ISSN 1821-1046
UDK 630

INSTITUTE OF FORESTRY
BELGRADE

INSTITUT ZA ŠUMARSTVO
BEOGRAD

SUSTAINABLE FORESTRY

ODRŽIVO ŠUMARSTVO

COLLECTION
Vol. 93

ZBORNIK RADOVA
Vol. 93

BELGRADE BEOGRAD
2026.

ISSN 1821-1046

ISSN 1821-1046
UDK 630

INSTITUTE OF FORESTRY
BELGRADE

INSTITUT ZA ŠUMARSTVO
BEOGRAD

SUSTAINABLE FORESTRY

COLLECTION
Vol. 93

ODRŽIVO ŠUMARSTVO

ZBORNIK RADOVA
Vol. 93

BELGRADE BEOGRAD
2026.

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

Editorial Board	**Redakcioni odbor**
Ljubinko Rakonjac, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Ljubinko Rakonjac Institut za šumarstvo, Beograd, Srbija
Biljana Nikolić, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Biljana Nikolić Institut za šumarstvo, Beograd, Srbija
Aleksandar Lučić, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Aleksandar Lučić Institut za šumarstvo, Beograd, Srbija
Vladan Popović, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Vladan Popović Institut za šumarstvo, Beograd, Srbija
Zlatan Radulović, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Zlatan Radulović Institut za šumarstvo, Beograd, Srbija
Ljiljana Brašanac-Bosanac, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Ljiljana Brašanac-Bosanac Institut za šumarstvo, Beograd, Srbija
Saša Eremija, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Saša Eremija Institut za šumarstvo, Beograd, Srbija
Miroslava Marković, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Miroslava Marković Institut za šumarstvo, Beograd, Srbija
Sonja Braunović, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Sonja Braunović Institut za šumarstvo, Beograd, Srbija
Đorđe Jović, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Đorđe Jović Institut za šumarstvo, Beograd, Srbija
Katarina Mladenović, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Katarina Mladenović Institut za šumarstvo, Beograd, Srbija
Suzana Mitrović, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Suzana Mitrović Institut za šumarstvo, Beograd, Srbija
Snežana Stajić, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Snežana Stajić Institut za šumarstvo, Beograd, Srbija
Nevena Čule, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Nevena Čule Institut za šumarstvo, Beograd, Srbija
Ilija Đorđević, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Ilija Đorđević Institut za šumarstvo, Beograd, Srbija
Goran Češljar, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Goran Češljar Institut za šumarstvo, Beograd, Srbija
Zoran Poduška, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Zoran Poduška Institut za šumarstvo, Beograd, Srbija
Tatjana Dimitrijević, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Tatjana Dimitrijević Institut za šumarstvo, Beograd, Srbija
Filip Jovanović, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Filip Jovanović Institut za šumarstvo, Beograd, Srbija
Milivoje Ćosić, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Milivoje Ćosić Institut za šumarstvo, Beograd, Srbija

Ivana Živanović, Ph.D. Institute of Forestry, Belgrade, Serbia	Dr Ivana Živanović Institut za šumarstvo, Beograd, Srbija
Prof. dr Makedonka Stojanovska, Faculty of Forestry, Ss. Cyril and Methodius University in Skopje, N. Macedonia	Prof. dr Makedonka Stojanovska, Šumarski fakultet Univerzitet Sv. Ćirilija i Metodija u Skoplju, S. Makedonija
Dr Zuzana Sarvašová National Forest Centre – Forest Research Institute, Slovakia	Dr Zuzana Sarvašová National Forest Centre – Forest Research Institute, Slovakia
Dr Alessandro Paletto Council for Agricultural Research and Economics, Italy	Dr Alessandro Paletto Savet za poljoprivredna istraživanja i ekonomiju, Italija
Associate Professor dr Sonia Quiroga Department of Economics, University of Alcalá, Spain	Associate Professor dr Sonia Quiroga Katedra za ekonomiju, Univerzitet u Alkali, Španija
Prof. dr Marijana Kapović Solomun Faculty of Forestry, Banja Luka, Republic of Srpska, Bosnia and Herzegovina	Prof. dr Marijana Kapović Solomun Šumarski fakultet, Banja Luka, Republika Srpska, Bosna i Hercegovina
Prof. dr Vanja Daničić Faculty of Forestry, Banja Luka, Republic of Srpska, Bosnia and Herzegovina	Prof. dr Vanja Daničić Šumarski fakultet, Banja Luka, Republika Srpska, Bosna i Hercegovina
Dr.Sc. Mirza Dautbašić Faculty of Forestry, Sarajevo, Bosnia and Herzegovina	Dr Mirza Dautbašić Šumarski fakultet, Sarajevo, Bosna i Hercegovina
Dr.Sc. Muhamed Bajrić Faculty of Forestry, Sarajevo, Bosnia and Herzegovina	Dr Muhamed Bajrić Šumarski fakultet, Sarajevo, Bosna i Hercegovina
Dr.Sc. Alma Bogunić Hajrudinović Faculty of Forestry, Sarajevo, Bosnia and Herzegovina	Dr Alma Bogunić Hajrudinović Šumarski fakultet, Sarajevo, Bosna i Hercegovina
Doc.dr Milić Čurović Biotechnical Faculty, University of Montenegro, Montenegro	Doc. dr Milić Čurović Biotehnički fakultet, Univerzitet Crne Gore, Crna Gora
Assistant Professor dr Špela Pezdevšek Malovrh Biotechnical Faculty, University of Ljubljana, Ljubljana, Slovenia	Assistant Professor dr Špela Pezdevšek Malovrh Biotehnički fakultet, Univerzitet Ljubljana, Ljubljana, Slovenija
Dr Dijana Vuletić Croatian Forest Research Institute, Jastrebarsko, Croatia	Dr Dijana Vuletić Hrvatski šumarski institut, Jastrebarsko, Hrvatska
Prof. dr Dragana Živojinović Faculty of Technology and Metallurgy, Belgrade, Serbia	Prof. dr Dragana Živojinović Tehnološko-metalurški fakultet, Beograd, Srbija

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

This journal was published with the support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia

All rights reserved. No part of this publication might be reproduced by any means: electronic, mechanical, copying or otherwise, without prior written permission of the publisher.

Belgrade, 2026

Preuzimanje članaka ili pojedinih delova ove publikacije u bilo kom obliku
nije dozvoljeno bez odobrenja izdavača.

Beograd, 2026

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

Naslovna strana: Autor fotografije Nenad Šurjanac, dipl. inž.

CONTENT SADRŽAJ

Vol. 93

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 93, 2026 ZBORNIK RADOVA 93, 2026

UDK: 630*187(497.11)=111
DOI: 10.5937/SustFor2693001M
Original scientific paper

DENDROFLORA COMPOSITION AND DIVERSITY OF MALI PARK IN OBRENOVAC

Suzana MITROVIĆ[1], Katarina MARINKOVIĆ[1], Vanja STOJANOVIĆ[1], Mihajlo MARKOVIĆ[1], Marija MILOSAVLJEVIĆ[2]*

Abstract: *Dendroflora as a basic element of a green area plays a key role in the fulfilment of ecosystem services in all landscape architecture structures within a city. The objective of this paper is to show dendroflora diversity through the analysis of dendrofloristic elements of Mali Park in Obrenovac. In the studied area of 0.65 ha 28 taxonomic categories were identified including 10 Gymnosperms and 18 Angiosperms, with 218 trees recorded in total. The most dominant species in the park are Cedrus atlantica (Endl.) G.Manetti ex Carrière (Gymnosperms) and Betula pendula Roth (Angiosperms). According to origin, the taxa are divided into four categories with different share: allochthonous taxa (13), autochthonous taxa (12), cultivars (2), hybrid taxa (1). The research indicates the importance of increasing the share of resistant species in the dendrofund, with an emphasis on autochthonous species, in order to maintain ecological stability and improve quality of life.*

Keywords: urban green spaces, biodiversity, taxa selection, origin of taxa, sustainable management.

SASTAV I RAZNOVRSNOST DENDROFLORE MALOG PARKA U OBRENOVCU

Apstrakt: *Dendroflora kao osnovni element zelene površine ima ključnu ulogu u ispunjavanju ekosistemsih usluga svakog od objekata pejzažne arhitekture u gradu. Cilj ovog rada je prikazati raznovrsnost dendroflore kroz analizu dendroflorističkih elemenata Malog parku u Obrenovcu. Na istraživanom području, površine 0.65 ha identifikovano je 28 taksonomskih kategorija, 10 u okviru golosemenica i 18 u okviru skrivenosemenica, sa ukuno 218 zabeleženih stabala. Najbrojnije vrste u parku su Cedrus atlantica (Endl.) G.Manetti ex Carrière (Golosemenice) i Betula pendula Roth (Skrivenosemenice). Prema poreklu, taksoni su podeljeni u 4 kategorije sa različitim učešćem: alohtoni taksoni (13), autohtoni taksoni (12), kultivari (2), hibridni taksoni (1). Istraživanje ukazuje na važnost povećanja udela otpornih vrsta u dendrofondu, potencirajući autohtone vrste, a sve u cilju održavanja ekološke stabilnosti i povećanja kvaliteta života.*

Ključne reči: urbane zelene površine, biodiverzitet, izbor taksona, poreklo taksona, održivo upravljanje.

[1]Institute of Forestry, Kneza Višeslava 3, 11030 Beograd, Serbia
[2] Institute of Entomology, Branisovska 31, 37005 České Budějovice, Czech Republic
*Corresponding author. E-mail: suzana.mitrovic@forest.org

© 2026 The Authors. Published by Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

1. INTRODUCTION

Urban green areas represent spaces of great importance for increasing biodiversity in cities. Therefore, cities play an important role in the preservation of biological diversity through management of green infrastructure (Aronson et al. 2017). A city park, as an element of green infrastructure, represents a public space (Vujković, 1995) and plays an important role in establishing contact between people and nature (Anastasijević, 2011). In addition to improving the physical and mental health of users, the importance of parks in a city reflected in their positive effect on microclimate of the space, mitigating the heat island effect, purifying air pollutants, reducing the impact of noise and wind, as well as preserving flora and fauna.

Mali Park is located in the eastern part of Obrenovac, within the Topolice settlement. This park is especially significant because it is located in the immediate vicinity of residential areas and is therefore intensively used on a daily basis. In addition to its pronounced social importance, the park also has ecological role as a habitat for various woody taxa that offer many benefits for the environment.

The objective of this research is the analysis of dendrofloristic elements in Mali Park in Obrenovac (including the character, origin, vitality and ornamentality of taxa), as well as to assess the ability of the recorded taxa to adapt to changing environmental conditions in an urban environment. Also, the importance of dendroflora in preservation of flora and fauna biodiversity in urban conditions is presented in this paper.

2. MATERIALS AND METHODS

The research area is Mali Park in Obrenovac. The City Municipality of Obrenovac (44°39'N; 20°12'E) is located in the central part of the lower Kolubara basin and territorially represents one of the 17 municipalities of the City of Belgrade. Kralja Aleksandra I Street to the north, Vojvode Putnika Street to the east, and Uzun Mirkova Street to the south and west define the park borders (Figure 1). The area of the researched green infrastructure object is 0.65 ha.

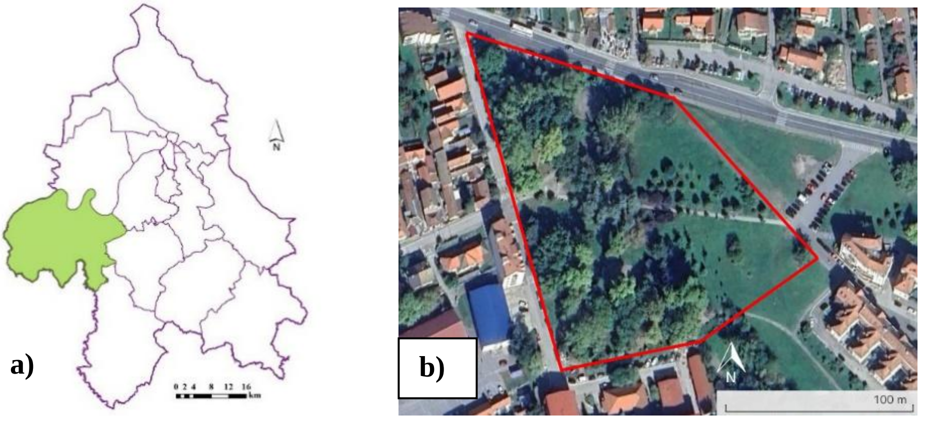


Figure 1. *a) The position of the City Municipality of Obrenovac, b) Study site*

The research is based on identification of dendrofund of the park, as well as the collection of basic parameters of all tree individuals, according to which vitality and ornamentality ratings are determined. The sample included 218 trees. The first procedure of the research was determination of tree taxa in Mali Park. When establishing the bioecological basis (Anastasijević, 2011) and collecting field data, vitality and ornamentality ratingswere assigned based on the researcher's visual assessment, ranging from 1 to 5, according to the established ordinal scale (Stojanović et al. 2011; Mitrović et al. 2025). The presence and types of damages, determined based on the recorded symptoms and classified as mechanical, physiological, entomological, and phytopathological, affected the overall estimate of vitality and ornamentality.

Mark for vitality was assigned for each tree according to the following valuation scale:

1 – heavily diseased, damaged or dry tree;
2 – significantly diseased, damaged or rotting tree, which still survives;
3 – vital tree that needs regular care measures to survive;
4 – vital tree that requires occasional care to maintain that vitality;
5 – completely healthy tree.

Guided by standard characteristics specific to each individual taxon (Ocokoljić and Petrov, 2022), ornamentality marks of each tree were evaluated as follows:

1 – a tree without decorative properties;
2 – a tree with poor decorative properties;
3 – a tree of standard habitus with certain defects;
4 – a tree with very good decorative properties, regular habitus with minor defects;
5 – a tree with excellent decorative properties, extremely well developed without visible defects in appearance.

3. RESULTS

In total, 28 tree taxa with 218 individuals were identified and classified in Mali Park (Table 1). 10 taxa, i.e. 41 trees belong to Gymnosperms, while 177 trees were recorded within Angiosperms, classified into 18 taxonomic categories. The presented distribution of dendroflora of Mali Park shows Angiosperms as dominant (81.19%) over Gymnosperms (18.81%).

On the researched area *Cedrus atlantica* (Endl.) G.Manetti ex Carrière with 18 trees, i.e. 43.90% share in Gymnosperms represents the most abundant taxon. For the remaining 9 taxa from this subdivision 7 or less individuals were recorded in the field. The most abundant deciduous taxa in the park are *Betula pendula* Roth (28 trees), *Platanus × hispanica* Mill. ex Münch. (22 trees), *Fraxinus angustifolia* Vahl. (21 trees), *Prunus cerasifera* 'Atropurpurea' (20 trees) and *Aesculus hippocastanum* L. (18 trees). For the remaining taxa from Angiosperms, 13 individuals or less were identified.

Table 1. *Representation of tree taxa in the park*

Subdivision	Taxon	Number of individuals	Mean vitality	Mean ornamentality
Gymnosperms	*Abies alba* Mill.	1	4	4
	Abies concolor (Gordon & Glend.) Lindl. ex Hildebr.	2	4	4
	Abies pinsapo Boiss.	2	2	2
	Cedrus atlantica (Endl.) G.Manetti ex Carrière	18	2.78	2.72
	Picea abies (L.) H.Karst	7	3.14	3.14
	Picea pungens Engelm.	5	3.80	3.80
	Pinus halepensis Mill.	1	3	4
	Pinus strobus L.	1	3	2
	Pinus sylvestris L.	1	4	4
	Pseudotsuga menziesii (Mirb.) Franco	3	3	3
Angiosperms	*Acer negundo* L.	13	3.31	3.23
	Acer platanoides L.	10	3.10	3.10
	Acer pseudoplatanus L.	2	3.50	3.50
	Acer pseudoplatanus 'Atropurpureum'	2	4	4
	Aesculus hippocastanum L.	18	2.89	2.89
	Betula pendula Roth	28	3.07	3.04
	Catalpa bignonioides Walter	8	3	3
	Celtis australis L.	3	3	3.67
	Fraxinus angustifolia Vahl.	21	3.14	3.14
	Fraxinus ornus L.	2	3.50	3.50
	Juglans regia L.	5	3	3
	Morus alba L.	1	4	4
	Platanus × hispanica Mill. ex Münch.	22	3.77	3.54
	Populus alba L.	1	4	5
	Prunus cerasifera 'Atropurpurea'	20	3.15	3.25
	Robinia pseudoacacia L.	9	3.67	3.56
	Styphnolobium japonicum (L.) Schott	3	4	3.67
	Tilia platyphyllos Scop.	9	4	3.89

According to their origin, the taxa recorded in Mali Park can be classified into the following four categories: autochthonous, allochthonous, hybrid taxa and cultivars. Allochthonous species are the most represented in the field compared to the other categories (Figure 2). A total of 13 allochthonous taxa (46.46%) were identified, namely: *Abies concolor* (Gordon & Glend.) Lindl. ex Hildebr., *Abies pinsapo* Boiss., *Cedrus atlantica* (Endl.) G.Manetti ex Carrière, *Picea pungens* Engelm., *Pinus halepensis* Mill., *Pinus strobus* L., *Pseudotsuga menziesii* (Mirb.) Franco, *Acer negundo* L., *Aesculus hippocastanum* L., *Catalpa bignonioides* Walter, *Morus alba* L., *Robinia pseudoacacia* L. and *Styphnolobium japonicum* (L.) Schott.

A total of 12 autochthonous taxa (42.84%) were determined in Mali Park: *Abies alba* Mill., *Picea abies* (L.) H.Karst, *Pinus sylvestris* L., *Acer platanoides* L., *Acer pseudoplatanus* L., *Betula pendula* Roth, *Celtis australis* L., *Fraxinus angustifolia* Vahl., *Fraxinus ornus* L., *Juglans regia* L., *Populus alba* L., and *Tilia platyphyllos* Scop.

Cultivars were used significantly less (7.14%) - *Acer pseudoplatanus* 'Atropurpureum', *Prunus cerasifera* 'Atropurpurea', while hybrids are the least represented in the park (3.57%) with only one taxon identified - *Platanus × hispanica* Mill. ex Münch.

