health and aesthetic value. These indicate that maintaining tree vitality not only supports ecological functions but also enhances visual and recreational quality in urban green spaces.

In the context of planned construction, less than 5% of the surveyed trees are proposed for removal, primarily targeting the most common species to minimize ecological and aesthetic impacts. Strategic greening measures, including the replacement of felled trees with suitable species and the creation of new green areas around buildings and on the roof of the sports hall, aim to enhance the overall vitality and decorativeness of the urban forest. These measures also help mitigate the potential negative impacts of construction on biodiversity, ecosystem services, and recreational value.

The study underscores the critical role of early visual assessment of trees in urban planning and landscape design. By identifying trees requiring protection, monitoring health status, and assessing ornamental value, planners can make informed decisions that balance development needs with the preservation of green infrastructure. Integrating construction projects into existing urban forests, as demonstrated in this case study, promotes environmental sustainability, supports ecosystem resilience, and ensures the continuity of vital ecological and aesthetic functions in densely populated urban areas.

VIZUELNA PROCENA DRVEĆA U URBANOJ ŠUMI U BEOGRADU: STUDIJA SLUČAJA PODRUČJA PLANIRANOG ZA IZGRADNJU MULTIFUNKCIONALNE DVORANE ZAVODA ZA SPORT I MEDICINU SPORTA REPUBLIKE SRBIJE

Suzana MITROVIĆ, Milorad VESELINOVIĆ, Snežana STAJIĆ, Nemanja LAZAREVIĆ, Katarina MARINKOVIĆ, Radmila ĐURAŠINOVIĆ, Marija MILOSAVLJEVIĆ

Rezime

Ovaj rad predstavlja sveobuhvatnu vizuelnu procenu drveća u urbanoj šumi Beograda, fokusirajući se na područje predloženo za izgradnju Multifunkcionalne dvorane zavoda za sport i medicinu sporta Republike Srbije. Primarni cilj je bio procena postojeće vegetacije drveća kako bi se podržalo održivo planiranje i razvoj sportskih objekata, uz očuvanje gradske zelene infrastrukture. Analizirano je ukupno 509 stabala, evidentirano je 30 vrsta drveca, uključujući pet četinarskih i dvadeset cetiri listopadnih vrsta. Procena je urađena korišćenjem metode vizuelne procene drveća (VTA). Procena je uzela u obzir kvalitativne atribute (vitalnost i dekorativnost), koji su ocenjeni na petostepenoj skali.

Četinari su bili dominantna grupa, pri čemu je *Pinus nigra* bila najčešća vrsta, dok su najčešće listopadne vrste bile *Quercus* sp., *Acer platanoides* i *Betula penudla*. Vrste koje su pokazale najveću vitalnost su *Cornus* sp., *Prunus avium*, *Picea abies* i *Aesculus hippocastanum*, dok su *Ficus carica*, *Pyrus pyraster* i *Morus* sp. pokazali najnižu vitalnost. Što se tiče dekorativnosti, najbolje rezultati se su imali *Cornus* sp., *Prunus avium*, *Picea abies* i *Pinus nigra*, dok su *Ficus carica*, *Pyrus* sp. i *Morus* sp. imali najnize ocene. Deskriptivna statistička analiza je pokazala da su prosečni rezultati vitalnosti i dekorativnosti kod svih

stabala bili 3,10 i 3,08, pri čemu su širokolisne vrste pokazale veću varijabilnost u oba atributa u poređenju sa četinarima.

Pirsonova korelaciona analiza pokazala je statistički značajnu i jaku pozitivnu korelaciju između vitalnosti i dekorativnosti ($r = 0,76$, $p < 0,001$), ističući blisku vezu između zdravstvenog stanja i estetske vrednosti drveca. Ovo ukazuje da održavanje vitalnosti drveća ne samo da podržava ekološke funkcije, već i poboljšava vizuelni i rekreativni kvalitet u urbanim zelenim površinama.

U kontekstu planirane izgradnje, manje od 5% ispitanih stabala je predloženo za uklanjanje, prvenstveno usmereno na najčešće vrste kako bi se minimizirali ekološki i estetski uticaji. Strateške mere ozelenjavanja, uključujući zamenu posečenih stabala odgovarajućim vrstama i stvaranje novih zelenih površina oko zgrada i na krovu sportske hale, imaju za cilj poboljšanje ukupne vitalnosti i dekorativnosti urbane šume. Ove mere takođe pomažu u ublažavanju potencijalnih negativnih uticaja izgradnje na biodiverzitet, ekosistemske usluge i rekreativnu vrednost.

Studija naglašava ključnu ulogu rane vizuelne procene drveća u urbanom planiranju i dizajnu pejzaža. Identifikovanjem drveća koje zahteva zaštitu, praćenjem zdravstvenog stanja i procenom estetske vrednosti, planeri mogu donositi sveobuhvatne odluke koje uravnotežuju potrebe razvoja sa očuvanjem zelene infrastrukture. Integrisanje građevinskih objekata u postojeće urbane šume, kao što je pokazano u ovoj studiji slučaja, promoviše ekološku održivost, podržava otpornost ekosistema i obezbeđuje kontinuitet vitalnih ekoloških i estetskih funkcija u gusto naseljenim urbanim područjima.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD
SUSTAINABLE FORESTRY COLLECTION 92, 2025
ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592117L
UDK: 502/504:712.41(450)=111
Original scientific paper

SPATIAL CLUSTERING OF PROTECTED FORESTS IN ITALY FOR STRATEGIC NATURE CONSERVATION

Polina LEMENKOVA [1]*

Abstract: *This research presented work on the actualisation of the existing landscape maps in the protected regions of Italy in northern, central and southern areas. The research aimed at evaluation of how land cover types change across Italy and what factors induce their changes: geology, climate change, natural hazards, anthropogenic activities (wood logging), and changes in forest dynamics (reforestation and deforestation). The methodology includes both the GIS-based analysis of the regional setting (climate and hydrology, topographic-geologic structure of the terrain) and fieldwork activities during the in-situ campaign (summer periods 2024 and 2025). Processing fieldwork data, aerial GEE images and maps, and integrating them into cartographic project through QGIS mapping enabled to extract valuable environmental information regarding land cover types in 3 different regions of Italy for analysis of landscape variability*.

Keywords: environmental monitoring, forest protection, nature, land planning.

PROSTORNO GRUPISANJE ZAŠTIĆENIH ŠUMA U ITALIJI U CILJU STRATEŠKOG PRISTUPA ZAŠTITI PRIRODE

Sažetak: *Ovo istraživanje je predstavilo rad na aktuelizaciji postojećih mapa pejzaža u zaštićenim regionima Italije u severnim, centralnim i južnim oblastima. Istraživanje je imalo za cilj da proceni kako se tipovi zemljišnog pokrivača menjaju širom Italije i koji faktori izazivaju njihove promene: geologija, klimatske promene, prirodne opasnosti, antropogene aktivnosti (seča drveta) i promene u dinamici šuma (pošumljavanje i krčenje šuma). Metodologija obuhvata i GIS-baziranu analizu regionalnog okruženja (klima i hidrologija, topografsko-geološka struktura terena) i terenske aktivnosti u okviru kampanje na licu mesta (letnji periodi 2024. i 2025. godine).Obrada podataka terenskog rada, GEE snimaka i mapa, i njihova integracija u kartografski projekat putem QGIS mapiranja, omogućila je izdvajanje vrednih informacija o okruženju u vezi sa tipovima zemljišnog pokrivača u 3 različita regiona Italije za analizu varijabilnosti pejzaža.).*

Ključne reči: praćenje životne sredine, zaštita šuma, priroda, planiranje zemljišta.

[1] Department of Biological, Geological and Environmental Sciences, Alma Mater Studiorum - University of Bologna, Via Irnerio 42, Bologna 40126, Emilia-Romagna, Italy.
*Corresponding author. Polina Lemenkova, e-mail: polina.lemenkova2@unibo.it

1. INTRODUCTION

Forests are essential for the environment sustainability and human society. As important habitats for biodiversity, forests regulate climate by absorbing carbon dioxide, and provide essential resources as ecosystem services. At the same time, the health of forests inextricably depends on the complex of several factors: soil, geology, climate, and topography. The combination of these factors creates specific site conditions for resources and environmental gradients that determine the growth of species and functionality of forest ecosystems. Each factor plays a critical role for sustainability of forests: climate setting control temperature and precipitation, soil setting provides nutrients and water, geologic setting determines soil parent material and structure, and topography influences microclimate and water flow.

Forests are subject to climate change, since they are sensible to fluctuations in temperature and precipitation balance. Variability of annual and seasonal climate cycle trigger processes of reforestation or deforestation (Albert & Schmidt, 2010; Lexer et al., 2002). Understanding the resilience of forest to climate-related processes requires analysis of multiple factors that affect the sustainability of forest ecosystems. This is possible through advanced data analysis (Suárez-Córdoba et al., 2025) and multi-scale mapping (Feng et al., 2025; Pang et al., 2024; Li et al., 2025). To this end, the Geographic Information System (GIS) support advanced methods of spatial data analysis in forestry (Alizadeh et al., 2025; Kienast et al., 1996; Shivaprakash et al., 2022).

Smart solutions to tackle the issues of forest management by observations and environmental mapping aims at monitoring landscape dynamics (Jones & Vukomanovic, 2025). Cartographic data processing supports monitoring changes in forest stands across various regions (Kondratev et al., 2025). Traditional methods of forest monitoring are time-consuming field-based sampling and includes manual laborious work on data collection (Matović et al., 2018, 2021; Taura & Gudžinskas, 2025; Kint et al., 2004). In turn, GIS for data integration enables rapid and accurate forest mapping through processing of images and mapping (Crosby & McConnell, 2025; Gebru et al., 2025; Sparks et al., 2025; Abreu-Dias et al., 2025).

The goal of this research is to perform landscape analysis and updated vegetation mapping in the protected forests across three diverse and geographically distinct regions of the Italian Peninsula located in the north, centre and south: 1) Dolomite Mountains (Mts.) in special protection area Lagorai; 2) Apennines Mts., Foreste Casentinesi National Park, Monte Falterona and Campigna National Park; 3) Sirente Velino Regional Park (Figure 1).

The aim is to detect major driving forces that cause land cover changes and to analyse and compare landscape dynamics in different regions. To achieve this goal, the main technical approach is to extract environmental information from the geospatial data such as maps and geospatial data. This is possible using integrated methods of geographical analysis using GIS mapping for comparative analysis of remote sensing (RS) data (Čurlin et al., 2024; Lemenkova, 2025a; Kofidou & Ampas, 2025; Thien & Phuong, 2023). The technical approach to spatial data analysis includes diverse methods: image classification, analysis of landscape fragmentation, computing patch area size, to mention a few.

This study focused on the forest ecosystems in Italy through multi-source data analysis. The multi-disciplinary aspect of this research consists of two approaches: 1) QGIS software for cartographic data integration and mapping; 2) environmental analysis of impact factors affecting forest health: climate, geology, soil, topography and land use.

2. MATERIAL AND METHODS

The methodology includes the integration and analysis of the multi-source data for forest mapping, since regional complexity of the environmental processes in the forests of Italy requires integrated multi-disciplinary approaches. We employed mapping based on the open data for forest detection within the environmental context. The thematic cartographic data were from the open source repositories and verified on the aerial images from the Google Earth Engine (GEE). These data included information on topography, climate, geology and soil setting of Italy. New data were used for ecological analysis, vegetation and forest conservation. Such data are crucial for national strategic decision-making in forest management and protection. We updated vegetation maps using novel data verified in the GEE.The methods use data-driven approaches in different areas of Italy with the use of cartographic techniques of QGIS and GEE.

The open-source QGIS was selected as a major software, as is presents a powerful, versatile, and accessible tool for geospatial analysis with cross-platform compatibility, extensive functionality and built-in tools with vast library of Python-based plugins. Many examples of the use of QGIS are reported, which proves its effectiveness (Vujović & Nikolić, 2022; Bîscoveanu et al., 2025; Nikolić et al., 2023; Lemenkova, 2022, 2023; Vujović et al., 2023; Fawaz et al., 2025). We applied GIS for mapping and environmental analysis. The maps were prepared using Lambert Conic projection. The standard coordinate reference system is based on the WGS 84 datum and EPSG: 4326. The following tasks were performed:

1. Finding cartographic approaches for semi-automated image processing;
2. Developing the repetitive workflow for mapping spatial data using QGIS;
3. Soil mapping of Italy based on the Digital Soil Map of the World (DSMW), Food and Agriculture Organization of the United Nations (FAO UN).
4. Geologic mapping on bedrock age in Italy, from OneGeology portal.
5. Lithology mapping using Environmental Systems Research Institute (ESRI) dataset on rock age in Italy showing geologic setting that form soil.
6. Climate mapping of Italy according to the Köppen climate classification.

The methodological approaches included data collection using GPS, data import to GIS, data converting and formatting, image processing and classification, mapping and analysis. The image analysis primarily aimed at classification of land cover types compared to the old maps to detect landscape changes. Satellite images were visualised with thematic environmental maps across diverse regions. Additionally, vulnerable areas to climate change are analysed for hazard risk in mountainous regions, deforestation and soil.

Using QGIS software, the updated maps were used to create thematic environmental maps of Italy. Several mountainous regions were visited to check location of diverse plant types and to monitoring vegetation growth. The topographic data were used for terrain analysis based on Digital Elevation Model (DEM) and visualisation of the relief. The environmental monitoring was based on the comparison of the topographic maps and aerials images and extracting information on land cover types which indicates landscape dynamics.

The opportunities of the advanced tools for environmental monitoring includes accurate and rapid data analysis. Satellite mage were classified to interpret the environmental information. In this study, we used QGIS to actualise landscape types across Italy. Applying cartographic techniques to processing aerial images brings new possibilities in environmental landscape analysis (Priyanka Biswas & Anup Prakash Upadhyay, 2025; Ukah et al., 2025). This software uses the principles of the semi-automated algorithms of geospatial data processing for technical mapping workflow. Using QGIS solutions and interface, we performed data modelling to analyse the complexity of spatial features in diverse forest regions of Italy by thematic mapping (geologic, soil, climate and topographic data).

Data collected from open repositories were processed for updating the existing vegetation maps. The spatial information was extracted from images and maps. During GIS analysis, the hydrological parameters of water balance included the collection of the parameters using Eddy covariance techniques: precipitation, moisture, evapotranspiration and temperature (Zhang et al., 2016; Liu et al., 2024; Diaz et al., 2025). This included tree transpiration sensors, images from the PhenoCam, throughfall and stemflow gauges, water discharge measurements, soil moisture sensors and epiphytes quantification. The methodology of the climate-hydrological measurement in forests was described in relevant studies (Wu et al., 2025; Lemenkova, 2025b, 2025c; Wang et al., 2025).