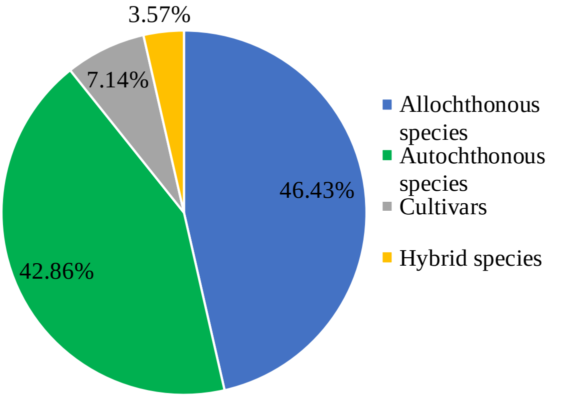


Figure 2. *Overview of representation of taxa according to origin (%)*

The taxa that received the highest average mark of vitality and ornamentality among Gymnosperms are *Abies alba* Mill., *Abies concolor* (Gordon & Glend.) Lindl. ex Hildebr. and *Pinus sylvestris* L. (mark 4). The species with the lowest vitality and ornamentality in the field is *Abies pinsapo* Boiss. (mark 2). These species were represented by 1-2 individuals in the park, so it is important to consider the most numerous species in the field - *Cedrus atlantica* (Endl.) G.Manetti ex Carrière whose average vitality mark amounts to 2.78, while average ornamentality mark is somewhat lower (2.72).

Among Angiosperms the highest average vitality and ornamentality marks were recorded for the taxa *Acer pseudoplatanus* 'Atropurpureum', *Morus alba* L., *Populus alba* L., *Styphnolobium japonicum* (L.) Schott. and *Tilia platyphyllos* Scop. (mark 4). *Aesculus hippocastanum* L. is a species from Angiosperms with the lowest average vitality and ornamentality mark, which is identical for both parameters and amounts to 2.89. For the species with the greatest number of individuals in the field, *Betula pendula* Roth, vitality and ornamentality marks are approximately equal (3.07; 3.04).

4. DISCUSSION

The results of the research show that the share of Angiosperms is significantly higher in the park compared to Gymnosperms. This ratio supports earlier research where it was also shown that the taxa from Angiosperms are dominant, and the reason is better adaptability to climate change and wider application in horticultural practice (Aronson et al., 2017; Sjöman & Nielsen, 2010). The presence of evergreen taxa, which are diverse, but represented by a small number of individuals, indicates the planned introduction of such species to achieve year-round aesthetic functionality of the park, which represents one of the important characteristics of landscape design.

The analysis of the origin of the taxa used in the park, whereby the ratio of autochthonous and allochthonous species is almost equal, is typical of many urban parks in Serbia (Djurdjević et al. 2025). Allochthonous species are frequently used due to their resistance to various urban stressors (Kovarik, 2011) such as air pollution, high temperatures, droughts, groundwater withdrawal, etc. On the other hand, significant use of native species helps in preservation of natural identity of the location and contributes to ecosystem stability through providing habitat for autochthonous species of fauna. The presence of cultivars and hybrid species is important due to their specific characteristics (great resistance to the conditions of urban environment in species *Platanus* × *hispanica* Mill. ex Münch.), but also due to aesthetic significance provided by certain taxa (colour of *Prunus cerasifera* 'Atropurpurea'). Similar results are recorded in various cities around the world, which indicates the trend of biotic homogenization of urban spaces (McKinney, 2006).

5. CONCLUSION

In this research, 28 taxonomic units with 218 individuals are identified in Mali Park, Obrenovac. The composition, diversity, vitality and ornamentality of dendroflora were analyzed based on bioecological basis of dominant, but also all recorded taxa. The most abundant taxa in the field are *Betula pendula* Roth, *Platanus* × *hispanica* Mill. ex Münch., *Fraxinus angustifolia* Vahl., *Prunus cerasifera* 'Atropurpurea', and *Cedrus atlantica* (Endl.) G.Manetti ex Carrière. The recorded number of taxa on the researched area indicates that Mali Park has a significant role in preservation of flora and fauna biodiversity.

The analysis of the origin of taxa showed almost equal representation of native and allochthonous species, maintaining a balance between biodiversity conservation and the use of taxa that are more resistant to specific urban environmental conditions. The research of dendrofloristic elements supports the monitoring and management of the dendroflora in urban green spaces.

The results of this paper confirm that urban parks represent complex socio-ecological systems in which natural conditions and anthropogenic influence (such as the introduction of non-native species) are closely intertwined. The park is located in the immediate vicinity of a residential zone, which is why the potential for greater diversity is limited, but, at the same time, it represents a valuable structure of landscape architecture for improvement of people's quality of life through fulfillment of important ecosystem functions.

To improve the ecological value of the park it is recommended to increase the share of resistant species, with an emphasis on resistant autochthonous species and application of integral management strategies that will enable preservation of natural processes while meeting the social needs of users. Such an approach would contribute to the long-term preservation of biodiversity and the functionality of this green infrastructure object.

Acknowledgement: *This research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-33/2026-03/200027, dated February 5, 2026).*

REFERENCES

Anastasijević, N (2011): Establishment of and care for green areas, University of Belgrade - Faculty of Forestry, Belgrade (Original title: Podizanje i negovanje zelenih površina, Univerzitet u Beogradu - Šumarski fakultet, Beograd).

Aronson FJ M., Lepczyk A C., Evans L K., Goddard A M., Lerman B S., Maclvor J S., Nilon H C., Vargo T. (2017). Biodiversity in the city: key challenges for urban green space management. Frontiers in Ecology and the Environment: Volume 15, Issue 4, 189-196. https://doi.org/10.1002/fee.1480

Djurdjević, K., Golubović Ćurguz, V., Skočajić, D., Petrov, Dj., Ocokoljić, M. (2025): Dendroflora composition and diversity in the urban green infrastructure of Belgrade. Book of proceedings ISBN-978-86-6211-152-4, 525-529.

Mitrović S., Veselinović M., Stajić S., Lazarević N., Marinković K., Đurašinović R., Milosavljević M. (2025). Visual assessment of trees in the urban forest in Belgrade: A case study of the area planted for the construction of the multifunctional hall of the Institute for sport and sports medicine of the Republic of Serbia. Sustainable Forestry: Collection 73-74, 11-18. DOI: 10.5937/SustFor2592107M

McKinney, M. L. (2006). *Biological Conservation*, 127(3), 247–260.

Ocokoljić, M., Petrov, Dj. (2022). Decorative dendrology. University of Belgrade – Faculty of Forestry, Belgrade (Original title: Dekorativna dendrologija, Univerzitet u Beogradu - Šumarski fakultet, Beograd).

Stojanović N, Galečić N, Mešiček M (2011). *Functionality assessment 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.

Sjöman, H., & Nielsen, A. B. (2010). Selecting trees for urban paved sites in Scandinavia. Urban Forestry & Urban Greening, 9(4), 281–293.

DENDROFLORA COMPOSITION AND DIVERSITY OF MALI PARK IN OBRENOVAC

Suzana MITROVIĆ, Katarina MARINKOVIĆ, Vanja STOJANOVIĆ,
Mihajlo MARKOVIĆ, Marija MILOSAVLJEVIĆ

Summary

This study deals with the determination of taxa and the analysis of dendrofloristic elements of trees in Mali Park in Obrenovac, as an important object of green infrastructure for preservation of biodiversity and improvement of environmental conditions. The objective of this paper is the analysis of the character, origin, vitality and ornamentality of the taxa, as well as the insight into ability of taxa recorded in the field to adapt to changed ecological conditions of urban environment. 28 taxa with 218 trees in total were identified and analysed in the researched area.

Angiosperms dominate the park with 177 trees (81.19%), whereby the most common species is *Betula pendula* Roth with 28 individuals. Gymnosperms are represented in the field with 41 trees (18.81%) and the most dominant species is *Cedrus atlantica* (Endl.) G.Manetti ex Carrière with 18 individuals. Based on the analysis of origin the taxa are divided into 4 categories and allochthonous species are the most dominant (46.46%), then, there are slightly fewer autochthonous species (42.84%), followed by cultivars (7.14%), while hybrid species are the least represented in the park (3.57%). Taxa with the best vitality and ornamentality marks are *Abies alba* Mill., *Abies concolor* (Gordon & Glend.) Lindl. ex Hildebr. and *Pinus sylvestris* L. (mark 4) while the species with the poorest marks for these two parameters is *Abies pinsapo* Boiss. (mark 2).

The obtained results indicate that the park has a great potential for the improvement of ecological, aesthetic and social functions through the enrichment of dendrofund by resistant, especially autochthonous taxa. Sustainable management of urban green infrastructure would enable ecosystem stability and increase diversity of flora and fauna as well as improve the quality of life in the city.

SASTAV I RAZNOVRSNOST DENDROFLORE MALOG PARKA U OBRENOVCU

Suzana MITROVIĆ, Katarina MARINKOVIĆ, Vanja STOJANOVIĆ, Mihajlo MARKOVIĆ, Marija MILOSAVLJEVIĆ

Rezime

Ova studija se bavi determinacijom taksona i analizom dendroflorističkih elemenata drveća u Malom parku u Obrenovcu, kao važnim objektom zelene infrastrukture za očuvanje biodiverziteta i unapređenje uslova životne sredine. Cilj rada je analiza karaktera, porekla, vitalnosti i dekorativnosti taksona kao i uvid u mogućnost taksona zabeleženih na terenu da se prilagode izmenjenim ekološkim uslovima urbane sredine. Na istraživanom području je identifikovano i analizirano 28 taksona sa ukupno 218 stabala.

U parku dominiraju skrivenosemenice sa 177 stabala (81.19%), pri čemu je najčešća vrsta *Betula pendula* Roth sa 28 jedinki. Golosemenice su na terenu identifikovane sa 41 stablom (18.81%) i najdominantnija vrsta je *Cedrus atlantica* (Endl.) G.Manetti ex Carrière sa 18 jedinki. Na osnovu analize o poreklu, taksoni su podeljeni u 4 kategorije i najdominantnije su alohtone vrste (46.46%), potom, neznatno manje ima autohtonih vrsta (42.84%), za njima slede kultivari (7.14%), dok su hibridne vrste najmanje zastupljene u parku (3.57%). Taksoni sa najboljim ocenama vitalnosti i dekorativnosti su *Abies alba* Mill., *Abies concolor* (Gordon & Glend.) Lindl. ex Hildebr. i *Pinus sylvestris* L. (ocena 4) dok je vrsta sa najlošijim ocenama za ova dva parametra - *Abies pinsapo* Boiss. (ocena 2).

Dobijeni rezultati ukazuju da park ima veliki potencijal za unapređenje ekološke, estetske i socijalne funkcije kroz obogaćivanje dendrofonda otpornim, posebno autohtonim, taksonima. Održivim upravljanjem urbanom zelenom infrastrukturom bila bi omogućena ekosistemska stabilnost i povećala bi se raznovrsnost flore i faune kao i kvalitet života u gradu.

SUSTAINABLE FORESTRY COLLECTION 93, 2026
ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 93, 2026

UDK: 630*907:582.632.2=111
DOI: 10.5937/SustFor2693009C
Original scientific paper

ANALYSIS OF THE CLIMATE ARIDITY IMPACT ON MACRONUTRIENT CONCENTRATION IN EUROPEAN BEECH LEAVES (*Fagus sylvatica* L.), USING CLIMATE INDICES

Tatjana ĆIRKOVIĆ-MITROVIĆ[1], Ljiljana BRAŠANAC-BOSANAC[1], Jelena BOŽOVIĆ[1], Vanja STOJANOVIĆ[1], Mihajlo MARKOVIĆ[1], Sabahudin HADROVIĆ[1], Nevena ČULE[1]*

Abstract. *The aim of this study is to analyse the affect of climate aridity impact, through to the climate indices – Forest Aridity Index (FAI) and Ellenberg climate quotient (EQ), on the nitrogen (N), phosphorus (P), potassium (K) content and N/P, N/K ratio in leaves of European beech in Serbia. The analysis of the macroelements concentration in the leaves shows that beech leaves contain: N – 9.82-19.62 mg/g, P – 0.82-1.53 mg/g, K – 4.83-11.11 mg/g. N/P ratio is 8.61-16.39 and N/K ratio 0.95-2.81. FAI index was in a range of values 3.19-7.10, and EQ quotient was in a range of values 15.27-30.24. Based on the research of the macronutrient content in beech leaves and the FAI and EQ at different altitudes, it can be concluded that FAI and EQ were statistically significant correlated with N and P content, and with N/K, respectively. An increase in indices values linearly causes a decrease in the concentration of key macronutrients N and P. The only parameter examined on which warmer and drier climate (through to the FAI and EQ index), did not have a statistically significant effec,t was the concentration of K.*
Keywords. nitrogen, phosphorus, potassium, Forest Aridity Index (FAI), Ellenberg climate quotient (EQ), Serbia

ANALIZA UTICAJA ARIDNOSTI KLIME NA KONCENTRACIJU MAKRONUTRIJENTA U LISTOVIMA EVROPSKE BUKVE (*Fagus sylvatica* L.), KORIŠĆENJEM KLIMATSKIH INDEKSA

Izvod: *Cilj ove studije bio je da se analizira uticaj aridnosti klime, putem klimatskih indeksa – Indeksa aridnosti šuma (FAI) i Elenbergovog klimatskog koeficijenta (EQ), na sadržaj azota (N), fosfora (P), kalijuma (K) i odnos N/P, N/K u lišću bukve u bukovim šumama u Srbiji. Analiza koncentracije makroelemenata u listovima pokazuje da listovi bukve sadrže: N – 9,82-19,62 mg/g, P – 0,82-1,53 mg/g, K – 4,83-11,11 mg/g. Odnos N/P je 8,61-16,39, a odnos N/K 0,95-2,81. FAI indeks je bio u rasponu vrednosti 3,19-7,10, a EQ u rasponu vrednosti 15,27-30,24. Na osnovu istraživanja sadržaja makronutrijenata u listovima bukve i FAI i EQ na različitim nadmorskim visinama, može se zaključiti da su FAI*

[1] Institute of Forestry, Kneza Višeslava 3, Belgrade, Serbia
*Corresponding author. E-mail: tanjacirk@yahoo.com
© 2026 The Authors. Published by Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

i EQ statistički značajno korelirani sa sadržajem N i P, odnosno sa N/K, respektivno. Povećanje vrednosti indeksa linearno uzrokuje smanjenje koncentracije ključnih makronutrijenata N i P. Jedini ispitivani parametar na koji toplija i sušnija klima (koristeći indekse FAI i EQ) nije imala statistički značajan uticaj, bila je koncentracija K.

Ključne reči: *Fagus sylvatica* L., azot, fosfor, kalijum, Forest Aridity Index (FAI), Ellenberg climate quotient (EQ)

1. INTRODUCTION

European Beech (*Fagus sylvatica* L.) as the most widespread woody species in Serbia. It has a great importance in forest ecosystems, wide ecological amplitude and growth on elevations from 50 to over 2,000 m. That indicate great adaptability of the species to different environmental conditions (Ćirković-Mitrović et al., 2023, Marković et al., 2025).

Nitrogen (N), phosphorus (P) and potassium (K) as essential macronutrients play very important role in plant growth metabolism, regulation of physiological mechanisms and ecosystem material and energy cycles (Ågren, 2004). N is important for the synthesis of chlorophyll and enzymes, P is a major metabolite in photosynthetic reactions and other energetic reactions. K is vital for plant growth because he improve disease resistance in plants, improve the size of seeds and quality of plant (Kumari et al., 2022). The content of N, P and K in leaves affects to function of plant enzymes, biochemical processes and integrity of plant cells (Uchid, 2000). Leaf nutrient stoichiometric relationships (N/P ratio, N/K ratio) are essential for photosynthesis and plant growth and development (Taylor et al., 2017, Wang et al., 2022). Numerous studies have indicated that climatic factors influence the leaf nutrient content, the functional traits of plant leaves by controlling plant metabolism, growth and development processes (Zhang et al., 2020, Krüger et al., 2021, Ognjenović et al., 2023, Köhler, 2023).

Light is one of the most important environmental factors influencing plant growth and development, plant morphology and metabolism. The concentration of nutrients in assimilation organs is different in the leaves that have been developed in full light from the ones that have grown in the shade (Kolić, 1988). Representative samples of leaves were taken from the upper third of the crown (sun-exposed foliage).

The content of nutrients in leaves has strong seasonal dynamics. Therefore, the amount of macronutrients in the leaves of the same tree vary in the spring, summer and autumn periods. The concentration of macronutrients in the leaves of broadleaved species at the beginning of the phenophase of leaf color change is taken as a representative of the tree nutritional status. It is the time when the sampling is performed on broadleaved sample plots.

The aim of this study is to analyse the affect of climate aridity, trough the aridity gradient (FAI and EQ), on content of nitrogen, phosphorus and potassium in the leaves of European beech in beech forests in Serbia.

2. MATERIALS AND METHODS

The sampling of leaves for the analysis of the nutrient status was conducted on five trees on 20 sample plots under pure beech stands on the territory of Serbia in 2022. Collected leaves was analyzed in the Laboratory of the Institute of Forestry Belgrade.

The samples are used to determine: total N (mg/g) by Kjeldahl (Dzamic et al. 1996, according Kjeldahl 1883), P content (mg/g) by colorimetric and K content (mg/g) by flame-photometric method (methods described in Tamm, 1955).

The non-reactive method, as a special scientific method, was used for the collection of the data on climate characteristics during the period 2002-2022. Its basic techniques were used: content analysis or observing the documents and use of the existing statistics, documents and their secondary analysis.

Based on the data of Republic Hydrometeorological Service of Serbia from main meteorological stations closest to the sample plots, the data on mean monthly and annual air temperature (°C), monthly and annual sum of precipitation (mm) were analysed. Due to the accuracy of the climate indices, an interpolation of climate parameters was performed for each sample area using vertical gradients based on data from the two nearest meteorological stations at the lowest and highest altitudes.

Forest Aridity Index (FAI) was calculated by the equation (1). Higher values represent warmer, drier climate (Führer et al. 2011), Ellenberg climate quotient (EQ) was calculated by the equation (2). A higher EQ index reflects an increase in climate aridity (Ellenberg and Leuschner, 2010).

$$\mathbf{FAI = 100\ T_{VII\text{-}VIII} / (P_{V\text{-}VII} + P_{VII\text{-}VIII})} \quad (1)$$

$T_{VII\text{-}VIII}$ – average temperature in July and August (°C)
$P_{V\text{-}VII}$ – sum of precipitation from May to July (°C)
$P_{VII\text{-}VIII}$ – sum of precipitation in July and August (mm)

$$\mathbf{EQ = T_{VII}\ 1000 / P} \quad (2)$$

T_{VII} – mean temperature of the warmest month (°C)
P – annual sum precipitation (mm)

Statistical analyses (Descriptive statistics, Linear regressions) were processed using statistical software Statgraphics (ver. XVI.I., 2009, Statpoint Technologies, Inc., Warrenton, VA, USA). Parameters considered with their measurement units were listed in Table 2.

Site characteristics and parameters with their measurement units of the 20 sample plots of European beech forests in Serbia are listed in Table 1.