3. RESULTS

This study primarily focused on forest monitoring in Italy in the context of environmental impact factors: 1) topographic and geologic setting, 2) soil types, 3) distribution of climate types; and 4) land use (anthropogenic activities) across Italy. Additionally, the impact of hydrological balance on health of the subalpine forests and the presence of lichens on the tree trunks were analysed and reported with comparison to earlier relevant studies on forest hydrology (Buttle et al., 2005; Lemenkova, 2025d, 2025e; Zhang & Wei 2015).

Environmental data analysis of forest areas is based on the analysis of integrated data and mapping the distribution of forests over the area of the Apennines Peninsula (coloured green in Figure 1). Using data collected in different information sources (CORINE, FAO, MODIS remote sensing data), it becomes possible to evaluate distribution of forest stands in Italy, to identify cases of reforestation and deforestation. The cartographic analysis shows that forests in Italy are concentrated in the mountainous regions of the Alps and Apennines, as well as in some parts of Sicily and Sardinia, according to the Land Use Land Cover (LULC) map prepared using dataset on Coordination of information on the environment (CORINE), Figure 1.

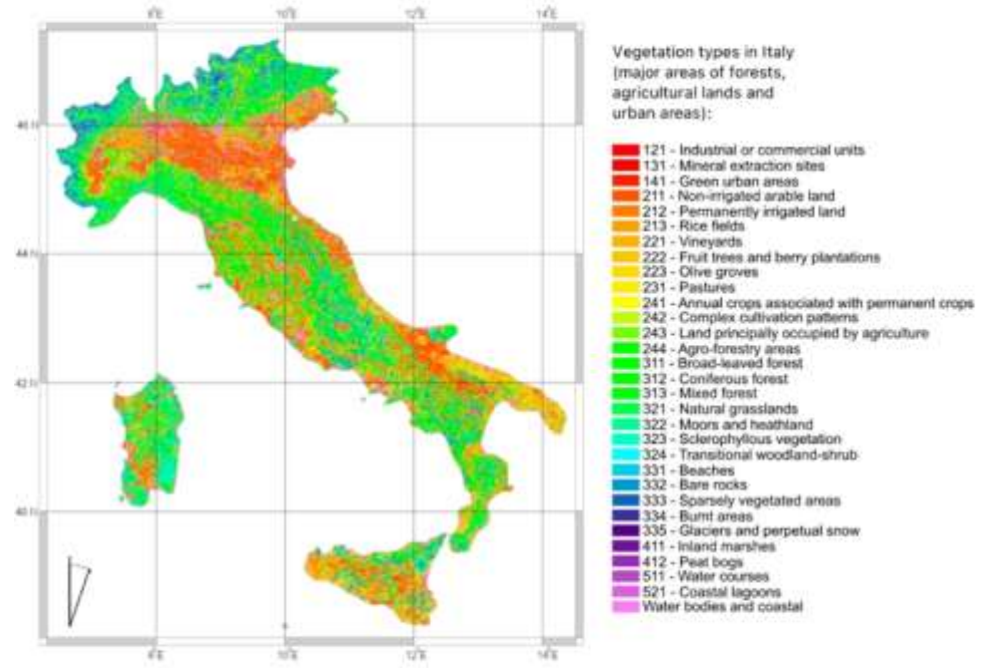


Figure 1. *Forests in northern, central and southern Italy.*
Data source: CORINE. Software: QGIS.
Map source: author.

Using examples of different regions, we presented the interpretation of a variability of landscapes from northern to southern gradient, using systematic environmental monitoring. Mapping was performed in QGIS as a series of thematic maps, which identified forest areas and setting: geologic, topographic, soil, climate, land cover types and categories of protected areas.

High forest cover is typical for the Alps and Apennine mountains, as well as central Italian mountain range. Low forest cover, i.e. with less than 10% forest cover are primarily in the Po valley, along the Adriatic coast, and in the flat areas of southern Sicily and Sardinia. Forest areas in Italy are expanding most rapidly in less accessible rural municipalities, particularly in central and southern Italy, due to land abandonment and reduced human pressure. Scattered forests are found in central and southern Italy on less accessible rural land where agriculture has been abandoned. Overall, forest cover is increasing, which shows the process of reforestation, with forests now covering ca. 1/3 of the territory, or 10-11 M ha.

Geologic history shapes physical landscape where forests are distributed, affecting geomorphic factors (slope, aspect, and elevation) and soil formation, which controls nutrient availability, water drainage and fertility. These factors influence microclimates and water availability in forest stands. The geologic setting of the country were analysed to find links with forest distribution. The analysis of geologic map shows that the bedrock rocks age in Italy differs, from the Precambrian (pC) basement to Cenozoic (Ce) and Quaternary (Q) formations in selected areas. Such variability represents complex geological history of the region, Figure 2.

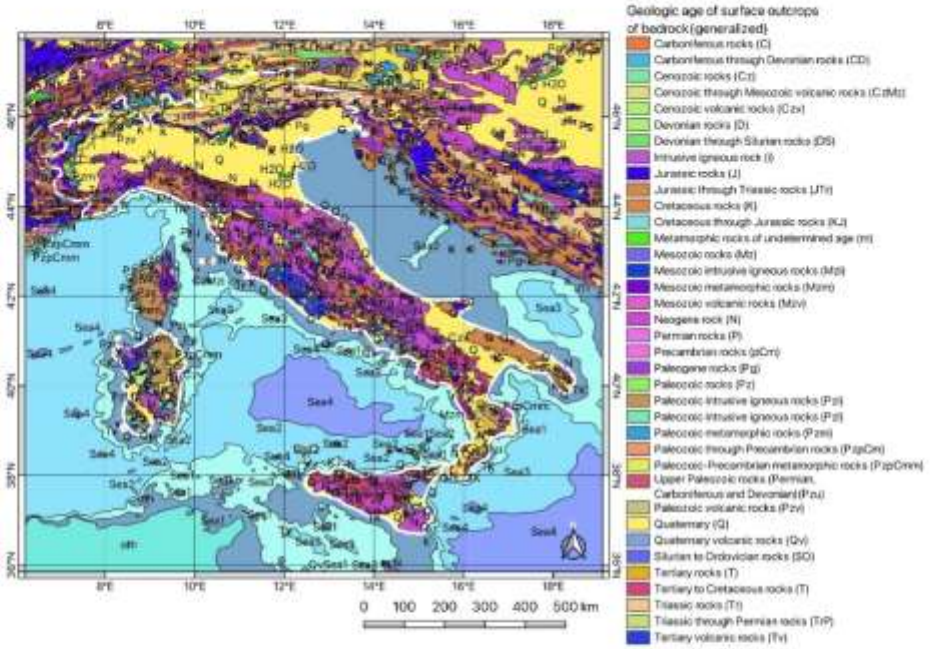


Figure 2. *Geologic map of Italy. Data: ESRI. Software: QGIS. Map source: author.*

The Alps, formed during the Mesozoic and Cenozoic eras, create a large, mountainous border in the north where coniferous forests are dominating. The Apennines, formed during the Oligocene, stretch along the peninsula, acting as a natural watershed for major types of broad-leaved forests and protected areas. The maps show that the oldest types include metamorphic basement rocks that are pC to Carboniferous (C), while younger sedimentary rocks in valleys can be aged 10 to 3 M years old, Figure 3.

The geologic setting has strong influence on soil types and formation. The comparison of maps in Figure 3 and Figure 4 shows links between the distribution of parent material and soil type across the peninsula. The diversified geology of Italy, including volcanic activity in the southern regions, sedimentary and metamorphic rocks in the Apennines, leads to a wide range of soil types that influence the distribution of specific vegetation types, e.g., coniferous of broad-leaved forests. The influence of geology consists in direct effects on the composition and properties of soil, and the geomorphology of the terrain, with processes including weathering and erosion.

Figure 3. *Geologic map of Italy: bedrock coverage age. Data source repository:* [*https://portal.onegeology.org/OnegeologyGlobal/*](https://portal.onegeology.org/OnegeologyGlobal/)

The distribution of soil types across Italy are highly diverse and depends on the geologic setting. Geologic strata act on the underlying bedrock and create unique soil profiles. For instance, the volcanic soil is rich in nutrients, while other soil types are derived from calcareous or siliclastic materials, Figure 4. In turn, soil affects forest stands through mineral composition, texture and structure. The international data from DSMW was used to map soil types in Italy, Figure 4. Cambisols are found in various forests, such as the silver fir (*Abies alba*) and beech forests (*Fagus sylvatica*) of the Vallombrosa Forest in Tuscany, the holm oak (*Quercus ilex*) forests of Sardinia, and the beech-fir (*Fagus sylvatica*) forests in the Eastern Prealps of Friuli Venezia Giulia.

These soils, also known as brown forest soils, form under a wide range of conditions and are a common soil type in mountain regions, associated with steep slopes and land use pressure, e.g., coppicing. Other significant soil types include Eutric Regosols, found on loose, unconsolidated sediments on Mount Etna (Sicily) and in parts of the Sardinian holm oak forests (*Quercus ilex*). This soil type supports diverse forest, but its shallow, weakly developed structure makes it prone to erosion. Vegetation succession can occur, leading to the development of stable soil horizons, e.g. Dystric Regosols and Podzols in recently deglaciated areas.

Dystric Cambisols, often associated with a broad range of forests: beech (*Fagus sylvatica*), oak (*Quercus ilex*), and fir (*Fagus sylvatica*). Dystric Cambisols are common in the mountainous or hilly regions which present acidic soil found in certain regions. The parent material of such soil is weathered, characterised by shallow cambic horizon, and associated with acid-resistant rocks, (phyllite).

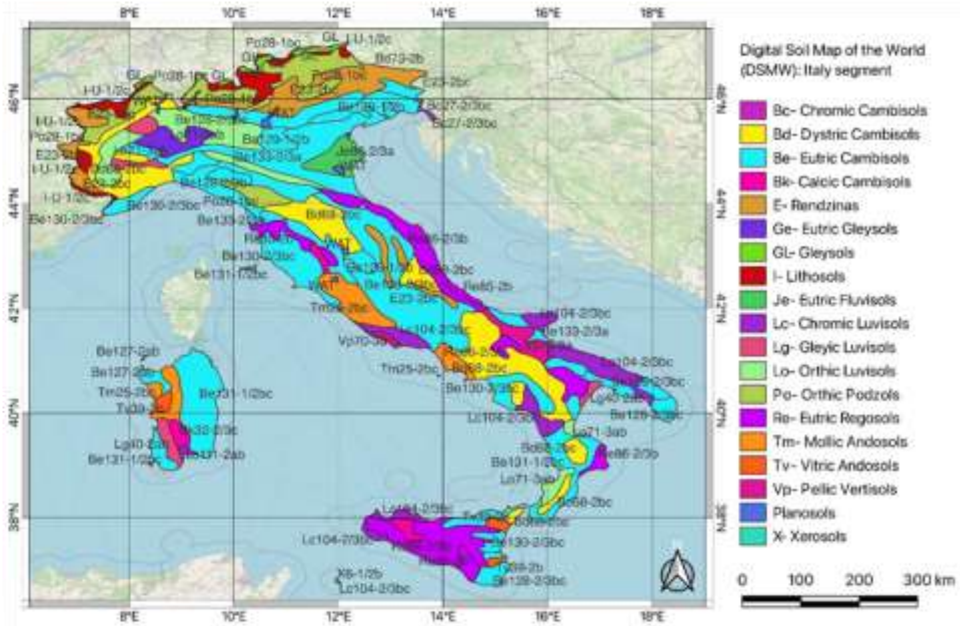


Figure 4. *Soil map of Italy. Data: DSMW, FAO. Software: QGIS. Source: author.*

Forest areas were analysed in climate context to identify regions affected by deforestation, aridification and periodical droughts, caused scarce precipitation and high temperature in summer periods. Such extremes are mainly caused by climatic processes related to the distribution of climate zones of Italy, Figure 5. Climate data were obtained from the analysis of Köppen climate types in Italy. Here, the legend of Köppen climate classification explains letter representing the following abbreviations: the first letter indicates a major climate group (A, B, C, D, or E), the second specifies precipitation patterns or dryness, and the third provides additional details, e.g., summer heat or winter severity. The dominating climate type according to Köppen classification scheme means "Csa" for Italy, i.e. "Hot-summer Mediterranean climate", and "Csb", - "Warm-summer Mediterranean climate". Such climate types are characterised by mild, wet winters and hot, dry summers. This climate is typical for the southern regions and along the coasts, particularly in central and southern Italy, where it is defined by the coldest month above (0°C), with an average T > 22°C, and at least four months with an average T > 10°C. The diverse climate setting was analysed, including Mediterranean (Csa/Csb) in coastal and southern areas, humid subtropical (Cfa) in the Po Valley, and humid continental in north and center.

The performed research updated current GIS maps over protected areas of Italy, to more accurately represent the distribution and location of the actual vegetation types in various soil types, geological rocks and diverse climate setting. The research reported the environmental setting of the subalpine forests in the Dolomites, Apennines and Alps. The forests in these areas differ in regional settings (climate, topography, soil and geology), but present fragile ecosystems with high importance for water resources and climate regulators. The collected data demonstrated land cover changes detected and visualised on the updated maps.

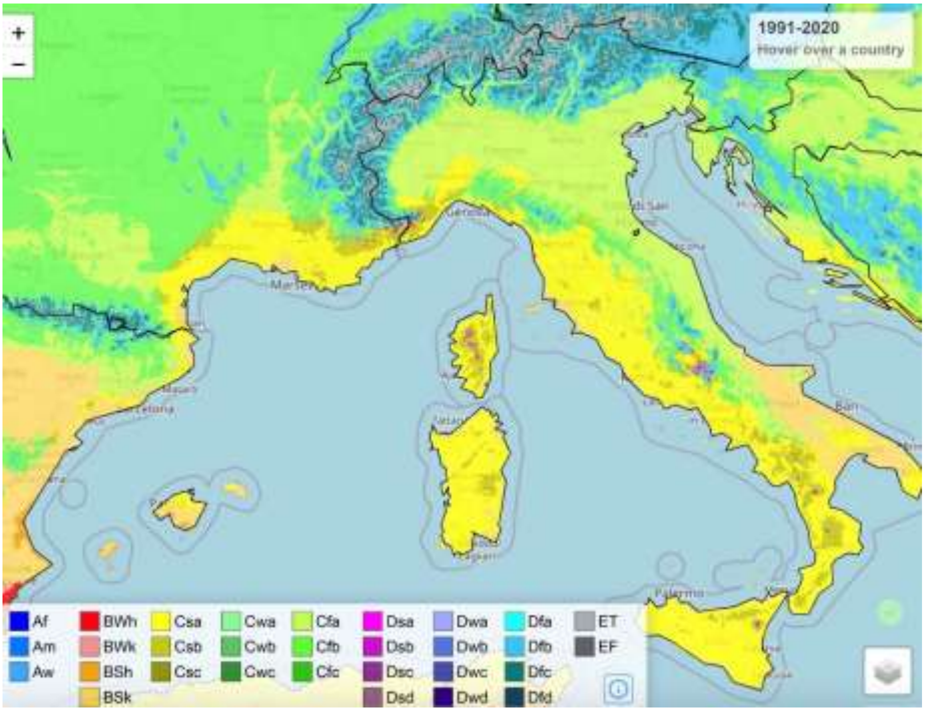


Figure 5. *Climate Köppen classification. Data: https://koppen.earth/*

The distribution of forests in the mountainous protected areas of Italy has undergone significant changes due to the advancement of forest management over the past three decades. Therefore, existing maps should be updated. As a response to these needs, the verification of the old maps (climate, topography, soil and geology) was done using multi-source data: OpenStreetMap (OSM) vector layers and thematic maps on geology, soil, forest distribution, protected areas and climate.