Table 1. *Site characteristics and parameters of the 20 sample plots of European beech forests in Serbia*

Sample plot	Latitude	Longitude	Elevation (m. a.s.l)	Soil type (FAO, 1988)	Orientation	MAT (°C)	MAP (mm)	FAI	EQ
1	42.568320	21.759793	850	Dystric Cambisols	N	7.8	679	4.81	23.66
2	42.531670	22.010776	868	Eutric Cambisols	NW	7.6	682	4.70	23.23
3	44.258629	21.880964	619	Rendzic Leptosols	S	10.8	667	6.40	27.90
4	44.387401	22.015005	495	Eutric Cambisols	E	11.2	664	6.82	29.33
5	43.895096	21.279792	421	Dystric Cambisols	N	11.4	662	7.10	30.24
6	43.384575	20.314288	1263	Eutric Cambisols	N	8.9	685	4.70	21.78
7	44.074552	21.805287	1145	Dystric Cambisols	S	9.3	682	4.96	22.76
8	43.769662	20.073291	471	Eutric Cambisols	NE	9.1	792	4.61	23.92

Sample plot	Latitude	Longitude	Elevation (m. a.s.l)	Soil type (FAO, 1988)	Orientation	MAT (°C)	MAP (mm)	FAI	EQ
9	43.851364	19.951284	455	Albic Luvisols	E	9.1	787	4.65	24.14
10	43.782423	20.322966	536	Albic Luvisols	NW	8.9	813	4.48	23.02
11	43.913889	19.476367	1098	Chromis Cambis.	NW	7.3	994	3.49	16.86
12	43.887200	19.358633	1150	Mollic Leptosols	S	7.2	1,011	3.41	16.40
13	43.546115	20.054804	860	Eutric Cambisols	N	8.0	917	3.87	19.17
14	43.392095	20.041293	1305	Dystric Cambisols	NE	6.7	1060	3.19	15.27
15	43.734226	20.463361	383	Albic Luvizols	NW	9.3	764	4.80	25.20
16	43.653042	20.485219	949	Dystric Cambisols	W	7.7	946	3.72	18.26
17	44.177959	20.346633	401	Dystric Cambisols	W	10.9	789	5.04	26.37
18	44.453023	19.253250	560	Rendzic Leptosols	SW	10.3	790	4.90	25.27
19	44.100643	19.610776	1035	Eutric Cambisols	E	8.6	793	4.45	22.24
20	44.128757	20.074041	630	Eutric Cambisols	N	10.0	791	4.83	24.78

Abbreviations: MAT – mean annual temperature (2002-2022.); MAP – mean annual precipitation (2002-2022.); FAI – Forest Aridity Index, EQ – Ellenberg climate quotient (EQ)

3. RESULTS AND DISCUSSION

Descriptive statistics for Beech foliar content of N, P, K and N/P, N/K ratio (average, min, max, Standard deviation, Coeficient of variation) with their measurement units are listed in Table 2.

Table 2. *Descriptive statistics for Beech foliar content of N, P, K and N/P, N/K ratio*

Sample plot	N (mg/g)	P (mg/g)	K (mg/g)	N/P	N/K
1	11.52	1.18	8.08	9.76	1.43
2	14.89	1.23	6.13	12.11	2.43
3	10.17	0.93	6.07	10.88	1.68
4	9.82	0.83	6.38	11.82	1.54
5	11.54	1.08	8.42	10.72	1.37
6	16.80	1.39	10.64	12.12	1.58
7	16.18	0.99	7.61	16.39	2.12
8	15.40	1.32	8.93	11.67	1.72
9	13.20	1.12	4.83	11.79	2.73
10	16.10	1.46	8.54	11.03	1.88
11	16.90	1.26	6.32	13.41	2.67
12	18.10	1.23	6.87	14.72	2.64
13	17.60	1.41	6.74	12.52	2.61
14	19.62	1.50	8.45	13.04	2.32
15	10.46	1.13	7.81	9.22	1.34
16	15.60	1.45	5.56	10.75	2.81
17	10.50	1.22	11.11	8.61	0.95
18	10.04	0.82	7.20	12.23	1.39
19	17.90	1.35	7.90	13.26	2.27
20	18.10	1.53	10.45	11.83	1.73
Average	**14.52**	**1.22**	**7.70**	**11.89**	**1.96**
Minimum	**9.82**	**0.82**	**4.83**	**8.61**	**0.95**
Maximum	**19.62**	**1.53**	**11.11**	**16.39**	**2.81**
Standard deviation	**3.28**	**0.21**	**1.70**	**1.80**	**0.56**
Coefic. of variation	**22.57**	**17.46**	**22.05**	**15.11**	**28.81**

The analysis of the concentration in the leaves shows that beech leaves contain 9.82-19.62 mg/g of N, 0.82-1.53 mg/g of P and 4.83-11.11 mg/g of K. Similar results were obtained by Pavlova et al. (2016) in their research on the different localities in Bulgaria. European beech leaf N concentration in Italian regions (Bussotti et al. 2005) was higher than in Serbia, and had values from 20.3 to 32.5 mg/g. The values for N obtained by this research are lower, while the values for P and K are within the limit values for Europe (N – 18.60-28.20 mg/g, P – 0.81-1.82 mg/g, K – 3.80-10.60 mg/g) (Rautio et al. 2020). N/P ratio is 8.61-16.39 and

N/K ratio 0.95-2.81. The suggested thresholds for growth of beech trees are 2.5-3 for N/K and 10-15 for N/P (Bussotti et al. (2005), according Flückiger et al. (1986) and Bonneau (1988)).

FAI for research area for sample plots was in a range of values 3.19-7.10. Similar results have been obtained in research Stojanovic et al. (2012). According to Führer et al. (2011), reference FAI values for beech forests are <4.75.

EQ in this research was in a range of values 15.27-30.24. Areas with lower EQ values (less than 30) are characterised by a humid climate and are dominated by beech in Europe (Ellenberg, 1988, Jahn, 1991; Fang and Lechowicz, 2006, Führer et al. 2011). The difference between the reference values for Hungary and the obtained results can be explained by the fact that beech in Serbia has adapted to a warmer climate, because it is located further south.

In this study it is found that with increasing values of FAI and EQ (which characterizes aridity), the concentrations of N and K decrease, while the concentration of P is uniform (Figure 1, 2).

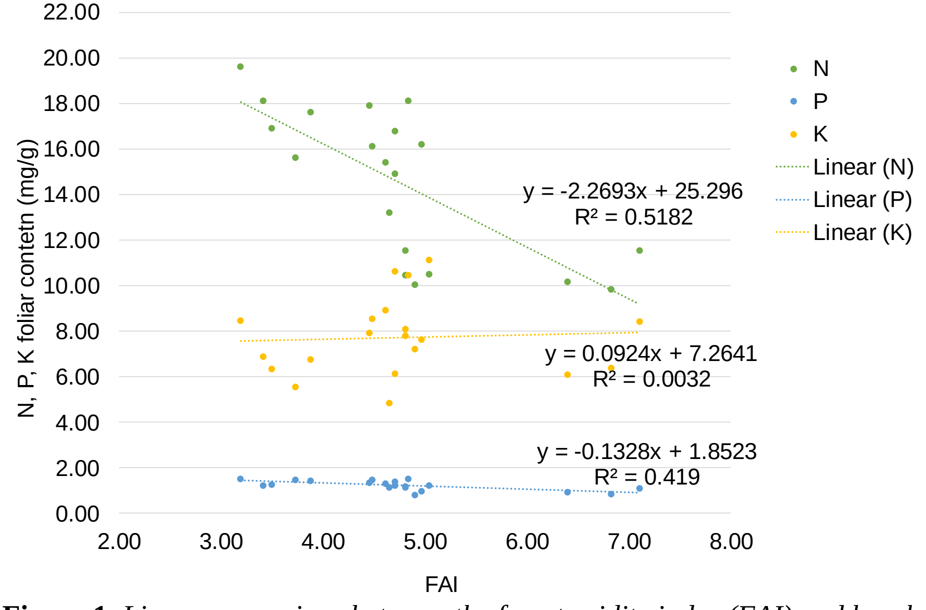


Figure 1. *Linear regressions between the forest aridity index (FAI) and beech foliar N, P, K content at the 20 saple plots*

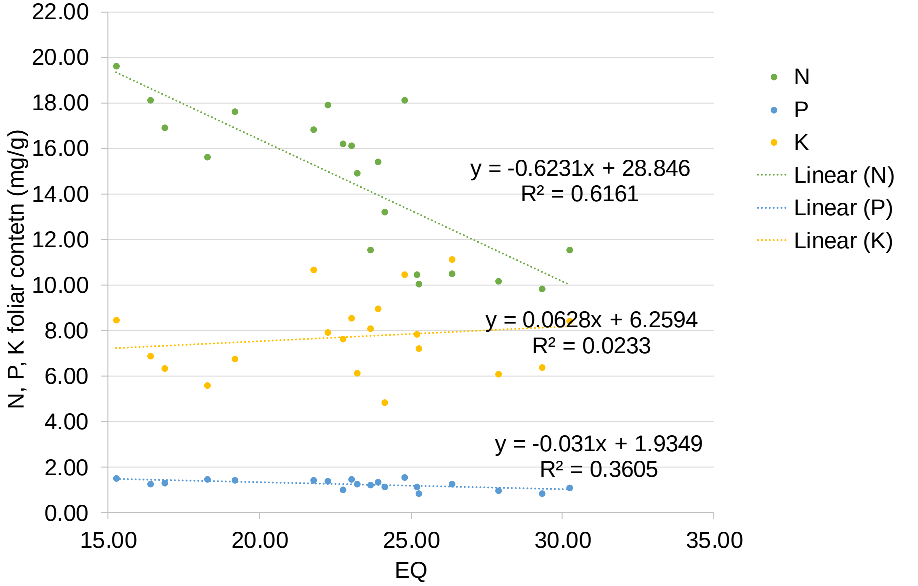


Figure 2. *Linear regressions between the Ellenberg climate quotient (EQ) and beech foliar N, P, K content at the 20 saple plots*

The N/P and N/K ratio in leaves decrease with increasing FAI and EQ values (Figure 3, 4).

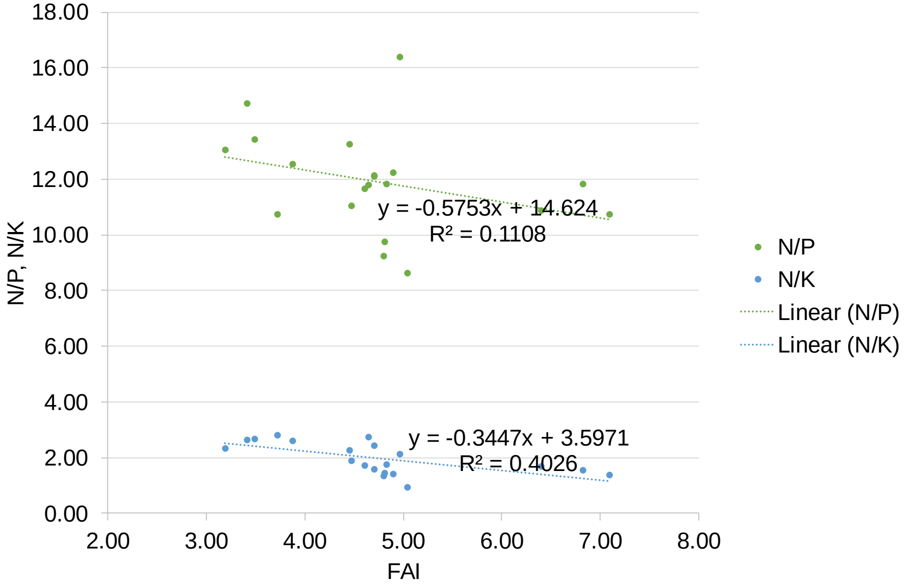


Figure 3. *Linear regressions between the forest aridity index (FAI) and beech foliar N/P, N/K ratio at the 20 saple plots*

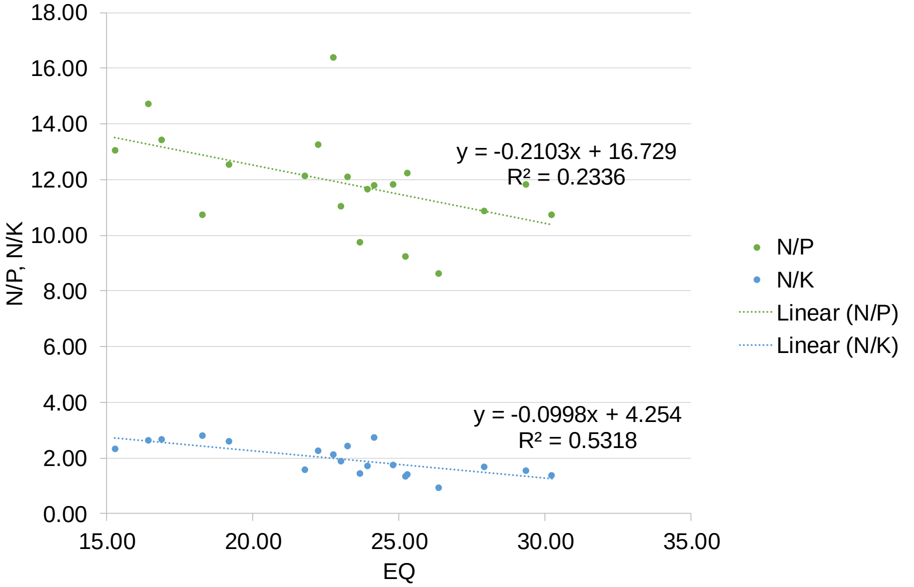


Figure 4. *Linear regressions between the Ellenberg climate quotient (EQ) and beech foliar N/P, N/K ratio at the 20 saple plots*

Table 3. *Correlation, determination and significance of regression analysis models*

	R^2	r	F	p
FAI				
N	0.5182	0.7199	19.40	0.0003
P	0.4190	0.6473	12.90	0.0021
K	0.0032	0.0566	0.06	0.8122
N/P	0.1108	0.3329	2.25	0.1511
N/K	0.4026	0.6345	12.15	0.0026
EQ				
N	0.6161	0.7849	28.88	0.0000
P	0.3605	0.6004	10.09	0.0052
K	0.0233	0.1526	0.43	0.5195
N/P	0.2336	0.4833	5.49	0.0308
N/K	0.5318	0.7292	20.53	0.0003

R^2 – coefficient of determination; r – Pearson correlation coefficient; F – F-ratio; p – significance level. Values of p < 0.05 indicate statistical significance

The results of linear regression analysis indicate that climatic aridity, expressed through the calculated FAI and EQ, has a selective, but significant effect on the chemical composition of leaves at the studied sites (Table 3). The most statistically significant effect of aridity, through to the FAI index, was observed on N concentration (R^2=0.5182, p=0.0003), followed by P concentration (R^2=0.4190, p=0.0021), which indicates that warmer, drier climate conditions linearly cause a decrease in these macronutrients in leaves. In contrast, P concentration (p=0.8122) and N/P ratio (p=0.1511) showed complete statistical independence from fluctuations in the FAI index, while a highly significant effect was again observed for the N/K ratio (R^2=0.4026, p=0.0026). The most pronounced negative effect of climate, trough to the EQ index, was found on N concentration (R^2=0.6161, p<0.001) and the N/K ratio (R^2=0.5318, p=0.0003). In addition, a statistically significant negative effect was observed on P concentration (R^2=0.3605, p=0.0052), as well as on the stoichiometry of the N/P ratio (R^2=0.2336, p=0.0308). These results clearly confirm that an increase in the EQ index value, linearly causes a decrease in the concentration of key macronutrients (N and P). The only parameter examined on which warmer and drier climate (through to the EQ index), did not have a statistically significant effect was the concentration of K (p=0.5195).

Increased N availability changes nutrient status, leads to rises in the N/P ratio of ecosystems (Peñuelas et al., 2013). Numerous previous studies have shown that temperature is a key factor in determining changes in nutritional properties of leaves, especially mean annual temperature (Miatto et al. 2016, Wright et al. 2017, Tian et al. 2019). Higher leaf N enhances photosynthesis under low-temperature stress, and when temperatures are higher, plants coordinate metabolic processes by reducing the N and increasing P content.

According to Guo et al. (2021), the concentration of N in leaves decreases significantly with increasing temperature. Since FAI and EQ are temperature dependent, the results of this study are consistent with the results of previous mentioned studies.

4. CONCLUSION

Based on the research of the affect of climate aridity, trough the aridity gradient (FAI and EQ), on content of nitrogen, phosphorus and potassium in the leaves of European beech in beech forests in Serbia, it can be concluded that climate factors have significant influence on dynamic balance of N and P. With increasing values of FAI and EQ (which characterizes aridity), the concentrations of N and P decrease, while the concentration of K is uniform.

Wide ecological amplitude and growth on elevations from 50 to over 2,000 m indicate great adaptability of the species to different environmental conditions. Global problem of sustainable management, forest health and climate changes, long-term changes in foliar mineral concentrations deserve further attention. Continued monitoring and further research are needed to ensure that appropriate measures are taken to protect the forest ecosystems.

Acknowledgement: *This study was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-33/2026-03/200027, 05.02.2026) and the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia – Forest Directorate (within the project: "Monitoring and Assessment of Air Pollution Impacts and its Effects on Forest Ecosystems in Republic of Serbia – Forest Condition Monitoring").*

REFERENCES

Ågren, G. I. (2004): *The C:N:P stoichiometry of autotrophs:theory and observations.* Ecol. Lett. 7, 185-191. https://doi.org/10.1016/j.envexpbot.2017.05.013

Biswas, D., Ma, B., Morrison, M.J. (2019): *Changes in leaf nitrogen and phosphorus, photosynthesis, respiration, growth and resource use efficiency of a rapeseed cultivar as affected by drought and high temperature.* Can. J. Plant Sci. 99, 413-419.

https://doi.org/10.1139/cjps-2018-0023

Bonneau, M. (1981): *Cycles biologiques en hêtraies. In Le Hêtre.* Eds. E. Tessier du Cros, F. Le Tacon, G. Nepveu, J. Pardé, R. Perrin and J. Timbal. INRA, Paris, France, pp 118-135.

Bussotti F, Prancrazi M, Matteucci G, Gerosa G. (2005): *Leaf morphology and chemistry in Fagus sylvatica (beech) trees as affected by site factors and ozone: results from CONECOFOR permanent monitoring plots in Italy.* Tree Physiol. Feb; 25(2):211-9. doi: https://doi.org/10.1093/treephys/25.2.211.