The integrated data analysis on soil, climate, forest distribution in land cover types, topography and geology enabled to classify the most important areas of the protected areas, and compare the updated map with the environmental map of Global National Parks, Figure 6. The integrated approach of data analysis enabled the identification of the forest areas in selected areas of Italy, and helped improving the conservation strategies of forest management related to major driving factors that affect forest health. Major driving factors that influence landscape dynamics in different forest regions of Italy were analysed with focus on the various factors: 1) geologic formation, 2) topography and geomorphology, 3) climate setting, 4) soil setting, 5) vegetation setting with specific focus on forests, 6) anthropogenic activities.

Figure 6. *Strategic areas of nature conservation as protected forests in Italy. Data source: Global National Parks cartographic survey (modified), https://www.globalnationalparks.com*

4. DISCUSSION

This study provides insights to environmental monitoring of the Italian forests through GIS-based analysis of the coniferous and broadleaved forest stands growing on various environmental setting: geologic conditions, soil types, climate setting and relief terrain. These factors present the essential factors that affect the dynamics of forest stands and contribute to the development of various types with high biodiversity, ecological significance and climate vulnerability. The ecological characteristics consists in mosaic of dense, old-growth forest sections, intertwined with young patches. Specific focus is on the geographic gradient (north-to-south) of forests from the subalpine to Mediterranean mountains. The effects of hydrological health of the coniferous forests were reported (Salcedo-Sanz et al., 2025; Sánchez-Falfan et al., 2023; Lemenkova, 2025f; Molina et al., 2025).

This study presented research project with the objective of detecting the links between forest sustainability and changes in land cover types of the ecosystems of Italy. This research involved the use of data obtained through GIS on forest in Italy, topographic, geologic, climate and soil maps. Advanced forest monitoring consists in data integration through GIS mapping. Environmental information on forest can be obtained from the satellite image processing (Mallinis et al., 2008). Due to the variety of Earth Observation missions, the formats of the remote sensing differ and many images are suitable for forest monitoring using their technical characteristics (Kindu et al., 2020; Günlü et al., 2008; Lemenkova, 2024). Data-driven research in silviculture requires advanced GIS tools where data integration plays a crucial role (Aguirre et al., 2022; Klaučo et al., 2013, 2017).

5. CONCLUSION

This study integrated topographic, climatic and geologic data to provide an estimation of forest distribution and heterogeneity across Italy. This analysis prioritised nature conservation in the protected forests and reserves. Recent climate change changed nature conservation policy which has been increasing, e.g. as increase number of National Parks, areas, reserved for conservation and biodiversity protection. To support monitoring of such areas, spatial data offer possibilities due to the spatial and temporal scale of satellite and aerial images, maps and statistical data on forest monitoring (forest extent and health, wood production and trade, and forestry activities, afforestation and felling). Spatial data collections for forest conservation is a robust approach that is available openly.

Operative processing of environmental datasets enables to extract thematic information on forest stands using data integration in QGIS software. A wide variety of GIS may be used for effective data handling, including both commercial and open source programs. In this study, the methodology was developed on QGIS to support systematic operative environmental monitoring in the protected areas of Italy. The technical approach is based on cartographic tools and environmental monitoring for spatial data processing. Mapping and processing spatial data by QGIS enabled to extract valuable environmental information regarding forest distribution in different regions of Italy for analysis of environmental variability.

REFERENCES

Abreu-Dias, R., Santos-Gago, J. M., Martín-Rodríguez, F., & Álvarez-Sabucedo, L. M. (2025). Advances in the Automated Identification of Individual Tree Species: A Systematic Review of Drone- and AI-Based Methods in Forest Environments. Technologies, 13(5), 187. https://doi.org/10.3390/technologies13050187

Aguirre, A., Moreno-Fernández, D., Alberdi, I., Hernández, L., Adame, P., Cañellas, I., Montes, F. (2022). Mapping forest site quality at national level. *Forest Ecology and Management*, 508:120043, https://doi.org/10.1016/j.foreco.2022.120043

Albert, M., Schmidt, M. (2010). Climate-sensitive modelling of site-productivity relationships for Norway spruce (*Picea abies* (L.) Karst.) and common beech (*Fagus sylvatica* L.). *Forest Ecology and Management*, 259(4):739–749. https://doi.org/10.1016/j.foreco.2009.04.039

Alizadeh, M., Abbod, M., Fathi Qarachal, J. (2025). Rhizosphere microbiome in trees: ecological roles, biocontrol potential, and implications for forest health monitoring. *Physiological and Molecular Plant Pathology*, 102937, https://doi.org/10.1016/j.pmpp.2025.102937

Bîscoveanu, O. M., Badea, G., Dragomir, P. I., & Badea, A. C. (2025). Evaluation of LULC Use Classification for the Municipality of Deva, Hunedoara County, Romania Using Sentinel 2A Multispectral Satellite Imagery—A Comparative Study of GIS Software Analysis and Accuracy Assessment. Applied Sciences, 15(21), 11437. https://doi.org/10.3390/app152111437

Buttle, J. M., Creed, I. F. & Moore, R. D. (2005), Advances in Canadian forest hydrology, 1999–2003. Hydrological Processes, 19, 169-200. https://doi.org/10.1002/hyp.5773

Crosby, M. K., & McConnell, T. E. (2025). Incorporating Spectral Unmixing to Estimate Carbon Sequestration Changes in an Urban Forest Canopy. Urban Science, 9(11), 454. https://doi.org/10.3390/urbansci9110454

Čurlin, M. T., Drobnjak, S. M., Potić, I. M., Đorđević, D. R., & Bakrač, S. T. (2024). Application of machine learning methods in the classification of satellite images. Tehnika, 79(2), 152-158. https://doi.org/10.5937/tehnika2402152C

Diaz, M. B., de Oliveira, P. E. S., Souza, V. d. A., Teichrieb, C. A., Zimermann, H. R., Veeck, G. P., Mergen, A., Pinheiro, M. E. O., Stefanello, M. B., de Moraes, O. L. L., de Oliveira, G., Santos, C. A. G., & Roberti, D. R. (2025). Contribution of Different Forest Strata on Energy and Carbon Fluxes over an Araucaria Forest in Southern Brazil. Forests, 16(6), 1008. https://doi.org/10.3390/f16061008

Fawaz, F. M., Baydoun, S., Bechara, J., Khalil, R., Chalak, L., & Saqalli, M. (2025). Spatializing Farmers' Perception of Agricultural Resources with Focus on Cereals Cultivation in Bekaa Valley, Lebanon. Land, 14(8), 1667. https://doi.org/10.3390/land14081667

Feng, K., Ma, S., Xi, H., Liang, L., Liu, W., Tsunekawa, A. (2025). Small-sample-data augmentation and transfer strategies for forest cover change monitoring. *Ecological Indicators*, 178:113870. https://doi.org/10.1016/j.ecolind.2025.113870

Gebru, A. B., Gebreyohannes, T., & Kahsay, G. H. (2025). Tracking the Past and Projecting the Future Land Use/Land Cover Dynamics in Semi-Arid Region of Giba Basin, Northern Ethiopia. *Biosphere*, *1*(1), 6. https://doi.org/10.3390/biosphere1010006

Günlü, A., Sivrikaya, F., Baskent, E. Z., Keles, S., Çakir, G., & Kadiogullari, A. İ. (2008). Estimation of Stand Type Parameters and Land Cover Using Landsat-7 ETM Image: A Case Study from Turkey. *Sensors*, 8(4), 2509-2525. https://doi.org/10.3390/s8042509

Jones, K., & Vukomanovic, J. (2025). Interactive Visualizations of Integrated Long-Term Monitoring Data for Forest and Fuels Management on Public Lands. Forests, 16(11), 1706. https://doi.org/10.3390/f16111706

Kienast, F., Brzeziecki, B., Wildi, O. (1996). Long-term adaptation potential of Central European mountain forests to climate change: a GIS-assisted sensitivity assessment. *Forest Ecology and Management*, 80(1):133–153. https://doi.org/10.1016/0378-1127(95)03633-4

Kindu, M., Angelova, D., Schneider, T., Döllerer, M., Teketay, D., Knoke, T. (2020). Monitoring of Urban Growth Patterns in Rapidly Growing Bahir Dar City of Northwest Ethiopia with 30 year Landsat Imagery Record. *ISPRS International Journal of Geo-Information*, 9(9), 548. https://doi.org/10.3390/ijgi9090548

Kint, V., Dewulf, R., Noël, L. (2004) Evaluation of sampling methods for the estimation of structural indices in forest stands. Ecological Modelling, 180(4), 461-476. https://doi.org/10.1016/j.ecolmodel.2004.04.032

Klaučo M, Gregorová B, Stankov U, Marković V, Lemenkova P (2013) Determination of ecological significance based on geostatistical assessment: A case study from the Slovak Natura 2000 protected area. *Open Geosciences*, 5(1): 28-42. https://doi.org/10.2478/s13533-012-0120-0

Klaučo, M., Gregorová, B., Koleda, P., Stankov, U., Marković, V. & Lemenkova, P. (2017). Land planning as a support for sustainable development based on tourism: A case study of Slovak rural region. Environmental Engineering and Management Journal, 16(2), 449-458. https://doi.org/10.30638/eemj.2017.045

Kofidou, M., & Ampas, V. (2025). Monitoring and Analyzing Aquatic Vegetation Using Sentinel-2 Imagery Time Series: A Case Study in Chimaditida Shallow Lake in Greece. Limnological Review, 25(3), 35. https://doi.org/10.3390/limnolrev25030035

Kondratev, M., Corrao, M. V., Armstrong, R., & Smith, A. M. S. (2025). Assessing the Uncertainty of Traditional Sample-Based Forest Inventories in Mixed and Single Species Conifer Systems Using a Digital Forest Twin. Forests, 16(11), 1617. https://doi.org/10.3390/f16111617

Lemenkova, P. (2022): Handling Dataset with Geophysical and Geological Variables on the Bolivian Andes by the GMT Scripts. *Data*, 7(6): 74. https://doi.org/10.3390/data7060074

Lemenkova, P. (2023): A GRASS GIS Scripting Framework for Monitoring Changes in the Ephemeral Salt Lakes of Chotts Melrhir and Merouane, Algeria. *Applied System Innovation*, 6(4): 61. https://doi.org/10.3390/asi6040061

Lemenkova, P. (2024). Artificial Neural Networks for Mapping Coastal Lagoon of Chilika Lake, India, Using Earth Observation Data. *Journal of Marine Science and Engineering*, 12(5), 709. https://doi.org/10.3390/jmse12050709

Lemenkova, P. (2025a). Machine Learning Algorithms of Remote Sensing Data Processing for Mapping Changes in Land Cover Types over Central Apennines, Italy. *Journal of Imaging,* 11(5), 153. https://doi.org/10.3390/jimaging11050153

Lemenkova, P. (2025b). On forest hydrology in South Tyrol: Processes, modelling and assessment. *Agriculture and Forestry*, 71(2). 7–22. https://doi.org/10.17707/AgricultForest.71.2.01

Lemenkova, P. (2025c). Multitask learning with statistical parametrization for ecohydrological analysis. *Transylvanian Review of Systematical and Ecological Research*, 27(2), 1-20. https://doi.org/10.2478/trser-2025-0009

Lemenkova, P. (2025d). Contribution of epiphytes and fog to patterns of atmospheric fluxes in mountainous forests (*Picea abies L.* and *Pinus cembra L.*). *Acta herbologica*, 34(1), 7-21. https://doi.org/10.5937/34ah-57901

Lemenkova, P. (2025e). An improved canopy interception scheme into biogeochemical analysis of water fluxes in subalpine coniferous forest (Northern Italy). *Bulletin of Natural Sciences Research*, 15(1): 1-8. https://doi.org/10.5937/bnsr15-57655

Lexer, M. J., Hönninger, K., Scheifinger, H., Matulla, C., Groll, N., Kromp-Kolb, H., Schadauer, K., Starlinger, F., Englisch, M. (2002). The sensitivity of austrian forests to scenarios of climatic change: a large-scale risk assessment based on a modified gap model and forest inventory data. *Forest Ecology and Management*, 162(1):53–72. https://doi.org/10.1016/S0378-1127(02)00050-6

Li, W., Liu, X., Samat, A., & Gamba, P. (2025). Automated Local Climate Zone Mapping via Multi-Parameter Synergistic Optimization and High-Resolution GIS-RS Fusion. Remote Sensing, 17(12), 2038. https://doi.org/10.3390/rs17122038

Liu, Y., Zhang, L., Yan, W., Peng, Y., Sun, H., & Chen, X. (2024). Drought-Induced Alterations in Carbon and Water Dynamics of Chinese Fir Plantations at the Trunk Wood Stage. Plants, 13(20), 2937. https://doi.org/10.3390/plants13202937

Mallinis, G., Koutsias, N., Tsakiri-Strati, M., Karteris, M. (2008). Object-based classification using quickbird imagery for delineating forest vegetation polygons in a mediterranean test site. *ISPRS Journal of Photogrammetry and Remote Sensing*, 63(2):237–250, https://doi.org/10.1016/j.isprsjprs.2007.08.007

Matović, B., Koprivica, M., Kisin, B., Stojanović, D., Kneginjić, I. & STJEPANOVIĆ, S. (2018). Comparison of stand structure in managed and virgin european beech forests in Serbia. Šumarski list, 142 (1-2), 47-57. https://doi.org/10.31298/sl.142.1-2.4

Matović, B., Stojanović, D. B., Stjepanović, S., Gutalj, M., & Miletić, B. (2021). A comparison of the accuracy of different types of samples for spatial structure indices determination in beech forests in Serbia. Topola, 207, 21-34. https://doi.org/10.5937/topola2101021M

Molina, L., Rajchenberg, M., Pildain, M. B., & Aime, M. C. (2025). Seasonal Turnover and Functional Structure of the Foliar Mycobiota in a Gondwanan Temperate Forest Keystone Tree. Journal of Fungi, 11(11), 795. https://doi.org/10.3390/jof11110795

Nikolić, N., Davidović Manojlović, M., & Mesaroš, M. (2023). The usage of geospatial tools in traffic sign detection. Zbornik radova Departmana za geografiju, turizam i hotelijerstvo, 52-2, 111-122. https://doi.org/10.5937/ZbDght2302111N

Pang, L., Xie, D., Sharma, R. P., Xu, D., & Fu, L. (2024). Developing GIS-Based Algorithm of Stand Spatial Structure Index and Its Implementation. Forests, 15(10), 1755. https://doi.org/10.3390/f15101755

Priyanka Biswas & Anup Prakash Upadhyay. (2025). A Study on Distribution and Diversity of major Non-wood Forest Produce (NWFP) Species in Sal & Teak Dominated Forests of Madhya Pradesh in Central India. International Journal of Environment and Climate Change, 15(8), 92–103. https://doi.org/10.9734/ijecc/2025/v15i84958

Salcedo-Sanz, S., Guijo-Rubio, D., Pérez-Aracil, J., Peláez-Rodríguez, C., Gomez-Orellana, A. M., & Gutiérrez-Peña, P. A. (2025). Artificial Intelligence-Based Methods and Algorithms in Fog and Atmospheric Low-Visibility Forecasting. Atmosphere, 16(9), 1073. https://doi.org/10.3390/atmos16091073

Sánchez-Falfan, A., Esperón-Rodríguez, M., Cervantes-Pérez, J., Ballinas, M., & Barradas, V. L. (2023). How Important Are Fog and the Cloud Forest as a Water Supply in Eastern Mexico? Water, 15(7), 1286. https://doi.org/10.3390/w15071286

Shivaprakash, K. N., Swami, N., Mysorekar, S., Arora, R., Gangadharan, A., Vohra, K., Jadeyegowda, M., & Kiesecker, J. M. (2022). Potential for Artificial Intelligence (AI) and Machine Learning (ML) Applications in Biodiversity Conservation, Managing Forests, and Related Services in India. Sustainability, 14(12), 7154. https://doi.org/10.3390/su14127154

Sparks, A. M., Corrao, M. V., Keefe, R. F., Armstrong, R., & Smith, A. M. S. (2025). Comparison of Field Sampling- and Airborne Laser Scanning-Derived Stand-Level

Inventories in a Mixed Conifer Forest and Volume Validation Using Log Scaling Data. Forests, 16(5), 784. https://doi.org/10.3390/f16050784

Suárez-Córdoba, Y. D., Barrera-García, J. A., Sterling, A., Rodríguez-León, C. H., & Tittonell, P. A. (2025). Evidence of Agroecological Performance in Production Systems Integrating Agroecology and Bioeconomy Actions Using TAPE in the Colombian Andean–Amazon Transition Zone. Sustainability, 17(20), 9024. https://doi.org/10.3390/su17209024

Taura, L., & Gudžinskas, Z. (2025). The Effect of Forest Habitats on the Traits and Demographic Structure of *Cardamine bulbifera* (Brassicaceae) Populations. Plants, 14(18), 2899. https://doi.org/10.3390/plants14182899

Thien, B. B., & Phuong, V. T. (2023). Using Landsat satellite imagery for assessment and monitoring of long-term forest cover changes in Dak Nong province, Vietnam. *Geographica Pannonica*, *27*(1), 69-82. https://doi.org/10.5937/gp27-41813

Ukah, C., Ejaro, S. P., Makwe, E., & Ahmad, H. A. (2025). An in-depth analysis of the Terrorists Activities on Land Use and Land Cover (LULC) Change of Sambisa Forest of Nigeria. American Journal of Geospatial Technology, 4(1), 104–118. https://doi.org/10.54536/ajgt.v4i1.4665

Vujović, F., & Nikolić, G. (2022). Geospatial assessment of vegetation condition pre-wildfire and post-wildfire on Luštica (Montenegro) using differenced Normalized Burn Ratio (dNBR) index. Bulletin of Natural Sciences Research, 12(2), 14-19. https://doi.org/10.5937/bnsr12-39990

Vujović, F., Nikolić, G., Đurđevac, T., & Brđanin, E. (2023). Geoecological evaluation of natural potentials of Šavnik (Montenegro) for the purposes of recreational tourism using V-Wert method in GIS environment. Zbornik radova - Geografski fakultet Univerziteta u Beogradu, 71, 5-17. https://doi.org/10.5937/zrgfub2371005V

Wang, F., Yang, F., Chang, X., & Ye, Y. (2025). Study on Forest Extraction and Ecological Network Construction of Remote Sensing Images Combined with Dynamic Large Kernel Convolution. Forests, 16(8), 1342. https://doi.org/10.3390/f16081342

Wu, H., Cui, T., & Cao, L. (2025). Simultaneous Reductions in Forest Resilience and Greening Trends in Southwest China. Remote Sensing, 17(13), 2227. https://doi.org/10.3390/rs17132227

Zhang M. & Wei X. (2015). Contrasted hydrological responses to forest harvesting in two large neighbouring watersheds in snow hydrology dominant environment: implications for forest management and future forest hydrology studies. Hydrological Processes, 28, 6183–6195. https://doi.org/10.1002/hyp.10107

Zhang, Y., Peña-Arancibia, J., McVicar, T., Chiew, F. H. S., Vaze, J., Liu, C., Lu, X., Zheng, H., Wang, Y., Liu, Y. Y., Miralles, D. G. & Pan, M. (2016). Multi-decadal trends in global terrestrial evapotranspiration and its components. Scientific Reports, 6, 19124. https://doi.org/10.1038/srep19124

SPATIAL CLUSTERING OF PROTECTED FORESTS IN ITALY FOR STRATEGIC NATURE CONSERVATION

Polina LEMENKOVA

Summary

Within the framework of this study, protected areas of Italy were clustered for environmental forest monitoring. Different regions were compared and the project were designed under the cumulative project which summarised forest management in Italy and compared major geographic zones in Italy (protected forests). These areas were selected to focus on the comparative analysis of landscape variability in specific regions of Italy. The methodology included the in-depth regional analysis of variability of the land cover types using aerial images, maps and fieldwork measurements.

PROSTORNO GRUPISANJE ZAŠTIĆENIH ŠUMA U ITALIJI U CILJU STRATEŠKE ZAŠTITE PRIRODE

Polina LEMENKOVA

Rezime

U okviru ove studije, 3 različita zaštićena područja Italije su grupisana za praćenje šuma u životnoj sredini. Tri terenska rada su osmišljena u severnim, centralnim i južnim oblastima. Različiti regioni su upoređeni, a projekat je osmišljen u okviru kumulativnog projekta koji je sumirao upravljanje šumama u Italiji i uporedio glavne geografske zone u Italiji (zaštićene šume). Ova područja su odabrana da bi se fokusirala na uporednu analizu varijabilnosti predela u određenim regionima Italije. Metodologija je obuhvatala detaljnu regionalnu analizu varijabilnosti tipova pokrivača zemljišta korišćenjem aero snimaka, mapa i terenskih merenja.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD
SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 92, 2025 ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592133D
UDK: 007.51:630*43(497.11)=111
Original scientific paper

SPATIO-TEMPORAL ANALYSIS OF LARGE WILDFIRES IN SERBIA BASED ON GIS AND VIIRS REMOTE SENSING DATA

Uroš DURLEVIĆ[1], Nina ČEGAR[1], Ljiljana BRAŠANAC-BOSANAC[2]*

Abstract: *The paper presents the results of spatio-temporal analysis of large wildfires in Serbia for the period 2012–2024, conducted using Geographic Information Systems (GIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) satellite data from NASA's FIRMS (Fire Information for Resource Management System) platform. The research integrates fire radiative power (FRP) indicators with environmental and anthropogenic factors to examine patterns of wildfire occurrence and intensity.*

The results show that most wildfires occur between July and October, when vegetation is dry, temperatures are high, and precipitation is scarce, while a secondary peak is observed in April due to agricultural burning practices. At the municipal level, wildfires were recorded across diverse regions, with higher concentration in Vojvodina and Kosovo and Metohija, while large wildfires were absent in western and most of eastern Serbia.

Research results highlight that areas at highest wildfire risk in Serbia are characterized by low to medium elevation, gentle slopes, southern exposure, moderate annual precipitation, and proximity to agricultural activities and human infrastructure. The integration of GIS and VIIRS remote sensing data provides valuable insights into the spatial and temporal dynamics of wildfires, supporting improved wildfire risk assessment and management.

Keywords: wildfires, remote sensing, GIS, environmental protection.

PROSTORNO-VREMENSKA ANALIZA VELIKIH POŽARA U SRBIJI ZASNOVANA NA GIS I VIIRS PODACIMA DALJINSKE DETEKCIJE

Sažetak: *U radu su prikazani rezultati prostorno-vremenske analize velikih-požara u Srbiji za period 2012–2024, dobijenih korišćenjem satelitskih podataka Geografskih informacionih sistema (GIS) i Vidljivog infracrvenog radiometarskog senzora (VIIRS) sa NASA platforme FIRMS (Fire Information for Resource Management System). Istraživanje integriše indikatore radijativne snage požara sa faktorima životne sredine i antropogenim uslovima kako bi se ispitali obrasci pojave i intenziteta požara.*

Rezultati pokazuju da se većina požara dešava između jula i oktobra, kada je vegetacija suva, temperature visoke, a padavine oskudne, dok se sekundarni vrhunac primećuje u aprilu zbog poljoprivrednih aktivnosti (spaljivanja). Prostorno posmatrano,

[1] Faculty of Geography, University of Belgrade, Studentski Trg 3/3, 11000 Belgrade, Serbia
[2] Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia

*Corresponding author. E-mail: uros.durlevic@gef.bg.ac.rs

veliki požari su zabeleženi u različitim regionima, sa većom koncentracijom u Vojvodini i na Kosovu i Metohiji, dok u zapadnoj i većem delu istočne Srbije nisu registrovani.

Rezultati istraživanja pokazuju da područja sa najvećim rizikom nastanka velikih požara u Srbiji karakterišu: mala nadmorska visina, relativno ravni tereni, južna ekspozicija, umerene godišnje količine padavina i blizina poljoprivrednih parcela i naselja. Integracija GIS i VIIRS podataka daljinske detekcije pruža dragocene uvide u prostornu i vremensku dinamiku požara, podržavajući poboljšanu procenu i upravljanje rizikom nastanka šumskih požara.

Ključne reči: požari, daljinska detekcija, GIS, zaštita životne sredine.

1. INTRODUCTION

The territory of the Republic of Serbia is prone to natural hazards, including wildfires. According to Statistical Office of the Republic of Serbia (2025), in 2024 98 fires were recorded only in states forests, excluding private forests and agricultural land. Fired area was 3,573 ha, and damaged timber volume was 19,121 m^3. Fired area in private forests amounted to 2,497 ha and damaged timber volume was 13,613 m^3.

Wildfires are complex phenomenon not only in terms of ecological and material damage (Sekulić et al., 2012), but also in terms of suitable conditions for their occurence (Pishahang et al., 2023), as well as spatial and temporal varibility.

Marković et al. (2016), Ratknic et al. (2018), Tošić et al. (2019), Tošić et al. (2020), Živanović & Gocić (2022) emphasize the influence of climate conditions. Among the climatic conditions, temperature and humidity are considered the most important and are studied through indices – SPI (Živanović & Gocić, 2022), Ångström (Tošić et al., 2019; Tošić et al., 2020), Nesterov (Tošić et al., 2019), the Lang precipitation factor (Tošić et al., 2019), the De Martonne index (Tošić et al., 2020), or developing a risk matrix (Marković et al., 2016).

Tabaković-Tošić et al. (2019) highlighted that fire occurrence is result of combined effect of natural and anthropogenic conditions, especially during spring season. In spring, amount of precipitation is low, burning material is scarce with humidity, therefore easily inflammable. Also, it's the season of agricultural burning of weeds and waste materials. High peak and frequency of fires during October and March Gajović & Todorović (2013) also connect with agricultural activity. Vranić and Mišić (2024) examined the spatial pattern of fire incidents at municipality level in Serbia, and showed that six out of eight high risk clusters are in Vojvodina region.

Using multiple criteria, the susceptibility to fire was assessed in Western Serbia (Gigović et al., 2019), on the Šar Mountains National Park (Durlević et al., 2025a), as well as in neighboring countries – Montenegro (Vujović et al., 2024) and Bosnia and Herzegovina (Gigović et al., 2018).

The aim of this study is spatio-temporal analysis of environmental and anthropogenic conditions which determined wildfire occurrence and intensity during the period 2012–2024 in Serbia. Novelty of this research is multiple:

1. Occurrence and intensity of the largest wildfires at the entire territory of Serbia is examined;
2. Besides natural and anthropogenic factors, FRP indicator is included in analysis;
3. Conditions are examined separately for each fire event.

2. MATERIAL AND METHODS

The Republic of Serbia covers an area of 88,361 km², with the largest urban centers being Belgrade (the capital), Novi Sad, Niš, and Pristina. According to the 2022 census, the population stands at 6.65 million, excluding data for the Autonomous Province of Kosovo and Metohija (Statistical Office of the Republic of Serbia, 2023). The country's geographical location has strongly shaped the diversity of its natural conditions.

Owing to the interplay of varied climatic, geomorphological, and hydrological characteristics, Serbia is distinguished by notable biodiversity and a wide range of protected natural areas. National parks such as Djerdap, Fruška Gora, Tara, Kopaonik, and Šar Planina, along with numerous nature reserves, are key zones for the conservation of plant and animal life (Durlević et al., 2024).

Figure 1. *Study area and inventory of large wildfires in Serbia*

Given the exceptionally rich biodiversity and the fertile agricultural land in Vojvodina, it is crucial to develop spatial models of wildfire susceptibility to ensure effective protective measures. The need for wildfire prediction in Serbia has become increasingly urgent due to the rising frequency and severity of such events

(Milanović et al., 2021). A notable example is the large-scale fire recorded on 7 July 2025, which caused severe ecological damage, posed risks to nearby settlements, and underscored the importance of wildfire risk analysis and preventive strategies (Sinko, 2025).

The VIIRS data from the NASA platform, FIRMS, which have a spatial resolution of 375 m, were used for the spatio-temporal analysis of wildfires in Serbia (FIRMS, 2025). For the period from 2012 to 2024, 32 large fires with an intensity exceeding 100 MW were identified. All spatial data were filtered and cartographically generated in the software package QGIS v3.28.10 (QGIS Development Team, 2023; Valjarević et al., 2025).