Ćirković-Mitrović, T., Brašanac-Bosanac, Lj., Hadrović, S., Eremija, S., Češljar, G., Konatar, B., Jovanović, F. (2023): *The influence of urban and suburban environmental conditions on the morphological characteristics of european beech leaves in the Belgrade area*, Sustainable Forestry 87-88, pp. 67-77, https://doi.org/10.5937/SustFor2388067C

Dzamic, R., Stevanovic, D., Jakovljevic M. (1996): *Manual for agrichemistry.* Faculty of Agriculture, Belgrade (in Serbian).

Ellenberg, H., Leuschner, C. (2010): Vegetation Mitteleuropas mit den Alpen: In ökologischer, dynamischer und historischer Sicht. 6th Ed. Stuttgart, UTB: 1357. (in German)

FAO (1997): *FAO-Unesco Soil Map of the World: Revised Legend with Corrections and Updates.* ISRIC Wageningen https://storage.googleapis.com/fao-maps-catalog-data/geonetwork/fao_unesco_soil_map/Europe_V_sheet1.pdf

Flückiger, W., S. Braun, S. Leonardi, N. Asche and H. Flückiger-Keller (1986): *Factors contributing to forest decline in northwestern Switzerland.* Tree Physiol. 1:177-184.

Führer, E., Horváth, L., Jagodics, A., Machon, A., Szabados, I. (2011): *Application ofnew aridity index in Hungarian forestry practice*. Idojárás 115 (3), 205-216.

Guo, Y.; Yan, Z., Zhang, Y.W., Zhou, G., Xie, Z., Tang, Z. (2021): *Environmental constraints on the inter-genus variation in the scaling relationship between leaf nitrogen and phosphorus concentrations.* J. Plant Ecol. 14, 616-627. https://doi.org/10.1093/jpe/rtab016

Kjeldahl, J. (1883): *A new method for the estimation of nitrogen in organiccompounds*, Z. Anal. Chem., 22, 366.

Köhler, J. (2023). The phosphorus and nitrogen nutrition of European beech under a future warmer and drier climate: climate chamber experiments and transect studies. https://dx.doi.org/10.53846/goediss-9774

Kolić, B. (1988): *Forest Ecoclimatology with the Fundamentals of Physics of the Atmosphere.* Naučna knjiga, Belgrade, p.1-397.

Krüger, I., Schmitz, A., & Sanders, T. G. (2021). *Climate condition affects foliar nutrition in main European tree species.* Ecological Indicators, 130, 108052. https://doi.org/10.1016/j.ecolind.2021.108052

Kumari, V. V., Banerjee, P., Verma, V. C., Sukumaran, S., Chandran, M. A. S., Gopinath, K. A., ... & Awasthi, N. K. (2022). *Plant nutrition: An effective way to alleviate abiotic stress in agricultural crops.* International Journal of Molecular Sciences, 23(15), 8519. https://doi.org/10.3390/ijms23158519

Marković, M., Gagić, S. R., Konatar, B., Božović, J., Stojanović, V., Rakonjac, L., & Lučić, A. (2025). *Assessment of the potential of albino beech compared to pigmented beech as a bioindicator of environmental conditions.* Sustainable Forestry: Collection, (92), 151-157. https://doi.org/10.5937/SustFor2592151M

Miatto R.C., Wright I.J., Batalha M.A. (2016): *Relationships between soil nutrient status and nutrient-related leaf traits in Brazilian cerrado and seasonal forest communities.* Plant Soil. 404:13-33. doi: https://doi.org/10.1007/s11104-016-2796-2 .

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

Pavlova, E., Doncheva, M., Kuzmanova, R. (2016): *Regional Values of Macro- and Microelement Contents in Leaves of European Beech (Fagus sylvatica L.).* Joumal of Balkan Ecology, vol. 19, No 2, pp.165-170.

Republic Hydrometeorological Service of Serbia (RHSS): *Annual Climate Characteristics for the Territory of Serbia,* Republic Hydrometeorological Service of Serbia, Belgrade.

http://www.hidmet.gov.rs/eng/meteorologija/klimatologija_produkti.php

Republic Hydrometeorological Service of Serbia (RHSS) *Climatological data.* Meteorological Annual, Republic Hydrometeorological Service of Serbia, Belgrade. http://www.hidmet.gov.rs/latin/meteorologija/klimatologija_godisnjaci.php

Stojanović, D., Matović, B., Orlović, S., Kržič, A., Đurđević, V., Galić, Z., Vuković, A., Vujadinović, M. (2012): *The use of forest aridity index for the evaluation of climate change impact on beech forests in Serbia*. Topola/Poplar No 189/190, 117-123

Tamm, O.C. (1955). Studie*s on forest nutrition. 1, Seasonal variation in the nutrient content of conifer needles.* p.1-34. https://research.slu.se/ws/portalfiles/portal/19037064/fulltext.pdf

Taylor, P.G., Cleveland, C.C.; Wieder, W.R., Sullivan, B.W., Doughty, C.E., Dobrowski, S.Z., Townsend, A.R. (2017): *Temperature and rainfall interact to control carbon cycling in tropical forests.* Ecol. Lett. 20, 779-788 https://doi.org/10.1111/ele.12765

Tian D., Yan Z., Niklas K.J., Han W., Kattge J., Reich P.B., Luo Y., Chen Y., Tang Z., Hu H. (2018): *Global leaf nitrogen and phosphorus stoichiometry and their scaling exponent.* Natl. Sci. Rev. 5:728-739. https://doi.org/10.1093/nsr/nwx142 .

Uchid, R. (2000): *Essential Nutrients for Plant Growth: Nutrient Functions and Deficiency Symptoms*, Chapter 3. In: Plant Nutrient Management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture J. A. Silva and R. Uchida, eds. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa https://www.ctahr.hawaii.edu/oc/freepubs/pdf/pnm3.pdf

Wang X, Wang J, Zhang L, Lv C, Liu L, Zhao H, Gao J. (2022): *Climatic factors determine the distribution patterns of leaf nutrient traits at large scales*. Plants. 11(16):2171. https://doi.org/10.3390/plants11162171

Zhang, S.; Zhang, Y.; Xiong, K.; Yu, Y.; Min, X. (2020): *Changes of leaf functional traits in karst rocky desertification ecological environment and the driving factors.* Glob. Ecol. Conserv. 24, e01381. https://doi.org/10.1016/j.gecco.2020.e01381

Peñuelas, J., Poulter, B., Sardans, J., Ciais, P., van der Velde, M., Bopp, L., et al. (2013): *Human-induced nitrogen-phosphorus imbalances alter natural and managed ecosystems across the globe.* Nat. Commun. 4:2934. https://doi.org/10.1038/ncomms3934

Rautio, P., Fürst, A., Stefan, K., Raitio, H., Bartels, U. (2020): *Part XII: Sampling and Analysis of Needles and Leaves.* Version 2020-3. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.): Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Thünen Institute of Forest Ecosystems, Eberswalde, Germany, 16 p. + Annex [http://www.icp-forests.org/Manual.htm]. www.icp-forests.org/pdf/manual/2020/ICP_Manual_part12_2020_Foliage_version_2020-3.pdf

Wright I.J., Dong N., Maire V., Prentice I.C., Westoby M., Díaz S. (2017): *Global climatic drivers of leaf size.* Nature. 357:917-921. https://doi.org/10.1126/science.aal4760.

ANALYSIS OF THE CLIMATE ARIDITY IMPACT ON MACRONUTRIENT CONCENTRATION IN EUROPEAN BEECH LEAVES (*Fagus sylvatica* L.), USING CLIMATE INDICES

Tatjana ĆIRKOVIĆ-MITROVIĆ, Ljiljana BRAŠANAC-BOSANAC, Jelena BOŽOVIĆ, Vanja STOJANOVIĆ, Mihajlo MARKOVIĆ, Sabahudin HADROVIĆ, Nevena ČULE

Summary

Nitrogen (N), phosphorus (P) and potassium (K) as essential macronutrients play essential roles in plant growth metabolism, regulation of physiological mechanisms and ecosystem material and energy cycles. Numerous studies have indicated that climatic factors influence the leaf nutrient content, the functional traits of plant leaves by controlling plant metabolism, growth and development processes. The aim of this study was to analyse the affect of climate aridity impact, through to the climate indices – Forest Aridity Index (FAI) and Ellenberg climate quotient (EQ) on content of nitrogen, phosphorus and potassium in the leaves of European beech in Serbia. To accomplish this, 20 plots were sampled in beech forests, located in Serbia at different altitudinal levels, varying from 383 to 1305 m.

The analysis of the macroelements concentration in the leaves shows that beech leaves contain: N – 9.82-19.62 mg/g, P – 0.82-1.53 mg/g, K – 4.83-11.11 mg/g. N/P ratio is 8.61-16.39 and N/K ratio 0.95-2.81. FAI index was in a range of values 3.19-7.10, and EQ quotient was in a range of values 15.27-30.24. Based on the research results, it was concluded that climate factors have significant influence on dynamic balance of nutrients N and K. With increasing values of FAI and EQ (which characterizes aridity), the concentrations of N and K decrease, while the concentration of P is uniform. The N/P and N/K ratio in leaves decrease with increasing FAI and EQ values.

Global problem of sustainable management, forest health and climate changes, long-term changes in foliar mineral concentrations deserve further attention. Continued monitoring and further research are needed to ensure that appropriate measures are taken to protect the forest ecosystems.

ANALIZA UTICAJA ARIDNOSTI KLIME NA KONCENTRACIJU MAKRONUTRIJENTA U LISTOVIMA EVROPSKE BUKVE (*Fagus sylvatica* L.), KORIŠĆENJEM KLIMATSKIH INDEKSA

Tatjana ĆIRKOVIĆ-MITROVIĆ, Ljiljana BRAŠANAC-BOSANAC, Jelena BOŽOVIĆ, Vanja STOJANOVIĆ, Mihajlo MARKOVIĆ, Sabahudin HADROVIĆ, Nevena ČULE

Rezime

Azot (N), fosfor (P) i kalijum (K), kao esencijalni makronutrijenti, igraju suštinsku ulogu u metabolizmu rasta biljaka, regulaciji fizioloških mehanizama i ciklusima materijala i energije ekosistema. Brojne studije su pokazale da klimatski faktori utiču na sadržaj hranljivih materija u listu, funkcionalne osobine listova biljaka kontrolišući metabolizam biljaka, procese rasta i razvoja. Cilj ove studije bio je da se analizira uticaj aridnosti klime, putem klimatskih indeksa – Indeksa aridnosti šuma (FAI) i Elenbergovog klimatskog koeficijenta (EQ), na sadržaj azota, fosfora i kalijuma u listovima evropske bukve u Srbiji. Da bi se to postiglo, izvršeno je uzorkovanje lišća na 20 oglednih površina u bukovim šumama, koje se nalaze u Srbiji na različitim nadmorskim visinama, u rasponu od 383 do 1,305 m.

Analiza koncentracije makroelemenata u listovima pokazuje da listovi bukve sadrže: N – 9,82-19,62 mg/g, P – 0,82-1,53 mg/g, K – 4,83-11,11 mg/g. Odnos N/P je 8,61-16,39, a odnos N/K 0,95-2,81. FAI indeks je bio u rasponu vrednosti 3,19-7,10, a EQ u rasponu vrednosti 15,27-30,24. Na osnovu rezultata istraživanja, zaključeno je da klimatski faktori imaju značajan uticaj na dinamičku ravnotežu hranljivih elemenata N i K. Sa povećanjem vrednosti FAI i EQ (koji karakterišu aridnost), koncentracije N i K se smanjuju, dok je koncentracija P ujednačena. Odnos N/P i N/K u listovima se smanjuje sa povećanjem vrednosti FAI i EQ.

Globalni problem održivog upravljanja, zdravlja šuma i klimatskih promena, dugoročne promene u koncentracijama folijarnih minerala zaslužuje dalju pažnju. Potrebno je kontinuirano praćenje i istraživanje, kako bi se osiguralo da se preduzmu odgovarajuće mere za zaštitu šumskih ekosistema.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY COLLECTION 93, 2026 | **ODRŽIVO ŠUMARSTVO** ZBORNIK RADOVA 93, 2026

UDK: 519.23:630*432.38(497.11)=111
DOI: 10.5937/SustFor2693021K
Original scientific paper

SPATIAL-STATISTICAL ANALYSIS OF FOREST FIRE DISTRIBUTION IN THE REPUBLIC OF SERBIA

Bojan KONATAR[1], Ilija ĐORĐEVIĆ[1], Jovana CVETKOVIĆ[1], Milijana CVEJIĆ[1], Radojica PIŽURICA[1], Katarina MLADENOVIĆ[1], Goran ČEŠLJAR[1]*

Abstract: *Fires represent a significant ecological disturbance which affects the structure and dynamics of forest ecosystems, whereby their spatial distribution depends on the combination of climatic, vegetational and anthropogenic factors. The objective of this research is the analysis of the spatial distribution of fire detections in the territory of the Republic of Serbia, at the level of administrative units (municipalities) in the period from 2012 to 2026, restricted to areas classified as forest-related by the CORINE Land Cover classification (classes 2, 3, 4 and 5). The research was conducted using the data obtained through VIIRS sensors available through NASA FIRMS system of satellite data on active fires, in combination with CLC+ Backbone data. Also, Fire Radiative Power (FRP) was analyzed in order to estimate variability of the radiation power of fires and their classification. The analysis of FRP included 504 forest fire detections. The results show pronounced variability of radiation power of forest fire detections, whereby the majority of detections belong to the lower and interquartile ranges of the FRP distribution, while a smaller number of events reaches extreme values (up to 300 MW). For identification of spatial patterns, the methods of spatial statistics were used, including Moran's I index, as well as Getis-Ord Gi* statistics, which enables identification of local clusters with statistically significantly high (hot spot) and low (cold spot) values. The distribution of fire detections is characterized by pronounced spatial heterogeneity, whereby the majority of municipalities records a small number of fire detections, while in a smaller number of municipalities increased frequency occurs. Statistically significant spatial clusters are identified, with the most pronounced zones in southern and southeastern parts of Serbia. The results obtained indicate that the fire risk assessment should not be based solely on their frequency, but also on FRP values. The application of integrated approach, which combines satellite data on occurrence of fire detections and classification of land cover, enables reliable identification of risk areas and it represents the basis for improving the monitoring system and planning of fire protection measures.*

Keywords: forest fire detections distribution in Serbia; VIIRS; CORINE Land Cover, Fire Radiation Power FRP, Moran's I, hot spot analysis.

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

© 2026 The Authors. Published by the Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

PROSTORNO-STATISTIČKA ANALIZA RASPOSTRANJENOSTI ŠUMSKIH POŽARA U REPUBLICI SRBIJI

Sažetak: *Požari predstavljaju značajan ekološki poremećaj koji utiče na strukturu i dinamiku šumskih ekosistema, pri čemu njihova prostorna distribucija zavisi od kombinacije klimatskih, vegetacionih i antropogenih faktora. Cilj ovog istraživanja je analiza prostorne distribucije detektovanih šumskih požara na teritoriji Republike Srbije, na nivou administrativnih jedinica (opština) u periodu 2012–2026, sa posebnim fokusom na vegetacione klase definisane CORINE Land Cover klasifikacijom (klase 2, 3, 4 i 5). Istraživanje je sprovedeno korišćenjem podataka dobijenih putem VIIRS senzora, dostupnih kroz NASA FIRMS sistem satelitskih podataka o aktivnim požarima, u kombinaciji sa CLC+ Backbone podacima. Takođe je analiziran Fire Radiative Power (FRP) u cilju procene varijabilnosti radijacione snage požara i njihove klasifikacije. Analiza FRP obuhvatila je 504 detekcije šumskih požara. Rezultati pokazuju izraženu varijabilnost radijacione snage detektovanih šumskih požara, pri čemu većina detekcija pripada nižem i srednjem delu raspodele FRP vrednosti, dok manji broj dostiže ekstremne vrednosti (do 300 MW). Za identifikaciju prostornih obrazaca korišćene su metode prostorne statistike, uključujući Moran's I indeks, kao i Getis-Ord Gi* statistiku, koja omogućava identifikaciju lokalnih klastera sa statistički značajno visokim (hot spot) i niskim (cold spot) vrednostima. Distribucija detektovanih šumskih požara karakteriše se izraženom prostornom heterogenošću, pri čemu većina opština beleži nizak broj detekcija, dok se u manjem broju opština javlja povišena frekvencija. Identifikovani su statistički značajni prostorni klasteri, sa najizraženijim zonama u južnim i jugoistočnim delovima Srbije. Dobijeni rezultati ukazuju da procena rizika od požara ne treba da se zasniva isključivo na njihovoj frekvenciji, već i na FRP vrednostima. Primena integrisanog pristupa, koji kombinuje satelitske podatke o detekcijama šumskih požara i klasifikaciju zemljišnog pokrivača, omogućava pouzdanu identifikaciju rizičnih područja i predstavlja osnovu za unapređenje sistema monitoringa i planiranja mera zaštite od šumskih požara.*

Ključne reči: distribucija šumskih požara u Srbiji; VIIRS; CORINE Land Cover (CLC); radijaciona moć požara (FRP); Moran's I; analiza žarišta

1. INTRODUCTION

Forests represent an important ecosystem resource that influences human health, improvement of life quality, climate change, and other key ecosystem functions (Cervinka et al., 2014; Psistaki et al., 2024). According to the data of the Second national forest inventory of the Republic of Serbia the area under the forests amounts to approximately 36.81% of the total territory. The forest structure is dominated by deciduous forests, conifer stands and mixed coniferous and deciduous forests are much less represented (The Directorate of forests of the Republic of Serbia, 2023).

Fires are ecological disturbances which affect the structure and dynamics of forest ecosystems (Smith et al., 2008). The spatial distribution and activity of fires is determined by a combination of climatic, vegetation and anthropogenic factors (Harrison et al., 2025; Park et al., 2021). Frequency, size, and intensity of fires determine their spatial and temporal patterns (Liu & Wimberly, 2015).

The effect of fires reflects in soil changes that include pH value, organic matter, microorganisms, thus influencing the changes in the ecosystem after the fire

(Liu et al., 2024; Smith et al., 2008). In addition to the impact on the soil, the impact of fire is reflected in the effect on vegetation and organic layers (Yang et al., 2022). According to Durlević et al., (2025), the distance from roads and settlements significantly affects the probability of fire occurrence, with events occurring more frequently in their immediate vicinity.

The development of satellite technologies enabled detailed monitoring of fires at the regional and global level (Justice et al., 1993). The data obtained through the visible infrared radiometer sensor (VIIRS) available through National Aeronautics and Space Administration Fire Information for Resource Management System (NASA FIRMS) is particularly noteworthy and enables detection of active fires of high spatial and temporal resolution (NASA/USGS, 2018). By combining the data of land cover classification, such as CORINE Land Cover (CLC) (EEA, 2020; Tešić, 2022), with the data of VIIRS sensor, the analysis of the connection between the type of surface and the occurrence of fire, as well as the identification of spatial patterns of their distribution, is enabled.