After the creation of the inventory of large wildfires, an overlap was made with natural and anthropogenic conditions in Serbia, within which the following were analyzed: elevation, slope, aspect, air temperature, precipitation, wind exposure, land use, distance from roads, distance from settlements, and distance from water surfaces. Elevation, slope, aspect, and wind exposure were derived from the analysis of the EU-DEM with a spatial resolution of 25 meters (European Environment Agency, 2016). The distance-from-roads dataset was generated by digitizing the content from OpenStreetMap, while land use, distance from settlements, and distance from water surfaces were obtained by downloading data from the ESRI (Environmental Systems Research Institute) Sentinel-2 Land Cover Explorer platform (Environmental Systems Research Institute, 2024; Humanitarian OpenStreetMap Team, 2025). Data for air temperature and precipitation were obtained from the geoportal of the Digital Climate Atlas of Serbia (Ministry for Environmental Protection, 2022). All spatial datasets were standardized to a pixel resolution of 25 meters.

3. RESULTS AND DISCUSSION

Based on the analysis of 32 large wildfires with natural and anthropogenic conditions, spatio-temporal patterns of the dynamics of fire occurrence were obtained. The table 1 presents data on fire intensity (FRP - Fire Radiative Power) from the FIRMS platform in combination with natural conditions such as elevation, terrain slope, aspect, mean annual air temperature, and annual precipitation.

The largest number of fires occurs during the summer and early autumn months, from July to October, which is expected because during this period, the vegetation is dry, temperatures are high, and precipitation is low. This creates conditions in which the fuel mass is most susceptible to ignition and intense fire spread. A significant number of fires are also recorded in April, which is most often the result of human activities in agriculture, such as burning stubble and clearing the land after winter, when the plant remains are dry and easily flammable.

Hypsometrically, most fires occur in lowland areas, with an altitude between 70 and 200 meters above sea level. In those locations, human influence is greater, therefore fires are more frequent. However, fires were also recorded at higher altitudes, over 1900 meters. This suggests that altitude alone is not the primary factor, but rather a combination of vegetation and climatic conditions. When examining the slope of the terrain, it is observed that most fires occur on gentle slopes with an angle of less than 5 degrees. There are also cases of fires on steep slopes exceeding 20 degrees, but these are rare. Gentle slopes and plains are more suitable for fires, while steeper terrains can contribute to the faster spread of fire.

Relief exposure has a significant impact. It is noticeable that fires often occur on the southern, southeastern, and southwestern slopes. These are the sides that receive the most solar energy in the northern hemisphere, so they are hotter and drier, which increases the risk of fires. The northern and eastern exposures have slightly lower FRP values, which confirms that the southern sides are more vulnerable.

The average annual fire temperature within the investigated locations ranges between 8 and 12 degrees. Higher FRP does not occur exclusively at higher temperatures, indicating that temperature alone is not a decisive factor. However, fires were mostly recorded at higher temperatures for this region, which indicates that it is one of the factors that determine the occurrence of fires.

Table 1. *Spatio-temporal analysis of natural conditions*

Wildfire	FRP	Date	Elevation (m)	Slope (°)	Aspect	Air temperature (°C)	Precipitation (mm)
1	241.8	7/14/2022	77.1	0.5	S	11.4	640
2	227.0	10/25/2019	118.4	0.4	W	11.4	636
3	209.8	4/10/2020	699.8	4.7	NW	9.6	784
4	205.9	4/10/2020	700.7	5.7	NE	9.6	784
5	181.4	10/9/2018	76.0	0.4	SE	11.3	590
6	175.3	10/2/2017	79.6	0.6	W	11.4	574
7	170.3	8/18/2018	106.0	0.3	N	11.0	580
8	161.9	9/23/2020	77.1	0.7	SW	11.3	557
9	158.7	7/18/2015	79.2	0.2	N	11.4	562
10	158.0	8/27/2017	76.5	0.8	NW	11.1	539
11	155.5	7/18/2015	79.4	1.3	SW	11.4	562
12	155.1	9/1/2012	1934.0	21.6	E	3.3	1035
13	149.3	10/13/2018	131.9	1.7	SE	11.2	637
14	138.9	9/8/2024	120.2	1.6	NW	10.8	545
15	136.5	4/1/2019	511.9	5.8	SE	11.0	826
16	136.5	4/1/2019	477.8	6.5	SE	11.1	828
17	127.3	9/28/2024	98.8	0.2	E	11.4	629
18	124.8	4/2/2021	73.7	0.4	W	11.0	526
19	121.8	8/9/2013	75.1	0.6	NE	11.6	664
20	121.2	8/31/2012	972.2	14.8	E	8.1	764
21	118.2	10/17/2018	84.0	0.4	SE	11.5	650
22	117.6	8/8/2019	80.4	0.3	S	11.1	623
23	116.3	8/9/2013	75.7	1.2	E	11.6	664
24	113.4	10/27/2018	82.8	0.5	S	11.2	601
25	113.4	8/22/2024	58.8	4.5	NE	12.1	596
26	109.5	8/2/2017	463.0	23.2	SE	12.4	879
27	108.9	7/20/2012	583.9	3.5	S	10.4	697
28	108.5	4/1/2019	518.9	12.2	W	11.1	826
29	107.7	9/3/2012	1113.0	7.8	E	7.6	692
30	107.7	9/3/2012	1079.8	26.6	NE	7.6	681
31	107.5	8/12/2021	75.0	4.2	N	12.0	603
32	104.1	9/4/2024	72.8	0.3	SE	11.4	598

Rainfall shows an interesting pattern. The most intense fires were not registered in areas with the lowest or highest amounts of precipitation, but rather in areas with average values between 500 and 700 millimeters. In such areas, there is sufficient vegetation to provide fuel, and the natural conditions are conducive to fires. In areas with very high rainfall, over 1000 mm, FRP values are lower, as moisture reduces the possibility of intensive combustion.

Based on the above, areas at lower and medium altitudes, with gentle slopes and southern exposure, in regions with moderate precipitation and typical summer temperatures, are at the greatest risk of wildfires. It is the combination of these factors that makes the terrain most susceptible to the occurrence and intensive development of fires.

Table 2. *Spatio-temporal analysis of natural and anthropogenic conditions*

Wildfire	**Wind exposition**	**Land use**	**Distance from roads (m)**	**Distance from settlements (m)**	**Distance from water surfaces (m)**	**Municipality**
1	Windward	Agricultural	975.0	3666.5	4656.8	Alibunar
2	Windward	Agricultural	353.6	4886.8	9251.8	Kovačica
3	Windward	Forest	348.2	442.3	10602.0	Srbica
4	Windward	Forest	255.0	230.5	10894.8	Srbica
5	Windward	Agricultural	675.0	715.9	3106.4	Sečanj
6	Windward	Agricultural	1278.9	1201.0	318.2	Zrenjanin
7	Leeward	Agricultural	1185.6	1106.8	5467.9	Mali Iđos
8	Leeward	Agricultural	2247.4	2590.0	546.0	Novi Bečej
9	Leeward	Agricultural	250.0	943.4	318.2	Zrenjanin
10	Windward	Agricultural	5145.7	4410.0	4038.9	Kikinda
11	Windward	Agricultural	355.3	1187.7	106.1	Zrenjanin
12	Windward	Rangeland	2954.8	617.5	12585.9	Peć
13	Leeward	Agricultural	1929.4	1765.1	1480.7	Irig
14	Leeward	Rangeland	1277.2	1280.6	2201.4	Subotica
15	Windward	Forest	355.3	637.4	4790.9	Istok
16	Leeward	Forest	901.7	989.0	4851.9	Istok
17	Windward	Agricultural	167.7	1950.0	5104.7	Inđija
18	Leeward	Agricultural	770.1	1118.0	2144.9	Čoka
19	Leeward	Agricultural	357.9	1456.5	5613.5	Pećinci
20	Windward	Forest	976.3	975.0	8399.0	Vučitrn
21	Leeward	Agricultural	965.7	1715.6	6919.9	Ruma
22	Windward	Agricultural	340.0	2390.9	1352.1	Odžaci
23	Leeward	Agricultural	570.1	1335.3	4927.5	Pećinci
24	Leeward	Agricultural	257.4	3193.9	313.2	Bačka Palanka
25	Leeward	Agricultural	176.8	50.0	477.6	Kladovo
26	Windward	Rangeland	614.9	602.1	391.3	Prizren
27	Windward	Agricultural	100.0	25.0	2840.9	Obilić
28	Windward	Forest	961.8	1089.2	5478.7	Istok
29	Windward	Rangeland	1934.7	1844.6	4128.7	Vitina
30	Windward	Forest	2128.7	2140.4	4242.6	Vitina
31	Windward	Rangeland	436.6	336.3	795.7	Kladovo
32	Leeward	Agricultural	430.1	353.6	419.1	Titel

Table 2 shows the occurrence of wildfires depending on wind exposure, land use type, distance from roads, settlements, and water bodies, as well as the municipalities where the fires were registered. The data enables the analysis of spatial susceptibility to fires in relation to human activities and natural factors.

Observing the wind exposure, fires were recorded on both the windward and leeward sides. The distribution between the two groups is approximately even, indicating that the wind exposure factor alone is insufficient to explain susceptibility.

Land use is an important indicator. Most fires occur on agricultural land, which indicates the importance of human activities, such as stubble burning. Meadows and pastures follow this, while a smaller number of fires were recorded in forest areas. This suggests that anthropogenic factors and open spaces play a greater role in fire susceptibility than dense forest ecosystems (Durlević et al., 2025b; Durlević et al., 2025c).

The distance from roads indicates that many fires originated relatively close to roads, often within a few hundred meters. This highlights the association of fires with human presence, as roads provide access and increase the risk of careless or deliberate ignition. A similar pattern is observed in the distance from settlements: a significant number of fires occurred within 1500 m of settlements, which confirms that human activities are a key factor. However, there are also cases of remote locations, over 4000 meters, which means that natural factors also contribute to the occurrence.

When looking at the distance from water surfaces, a large variability is observed. Some fires were registered very close, at approximately 100 meters, while others were more than 10 km away. This shows that proximity to water does not have a direct protective effect in terms of fire prevention, but that fires can occur in different places, independent of hydrological conditions.

The spatial distribution by municipality reveals that fires were recorded throughout Serbia, from Vojvodina (Alibunar, Zrenjanin, Kikinda) to Kosovo and Metohija (Istok, Vitina, Prizren). This indicates that fire susceptibility is widespread across different ecological and social contexts, further confirming that a combination of local factors, rather than just one parameter, determines the likelihood of occurrence. There is an absence of large fires in western Serbia, which may be related to the large amount of precipitation and fewer agricultural plots, unlike those in Vojvodina. Also, in eastern Serbia (except in Kladovo), no large fires were recorded. This region has been exposed to depopulation and deagrarianization in recent years.

Based on these data, it can be concluded that agricultural lands near roads and settlements are particularly susceptible to fires, with wind exposure and distance from water bodies being of secondary importance. Human activity and terrain accessibility remain the main risk factors, while natural conditions determine the intensity and spread of fires once they occur.

4. CONCLUSION

In Serbia, from 2012 to 2024, 32 fires intensity higher then 100 MW were recorded. Analzysis of spatial pattern indicate that in northern (AP Vojvodina) and southern parts (AP Kosovo i Metohija) of Serbia are areas where the largest fire occured in previos twelwe years. In contrary to research of Tabaković-Tošić et al. (2019) where insuficient number of fires excluded Vojvodina from the analysis, this paper show that two most intense fire occured in Vojvodina Province. According to temporal pattern, two peaks can be singled out. First from July to October, and second in April.

In this study six environmental, and four anthropogenic conditions are considered for determing fire susceptibilty. The results indicate that combination of local conditions determines the susceptability of fire occurence. While enivironmental conditions influence the intensity and direction of spreading, human activity and terrain accessibility are the leading conditions for wildfire occurence.

Risk assessment for complex hazards such as wildfires is challenging, but inevitable for adequate prevention strategies and coordinated emergency actions.

Acknowledgement: This research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract number 451-03-136/2025-03/200091).

REFERENCES

Durlević, U., Srejić, T., Valjarević, A., Aleksova, B., Dedanski, V., Vujović, F., & Lukić, T. (2025a). GIS-Based Spatial Modeling of Soil Erosion and Wildfire Susceptibility Using VIIRS and Sentinel-2 Data: A Case Study of Šar Mountains National Park, Serbia. Forests 2025, 16, 484. https://doi.org/10.3390/f16030484

Durlević, U., Valjarević, A., Novković, I., Vujović, F., Josifov, N., Krušić, J., Komac, B., Djekić, T., Singh, S. K., Jović, G., Radojković, M., & Ivanović, M. (2024). Universal snow avalanche modeling index based on SAFI–Flow-R approach in poorly-gauged regions. ISPRS International Journal of Geo-Information, 13(9), 315. https://doi.org/10.3390/ijgi13090315

Durlević, U., Ilić, V., & Valjarević, A. (2025b). Wildfire Susceptibility Mapping Using Deep Learning and Machine Learning Models Based on Multi-Sensor Satellite Data Fusion: A Case Study of Serbia. *Fire*, *8*(10), 407. https://doi.org/10.3390/fire8100407

Durlević, U., Čegar, N., Ilić, V., & Kovjanić, A. (2025c). Machine learning and deep learning approaches for wildfire susceptibility prediction: A case study of the Djerdap Geopark, Serbia. *Earth Systems and Environment*. https://doi.org/10.1007/s41748-025-00945-z

European Environment Agency (EEA). (2016). European Digital Elevation Model (EU-DEM) (Version 1.1). https://www.eea.europa.eu/data-and-maps/data/eu-dem

Environmental Systems Research Institute (ESRI). (2024). Sentinel-2 Land Cover Explorer. https://livingatlas.arcgis.com/landcoverexplorer/#mapCenter=21.076%2C42.197%2C13&mode=step&timeExtent=2017%2C2023&year=2023

Fire Information for Resource Management System (FIRMS). (2025). Archive download. NASA. https://firms.modaps.eosdis.nasa.gov/download/

Gajović, V., & Todorović, B. (2013). Spatial and temporal analysis of fires in Serbia for period 2000-2013. Journal of the Geographical Institute „Jovan Cvijic“, SASA 2013 Volume 63, Issue 3 Conference Issue, Pages: 297-312 https://doi.org/10.2298/IJGI1303297G

Gigović, Lj., Jakovljević, G., Sekulović, D., & Regodić, M. (2018). GIS Multi-Criteria Analysis for Identifying and Mapping Forest Fire Hazard: Nevesinje, Bosnia and Herzegovina. Tehnički vjesnik, *25* (3), 891-897. https://doi.org/10.17559/TV-20151230211722

Gigović, Lj., Pamučar, D., Drobnjak, S., & Pourghasemi, H. R. (2019). Modeling the spatial variability of forest fire susceptibility using geographical information systems and the analytical hierarchy process. In Spatial modeling in GIS and R for earth and environmental sciences (pp. 337-369). Elsevier. https://doi.org/10.1016/B978-0-12-815226-3.00015-6

Humanitarian OpenStreetMap Team. (2025). *Serbia Roads (OpenStreetMap Export).* HDX – Humanitarian Data Exchange. https://data.humdata.org/dataset/hotosm_srb_roads

Republički zavod za statistiku. (2025). Početna. Republički zavod za statistiku Republike Srbije. Preuzeto 2. oktobra 2025. https://www.stat.gov.rshttps://www.stat.gov.rs (on Serbian)

Marković, V., Nagy, I., Sik, A., Perge, K., Laszlo, P., Papathoma-Köhle, M., Promper, C. & Glade, T. (2016). Assessing drought and drought-related wildfire risk in Kanjiza, Serbia: the SEERISK methodology. Nat Hazards **80**, 709–726, https://doi.org/10.1007/s11069-015-1991-4

Milanović, S., Marković, N., Pamučar, D., Gigović, L., Kostić, P., & Milanović, S. D. (2021). Forest fire probability mapping in Eastern Serbia: Logistic regression versus random forest method. Forests, *12* (1), 5. https://doi.org/10.3390/f12010005

Ministry for Environmental Protection. (2022). *Digital Climate Atlas of Serbia (Project "Advancing Medium and Long-Term Adaptation Planning in the Republic of Serbia").* https://atlas-klime.eko.gov.rs

Pishahang, M., Jovcic, S., Hashemkhani Zolfani, S., Simic, V., & Görçün, Ö. F. (2023). MCDM-Based Wildfire Risk Assessment: A Case Study on the State of Arizona. *Fire*, *6*(12), 449. https://doi.org/10.3390/fire6120449

QGIS Development Team. (2023). QGIS geographic information system (Version 3.28.10) with GRASS. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

Ratknic, T., Ratknic, M., Cirkovic-Mitrovic, T., & Brasanac-Bosanac, L. (2018). The impact of climate factors on the wildfire occurrence in Serbia. Fresenius Environmental Bulletin, Germany, 27(6), 4014-4022.