Similar research in Europe was conducted by Parente et al., (2016) who analyzed the spatial and temporal distribution of forest fires in Portugal. The research of Lorent et al. (2025) includes CORINE Land Cover (CLC 2018) data as one of the parameters, while VIIRS data was used for validation of the model of forest ecosystems sensitivity to fires in the territory of Romania. Pausas and Fernández-Muñoz (2012) have examined changes in forest fire regimes in the provinces of Valencia (Spain, Eastern Iberian Peninsula, Western Mediterranean Basin), by unification of 130 year of data, whereby a significant change was identified around the 1970s, with a doubling of fire frequency. In the research of Wang and Wang (2025) spatial and temporal activity of fires in China was analyzed, for the period from 2003 to 2024, using Moderate Resolution Imaging Spectroradiometer (MODIS) data, available through NASA FIMRS system.

Studies that dealt with this subject link the occurrence of an increased number of fires on the territory of the Republic of Serbia to climate change (Durlević et al., 2025; Vranić & Mišić, 2024). Novković et al., (2021) and Ćurić et al., (2022) examined susceptibility of forest stands to occurrence of forest fires. The research that relates to forest fires in Serbia also used CLC data (Gigović et al., 2019; Gajović and Todorović, 2013), as well as the combination of CLC and FIRMS data, conducted by Milanović et al., (2021). At the level of the entire territory of the Republic of Serbia two studies were identified which analyzed the occurrence of fires: Brovkina et al., (2020), with the focus on post-fire forest scars in Serbia using Sentinel-2 data, and Gajović and Todorović (2013), who carried out spatial and temporal analysis of fires for the period from 2000 to 2013.

The objective of this research is the analysis and quantification of spatial distribution of detected forest fires, with a special focus on their spatial patterns. The emphasis is placed on the identification of spatial clusters and areas with an increased frequency of detected forest fires.

Radiative power of fires was observed through Fire Radiative Power (FRP), which represents the measure of energy emitted during biomass burning. The main contributions include integration of VIIRS and CLC+ Backbone data, the analysis of frequency of detected forest fire occurrence at the municipal level and classification of detections based on the FRP values.

2. MATERIALS AND METHODS

2.1. The Study Area

The research was conducted on the territory of the Republic of Serbia, latitude 43° 11′ 13″ - 46° 11′ 25″ N, and longitude 19° 40′ 00″ - 23° 00′ 47″ E (Figure 1). The Republic of Serbia is located in the central part of the Balkan Peninsula and along the southern margin of the Pannonian Basin, covering an area of 88,499 km² (Manić et al., 2022). The country is characterized by pronounced geographical diversity, with relief conditions ranging from the lowlands of the Pannonian Plain in the north to mountainous regions in the south and east. It is situated in a predominantly highland-mountain zone intersected by numerous river basins, while its geographical position has made it an important migration and transportation corridor connecting Southwest Asia with Central and Western Europe (Manić et al. 2022). About 2,854,955 ha or 36.81% of the total area of the territory of Serbia is under forests, 1,191,466 ha or 41.73% of which are state-owned and 1,663,489 ha or 58.27% are private-owned (The Directorate of forests of the Republic of Serbia, 2023). The distribution of annual precipitation in Serbia is uneven, with lower values recorded in the northern and northeastern lowlands (500–600 mm) and substantially higher amounts, exceeding 1000 mm, occurring in the mountainous areas of southwestern Serbia (Živanović & Gocić, 2022). The annual precipitation regime in Serbia is characterized by a maximum occurring predominantly in June and a minimum in February across the majority of meteorological stations (Milovanović et al., 2017).

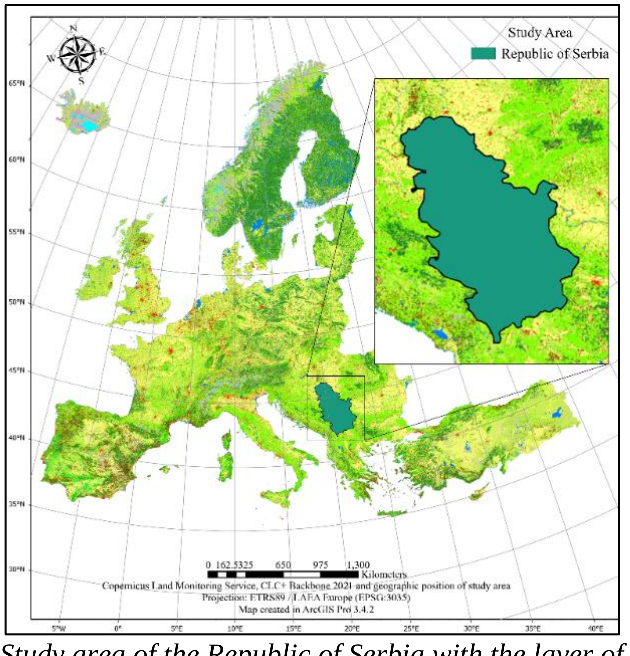


Figure 1: *Study area of the Republic of Serbia with the layer of CLC2021*

2.2. Data Collection

The data necessary for realization of the research is collected from several sources. The file that contains administrative border of the Republic of Serbia as well as borders of administrative units (municipalities) was downloaded from online platform GeoSrbija in shapefile format (Republic Geodetic Authority). Vegetation and land cover data were obtained from the CLC+ Backbone raster for period from 2020 to 2022 (CLC 2021) dataset (https://land.copernicus.eu/en/products/clc-backbone/clc-backbone-2021) with 10 m resolution, projections ETRS89 / LAEA Europe (EPSG:3035). Fire detection data were obtained from NASA FIRMS, using the VIIRS 375 m Active Fire product (Suomi NPP, Collection 2).

The primary focus of the research was on forest classes 2, 3, 4 and 5 according to CLC classification.

- Class 2: Woody needle-leaved trees
- Class 3: Woody broadleaved deciduous trees
- Class 4: Woody broadleaved evergreen trees
- Class 5: Low-growing woody plants

For segregation of classes 2, 3, 4 and 5 Geographic Information System Professional ArcGIS Pro (Esri, 2024) was used into which CLC 2021 raster was imported, as well as shapefile administrative borders of the Republic of Serbia. Both data sets are in identical coordinate reference system, and they have same spatial settings, which is necessary to provide methodological consistency in further spatial analysis.

Due to the spatial limitation, only pixels that are spatially located within the state border of the Republic of Serbia were selected. During this procedure, attribute tables of new files were also checked, whereby it was verified if the raster retains all classes and attributes present in the original dataset. This confirmed that no loss or alteration of the source data occurred during the selection process thus ensuring consistency between the original and the created dataset.

It should be emphasized that the CLC+ Backbone 2021 dataset was not used as a historical representation of land cover conditions throughout the entire study period (2012–2026). Instead, the dataset served exclusively as a reference layer for identifying forest-related land cover classes and restricting the analysis to fire detections located within areas classified as forest ecosystems. Therefore, the objective of this study was not to reconstruct historical land-cover dynamics, but to analyze the spatial distribution of forest fire detections within forest environments identified by the CLC+ Backbone 2021 dataset.

The used dataset includes period from 20 January 2012 to 17 March 2026. The source VIIRS dataset was reprojected in order to be aligned with the coordinate system of CLC+ Backbone data and administrative borders. The focus is on spatial distribution of fire detections, and dataset was used solely as spatial indicator of sites. The table of attributes includes information on the level of confidence for each fire detection (low, nominal, high). Only detections marked with "h" more than 80% - high confidence, (EEA, 2024) were used in this research. The table of attributes also includes information on the fire detection location (geographic coordinates), time of detection (date and time), as well as the value of FRP which represents the measure of energy emitted by the detected fires in the form of thermal radiation, expressed in megawatts (MW) (NASA Earthdata, 2025).

2.3. Data Processing

CLC2021 raster was filtered to select only CLC classes 2, 3, 4 and 5, while other values were treated as NoData. After that, the value of the CLC class the detected fire was in, was assigned to each of them. The detections with the value NoData (−9999) were eliminated from further analysis, which resulted in a set of detections located exclusively on forest areas according to the CLC classification.

For the analysis of spatial distribution of detected forest fires Spatial Join tool was used, by which an attribute of forest fire location was assigned to each of the municipalities. As a result, the Join Count field was obtained, which represents the total number of forest fire detections within each municipality. For each of the municipalities geometry was calculated in km^2, which served as a basis for calculation of fire detections density per km^2. Based on this data the values of Moran's I (row-standardized) were obtained, which is used for identification of spatial clusters (Vranić & Mišić, 2024). For the purposes of the test (contiguity edges corners) was used, often called *Queens Case* which includes adjacent polygons based on common borders and common vertices. The values of this test range between -1 and 1, where the values close to -1 indicate that spatial autocorrelation is negative, while values that are closer to 1 have positive correlation, i.e. the results with similar values tend to group in space. After Moran's I test hot spot analysis was applied using Getis-Ord Gi* spatial statistics which graphically showed areas with "hot" and "cold" values by municipalities (Guerri et al., 2021).

2.4. Statistical Analysis

Statistical analysis was carried out using the software for statistical analysis SPSS ver 26 (IBM Corp., 2019). The research was carried out using descriptive statistics with a focus on FRP value of detections, whereby quartiles were used as the basis for classification. The selection of quartile classification was based on the need to avoid introduction of arbitrary fixed thresholds, considering that there is no single limit for the classification of FRP values in the literature. The methods of descriptive statistics which consist of arithmetic mean (Mean), standard deviation (SD), minimum and maximum value were used. The distribution of the number of forest fire detections by municipalities was analyzed, as well as the frequency of fire occurrence for each municipality individually. Based on the ratio between mean value and standard deviation, the variability of the distribution was estimated.

3. RESULTS AND DISCUSSION

3.1 Analysis of FRP data

Based on the classification of fires according to FRP values, the fire detections are classified in three classes:

- Lower-quartile FRP events (<9.34 MW);
- Interquartile FRP events (9.34 – 20.95 MW);
- Upper-quartile FRP events (>20.95 MW).

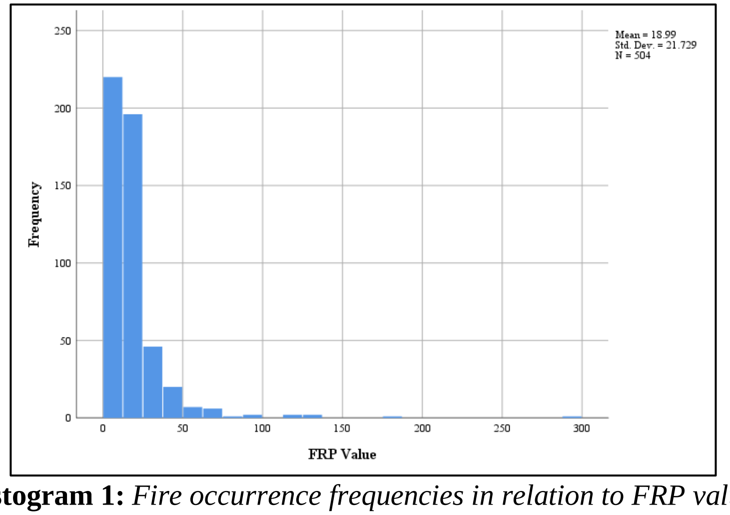
The results of these analyses are presented in Table 1.

Table 1. *The analysis of FRP values*

Percentiles		5	10	25	50	75	90	95
Weighted Average	FRP	5.75	6.94	9.33	13.42	21.04	33.88	47.89
Tukey's Hinges	FRP			9.34	13.42	20.95		

The lower quartile (Q1) was used to distinguish detections belonging to the lower quartile of the FRP distribution, the interquartile range (Q1-Q3) for detections within the interquartile range, while values above the upper quartile (Q3) were treated as detections belonging to the upper quartile of the FRP distribution. The above classification does not represent absolute assessment of fire intensity, but enables comparative analysis of variability of FRP values within the detected forest fires in the territory of the Republic of Serbia. The classification is therefore dataset-specific and intended solely for comparative analysis within the analyzed sample. Also, it is important to emphasize that the FRP values represent the radiative power at the moment of detection, and not the total energy released during the entire duration of the fire.

The results of the descriptive statistics of FRP presented in Histogram 1 indicate pronounced variability of fire radiative power (Mean = 18.99 MW; SD = 21.73 MW). The distribution of FRP values shows pronounced right asymmetry, which indicates the domination of occurrence of detections concentrated within the lower part of the FRP distribution, while smaller number of fires reaches very high values (up to 300 MW). This pattern confirms the presence of fewer fire detections belonging to the upper part of the FRP distribution, which may indicate relatively higher combustion energy compared to other events within the analyzed sample.



Histogram 1: *Fire occurrence frequencies in relation to FRP values*

Although this analysis does not include directly spatial distribution of FRP values, identified hot spot regions do not represent only the areas with larger number of fire detections, but indicate potential areas with increased risk of fire with higher values of radiative power. Based on the results obtained, fire risk assessment should not be based solely on their frequency, but also on radiative power expressed through FRP values. Fire detections belonging to the upper quartile of the FRP distribution may indicate events with comparatively greater combustion energy and potentially greater ecological significance compared to other detections within the analyzed sample. Such events may be associated with greater ecological effects, as suggested by previous studies, where fires can lead to significant changes in landscape, thereby triggering structural and functional adaptations of forest ecosystems (Lee et al., 2025). FRP values are directly connected with the quantity of the biomass burned (Wooster et al., 2005). These data provide information on potential impact of forest fires on ecosystem, which makes them an important parameter in radiative power analysis and fire risk assessment.

3.2 Analysis of Forest Fire Distribution

The analysis of forest fire detection distribution (Table 2) showed that the number of forest fire detections by municipalities ranges from 0 to 28, with a mean value of 2.56 detections and standard deviation of 4.57.

Table 2. *Analysis of forest fire occurrence distribution*

Descriptive Statistics	N	Minimum	Maximum	Mean	Std. Deviation
Join Count	197	0	28	2.56	4.570
Valid N (listwise)	197				

The high value of standard deviation compared to arithmetic mean indicates pronounced spatial variability of the number of fires, i.e., uneven distribution of fire detections between analyzed spatial units.

The results of spatial autocorrelation (Table 3) (Moran's I = 0.435) indicate statistically significant positive spatial dependance of the forest fire detection density at the level of municipalities ($Z = 10.15$; $p < 0.001$). The obtained value deviates from the expected value for a random distribution ($I = -0.005$), which confirms there is a positive spatial autocorrelation. The result shows that the municipalities with similar values of forest fire detections density are grouped spatially.

Table 3. *Moran's I Summary*

Moran's I Summary	Moran's Index	Expected Index	Variance	z-score	p-value
	0.434860	-0.005102	0.001881	10.145626	0.000000

The results obtained indicate there are pronounced cluster patterns, i.e. spatial concentrations of forest fire detections, whereby certain areas represent the zones of increased risk. The result of Moran's I test confirms that fire detection distribution is not random, but spatially structured, which is in accordance with the findings of Gajović and Todorović (2013), who determined similar grouping of the occurrence of fires in the southern, southeastern and eastern parts of the Republic of Serbia. Previous studies have shown that the frequency and distribution of fire detections are conditioned by a combination of factors such as the type of vegetation, season, climatic conditions, and specificities of local conditions (Ray et al., 2023). Although climatic, vegetation, topographic and anthropogenic variables were not directly analyzed in this study, previous research suggests that these factors may contribute to the observed spatial patterns of forest fire detections. Higher concentration of forest fires can be associated with unfavorable climatic conditions, such as higher temperatures and more pronounced periods of drought, as well as specific structure of vegetation which contributes to higher flammability (Park et al., 2021). In addition to climatic conditions, anthropogenic factors also have a significant role, since areas with more intensive agricultural activities and more frequent burning of plant residues are characterized by an increased frequency of fires, especially in transition zones between agricultural and forest areas (Ga et al., 2025). On sites where fires occur there may be changes in the nutrient cycle, because biological elements from biomass can return to the soil in the form of ash, which can cause losses in macroelements and organic matter (Yang et al., 2022). The results are consistent with the findings of Shazard et al., (2026), which suggest that even a slight increase in fire intensity can cause significant losses in ecosystem productivity, which is especially significant considering that dense forest stands have a slower regeneration compared to less dense stands and areas covered with grass vegetation (Lee et al., 2025). Spatial distribution of fires varies throughout different regions, and it is conditioned by natural characteristics of the space (Archibald et al., 2013).

The results presented in Table 4 indicate that the largest share of municipalities are without detected forest fires (47.7%), while with one forest fire detection there are 15.7% of municipalities, and with two forest fires detection 9.1%. All other categories individually participate with significantly smaller percentages (below 5%).

Table 4. *The analysis of frequencies and percentage share of forest fire detections on classes 2, 3, 4 and 5*

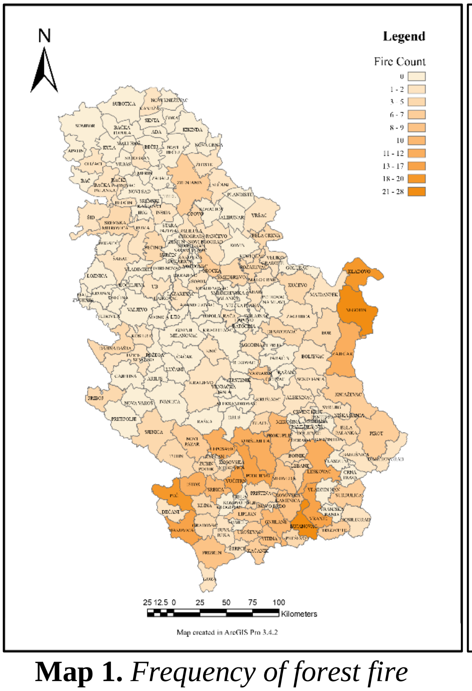
Number of detections	Frequency	Percentage	Cumulative percentage
0	94	47.7	47.7
1	31	15.7	63.5
2	18	9.1	72.6
3	7	3.6	76.1
4	10	5.1	81.2
5	6	3.0	84.3
6	9	4.6	88.8
7	2	1.0	89.8
8	2	1.0	90.9
9	2	1.0	91.9
10	3	1.5	93.4
11	3	1.5	94.9
12	2	1.0	95.9
15	1	0.5	96.4
16	1	0.5	97.0
17	2	1.0	98.0
18	1	0.5	98.5
20	1	0.5	99.0
26	1	0.5	99.5
28	1	0.5	100.0
Total	**197**	**100.0**	**100.0**

The cartographic representation (Map 1) shows that 10 municipalities with the highest frequency of detections are Bujanovac (28) and Negotin (26), then Peć (20), Kladovo (18), as well as Podujevo and Vranje with 17 detected forest fires in each. High values were detected also in municipalities Vučitrn (16), Đakovica (15), Istok (12) and Leposavić (12). These results indicate that the zones with the most pronounced fire detections in forests are mostly grouped in southern, southeastern, and partly in eastern parts of the researched space.