Sekulić, G., Dimović, D., Kalmar Krnajski Jović, Z., & Todorović, N. (2012). Climate Vulnerability Assessment-Serbia.WWF (World Wide Fund for Nature); Environmental Improvement Centre. http://awsassets.panda.org/downloads/cva_srbija_english.pdf

Sinko, V. (2025). 620 wildfires in Serbia over 12 hours; Two firefighters and four civilians injured. Blic. https://www.blic.rs/vesti/drustvo/pozari-sirom-srbije-620-zabelezenih-incidenata-u-jednom-danu-povredjeni-vatrogasci/9lf3djl

Statistical Office of the Republic of Serbia. (2023). Final results of the census of population, households and dwellings, 2022. Statistical Office of the Republic of Serbia. https://popis2022.stat.gov.rs/en-US/0-popisi

Statistical Office of the Republic of Serbia. (2025). Damages to forests, 2024. Statistical Office of the Republic of Serbia. https://www.stat.gov.rs/en-us/vesti/20250606-stete-u-sumama-2024/

Tabaković-Tošić, M., Milosavljević, M., & Vasiljević, A. (2019). Wildfires in Republic of Serbia in the period 2009-2017. Silva Balcanica, 20(1).

Tošić, I., Mladjan, D., Gavrilov, M., Živanović, S., Radaković, M., Putniković, S., Petrović, P., Mistridželović, I. & Marković, S. (2019). Potential influence of meteorological variables on forest fire risk in Serbia during the period 2000-2017. Open Geosciences, 11(1), 414-425. https://doi.org/10.1515/geo-2019-0033

Tošić, I., Živanović, S., & Tošić, M. (2020). Influence of extreme climate conditions on the forest fire risk in Timočka Krajina region (Northeastern Serbia). Idojaras, 124(3), 331-347. DOI:10.28974/idojaras.2020.3.2

Valjarević, A., Morar, C., Brasanac-Bosanac, L., Cirkovic-Mitrovic, T., Djekic, T., Mihajlović, M., Milevski, I., Culafic, G., Luković, M., Niemets, L., Sehida, K., & Kaplan, G. (2025). Sustainable land use in Moldova: GIS & remote sensing of forests and crops. *Land Use Policy*, *152*, 107515. https://doi.org/10.1016/j.landusepol.2025.107515

Vranić, P., & Mišić, N. (2024). Spatial Distribution Patterns of Wild-Fires Incidents in Serbia Based on VIIRS 375 m Data for the Period 2013-2023. Facta Universitatis, Series: Working and Living Environmental Protection, 21(2),87 – 96 https://doi.org/10.22190/FUWLEP240605008V

Vujović, F., Valjarević, A., Vila-Subirós, J., Šiljeg, A. & Lukić, T. (2024). Geospatial modeling of wildfire susceptibility on a national scale in Montenegro: A comparative evaluation of F-AHP and FR methodologies. Open Geosciences, 16(1), 20220694. https://doi.org/10.1515/geo-2022-0694

Živanović, S., & Gocić, M. (2022). Forest fires in Serbia—Influence of humidity conditions. Journal of the Geographical Institute „Jovan Cvijić", SASA, 72(2), 221–228. https://doi.org/10.2298/IJGI2202221Z

SPATIO-TEMPORAL ANALYSIS OF LARGE WILDFIRES IN SERBIA BASED ON GIS AND VIIRS REMOTE SENSING DATA

Uroš DURLEVIĆ, Nina ČEGAR, Ljiljana BRAŠANAC-BOSANAC

Summary

The paper presents the results of spatiotemporal patterns of large wildfires in Serbia from 2012 to 2024, utilizing GIS and VIIRS data from the FIRMS platform. Thirty-two large fires (FRP > 100 MW) were identified, most often occurring during July–October due to high temperatures and drought, while in April, fires are mostly caused by agricultural burning. Fires are most prevalent in Vojvodina and Kosovo and Metohija, while they are almost non-existent in western and most of eastern Serbia. The riskiest areas are characterized by low to medium altitudes, gentle slopes, southern exposures, and moderate annual precipitation, with proximity to agricultural areas, roads, and settlements. The analysis shows that human activities have a decisive influence on the occurrence of fires, while natural factors shape their intensity and spread. The integration of GIS and satellite data provides valuable insight for risk assessment and improvement of fire protection strategies in Serbia.

PROSTORNO-VREMENSKA ANALIZA VELIKIH POŽARA U SRBIJI ZASNOVANA NA GIS I VIIRS PODACIMA DALJINSKE DETEKCIJE

Uroš DURLEVIĆ, Nina ČEGAR, Ljiljana BRAŠANAC-BOSANAC

Rezime

U radu su analizirani prostorno-vremenski obrasci velikih požara u Srbiji u periodu 2012–2024, koristeći GIS i VIIRS podatke sa FIRMS platforme. Identifikovana su 32 velika požara (FRP >100 MW), najčešće tokom jula–oktobra zbog visokih temperatura i suše, dok u aprilu požari uglavnom nastaju usled poljoprivrednog spaljivanja. Požari su najzastupljeniji u Vojvodini i na Kosovu i Metohiji, dok ih gotovo nema u zapadnoj i većem delu istočne Srbije. Najrizičnija područja odlikuju se malim do srednjim nadmorskim visinama, blagim nagibima, južnim ekspozicijama i umerenim padavinama, uz blizinu poljoprivrednih površina, puteva i naselja. Analiza pokazuje da ljudske aktivnosti imaju presudan uticaj na pojavu požara, dok prirodni faktori oblikuju njihov intenzitet i širenje. Integracija GIS i satelitskih podataka pruža dragocen uvid za procenu rizika i unapređenje strategija zaštite od požara u Srbiji.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 92, 2025 ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592145J
UDK: 811.111:630=111
Review paper

THE IMPORTANCE OF THE ENGLISH LANGUAGE IN FORESTRY

Emina JEREMIĆ MARKOVIĆ[1], Doloris BEŠIĆ-VUKAŠINOVIĆ*[2]

Abstract: *English has become the primary medium for global communication, scientific discourse, and professional exchange. Within forestry, its significance is evident in education, research, international collaboration, and access to information. This paper examines the role of English as the lingua franca in forestry, highlighting its influence on academic publishing, knowledge dissemination, and international networking among forestry professionals. Through case studies from forestry education, international projects, and research distribution, the study demonstrates the necessity of English proficiency for both students and professionals in the field. The findings suggest that English serves not only as a means of communication but also as a catalyst for innovation and sustainable forest management globally.*

Keywords: English language, forestry, communication, education, research, globalization.

VAŽNOST ENGLESKOG JEZIKA U ŠUMARSTVU

Sažetak: *Engleski jezik je postao globalno sredstvo komunikacije, nauke i stručne razmene. U šumarstvu se njegova važnost ogleda u obrazovanju, istraživanju, međunarodnoj saradnji i pristupu informacijama. Rad istražuje značaj engleskog jezika kao lingua franca u šumarstvu, sa posebnim naglaskom na njegovu ulogu u akademskom izdavaštvu, transferu znanja i globalnom umrežavanju stručnjaka. Kroz primere iz šumarskog obrazovanja, međunarodnih projekata i širenja istraživačkih rezultata, pokazuje se da je znanje engleskog jezika neophodno za studente i profesionalce u šumarstvu. Rezultati ukazuju na to da engleski nije samo sredstvo komunikacije već i put ka inovacijama i održivom upravljanju šumama na globalnom nivou.*

Ključne reči: engleski jezik, šumarstvo, komunikacija, obrazovanje, istraživanje, globalizacija.

[1] Center for globalization studies (CGS), Belgrade, Serbia
[2] Academy of Technical and Art Applied Studies - School of Electrical and Computer Engineering, Belgrade, Serbia; doloris.besic@yahoo.com
*Corresponding author. E-mail: eminajeremic@gmail.com

1. INTRODUCTION

Language is a fundamental instrument in society, shaping communication, education, culture, and scientific progress. English has emerged as the dominant lingua franca, serving as the principal medium for international research, politics, economics, and technology. Its role in forestry is critical because environmental and ecological challenges are inherently global in scope. However, while English serves as a bridge for international collaboration, it is not a replacement for local expertise and languages, which remain crucial in addressing unique regional forestry realities. The discipline of forestry depends on ongoing knowledge exchange and cross-border collaboration. Issues such as climate change, biodiversity conservation, and sustainable forest management require international cooperation. English enables forestry professionals to participate effectively in global discussions and contribute to shared solutions.

In recent decades, universities and research institutions worldwide have integrated English into their forestry programs. Scientific journals with the highest impact factors in forestry are almost exclusively published in English, making it the essential language for the dissemination of research. Moreover, international organisations such as the Food and Agriculture Organisation of the United Nations (FAO) and International Union of Forest Research Organizations (IUFRO) publish guidelines, reports, and strategies in English, requiring forestry professionals to be proficient in English. (Unasylva - No. 153 - The changing face of forest industry - Report: IUFRO forestry science serving society, n.d.) This introduction provides an overview of why English has become indispensable in forestry education, practice, and research (Crystal, 2003).

2. MATERIAL AND METHODS

The methodological framework of this paper is based on a literature review and qualitative analysis of international forestry sources. Scientific articles, official reports, and guidelines issued by FAO, IUFRO, and other international institutions form the basis of this research. Particular attention was given to the role of English in forestry education curricula, the availability of academic materials in English, and its presence in professional forestry practice.

The analysis also examined international conferences, such as the IUFRO World Congress, where English is the official working language. By comparing the accessibility of information in English with that available in local languages, this study identified the advantages and limitations that English presents to forestry professionals and students (Graddol, 2006).

3. RESULTS

The results of the literature analysis indicate several key dimensions of the importance of English in forestry:

3.1. Education

English is becoming the predominant medium of instruction in forestry faculties worldwide. As noted in paper *The English language dominates global conservation science – which leaves 1 in 3 research papers virtually ignored* (2021), the growing reliance on English reflects its central role in scientific communication. Numerous universities in Europe and Asia now offer master's programmes delivered entirely in English, and an increasing number of undergraduate courses rely on English-language textbooks. This trend provides students with access to a broader body of academic literature and strengthens their competitiveness in the international labour market.

3.2. Research

Most forestry journals, including Forest Ecology and Management and the Journal of Forestry Research, are published in English. This prevalence facilitates global exchange of research findings but poses challenges for researchers who lack proficiency in English. However, the use of standardised English allows forestry knowledge to be disseminated widely and accessed by a larger international audience.

3.3. Professional Practice

Forestry professionals engaged in international projects use English as the primary language for communication. Initiatives focused on climate adaptation, forest certification, and biodiversity monitoring involve multinational teams, with English facilitating effective coordination and communication. Local forest management plans also frequently incorporate English terminology to align with international standards.

3.4. Digital Resources

The digitalisation of forestry knowledge has reinforced the prominence of English. Online databases, such as Scopus and Web of Science, and educational platforms like Coursera and edX primarily offer forestry-related content in English. This trend benefits English-proficient professionals but restricts access for individuals without these language skills (Crystal, 2003).

4. DISCUSSION

The research findings emphasise the central role of English in advancing forestry as both a scientific discipline and a profession. Although English proficiency offers significant advantages, it also contributes to disparities. Students and practitioners in countries with limited English education encounter barriers to accessing current research and engaging in international collaborations. Regions such as Sub-Saharan Africa and parts of South Asia face particular challenges, as limited English language resources hinder their participation in the global forestry community. This situation may widen the gap in forestry expertise between developed and developing countries.

A further concern is the potential marginalisation of local languages and traditional ecological knowledge. Indigenous forest management practices, typically maintained and communicated in native languages, risk diminished visibility within the global discourse dominated by English. This challenge underscores the need to strike a balance between effective global communication and the preservation of cultural and linguistic diversity.

A dual strategy may address these challenges: enhancing English language education for forestry students and professionals, while also supporting the translation of essential scientific materials into local languages. This approach would help prevent the exclusion of valuable knowledge and promote inclusivity in international forestry discussions (Crystal, 2003).

5. CONCLUSION

English is now firmly established as the global language of forestry. Its influence extends beyond communication, affecting access to knowledge, international collaboration, and professional growth. The study's results suggest that without English proficiency, forestry professionals may become isolated from the global scientific community. Incorporating English into forestry education is therefore essential for preparing future foresters to address global challenges, including climate change, deforestation, and biodiversity loss.

The paper concludes that enhancing English language proficiency in forestry represents a long-term investment in the discipline's resilience and continued relevance. However, this advancement should not undermine local knowledge and linguistic diversity, both of which are essential for sustainable forest management.

REFERENCES

Crystal, D. (2003). English as a Global Language. Cambridge University Press.

FAO. (2020). Global Forest Resources Assessment (2020). Food and Agriculture Organization of the United Nations.

Graddol, D. (2006). English Next: Why global English may mean the end of ‘English as a Foreign Language’. British Council.

IUFRO. (2019). Interconnecting Forests, Science and People. International Union of Forest Research Organizations.

Nair, C.T.S. (2004). Forestry education for the 21st century. Unasylva, 55(217), 3–10.

Pettenella, D., & Secco, L. (2015). Forestry education between local and global perspectives. Forest Policy and Economics, 59, 44–51.