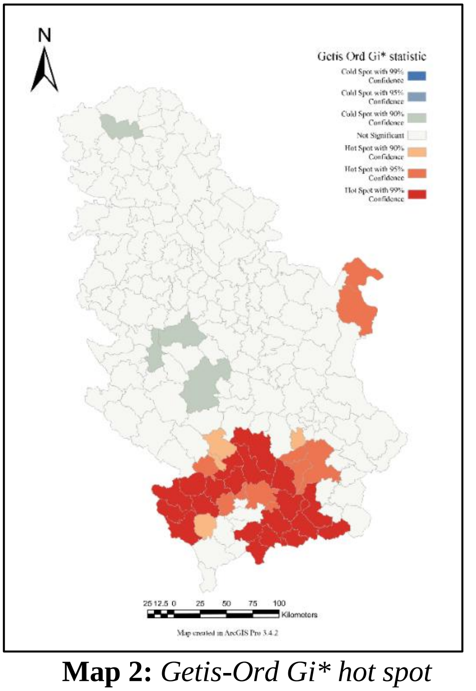
Getis-Ord Gi* analysis identified statistically significant spatial clusters of forest fire detection density (Map 2). The most pronounced hot spot regions are observed in southern and southwestern parts of the country, where municipalities with a high-density detection of forest fires are spatially grouped and form continuous zones of increased risk.

On the other hand, a large number of municipalities of central, western, and northern Serbia show very low number of forest fires detection or complete absence of registered events. Such pattern confirms the presence of pronounced positive asymmetry of distribution, where a small number of municipalities carries the main part of the total activity.

The cartographic representation additionally confirms the spatial concentration. The municipalities with the highest values are clearly distinguished as hot spots, the border municipalities, and hilly-mountainous municipalities of southeastern Serbia, as well as some municipalities of eastern Serbia, stand out in particular.



Map 1. *Frequency of forest fire detections by municipalities*



Map 2: *Getis-Ord Gi* hot spot analysis*

Map 1 and Map 2 show that forest fire detections are spatially concentrated in limited zones, while the largest part of the territory is affected with a significantly lower intensity. The similar result which shows grouping of clusters in southern and eastern parts of the Republic of Serbia was established by Gajović and Todorović (2013) using Moran's I and Getis Ord Gi*. Hot spot regions identify spatial clusters with increased frequency of fire detections, while the assessment of their radiative power requires additional analysis of FRP values. This is important information considering that previous studies have shown that frequent forest fires significantly change microbiological structure of soil and decrease ecosystem productivity (Smith et al., 2008).

4. CONCLUSION

The identified hot spot regions indicate that forest fire detections are not randomly distributed but tend to be spatially clustered. Previous studies have shown that repeated fire occurrence within the same areas may contribute to cumulative changes in soil and vegetation.

The results of the analysis show pronounced spatial heterogeneity of forest fire detection distribution, where the majority of municipalities have a low number of detections, while in the smaller number of municipalities zones of high concentrations occur, which is confirmed through spatial autocorrelation (Moran's I), as well as by Getis-Ord Gi* hot spot analysis.

By focusing the analysis on CLC classes 2, 3, 4 and 5 a more precise overview of the distribution of fire detections within forest ecosystems is enabled, whereby the results provide an overview of the spatial distribution of fire detections occurring within forest-related CLC classes. Such finding emphasizes their importance in the context of risk assessment and planning of protection measures.

The results obtained indicate that the assessment of the risk of forest fire should not be based solely on their frequency, but on the values of the radiative power. Although detections belonging to the upper quartile of the observed FRP distribution are less frequent, they may represent events with comparatively greater combustion energy and therefore deserve special attention in fire risk assessments.

Based on the identified spatial patterns it can be concluded that for the efficient management of forest fires the organization of protection system at the regional level is necessary, whereby preventive and protection measures should be directed to the identified hot spot zones as a matter of priority.

The application of integrated approach, using VIIRS and CLC, proved to be an effective tool for analyzing the spatial distribution of forest fire detections and identification of risk areas, which contributes to the improvement of the system of monitoring and protection measure planning.

Although all the used data are aligned in the same coordinate system and originate from reliable sources, certain limitations continue to exist. The difference in spatial resolution between VIIRS detections (375 m) and CLC data (10 m) can influence the precision of land cover class assignment, while aggregation of data at the level of municipalities can lead to the occurrence of modifiable areal unit problem (MAUP) effect. Additionally, VIIRS detections can be limited by the recording conditions, such as cloudiness and radiative power of forest fires.

VIIRS active fire records represent satellite detections rather than unique fire events. Consequently, multiple detections may originate from the same fire occurring during successive satellite overpasses or across adjacent pixels. Therefore, the reported frequencies should be interpreted as fire detection frequencies rather than exact counts of independent forest fires.

An additional limitation is that CLC+ Backbone 2021 represents a single reference period and does not capture potential land-cover changes that occurred between 2012 and 2026. Consequently, the results should be interpreted as a spatial analysis of forest fire detections within areas classified as forest land according to the CLC+ Backbone 2021 dataset, rather than as a reconstruction of historical vegetation conditions at the exact time of each fire event.

Despite these limitations, the research results provide insight into the spatial patterns of forest fire occurrence and represent the basis for further research. The research can be directed toward integration of climatic parameters (temperature, precipitation, drought indices) and socio-economic factors into forest fire spatial distribution models.

Acknowledgement: *This study was supported by the Republic of Serbia, Ministry of Education, Science and Technological Development, under Agreement No. 451-03-33/2026-03/200027, dated 5 February 2026.*

REFERENCES

Archibald, S., Lehmann, C. E. R., Gómez-Dans, J. L., & Bradstock, R. A. (2013). Defining pyromes and global syndromes of fire regimes. *Proceedings of the National Academy of Sciences, 110*(16), 6442–6447. https://doi.org/10.1073/pnas.1211466110

Brovkina, O. V., Stojanović, M., Milanović, S., Latypov, I., Marković, N., & Cienciala, E. (2020). Monitoring of post-fire forest scars in Serbia based on satellite Sentinel-2 data. *Geomatics, Natural Hazards and Risk, 11*(1), 2315–2339. https://doi.org/10.1080/19475705.2020.1836037

Cervinka, R., Höltge, J., Pirgie, L., Schwab, M., Sudkamp, J., Haluza, D., Arnberger, A., Eder, R., & Ebenberger, M. (2014). *Green public health: Benefits of woodlands on human health and well-being*. Bundesforschungszentrum für Wald. ISBN 978-3-902762-32-0

Ćurić, V., Durlević, U., Ristić, N., Novković, I., & Čegar, N. (2022). GIS application in analysis of threat of forest fires and landslides in the Svrljiški Timok basin (Serbia). Glasnik Srpskog geografskog društva, 102(1), 107–130. https://doi.org/10.2298/GSGD2201107C

Durlević, U., Čegar, N., & Brašanac-Bosanac, Lj. (2025). Spatio-temporal analysis of large wildfires in Serbia based on GIS and VIIRS remote sensing data. *Održivo šumarstvo, 92*, 133–143. https://doi.org/10.5937/SustFor2592133D

Durlević, U., Ilić, V., & Valjarević, A. (2025). Wildfire susceptibility mapping using deep learning and spatial analysis. *Fire, 8*(10), 407. https://doi.org/10.3390/fire8100407

Esri. (2024). *ArcGIS Pro (Version 3.4.0)* [Computer software]. https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview

European Environment Agency. (2020). *Corine land cover change 2000–2006 (CLC change)*. https://sdi.eea.europa.eu

European Environment Agency. (2024). *CLC+ Backbone 2021: Product user manual* [Technical report]. Copernicus Land Monitoring Service. https://land.copernicus.eu

Ga, R., Liu, X., Ma, B., Na, M., Zhang, J., Tong, Z., Wei, X., & Xu, J. (2025). The individual and combined effects of natural–human factors on forest fire frequency in Northeast China. *Remote Sensing, 17*(10), 1685. https://doi.org/10.3390/rs17101685

Gajović, V., & Todorović, B. (2013). Spatial and temporal analysis of fires in Serbia for period 2000–2013. *Journal of the Geographical Institute "Jovan Cvijić" SASA, 63*(3), 297–312. https://doi.org/10.2298/IJGI1303297G

Gigović, L., Pourghasemi, H. R., Drobnjak, S., & Bai, S. (2019). Testing a new ensemble model based on SVM and random forest in forest fire susceptibility assessment and its mapping in Serbia's Tara National Park. *Forests, 10*(5), 408. https://doi.org/10.3390/f10050408

Guerri, G., Crisci, A., Messeri, A., Congedo, L., Munafò, M., & Morabito, M. (2021). Thermal summer diurnal hot-spot analysis: The role of local urban features layers. *Remote Sensing*, *13*(3), 538. https://doi.org/10.3390/rs13030538

Harrison, S. P., Haas, O., Bartlein, P. J., Sweeney, L., & Zhang, G. (2025). Climate, vegetation, people: Disentangling the controls of fire at different timescales. *Philosophical Transactions of the Royal Society B: Biological Sciences, 380*(1924), 20230464. https://doi.org/10.1098/rstb.2023.0464

IBM Corp. (2019). *IBM SPSS Statistics (Version 26)* [Computer software]. https://www.ibm.com/products/spss-statistics

Justice, C. O., Malingreau, J.-P., & Setzer, A. W. (1993). Satellite remote sensing of fires: Potential and limitations. In P. J. Crutzen & J. G. Goldammer (Eds.), *Fire in the environment* (pp. 77–88). John Wiley & Sons.

Liu, Z., & Wimberly, M. C. (2015). Climatic and landscape influences on fire regimes from 1984 to 2010 in the western United States. *PLOS ONE, 10*(10), e0140839. https://doi.org/10.1371/journal.pone.0140839

Liu, G., Gu, Z., Liu, X., & Li, B. (2024). Microenvironment heterogeneity affected by anthropogenic wildfire-perturbed soil mediates bacterial community in Pinus tabulaeformis forests. *Frontiers in Microbiology, 15,* 1415726. https://doi.org/10.3389/fmicb.2024.1415726

Lorent, A., Petrila, M., Apostol, B., Capalb, F., Chivulescu, Ș., Șamșodan, C., Marcu, C., & Badea, O. (2025). Assessing and mapping forest fire vulnerability in Romania using maximum entropy and eXtreme gradient boosting. Forests, 16(7), 1156. https://doi.org/10.3390/f16071156

Manić, E., Nikitović, V., & Đurović, P. (Eds.). (2022). The geography of Serbia: Nature, people, economy. Springer. https://link.springer.com/book/10.1007/978-3-030-74701-5

Milovanović, B., Schuster, P., Radovanović, M., Ristić Vakanjac, V., & Schneider, C. (2017). Spatial and temporal variability of precipitation in Serbia for the period 1961–2010. Theoretical and Applied Climatology, 130(1–2), 687–700. https://doi.org/10.1007/s00704-017-2118-5

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

NASA/USGS. (2018). *VIIRS active fire product user guide*. https://lpdaac.usgs.gov

NASA Earthdata. (2025). *Fire radiative power (FRP) – Los Angeles fires dashboard*. https://www.earthdata.nasa.gov/dashboard/data-catalog/la-fires-frp

Novković, I., Radovanović, M., Milošević, D., Pavićević, N., & Marković, V. (2021). GIS-based forest fire susceptibility zonation with IoT sensor network support. *Sensors, 21*(19), 6520. https://doi.org/10.3390/s21196520

Park, I. W., Mann, M. L., Flint, L. E., Flint, A. L., & Moritz, M. (2021). Relationships of climate, human activity, and fire history to spatiotemporal variation in annual fire probability across California. *PLOS ONE, 16*(11), e0254723. https://doi.org/10.1371/journal.pone.0254723

Parente, J., Pereira, M. G., & Tonini, M. (2016). Space-time clustering analysis of wildfires: The influence of dataset characteristics, fire prevention policy decisions, weather and climate. Science of the Total Environment, 559, 151–165. https://doi.org/10.1016/j.scitotenv.2016.03.129

Pausas, J. G., & Fernández-Muñoz, S. (2012). Fire regime changes in the Western Mediterranean Basin: From fuel-limited to drought-driven fire regime. Climatic Change, 110(1–2), 215–226. https://doi.org/10.1007/s10584-011-0060-6

Psistaki, K., Tsantopoulos, G., & Paschalidou, A. K. (2024). An overview of the role of forests in climate change mitigation. *Sustainability, 16*(14), 6089. https://doi.org/10.3390/su16146089

Ray, T., Malasiya, D., Verma, A., Purswani, E., Qureshi, A., Khan, M. L., & Verma, S. (2023). *Characterization of spatial–temporal distribution of forest fire in Chhattisgarh, India, using MODIS-based active fire data*. Sustainability, 15(9), 7046. https://doi.org/10.3390/su15097046

Republički geodetski zavod. (n.d.). *GeoSrbija geoportal*. https://a3.geosrbija.rs/

Shahzad, F., Mehmood, K., Anees, S. A., Adnan, M., Haidar, I., Jabbarov, U., Yaxshimuratov, M., & Oliveira, M. (2026). *Remote sensing analysis of forest fire impacts on ecosystem productivity, greenhouse gas emissions, and fire risk in Pakistan*. Carbon Balance and Management, 21, 54. https://doi.org/10.1186/s13021-026-00410-y

Smith, N. R., Kishchuk, B. E., & Mohn, W. W. (2008). Effects of wildfire and harvest disturbances on forest soil bacterial communities. *Applied and Environmental Microbiology, 74*(1), 216–224. https://doi.org/10.1128/AEM.01355-07

Tešić, D. (2022). Corine land cover change detection in Serbia and Bosnia and Herzegovina. *Researches Reviews of the Department of Geography, Tourism and Hotel Management, 51*(2), 98–110. http://www.dgt.uns.ac.rs/dokumentacija/zbornik/51-2/en/02en.pdf

Directorate for Forests of the Republic of Serbia. (2023). *The Results of the second national forest inventory of the Republic of Serbia*. Ministry of Agriculture (Original title: Uprava za šume Republike Srbije. (2023). *Rezultati druge nacionalne inventure šuma Republike Srbije*. Ministarstvo poljoprivrede).

Van, L. N., & Lee, G. (2025). Investigating the relationship between topographic variables and wildfire burn severity. Geographies, 5(3), 47. https://doi.org/10.3390/geographies5030047

Vranić, P., & Mišić, N. (2024). Spatial distribution patterns of wildfire incidents in Serbia based on VIIRS data. *Facta Universitatis, Series: Working and Living Environmental Protection*, *21*(2), 87–96. https://casopisi.junis.ni.ac.rs/index.php/FUWorkLivEnvProt/article/view/12768

Wang, W., & Wang, C. (2025). Spatiotemporal dynamics of active fire in China (2003–2024): Regional patterns and land cover associations. Fire, 8(11), 445. https://doi.org/10.3390/fire8110445

Wooster, M. J., Roberts, G., Perry, G. L. W., & Kaufman, Y. J. (2005). Retrieval of biomass combustion rates and totals from fire radiative power observations: FRP derivation and calibration relationships between biomass consumption and fire radiative energy release. *Journal of Geophysical Research: Atmospheres*, *110*(D24), D24311. https://doi.org/10.1029/2005JD006318

Yang, X., Liu, R.-T., Shao, M.-A., Wei, X.-R., Li, T.-C., Chen, M.-Y., Li, Z.-Y., Dai, Y.-C., & Gan, M. (2022). Short-term effects of wildfire on soil arthropods in a semi-arid grassland on the Loess Plateau. *Frontiers in Microbiology*, *13*, 989351. https://doi.org/10.3389/fmicb.2022.989351

Živanović, S., & Gocić, M. (2022). Forest fires in Serbia—Influence of humidity conditions. Geographical Institute Jovan Cvijić SASA Journal of the Geographical Institute Jovan Cvijić SASA, 72(2), 221–235. https://doi.org/10.2298/IJGI2202221Z

SPATIAL-STATISTICAL ANALYSIS OF FOREST FIRE DISTRIBUTION IN THE REPUBLIC OF SERBIA

Bojan KONATAR, Ilija ĐORĐEVIĆ, Jovana CVETKOVIĆ, Milijana CVEJIĆ, Radojica PIŽURICA, Katarina MLADENOVIĆ, Goran ČEŠLJAR

Summary

Fires represent one of the key ecological factors that affect the structure and dynamics of forest ecosystems, whereby their spatial distribution depends on the combination of climatic conditions, type of vegetation, and anthropogenic influences. In the last decades, the development of satellite technologies enabled more precise monitoring and analysis of spatial distribution of fires. The objective of this research was to analyze spatial distribution of forest fire detections in the territory of the Republic of Serbia in the period from 2012 to 2026, restricted to forest-related CLC classes (2, 3, 4 and 5). The analysis was based on the data of VIIRS sensors available through NASA FIRMS system, in combination with CLC+ Backbone data, along with the application of geospatial and statistical methods. Special emphasis was placed on the assessment of the radiative power of the fire detections through Fire Radiative Power (FRP), which represents a measure of the energy emitted during combustion. The results show pronounced spatial unevenness of fire detection distribution, whereby the majority of municipalities record a low number of events or their absence, while in a smaller number of municipalities there are zones with an increased frequency. Examination of spatial autocorrelation (Moran’s I = 0.435; $p < 0.001$) indicates statistically significant grouping of fire detections, which was confirmed also by Getis-Ord Gi* hot spot analysis. The most pronounced clusters were identified in the southern, southeastern and eastern parts of Serbia. The analysis of FRP values shows high variability, where lower- and mid-range FRP events dominate the dataset, while a smaller number of detections belong to the upper quartile of the FRP distribution and may potentially have a greater influence on

ecosystem processes. The results obtained indicate that fire risk assessment should not be based solely on their frequency, but also on radiative power. The identified spatial patterns indicate the need for regionally oriented approach to risk management, whereby preventive and protective measures should be directed toward identified risk zones. Although data from reliable sources were used and aligned in the same coordinate system, there are certain limitations, primarily regarding the difference in spatial resolution between VIIRS detections and CLC data, as well as possible influence of the aggregation effect of spatial units (MAUP). Despite this, the application of an integrated approach that combines satellite data and land cover classification is an effective tool for the analysis and identification of risk areas and contributes to the improvement of the system of monitoring and planning of fire protection measures.