Phillipson, R. (2009). Linguistic Imperialism Continued. Routledge.

Shrestha, B. B. (2017). The role of English in higher forestry education. Journal of Forest and Livelihood, 15(1), 65–72.

UNESCO. (2019). The Role of Indigenous Languages in Preserving Traditional Knowledge. UNESCO Publishing.

Wang, L., & Lin, J. (2013). Global English and local language in higher education. Language and Education, 27(1), 59-73.

https://theconversation.com/the-english-language-dominates-global-conservation-science-which-leaves-1-in-3-research-papers-virtually-ignored-168951

THE IMPORTANCE OF THE ENGLISH LANGUAGE IN FORESTRY

Emina JEREMIĆ MARKOVIĆ, Doloris BEŠIĆ-VUKAŠINOVIĆ

Summary

English has become a vital tool in forestry, facilitating international collaboration, the dissemination of research, and technological advancements. This paper examines the importance of English in forestry education, scientific communication, and professional contexts. English enables access to global scientific literature, participation in international conferences, and collaboration with multinational organisations, thereby empowering forestry professionals to exchange knowledge and implement innovative solutions to environmental challenges. The integration of English into forestry curricula also promotes student mobility and expands career prospects, while supporting the global exchange of sustainable practices. The study concludes that English serves not only a linguistic function but also a strategic role by integrating forestry into a global framework for ecological preservation and sustainable development.

VAŽNOST ENGLESKOG JEZIKA U ŠUMARSTVU

Miroslava MARKOVIĆ, Renata GAGIĆ-SERDAR, Bojan KONATAR, Jelena BOŽOVIĆ, Vanja STOJANOVIĆ, Ljubinko RAKONJAC, Aleksandar LUČIĆ

Rezime

Engleski jezik postao je ključni alat u oblasti šumarstva, služeći kao most za međunarodnu saradnju, širenje istraživanja i tehnološki napredak. Ovaj rad istražuje značaj engleskog jezika u obrazovanju iz oblasti šumarstva, naučnoj komunikaciji i profesionalnoj praksi. Omogućavajući pristup globalnoj naučnoj literaturi, učešće na međunarodnim konferencijama i saradnju sa multinacionalnim institucijama, engleski jezik osnažuje stručnjake iz šumarstva da dele znanje i primenjuju inovativna rešenja za ekološke izazove. Pored toga, uvođenje engleskog jezika u nastavne programe šumarstva podstiče mobilnost studenata i otvara karijeru, dok istovremeno jača globalnu razmenu održivih praksi. Studija zaključuje da uloga engleskog jezika nije samo jezička, već i strateška, jer podstiče integraciju šumarstva u globalni okvir ekološke zaštite i održivog razvoja.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY COLLECTION 92, 2025

ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 92, 2025

DOI: 10.5937/SustFor2592151M
UDK: 504.05/.06:633.872=111
Preliminary communication

ASSESSMENT OF THE POTENTIAL OF ALBINO BEECH COMPARED TO PIGMENTED BEECH AS A BIOINDICATOR OF ENVIRONMENTAL CONDITIONS

Miroslava MARKOVIĆ[1], Renata GAGIĆ-SERDAR[1], Bojan KONATAR[1], Jelena BOŽOVIĆ [1], Vanja STOJANOVIĆ[1], Ljubinko RAKONJAC[1], Aleksandar LUČIĆ[1]*

Abstract: *The common beech (Fagus sylvatica L.) can be used in forest ecosystem monitoring as a model for assessing environmental changes. Its long lifespan and wide distribution make it a suitable bioindicator of atmospheric deposition, soil acidification, and stress related to climate changes. Numerous studies have shown that foliar analysis of beech reflects both regional trends in acidic depositions and heavy metal input, as well as local pollution gradients. Crown defoliation and vitality parameters further complement this chemical signal by integrating complex stress factors such as drought and temperature-related ecosystems. In addition, recent years have seen growing interest in rare albino individuals of woody species, including albino beech. Due to the absence of chlorophyll and altered relationships between the phloem and xylem, albino shoots may act as "traps for mineral nutrients." Studies on albino sequoias have confirmed elevated concentrations of Cd, Cr, and Ni in albino leaves compared to pigmented ones, indicating potentially high sensitivity to environmental pollution and possible applications in phytoremediation. A similar pattern of heavy metal accumulation can also be observed in albino beech, which can accumulate higher concentrations of heavy metals such as Ni and Cd compared to pigmented individuals. This paper summarizes the current knowledge on the use of beech as a bioindicator of environmental conditions and compares it with available data for albino woody species, with special emphasis on albino beech. It is concluded that the greatest potential lies in combining standardized regional monitoring of common beech with targeted research of albino individuals as extreme models for studying element cycling and heavy metal accumulation.*

Keywords: common beech, albino beech, bioindicators, heavy metals.

ISPITIVANJE POTENCIJALA ALBINO BUKVE U ODNOSU NA BUKVU SA PIGMENTOM, KAO BIOINDIKATORA STANJA ŽIVOTNE SREDINE

Sažetak: *Obična bukva (Fagus sylvatica L.) može se koristiti u monitoringu šumskih ekosistema kao model za procenu promena u životnoj sredini. Njen dug životni vek i široka rasprostranjenost čine je pogodnim bioindikatorom atmosferskog deponovanja,*

[1] Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
*Corresponding author. E-mail: mira013@gmail.com

zakišeljavanja zemljišta i stresa povezanog sa klimatskim promenama. Brojna istraživanja pokazala su da folijarna analiza bukve odražava i regionalne trendove u kiselim depozicijama i unosu teških metala, kao i lokalnim gradijentima zagađenja. Parametri defolijacije krošanja i vitalnosti dodatno dopunjuju ovaj hemijski signal integrišući kompleksne stresove, kao što su suša i temperaturni ekosistemi. Paralelno sa tim, u poslednje vreme raste interesovanje za retke albino jedinke drvenastih vrsta, uključujući i albino bukvu. Zbog odsustva hlorofila i izmenjenih odnosa između floema i ksilema, albino izdanci mogu delovati kao „zamke za mineralne hranljive materije". Studije na albino sekvojama potvrdile su povišene koncentracije Cd, Cr i Ni u albino listovima u poređenju sa pigmentisanim, što ukazuje na potencijalno visoku osetljivost na zagađenje životne sredine i moguće primene u fitoremedijaciji. Slična dinamika akumulacije teških metala može se posmatrati i kod albino bukve, koja može akumulirati veće koncentracije teških metala kao što su Ni i Cd u poređenju sa pigmentisanim jedinkama. U ovom radu sumirana su postojeća saznanja o upotrebi bukve kao bioindikatora uslova životne sredine i upoređena sa raspoloživim podacima za albino drvenaste vrste, sa posebnim osvrtom na albino bukvu. Zaključuje se da najveći potencijal leži u kombinovanju standardizovanog regionalnog monitoringa na običnoj bukvi, sa ciljanim istraživanjima albino jedinki kao ekstremnih modela za proučavanje kruženja elemenata i akumulacije teških metala.

Ključne reči: obična bukva, albino bukva, bioindikatori, teški metali

1. INTRODUCTION

Living organisms are widely used as bioindicators of environmental conditions because they integrate the effects of various stressors over an extended period of time, unlike chemical analyses which provide only a snapshot of the current situation (Božović *et al*., 2024). Woody species are particularly suitable as bioindicators, as they are long-lived, permanently attached to their habitat, and accumulate signals of pollution and changes in nutrient status in their organs (leaves, roots, wood) (Božović *et al*., 2025).

The common beech (*Fagus sylvatica* L.), or its Balkan taxon Fagus moesiaca, is one of the key forest species in Europe and southeastern Europe. Due to its wide distribution and its role as a dominant species in many stands, beech is a focus of international monitoring programs (ICP Forest) and is often used as a model species for tracking acidification, atmospheric deposition, and climate change (Berger *et al*., 2016; Ognjenović *et al*., 2023).

In parallel with this, interest has been steadily increasing in rare albino forms of woody species, including albino beech (*Fagus sylvatica* subsp. *moesiaca* f. *albina*). Previous studies on albino shoots and albino sequoias indicate that such organs can accumulate more nutrients and heavy metals than pigmented tissues (Lo Gullo *et al*., 2012; Pittermann *et al*., 2018). The accumulation of higher concentrations of heavy metals, especially nickel (Ni), in albino beech compared to common beech growing under the same conditions is particularly important for understanding local contamination (Božović *et al*. 2025).

The aim of this paper is to present previous research on the potential of beech as a bioindicator of environmental conditions and to compare it with results obtained for albino woody species, with special emphasis on albino beech.

2. OVERVIEW OF PREVIOUS RESEARCH

2.1. Common beech as a bioindicator of environmental conditions

Foliar analysis of beech (the content of macro- and microelements in leaves) forms the basis of numerous studies and represents an integral part of European forest monitoring networks. In the Vienna forest region, the process of recovery from acid rain has been monitored over several decades. Berger *et al*. (2016) analyzed 97 beech stands and found that soil pH and sulfur deposition were gradually improving, but that the macronutrient status of beech (especially Ca, Mg, and P) had not improved at the same rate, indicating a slow recovery of forest ecosystems.

In the same areas, Türtscher *et al*. (2017) showed that the decline in atmospheric deposition of heavy metals (Pb, Ni, etc.) over three decades was clearly reflected in the metal content of both the soil and beech leaves. The Pb content in the surface soil horizon, as well as foliar concentrations of Pb, Cu, Zn, and Ni, decreased significantly compared to the 1980s, confirming that beech leaves can serve as an archive of pollution history.

In addition to regional studies, foliar metal concentrations in beech leaves have also been used in urban and industrial environments, where higher levels of Pb, Zn, Cu, and Cd were found in the leaves of trees located closer to roads and emission sources (e.g., studies on urban forests in Central Europe). These findings confirm that beech responds to local pollution gradients.

Ognjenović *et al*. (2023) showed that the nutritional status of beech leaves (N, P, K, Ca, Mg, and microelements) and crown defoliation depend on the combined effects of climate, altitude, and other environmental factors. Defoliation is thus used as a complementary indicator of complex stress (such as drought, extreme temperatures, pollution) together with foliar analysis.

2.2. Albino woody species as nutrient traps

Albino shoots on woody species most likely arise due to different mutations. Lo Gullo *et al*. (2012) compared albino shoots of Citrus sinensis and Nerium oleander with the hemiparasitic mistletoe Scurrula elata. It was determined that albino leaves contain significantly higher concentrations of K, S and Zn compared to the green leaves of the host, and the authors introduced the concept of a "mineral nutrient trap" – albino shoots function as traps for nutrients, since due to the absence of photosynthesis and altered phloem–xylem dynamics, they do not participate in the usual recycling of elements.

Albino redwoods (*Sequoia sempervirens*) further illustrate the extremity of this physiological condition. Pittermann *et al*. (2018) showed that albino shoots have a different water regime, higher stomatal conductivity, and greater susceptibility to cavitation compared to green shoots. Reviews of previous research also indicate that albino redwoods accumulate heavy metals (Ni, Cu, Cd) in higher concentrations than healthy needles, which has led to the hypothesis that these individuals may function as the "kidneys" of the forest ecosystem.

Marković *et al*. (2024) described an adult albino *Fagus sylvatica* subsp. *moesiaca* tree (picture 1) in central Serbia. Its leaves are smaller, the growth habit is dwarf and bush-like, and the authors point out the possible parasitic nature of the individual and the potential importance of the underground mycorrhizal network.

Picture 1. *Albino beech from the studied site*

These studies together suggest that the albino parts of trees physiologically and pathologically amplify the signal of element cycling and potential contamination.

3. DISCUSSION

Previous research shows that common beech and albino woody species lie at the opposite ends of the same bioindication spectrum. Common beech is an ecologically relevant and practical bioindicator. Its wide distribution, standardized sampling protocols (ICP Forest), and the availability of reference ranges for foliar nutrient and metal concentrations enable regional comparative analyses. Foliar analysis of the chemical composition of beech reliably reflects spatial and temporal trends of acidification and heavy metal pollution, while defoliation and tree vitality complement the picture of complex stress (Berger *et al*., 2016; Türtscher *et al*., 2017; Ognjenović *et al*., 2023).

Marković *et al*. (2024) present the morphological characteristics of albino beech, noting that in comparison with common beech there are clear differences in leaf size among trees from the same site.

On the other hand, albino woody individuals, including albino beech, are very rare and locally restricted. The "nutrient trap" concept (Lo Gullo *et al*., 2012) and results obtained from albino redwoods (Pittermann *et al*., 2018) indicate that albino leaves may reach significantly higher concentrations of certain elements, including Cd, Cr, and Ni. The accumulation of higher concentrations of heavy metals in albino species further increases their importance as a local bioindicator.

In that sense, common beech is most suitable for:

- long-term, regional monitoring of forest biochemistry and atmospheric deposition,
- comparisons between different regions, altitudes, and types of habitats,

- detection of trends related to climate changes and declining emissions.

Albino beech and other albino woody species may, in contrast, be useful for:

- identifying local hotspots of heavy metal contamination,
- understanding the flow of elements within shared root and mycorrhizal systems,
- investigating the potential for hyperaccumulation of pollutants and possible phytoremediation.

However, their application is limited by their rarity and physiological instability. It is therefore realistic to view them as specialized research models that complement, but do not replace, classical monitoring on common beech.

4. CONCLUSION

1. Common beech (*Fagus sylvatica* / *Fagus moesiaca*) is a confirmed bioindicator of forest ecosystem status, particularly regarding acidification, atmospheric deposition, and heavy metal contamination.
2. Foliar analysis of beech and the vitality parameters (defoliation, growth) reliably reflect long-term changes in pollution and climatic stress at the regional scale.
3. The greatest potential lies in a combined approach: standardized monitoring of common beech for regional analyses, with targeted inclusion of albino individuals as special models for studying element cycling and the hyperaccumulation of heavy metals.
4. Future research should focus on the upper limit of the adsorptive capacity of albino beech and potential applications of albino individuals in sites with elevated concentrations of macro- and microelements.

Acknowledgement: *The study was carried out within projects financed by the Republic of Serbia - Ministry of Education and Science. The registration number of the Agreement for the current year - season 2024 is 451-03-66/2024-03/200027 dated February 5th, 2024.*

REFERENCES

Božović, J., Radulović, Z., Konatar, B., Stajić, S., Čule, N., Pižurica, R., Živojinović, D. (2024): Analysis of the chemical composition of three fungal species with medicinal properties to investigate their medical and ecological potential, Sustainable Forestry: Collection 89-90:149-160

Božović, J., Cvetković, J., Konatar, B., Stojanović, V., Konatar, S., Vemić, A., Živojinović, D. (2025): Spatial distribution and concentration of nickel (Ni) in organic horizon and surface mineral soil of forest ecosystems in the Republic of Serbia, Sustainable Forestry: Collection 91:83-92

Berger, T. W., Türtscher, S., Berger, P., & Lindebner, L. (2016): A slight recovery of soils from acid rain over the last three decades is not reflected in the macro nutrition of beech

(*Fagus sylvatica*) at 97 forest stands of the Vienna Woods. Environmental Pollution, 216, 624–635.