PROSTORNO-STATISTIČKA ANALIZA RASPORSTRANJENOSTI ŠUMSKIH POŽARA U REPUBLICI SRBIJI

Bojan KONATAR, Ilija ĐORĐEVIĆ, Jovana CVETKOVIĆ, Milijana CVEJIĆ, Radojica PIŽURICA, Katarina MLADENOVIĆ, Goran ČEŠLJAR

Rezime

Požari predstavljaju jedan od ključnih ekoloških faktora koji utiču na strukturu i dinamiku šumskih ekosistema, pri čemu njihova prostorna distribucija zavisi od kombinacije klimatskih uslova, tipa vegetacije i antropogenih uticaja. U poslednjim decenijama, razvoj satelitskih tehnologija omogućio je preciznije praćenje i analizu prostorne distribucije požara. Cilj ovog istraživanja bio je da se analizira prostorna distribucija detektovanih šumskih požara na teritoriji Republike Srbije u periodu 2012–2026, sa posebnim fokusom na šumske kategorije definisane CLC klasifikacijom (klase 2, 3, 4 i 5). Analiza je zasnovana na podacima VIIRS senzora dostupnih kroz NASA FIRMS sistem, u kombinaciji sa CLC+ Backbone podacima, uz primenu geoprostornih i statističkih metoda. Poseban akcenat stavljen je na procenu radijacione snage požara kroz Fire Radiative Power (FRP), koji predstavlja meru energije emitovane tokom sagorevanja. Rezultati pokazuju izraženu prostornu neujednačenost distribucije detektovanih šumskih požara, pri čemu većina opština beleži nizak broj događaja ili njihovo odsustvo, dok se u manjem broju opština javljaju zone sa povišenom frekvencijom. Ispitivanje prostorne autokorelacije (Moran's I = 0.435; $p < 0.001$) ukazuje na statistički značajno grupisanje požara, što je potvrđeno i Getis-Ord Gi* hot spot analizom. Najizraženiji klasteri identifikovani su u južnim, jugoistočnim i istočnim delovima Srbije. Analiza FRP vrednosti požara pokazuje visoku varijabilnost, gde dominiraju detekcije koje pripadaju nižem i srednjem delu raspodele FRP vrednosti, dok manji broj detekcija pripada gornjem kvartilu raspodele FRP vrednosti i može ukazivati na događaje sa većom energijom sagorevanja i potencijalno većim ekološkim efektima. Dobijeni rezultati ukazuju da procena rizika od požara ne treba da se zasniva isključivo na njihovoj učestalosti, već i na radijacionoj snazi. Identifikovani prostorni obrasci ukazuju na potrebu za regionalno orijentisanim pristupom upravljanju rizikom, pri čemu bi preventivne i zaštitne mere trebalo usmeriti ka identifikovanim rizičnim zonama. Iako su korišćeni podaci iz pouzdanih izvora i usklađeni u istom koordinatnom sistemu, određena ograničenja postoje, pre svega u pogledu razlike u prostornoj rezoluciji između VIIRS detekcija i CLC podataka, kao i mogućeg uticaja efekta agregacije prostornih jedinica (MAUP). Uprkos tome, primena integrisanog pristupa koji kombinuje satelitske podatke i klasifikaciju zemljišnog pokrivača predstavlja efikasan alat za analizu i identifikaciju rizičnih područja i doprinosi unapređenju sistema monitoringa i planiranja mera zaštite od požara.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY COLLECTION 93, 2026 | **ODRŽIVO ŠUMARSTVO** ZBORNIK RADOVA 93, 2026

UDK: 712.253(497.11)=111
DOI: 10.5937/SustFor2693037M
Original scientific paper

VISUAL ASSESSMENT OF TREE CONDITION AS A BASIS FOR URBAN GREEN SPACE MANAGEMENT: A CASE STUDY OF GAVRILO PRINCIP PARK IN BELGRADE

Katarina MARINKOVIĆ[1]*, *Suzana MITROVIĆ*[1], *Miloš RAČIĆ*[1], *Nikola MARTAĆ*[1], *Nemanja LAZAREVIĆ*[1], *Jovana CVETKOVIĆ*[1]

Abstract: *Urban green areas are essential for improvement of ecosystem services, biodiversity, and well-being of people, but their sustainability depends on the long-term vitality and aesthetic quality of the trees. In this paper, the goal was to present the results of the research of health and aesthetic condition of trees in Gavrilo Princip Park in Belgrade. Vitality and ornamentality marks were evaluated on a 1 to 5 scale using Visual Tree Assessment (VTA) method. 172 trees were recorded on the researched location with an area of 1.92 ha. A total of 39 taxonomic categories were identified, of which 8 within Gymnosperms and 31 from Angiosperms. The most dominant taxa in the park are Pinus nigra J.F. Arnold (within Gymnosperms) and Tilia cordata Mill. (within Angiosperms). The average vitality mark of all trees in the park is 3.01 and ornamentality mark is 3.19. These research studies as a part of regular monitoring of urban green areas should contribute to the preservation and proper management of urban spaces green infrastructure.*

Keywords: VTA method, vitality, ornamentality, green infrastructure, Gavrilo Princip Park.

VIZUELNA PROCENA STANJA DRVEĆA KAO OSNOVA ZA UPRAVLJANJE URBANIM ZELENIM POVRŠINAMA NA PRIMERU PARKA GAVRILA PRINCIPA U BEOGRADU

Sažetak: *Urbane zelene površine su od suštinskog značaja za unapređenje ekosistemskih usluga, biodiverziteta i dobrobiti ljudi, ali njihova održivost zavisi od dugoročne vitalnosti i estetskog kvaliteta drveća. U ovom radu cilj je bio da se prikažu rezultati istraživanja zdravstvenog i estetskog stanja drveća u parku Gavrila Principa u Beogradu. Ocene vitalnosti i dekorativnosti vrednovane su skalom od 1 do 5 korišćenjem metode vizuelne procene stabala (VTA). Na istraživanoj lokaciji, površine od 1.92 ha, zabeleženo je 172 stabla. Ukupno je identifikovano 39 taksonomskih kategorija, od čega 8 u okviru golosemenica i 31 u okviru skrivenosemenica. Najdominantniji taksoni u parku su Pinus nigra J.F. Arnold (u okviru golosemenica) i Tilia cordata Mill. (u okviru skrivenosemenica). Prosečna ocena vitalnosti svih stabala u parku iznosi 3.01 a dekorativnosti 3.19. Ova istraživanja kao deo redovnog monitoringa urbanih zelenih*

[1] Institute of Forestry, Kneza Višeslava 3, 11030 Beograd, Serbia
*Corresponding author. E-mail: 014katarina@gmail.com

© 2026 The Authors. Published by Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

površina treba da doprinose očuvanju i pravilnom upravljanju zelenom infrastrukturom urbanih prostora.

Ključne reči: VTA metoda, vitalnost, dekorativnost, zelena infrastruktura, park Gavrila Principa.

1.INTRODUCTION

A city park as an object of green infrastructure is of great importance in improving the quality of life in a city (Biddulph, 1999; Ćirković-Mitrović et al., 2016; Galečić et al., 2016). In conditions of intensive urbanization, where plants are exposed to the influence of various biotic and abiotic factors, such as air pollution, limited space for root system development and changed microclimatic conditions, it is necessary to carry out regular and systematic assessments of their condition in order to identify potential risks and define adequate care and protection measures (Nowak et al., 2004; Roloff, 2001; Anastasijević, 2011).

Effective management of urban greenery implies continuous monitoring of the condition of trees, as well as the assessment of their mechanical stability, especially in densely populated areas where potential risks can have serious consequences for users and the surrounding infrastructure (Konijnendijk et al., 2005). For this reason, in this study the method of visual assessment– VTA (Visual Tree Assessment) was applied to determine the mark of the condition of the trees. The method represents an effective and widely applied approach in arboriculture, because it enables the provision of guidelines aimed at safe use of public areas, but also the improvement of ecosystem services provided by urban trees (Mattheck & Breloer, 1994; Mitrović et al., 2025).

Considering that a city park should provide conditions to meet the needs of users such as recreation, relaxation, play and social activities, while the ecological and aesthetic function of the park should not be neglected, the objective of this paper is to present the value, health and aesthetic condition of dendroflora in Gavrilo Princip Park, as necessary factors in the management of urban green infrastructure.

Gavrilo Princip Park has significant cultural and historical heritage and ecological value. It was founded in 1836 as the garden of Prince Miloš's residence, while it was opened to visitors in 1864, which earned it the title of the first public city park in Belgrade. It is located in the central part of Belgrade in the territory of the city municipality of Savski Venac. The park has changed names throughout history, and these are: Soviet Park, Council Park and Financial Park. The park was originally designed in the English style and was reconstructed in 2004. The most recent reconstruction was completed in 2011.

2. MATERIAL AND METHOD

The study area is Gavrilo Princip Park (44°49'14"N, 20°27'44"E), located in the inner-city core of Belgrade. The boundaries of the researched part of the green infrastructure are Admirala Geprata Street in the north, Balkanska Street in the west, Nemanjina Street in the south and Kneza Miloša Boulevard in the east (Figure 1). The park covers an area of 1.92 ha. Field research was conducted in April 2024.

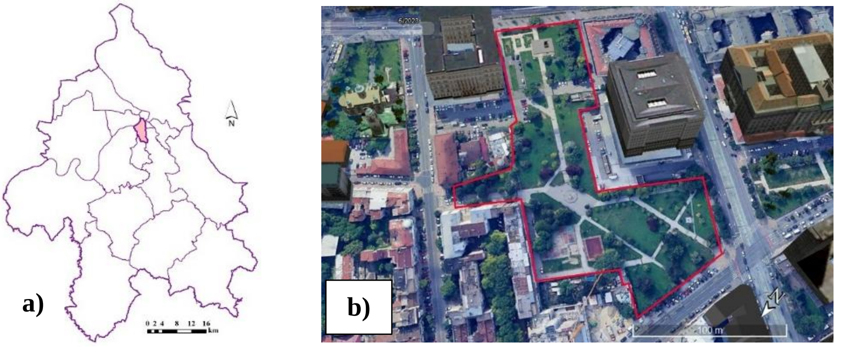


Figure 1. *a) Position of the city municipality of Savski Venac on the territory of Belgrade, b) Study area*

The paper analyzes the connection between the marks of vitality and ornamentality of trees, as well as the difference between Gymnosperms and Angiosperms. The data were collected using the basic method of visual tree assessment – VTA. The sample included 172 trees, of which 31 trees belonged to Gymnosperms and 141 individuals belonged to Angiosperms. The marks of vitality and ornamentality are expressed on an ordinal scale from 1 to 5 (Table 1) and they are obtained using visual assessment by the researcher.

The mark of vitality is based on basic measurements, such as tree height, diameter at breast height, height of the stem without branches, crown width, but also on visual assessment of the existence of broken and dry branches in the crown, top dieback, mechanical and entomological damages, as well as phytopathological diseases.

Tree ornamentality basically represents the aesthetic value of trees. This parameter is based on the subjective assessment of the researcher whereby, habitus form, symmetry, leaf mass density and coloration are considered. The ornamentality rating is also affected by the potential presence of mechanical damage, insects and fungi.

Table 1. *The scale for evaluating tree vitality and ornamentality (Stojanović et al. 2013)*

Mark	Parameters for evaluating tree vitality	Parameters for evaluating tree ornamentality
1	Dead tree. Wry or sick tree. A tree on the verge of decay. Broken or mechanically significantly damaged tree in any way. A tree that has no possibility of further recovery.	Visually unbalanced tree without symmetry. A tree that spoils the impression in the overall impression of space. Without pronounced color, changeability, dynamism, without clearly defined mass and area.
2	Still vital tree, mechanically damaged or sick in any way. A tree with part of its crown missing. A severely damaged tree that may still survive.	A tree with an inharmonious silhouette and a disproportionate and insufficiently clearly delineated habitus. Poor color ratio. Poor ratio of mass and area.
3	A tree with damages that can be revitalized with care measures. A Crown with clearly defined form. A tree with medium intensity of occurrence of phytopathological diseases and mechanical damages.	Crown with clearly defined form. Coloristically uniform, monotonous. Trees inappropriately fit into the given space, out of proportion.
4	Vital tree with small intensity of phytopathological diseases or entomological damages. A tree with minor defects that can be corrected with appropriate care measures.	A tree in a visually balanced form, with less pronounced asymmetry. Recognizable ratio of colors, area and mass.
5	A completely healthy and undamaged tree. A tree of exceptional vitality, well adapted to environmental conditions.	Visually imposing and aesthetically extremely valuable tree. A tree of clear proportions and symmetry in accordance with the characteristics of the taxon. Coloristically emphasized tree. A tree that positively stands out in any way in space, by its build, figure, shape.

The descriptive analysis includes basic statistical indicators, including the arithmetic mean, standard deviation, median, and minimum and maximum values. Since the variables were ordinal, the association between the observed variables was examined using Spearman's correlation coefficient and Kendall's τ coefficient. The difference in vitality and ornamentality between Gymnosperms and Angiosperms was examined using the Mann–Whitney U test for two independent samples. Statistical significance was set at $p < 0.05$. Statistical data processing was performed in the IBM SPSS Statistics software.

3. RESULTS

In Gavrilo Princip Park, 39 tree taxa with 172 individuals were identified. The trees from Gymnosperms are dominant with 31 taxa that include 141 individuals, i.e. 81.98% compared to the total number of trees. Gymnosperms are represented by 8 species and a total of 31 trees in a percentage of 18.02 of the total number of trees.

Within Gymnosperms the most abundant species is *Pinus nigra* J.F. Arnold (15 individuals), followed by species *Platycladus orientalis* L. and *Taxus baccata* L. with 4 trees each, while other species within this group were represented by 3 or fewer individuals.

Among Angiosperms, the most abundant taxon is *Tilia cordata* Mill. (20 individuals), followed by *Acer pseudoplatanus* L. (16), *Robinia pseudoacacia* 'Umbraculifera' (13), *Fraxinus excelsior* 'Globosa' (9), *Prunus cerasifera*

'Atropurpurea' (9), *Acer platanoides* L. (8), *Tilia platyphyllos* Scop. (7) and *Betula pendula* Roth (7). Other taxa from Angiosperms are represented by 5 or fewer individuals.

The average mark of tree vitality (collectively for Gymnosperms and Angiosperms) amounts to 3.01, while the average mark for ornamentality is 3.19.

Taxa of Gymnosperms which showed the greatest vitality and ornamentality include the following: *Taxus baccata* L. (mark 4.5), *Picea pungens* Engelm. and *Platycladus orientalis* L. (mark 4). These taxa are represented in the field by 1-4 individuals, so the most numerous taxon from this group should not be ignored - *Pinus nigra* J.F. Arnold (15 individuals), whose average vitality mark is 3.0, and average ornamentality mark is 3.3. The lowest vitality and ornamentality mark was given to the species *Abies alba* Mill. (mark 2), which was considering the ecological requirements of the species (Ocokoljić and Petrov, 2022).

Deciduous species that showed the highest vitality are *Cercis siliquastrum* L., *Fraxinus angustifolia* Vahl. with an average mark of 5, while the lowest average vitality mark was given to taxa *Acer negundo* L., *Catalpa bignonioides* Walter, *Salix babylonica* var. *matsudana* 'Tortuosa' and *Scandosorbus intermedia* Pers. (mark 2).

Taxa of Angiosperms that showed the highest ornamentality are the following: *Cercis siliquastrum* L., *Fraxinus angustifolia* Vahl., *Liquidambar styraciflua* L., *Magnolia x soulangeana* Soul.-Bod., *Platanus* × *hispanica* Mill. ex Münch., *Quercus robur* L., *Quercus robur* 'Fastigiata' with an average mark 5; then *Prunus cerasifera* 'Atropurpurea' (mark 4.2). The most abundant species in the park within Angiosperms is *Tilia cordata* Mill., whose average vitality mark is 2.65, and average ornamentality mark is 2.70.

Descriptive statistical analysis (Table 2) indicates that average values of vitality and ornamentality mark are higher in gymnosperms, compared to angiosperms. The average vitality mark for trees from *Pinophyta* subdivision is 3.32 ± 0.70, while for *Magnoliophyta* subdivision it is 2.94 ± 0.99. The average ornamentality mark showed a similar trend, whereby average value in gymnosperms was 3.48 ± 0.72, while in angiosperms it was 3.12 ± 0.99. The median value was 3 in all cases.

Table 2. *Descriptive statistics for the value of vitality and ornamentality*

	Phylogenomics	Frequency	Mean ± Std. Dev.	Median	Min	Max
Vitality	Gymnosperms	31	3.32 ± 0.70	3	2	5
	Angiosperms	141	2.94 ± 0.99	3	1	5
	Both	172	3.01 ± 0.95	3	1	5
Ornamentality	Gymnosperms	31	3.48 ± 0.72	3	2	5
	Angiosperms	141	3.12 ± 0.99	3	1	5
	Both	172	3.19 ± 0.95	3	1	5

The results of Mann–Whitney U test (Table 3) show statistically significant differences between Gymnosperms and Angiosperms, both in vitality ($U = 1618.50$; $Z = -2.38$; $p = 0.017$), and in ornamentality ($U = 1656.00$; $Z = -2.23$; $p = 0.026$). Higher mean rank values in Gymnosperms indicate that these taxa are evaluated as more vital and decorative on average compared to taxa from Angiosperms.

Table 3. *Results of the Man –Whitney U Test for differences in vitality and ornamentality values between Gymnosperms and Angiosperms*

	Phylogenomics	N	Mean Rank		Mann – Whitney U	Z	p - value
			Gymnosperms	Angiosperms			
Vitality	Gymnosperms	31	104.79	89.48	1618.50	-2.38	0.017
	Angiosperms	141					
	Both	172					
Ornamentality	Gymnosperms	31	103.58	82.74	1656.00	-2.23	0.026
	Angiosperms	141					
	Both	172					

The analysis of correlation between vitality and ornamentality (Table 4) showed a statistically significant positive correlation in all the observed groups. For the entire sample, Spearman's correlation coefficient was 0.906 ($p < 0{,}001$), which indicates a very strong correlation between the observed variables. Similar results were obtained within individual groups, whereby the correlation is somewhat weaker in conifers ($\rho = 0.812$), while in deciduous trees it is nearly identical to the total sample ($\rho = 0.906$). The Kendall's τ coefficient additionally confirms the results of the correlation analysis.

Table 4. *Correlation between vitality and ornamentality*

Phylogenomics	N	Spearman ρ	Kendall τ	p - value
Gymnosperms	31	0.812	0.804	<0.001
Angiosperms	141	0.906	0.875	<0.001
Both	172	0.906	0.874	<0.001

4. DISCUSSION

The obtained results support previous research (Vratuša and Anastasijević, 1998) and indicate that the vitality and ornamentality of plants are significantly influenced by the characteristics of the site, the plant species selection, the microclimatic characteristics of the space and the level of exposure to adverse urban conditions. Although the ecological conditions of the site have changed, some taxa have adapted well to them (*Taxus baccata* L., *Platanus* × *hispanica* Mill. ex Münch., *Prunus cerasifera* 'Atropurpurea', *Quercus robur* L., *Quercus robur* 'Fastigiata', *Tilia platyphyllos* Scop., *Tilia tomentosa* Moench).