Lo Gullo, M. A., Glatzel, G., Devkota, M., Raimondo, F., Trifilò, P., & Richter, H. (2012): Mistletoes and mutant albino shoots on woody plants as mineral nutrient traps. Annals of Botany, 109(6), 1101–1109. https://doi.org/10.1093/aob/mcs033

Marković, M., Gagić-Serdar, R., Rakonjac, L., Konatar, B., Lučić, A., Radovanović, T., & Tešović, M. (2024): Research of the characteristics of an adult woody albino Mesian beech (*Fagus moesiaca*, Asine Pigmente), as a tree form in Central Serbia. Agriculture and Forestry, 70(2). https://doi.org/10.17707/AgricultForest.70.2.13

Ognjenović, M., Seletković, I., Marušić, M., Jonard, M., Rautio, P., Timmermann, V., ... Potočić, N. (2023): The Effect of Environmental Factors on the Nutrition of European Beech (*Fagus sylvatica* L.) Varies with Defoliation. Plants, 12(1), 168. https://doi.org/10.3390/plants12010168

Pittermann, J., Cowan, J., Kaufman, N., Baer, A., Zhang, E., & Kuty, D. (2018): The water relations and xylem attributes of albino redwood shoots (Sequoia sempervirens (D. Don) Endl.). PLoS ONE, 13(3), e0191836. https://doi.org/10.1371/journal.pone.0191836

Türtscher, S., Berger, P., Lindebner, L., & Berger, T. W. (2017): Declining atmospheric deposition of heavy metals over the last three decades is reflected in soil and foliage of 97 beech (*Fagus sylvatica*) stands in the Vienna Woods. Environmental Pollution, 230, 561–573. https://doi.org/10.1016/j.envpol.2017.06.080

ASSESSMENT OF THE POTENTIAL OF ALBINO BEECH COMPARED TO PIGMENTED BEECH AS A BIOINDICATOR OF ENVIRONMENTAL CONDITIONS

Miroslava MARKOVIĆ, Renata GAGIĆ-SERDAR, Bojan KONATAR, Jelena BOŽOVIĆ, Vanja STOJANOVIĆ, Ljubinko RAKONJAC, Aleksandar LUČIĆ

Summary

Common beech (*Fagus sylvatica* L.) occupies a central position in forest monitoring programs in Serbia. Due to its wide distribution, longevity, and importance in the structure of forest ecosystems, it can be used as a model species for the assessment of environmental conditions. Long-term studies in beech stands of the Vienna Forest region have shown that the decline in atmospheric deposition of sulfur and heavy metals follows the reduction in their content in soil and leaves, but that nutritional imbalances (e.g., deficiency of base cations) persist longer, indicating a slow ecosystem recovery. In urban and industrial areas, foliar concentrations of Pb, Zn, Cu, and Cd clearly reflect spatial gradients of pollution. At the same time, vitality parameters such as defoliation and crown damage complement the chemical composition, integrating stresses arising from climate, pollution, and habitat conditions.

At the same time, over the past decade there has been a growing interest in rare albino individuals of woody species. In albino shoots and albino trees, we assume that there is a complete absence of chlorophyll synthesis and altered phloem–xylem dynamics. Experimental studies have shown that albino shoots can accumulate significantly higher

amounts of nutrients (K, S, Zn) compared to green leaves, which led to the formulation of the “mineral nutrient trap” concept. Research on albino redwoods indicates increased accumulation of heavy metals (Ni, Cu, Cd) in albino needles. These findings suggest that albino beech may act as a highly sensitive local bioindicator of heavy metal contamination, with potential application in the phytoremediation of degraded habitats.

Based on the literature review, it can be concluded that common beech remains a key, “standard” bioindicator for regional monitoring of forest ecosystem status, while albino woody individuals represent specialized models that allow a deeper understanding of nutrient flows and hyperaccumulation of metals. The greatest potential lies in a combined approach, where standardized monitoring of common beech is complemented by targeted studies of albino individuals at sites of particular interest.

ISPITIVANJE POTENCIJALA ALBINO BUKVE U ODNOSU NA BUKVU SA PIGMENTOM, KAO BIOINDIKATORA STANJA ŽIVOTNE SREDINE

Miroslava MARKOVIĆ, Renata GAGIĆ-SERDAR, Bojan KONATAR, Jelena BOŽOVIĆ, Vanja STOJANOVIĆ, Ljubinko RAKONJAC, Aleksandar LUČIĆ

Rezime

Obična bukva (*Fagus sylvatica* L.) zauzima centralno mesto u programima monitoringa šuma u Srbiji. Zbog široke rasprostranjenosti, dugovečnosti i važnosti u strukturi šumskih ekosistema, ona se može koristiti kao model vrste za procenu stanja životne sredine. Dugoročna istraživanja u bukovim sastojinama Bečkog šumskog područja pokazale su da opadanje atmosferske depozicije sumpora i teških metala prati smanjenje njihovog sadržaja u zemljištu i lišću, ali da se nutritivni disbalansi (na pr. nedostatak bazičnih katjona) zadržavaju duže, što ukazuje na spor oporavak ekosistema. U urbanim i industrijskim sredinama folijarne koncentracije Pb, Zn, Cu i Cd jasno prate prostorne gradijente zagađenja. Istovremeno, parametri vitalnosti kao što su defolijacija i oštećenost krošanja dopunjuju hemijski sastav, integrišući stresove koji potiču od klime, zagađenja i uslova staništa.

Uporedo sa time, u poslednjoj deceniji raste interesovanje za retke albino jedinke drvenastih vrsta. Kod albino izdanaka i albino stabala pretpostavljamo da dolazi do potpunog izostanka sinteze hlorofila, promenjene floem–ksilem dinamike. Eksperimentalne studije su pokazale da albino izdanci mogu da akumuliraju znatno više hranljivih elemenata (K, S, Zn) u odnosu na zelene listove, što je dovelo do formulisanja koncepta „mineral nutrient trap“. Istraživanja na albino sekvojama ukazuju na povećanu akumulaciju teških metala (Ni, Cu, Cd) u albino iglicama. Ovi nalazi navode na zaključak da albino bukva može delovati kao lokalno vrlo osetljiv bioindikator kontaminacije teškim metalima, uz potencijalnu primenu u fitoremedijaciji degradiranih staništa.

Na osnovu pregleda literature može se zaključiti da obična bukva ostaje ključni, „standardni“ bioindikator za regionalno praćenje stanja šumskih ekosistema, dok albino drvenaste jedinke, predstavljaju specijalizovane modele koji omogućavaju dublje razumevanje tokova elemenata i hiperakumulacije metala. Najveći potencijal leži u kombinovanom pristupu, u kojem se standardizovani monitoring na običnoj bukvi dopunjuje ciljanim istraživanjima albino jedinki na lokalitetima od posebnog interesa.

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.

All papers in journal **SUSTAINABLE FORESTRY** are licensed from 2023, **license CC BY 4.0 DEED** (https://creativecommons.org/licenses/by/4.0/?ref=chooser-v1).

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.

Professional Articles

1. Professional paper (annex in which are offered the experiences for improving professional practice, but which are not necessarily based on scientific method).

This guide and the paper template can be found at the following link:
https://www.forest.org.rs/?%D0%9D%D0%B0%D1%98%D0%BD%D0%BE%D0%B2%D0%B8%D1%98%D0%B8-%D0%B1%D1%80%D0%BE%D1%98-%D1%87%D0%B0%D1%81%D0%BE%D0%BF%D0%B8%D1%81%D0%B0-sustainable-forestry-

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)
11pt
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.
11pt
11pt
11pt

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).

11pt
11pt

PAPER TITLE IN SERBIAN IN LATIN ALPHABET (capital letters, 11 points, bold, centered)
11pt

Sažetak: Text of the abstract in Serbian in Latin alphabet (Font Size 10pt, italic)

Ključne reči: in Serbian (Font Size 10pt, normal).

11pt
11pt

1. INTRODUCTION (Font Size 11pt, bold, align left)
11pt

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).

---

[1] Affiliation, address (9pt, normal)
*Corresponding author. E-mail: (9pt, normal)

11pt

2. MATERIAL AND METHODS (Font Size 11pt, bold, align left)

11pt

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.

11pt

3. RESULTS (Font Size 11pt, bold, align left)

11pt

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.

11pt

3.1. Subchapter title (Font Size 11pt, bold, align left)

11pt

Subchapter text (Font Size 11pt, normal, justify, first line 1.27)

11pt

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)

Source (Font Size 8pt, bold)**:** Author (year) (Font Size 8pt, italic) {if not original}

11pt

In text (Table 1); Continuation of the text, 11 points, justify, first line 1.27.

11pt

Figure 1. 11pt, bold Figure title, (11pt, italic, centered)

11pt

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).

11pt

4. DISCUSSION (Font Size 11pt, bold, align left)

11pt

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).

11pt

5. CONCLUSION (Font Size 11pt, bold, align left)

11pt

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).

11pt

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).

11pt

REFERENCES (11pt, bold, align left)

11pt

Cite Literature in APA Style according to the Guide:
https://www.cogitatiopress.com/doc/APA_Style_Guide_7th_edition_2022-08-25.pdf.
References should be listed in alphabetical order in the reference list.
(10pt, justify, space between references)

Journal Article (1 author)**:**
Lastname, A. (year). Title of the article in sentence case. Journal in Title Case, Volume(Issue), Firstpage–Lastpage. Doi
Citation in text: Lastname (year),
Parenthetical citation in text: (Lastname, year)

Journal Article (2-19 authors)**:**
Lastname, A., & Lastname, B. (year). Title of the article in sentence case. Journal in Title Case, Volume(Issue), Firstpage–Lastpage. Doi
Citation in text: Lastname and Lastname (year); Lastname et al. (year)
Parenthetical citation in text: (Lastname & Lastname, year); (Lastname et al., year)

Journal Article (more than 20 authors)**:**
Lastname, A., Lastname, B., Lastname, C., Lastname, D., Lastname, E., Lastname, F., Lastname, G., Lastname, H., Lastname, I., Lastname, J., Lastname, K., Lastname, L., Lastname, M., Lastname, N., Lastname, O., Lastname, P., Lastname, Q., Lastname, R., Lastname, S., . . . Lastname, Z. (year). Title of the article in sentence case. Journal in Title Case, Volume(Issue), Firstpage–Lastpage. Doi
Citation in text: Lastname et al. (year)
Parenthetical citation in text: (Lastname et al., year)
Example:
Martać, N., Kanjevac, B., Čokeša, V., Momirović, N., Pavlović, B., & Furtula, D. (2021). Fir and Norway spruce stands from the planning aspect in the area of Djerekarski Omar forest management unit in southwestern Serbia. Sustainable Forestry: Collection, 83–84, 49–63. https://doi.org/10.5937/SustFor2183049M

Book
Lastname, A. (year). Title of the book in sentence case (edition, Volume). Publisher. Doi

(The edition, volume, and DOI are not compulsory)
Example:
Kostadinov, S. (2008). Bujični tokovi i erozija. Univerzitet u Beogradu – Šumarski fakultet

Book Chapter:

Lastname, A. (year). Title of the chapter in sentence case. In B. Lastname, C. Lastname, & D. Lastname (Eds.), Title of the book in sentence case (Volume, pp. Firstpage–Lastpage). Publisher. doi
Example:
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

Published Thesis or Dissertation:
Lastname, A. A. (year). Title of thesis in sentence case [Doctoral, Master, or Bachelor's thesis or dissertation, Name of the Institution]. Name of Repository. www.website.com
Example:
Braunović, S. Z. (2013). Efekti protiverozionih radova na stanje erozije u Grdeličkoj klisuri i Vranjskoj kotlini [Doktorska disertacija, Univerzitet u Beogradu, Šumarski fakultet]. Phaidra. https://doi.org/10.2298/bg20131004braunovic

Conference paper in Proceedings/Book of abstracts:
Lastname, A. B. (Year). Title of paper. In A. Lastname (Ed.; if applicable), Proceedings book title in sentence case (pp. Firstpage–Lastpage). Publisher. Link
Example:
Jovanović, F., Obratov-Petković, D., Bjedov, I., Mačukanović-Jocić, M., Braunović, S., Rakonjac, L., & Nikolić, B. (2022). Pollen micromorphology of Galanthus reginae-olgae subsp. vernalis Kamari from the eastern Adriatic coast. In N. Vuković, & V. Šegota (Eds.), Book of abstracts of the 7th Croatian Botanical Symposium with International Participation. Croatian Botanical Society. https://www.hbod.hr/wp-content/uploads/2022/09/Knjiga-sazetaka_7HBS.pdf

Brochure, Pamphlet, or Painting:
Author. (Year). Title of document [Type of document]. Publisher.

Website:
Lastname, A. (year, month day). Title of the webpage in sentence case. Name of the Website in Title Case. www.website.com
Citation in text: Lastname (year),
Parenthetical citation in text: (Lastname, year)

Legal or Government document:
Author. (year). Title of the legal/government document (Number/Code of the document if applicable). Publisher.
Citation in text: Author (year),
Parenthetical citation in text: (Author, year)
Example:

Republički hidrometeorološki Zavod Republike Srbije. (2022). Meteorološki godišnjak 1 klimatološki podaci. Republički hidrometeorološki Zavod Republike Srbije.
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
Example:
(e.g., Bergstrom et al., 2006; Clément, 2010; Harris & Corriveau, 2011; Harris & Koenig, 2006; Heyman, 2008; Heyman & Legare, in press; Koenig & Harris, 2005).

10pt

PAPER TITLE IN ENGLISH (10pt, bold, centered)

10pt

Name and SURNAME (10pt, italic)

10pt

Summary (10 points, bold, centered)

10pt

Summary text in English (10pt, justify, first line 1.27)

10pt

PAPER TITLE IN SERBIAN (10pt, bold, centered)

10pt

Name and SURNAME (10pt, italic, centered)

10pt

Rezime (10pt, bold, centered)

10pt

Summary text in Serbian (10pt, justify, first line 1.27).

***

In this text a detailed structured instruction for writing papers is given. Papers that do not satisfy the propositions of this Guide will not be forwarded for review and will be returned to the author.

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

630

SUSTAINABLE Forestry : collection = Održivo šumarstvo = zbornik radova / editor-in-chief Tatjana Ćirković-Mitrović. - 2008, t. 57/58- . - Belgrade: Institute of forestry, 2008- (Beograd : Black and White). - 24 cm

Godišnje. - Je nastavak: Zbornik radova - Institut za šumarstvo = ISSN 0354-1894
ISSN 1821-1046 = Sustainable Forestry
COBISS.SR-ID 157148172