Species sensitive to urban conditions have been identified in the park (*Abies alba* Mill.). Therefore, poor marks of vitality and ornamentality were expected for them.

The poor vitality of the trees reduces their ornamental value in green spaces, but also the ability of these taxa to provide ecological benefits (Mitrović et al., 2025). 42 trees which are considered potentially dangerous for the users of a city park, but also provide favorable conditions for the development of pathogens and insects, got mark 1 or 2, therefore, their removal is recommended.

In addition to its important role in preserving and improving the urban biodiversity environmental quality (Maričić, 2007), the value of Gavrilo Princip Park is also reflected in the positive effects of dendroflora in air purification from pollutants and dust, reduction of solar radiation, and lowering the air temperature in the urban core of Belgrade during the summer months.

5. CONCLUSION

In this research, 39 taxa of trees with a total of 172 individuals were analyzed. Using a five-point rating scale, the average tree vitality mark was 3.01, and the average ornamentality mark was 3.19. The taxa with high average marks of vitality are *Taxus baccata* L., *Cercis siliquastrum* L., *Fraxinus angustifolia* Vahl. and *Prunus cerasifera* 'Atropurpurea'. The taxa with the highest average mark of ornamentality are *Cercis siliquastrum* L., *Fraxinus angustifolia* Vahl., *Liquidambar styraciflua* L., *Liriodendron tulipifera* L., *Magnolia* × *soulangeana* Soul.-Bod., *Platanus* × *hispanica* Mill. ex Münch., *Prunus cerasifera* 'Atropurpurea', *Quercus robur* L., and *Quercus robur* 'Fastigiata'.

Abies alba Mill., *Acer negundo* L., *Catalpa bignonioides* Walter, *Salix babylonica* var. *matsudana* 'Tortuosa' and *Scandosorbus intermedia* Pers received the lowest marks for vitality and ornamentality. Significant differences in vitality and ornamentality marks at the taxonomic level indicate that it is necessary to develop separate management strategies adjusted to different taxa with the aimed of preserving the aesthetic and ecological value of urban greenery. Also, such research is useful in the selection of species both for the reconstruction and restoration of flora elements of already existing green spaces, and in the design of new ones under altered ecological conditions of urban environments.

The trees identified in the field are taxonomically and biogeographically very diverse which indicates the high ability of these taxa to acclimatize in the conditions of the urban environment.

Visual assessment of dendroflora plays a significant role in preservation and management of urban green infrastructure. In this way, potential risks of endangering user safety are minimized, but also further spread of pathogens and insects is prevented by giving adequate guidelines for measures of care and recovery of plants.

Acknowledgement: *This research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-33/2026-03/200027, dated February 5, 2026).*

REFERENCES

Anastasijević N. (2011): Establishing and care of green areas, 2nd edition, University of Belgrade - Faculty of Forestry, Belgrade, (Original title: Podizanje i negovanje zelenih površina, drugo izdanje, Univerzitet u Beogradu – Šumarski fakultet, Beograd). ISBN: 978-86-7299-321-9

Biddulph, M. (1999): Bringing Vitality to a Campus Environment. Urban Design Int., 4(3&4), 153-166.

Ćirković-Mitrović T., Brašanac-Bosanac Lj., Mladenović K., Milenković I. (2016). The comparative analysis of the state of dendrological plants in Belgrade parks, Serbia. *Sustainable Forestry: Collection Vol. 92*, p107-116.

Galečić N., Tomićević-Dubljević J., Ocokoljić M., Vujičić D., Skočajić D. (2016). Quality and utilization potential of urban parks: Case study Tašmajdan park, Belgrade, Serbia. *Šumarski list: 9-10,* p493-501.

Konijnendijk, C., Nilsson, K., Randrup, T. B., & Schipperijn, J. (2005). Urban forests and trees: A reference book. Springer, p9-15.

Maričić, T.: The system of green areas in big cities – on the examples of Berlin and Belgrade, IAUS, Belgrade (Original title: Sistem zelenih površina u velikim gradovima - na primerima Berlina i Beograda, IAUS, Beograd), 2007.

Mattheck, C. & Breloer, H. (1994). Field Guide for Visual Tree Assessment (VTA). Arboricultural Journal, 18(1), p1–23. https://doi.org/10.1080/03071375.1994.9746995

Mitrović S., Veselinović M., Stajić S., Lazarević N., Marinković K., Đurašinović R., Milosavljević M. (2025). Visual assessment of trees in the urban forest in Belgrade: A case study of the area planted for the construction of the multifunctional hall of the Institute for sport and sports medicine of the Republic of Serbia. *Sustainable Forestry: Collection 73-74*, 11-18. https://doi.org/10.5937/SustFor2592107M

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. South-east Eur for 16(2): 207-213. https://doi.org/10.15177/ seefor.25-20.

Nowak, D. J., Crane, D. E., & Stevens, J. C. (2004). Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry & Urban Greening*, 4(3–4), 115–123.

Ocokoljić, M., Petrov, Dj.: Decorative dendrology, University of Belgrade – Faculty of Forestry, Belgrade, (Original title: Dekorativna dendrologija, Univerzitet u Beogradu - Šumarski fakultet, Beograd), 2022. ISBN 978-86-7299-339-4.

Roloff, A. (2001). *Baumkronen: Verständnis und praktische Bedeutung eines komplexen Naturphänomens*. Stuttgart: Ulmer.

Stojanovic N., Anastasijevic N., Anastasijevic V., Mesicek M. (2013): *Dendroflora functionality assessment of Financial Park in Belgrade*, XXI International Scientific and Professional Meeting Ecological Truth Proceedings, Bor, Serbia, p436-437. ISBN: 978-86-80987-98-9.

Vratuša V., Anastasijević N. (1998): The role of urban greens cape in Belgrade - Yugoslavia, Proceedings of AISF-EFI International Conference on Forest Management in Designated Conservation and Recreation areas, University of Padua Press, Florence. p.461-473.

VISUAL ASSESSMENT OF TREE CONDITION AS A BASIS FOR URBAN GREEN SPACE MANAGEMENT: A CASE STUDY OF GAVRILO PRINCIP PARK IN BELGRADE

Katarina MARINKOVIĆ, Suzana MITROVIĆ, Miloš RAČIĆ, Nikola MARTAĆ, Nemanja LAZAREVIĆ, Jovana CVETKOVIĆ

Summary

The focus of this study is the identification and analysis of vitality and ornamentality parameters of the trees in Gavrilo Princip Park, as an object of cultural-historical, sociological and ecological importance for the green infrastructure of Belgrade. The objective of the paper is to present the importance of regular monitoring of green areas in management of urban green spaces. On the researched location, a total of 172 trees within 39 taxa (Gymnosperms 8 taxa and Angiosperms 31 taxa) were identified and analyzed. The assessment of trees was conducted using the method of Visual Tree Assessment (VTA). The attributes based on which the analysis was carried out are vitality and ornamentality marks expressed according to the established five-point scale.

The taxa within the Angiosperms dominate in the park with 141 trees, and the most frequently recorded species is *Tilia cordata* Mill. with 20 individuals. As for Gymnosperms 31 trees were identified, whereby Austrian pine is the most frequent with 15 trees. According to the vitality assessment the highest ranked species are *Taxus baccata* L., *Cercis siliquastrum* L., *Fraxinus angustifolia* Vahl. and *Prunus cerasifera* 'Atropurpurea', while *Cercis siliquastrum* L., *Fraxinus angustifolia* Vahl., *Liquidambar styraciflua* L., *Liriodendron tulipifera* L., *Magnolia × soulangeana* Soul.-Bod., *Platanus × hispanica* Mill. ex Münch., *Quercus robur* L., *Quercus robur* 'Fastigiata' were rated as the most decorative species. The taxa *Abies alba* Mill., *Acer negundo* L., *Catalpa bignonioides* Walter, *Salix babylonica* var. *matsudana* 'Tortuosa' and *Scandosorbus intermedia* Pers. had the lowest marks for both analyzed parameters.

Descriptive statistical analysis showed that the average marks of vitality and ornamentality in Gymnosperms (3.32; 3.48) were higher than in Angiosperms (2.94; 3.12). The results of the Mann–Whitney U test show that there are statistically significant differences between gymnosperms and angiosperms, both in vitality ($U = 1618.50$; $Z = -2.38$; $p = 0.017$), and ornamentality ($U = 1656.00$; $Z = -2.23$; $p = 0.026$). For the entire sample, Spearman's correlation coefficient was 0.906 ($p < 0.001$), which indicates a very strong correlation between vitality and ornamentality. The Kendall's τ coefficient further confirmed the correlation analysis.

This paper indicates the crucial importance of early visual assessment of dendroflora in urban areas in order to apply care and protection measures adequately and in a timely manner. In this way, potential risks for users of public green areas would be prevented, but also possible centers of occurrence of phytopathological diseases, entomological damage and chains of damage.

VIZUELNA PROCENA STANJA DRVEĆA KAO OSNOVA ZA UPRAVLJANJE URBANIM ZELENIM POVRŠINAMA NA PRIMERU PARKA GAVRILA PRINCIPA U BEOGRADU

Katarina MARINKOVIĆ, Suzana MITROVIĆ, Miloš RAČIĆ, Nikola MARTAĆ, Nemanja LAZAREVIĆ, Jovana CVETKOVIĆ

Rezime

Fokus ove studije je identifikacija i analiza parametara vitalnosti i dekorativnosti drveća u parku Gavrila Principa, kao objekta od kulturno-istorijskog, sociološkog i ekološkog značaja za zelenu infrastrukturu Beograda. Cilj rada je prikazati značaj redovnog monitoringa zelenih površina pri upravljanju zelenilom urbanih prostora. Na istraživanoj lokaciji ukupno je identifikovano i analizirano 172 stabla, u okviru 39 taksona (golosemenice 8 taksona i skrivenosemenice 31 takson). Procena stabala rađena je primenom metode vizuelne procene drveća (VTA). Atributi na osnovu kojih je rađena analiza su ocene vitalnosti i dekorativnosti izražene prema ustaljenoj petostepenoj skali.

U parku dominiraju taksoni u okviru skrivenosemenica sa 141 stablom, a najčešće zabeležena vrsta je *Tilia cordata* Mill. sa 20 jedinki. Što se tiče golosemenica, identifikovano je 31 stablo, pri čemu je najčešći crni bor sa 15 stabala. Prema oceni vitalnosti najviše su rangirane vrste *Taxus baccata* L., *Cercis siliquastrum* L., *Fraxinus angustifolia* Vahl. i *Prunus cerasifera* 'Atropurpurea', dok su najboljom dekorativnošću ocenjeni *Cercis siliquastrum* L., *Fraxinus angustifolia* Vahl., *Liquidambar styraciflua* L., *Liriodendron tulipifera* L., *Magnolia × soulangeana* Soul.-Bod., *Platanus × hispanica* Mill. ex Münch., *Quercus robur* L., *Quercus robur* 'Fastigiata'. Taksoni *Abies alba* Mill., *Acer negundo* L., *Catalpa bignonioides* Walter, *Salix babylonica* var. *matsudana* 'Tortuosa' i *Scandosorbus intermedia* Pers. najniže su ocenjeni po oba analizirana parametra.

Deskriptivnom statističkom analizom utvrđeno je da su prosečne ocene vitalnosti i dekorativnosti kod golosemenica (3.32; 3.48) više nego kod skrivenosemenica (2.94; 3.12). Rezultati Mann–Whitney U testa pokazuju da postoje statistički značajne razlike između golosemenica i skrivenosemenica, kako vitalnosti ($U = 1618.50$; $Z = -2.38$; $p = 0.017$), tako i dekorativnosti ($U = 1656.00$; $Z = -2.23$; $p = 0.026$). Na nivou celokupnog uzorka, Spearmanov koeficijent korelacije iznosi 0.906 ($p < 0.001$), što ukazuje na veoma jaku povezanost vitalnosti i dekorativnosti. Kendallovim τ koeficijentom dodatno je potvrđena sprovedena korelaciona analiza.

Ovim radom ukazuje se na krucijalnu važnost rane vizuelne procene dendroflore u urbanim područjima kako bi se blagovremeno i adekvatno primenjivale mere nege i zaštite. Na taj način, bili bi sprečeni potencijalni rizici po korisnike javnih zelenih površina, ali i moguća žarišta nastanka fitopatoloških oboljenja, entomoloških očtećenja i ulančavanja šteta.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY COLLECTION 93, 2026

ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 93, 2026

UDK: 712.252:504.5“2025“(497.11)=111
DOI: 10.5937/SustFor2693047M
Original scientific paper

AIR QUALITY IN BELGRADE DURING 2025: SEASONAL DYNAMICS, METEOROLOGICAL CONDITIONS, AND THE POTENTIAL OF URBAN FORESTS AND GREENERY IN MITIGATING AIR POLLUTION

Miroslava MARKOVIĆ[1], Goran ČEŠLJAR[1], Bojan KONATAR[1], Katarina MLADENOVIĆ[1]*

Abstract: *Air pollution is one of the key environmental and public health problems of contemporary cities. The aim of this paper was to examine the seasonal dynamics of air pollution in Belgrade during 2025, with particular attention to the role of meteorological conditions and the potential of urban forests and green infrastructure in mitigating population exposure to pollution. The paper is based on a literature review and an analysis of publicly available secondary data, including additional sources on the structure and maintenance of urban greenery in Belgrade. The results indicate a pronounced seasonal variability in air quality, with dominant episodes of suspended particles during the colder part of the year and a greater importance of ground-level ozone during the warmer period. It was observed that meteorological conditions, particularly wind and air ventilation, play an important role in the formation and dispersion of air pollution episodes. The literature review shows that urban forests and green infrastructure can contribute to reducing population exposure to pollution, but that their effect depends on spatial scale, urban form, vegetation structure, and local climatic conditions. The most useful urban planting approach is not based on a single species, but on site-adapted combinations of tolerant trees with high leaf area and suitable crown architecture, including tree avenues and shade trees where ventilation is not obstructed. It is concluded that urban greenery represents an important complementary measure, but not a substitute for reducing emissions at the source.*

Keywords: particulate matter; ground-level ozone; tree avenues; green zones; shade trees.

KVALITET VAZDUHA U BEOGRADU TOKOM 2025. GODINE: SEZONSKA DINAMIKA, METEOROLOŠKI USLOVI I POTENCIJAL URBANIH ŠUMA I ZELENILA U UBLAŽAVANJU AEROZAGAĐENJA

Sažetak: *Zagađenje vazduha predstavlja jedan od ključnih ekoloških i javnozdravstvenih problema savremenih gradova. Cilj ovog rada bio je da se sagleda sezonska dinamika aerozagađenja u Beogradu tokom 2025. godine, uz razmatranje uloge*

[1] Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
*Corresponding author. E-mail: mira019@gmail.com

© 2026 The Authors. Published by the Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

meteoroloških uslova i potencijala urbanih šuma i zelene infrastrukture u ublažavanju izloženosti zagađenju. Rad je zasnovan na pregledu literature i analizi javno dostupnih sekundarnih podataka, uključujući dodatne izvore o strukturi i održavanju urbanog zelenila u Beogradu. Rezultati ukazuju na izraženu sezonsku promenljivost kvaliteta vazduha, sa dominantnim epizodama suspendovanih čestica u hladnijem delu godine i većim značajem prizemnog ozona tokom toplijeg perioda. Uočeno je da meteorološki uslovi, naročito vetar i ventilacija vazduha, imaju važnu ulogu u formiranju i disperziji epizoda aerozagađenja. Pregled literature pokazuje da urbane šume i zelena infrastruktura mogu doprineti ublažavanju izloženosti stanovništva zagađenju, ali da njihov efekat zavisi od prostorne razmere, urbanog oblika, strukture vegetacije i lokalnih klimatskih uslova. Najkorisniji pristup ozelenjavanju ne zasniva se na jednoj vrsti, već na lokalno prilagođenim kombinacijama tolerantnih stabala sa velikom lisnom površinom i odgovarajućom arhitekturom krošnje, posebno u drvoredima i zelenim zonama u kojima se ne ometa ventilacija. Zaključuje se da urbano zelenilo predstavlja važnu dopunsku meru, ali ne i zamenu za smanjenje emisija na izvoru.

Ključne reči: suspendovane čestice; prizemni ozon; drvoredi; zelene zone; stabla senke.

1. INTRODUCTION

Air pollution is one of the most significant environmental and public health problems of contemporary cities. Suspended particles, particularly PM2.5 and PM10, as well as NO2 and ground-level O3, are associated with an increased risk of respiratory and cardiovascular diseases, which is why air quality occupies an important place in contemporary urban and public health policies. Additional weight is given to this issue by the more recent guidelines of the World Health Organization, which have tightened the recommended values for key pollutants (WHO, 2021).

Belgrade has long stood out as an urban area where air pollution is pronounced particularly during the colder part of the year. Official monthly reports of the Serbian Environmental Protection Agency for 2025 confirm a marked seasonal pattern, with a higher number of exceedances of the daily limit value for PM10 at several Belgrade monitoring stations during the winter months. For example, in January 2025, 5 days with exceedances were recorded at the Belgrade Stari Grad station, 7 in Novi Beograd, 11 at Mostar, 6 at Vračar, and 5 at Zeleno brdo, clearly indicating a pronounced problem of suspended particles during the winter period (SEPA, 2025).

In addition to emissions themselves, air quality in Belgrade also depends on meteorological conditions, especially ventilation and the dispersion of air pollutants. In this respect, the Košava wind is of particular importance, as it can contribute to the dilution of pollution and the mitigation of smog episodes. Therefore, air pollution in Belgrade cannot be interpreted solely through emission intensity, but also through local climatic and anemological specificities (Milošević Pantović et al., 2024).

Urban forests and green infrastructure are increasingly being considered as complementary measures for mitigating the effects of air pollution. Trees and other forms of urban greenery can contribute to particle deposition, changes in microclimatic conditions, reductions in air temperature, and reduced population exposure to certain pollutants. However, recent literature shows that their impact is not unambiguous: at the broader urban scale, greenery may contribute to improved air quality, but this effect is most often moderate, while at the level of street canyons and densely built-up areas it may depend on spatial configuration, vegetation type, and aerodynamic conditions (Venter et al., 2024). Similarly, some studies indicate that the more favorable effects of green spaces on PM10 become more apparent only above a certain threshold of spatial coverage, which further supports a cautious interpretation of the relationship between greening and air quality (Islam et al., 2024).

An additional methodological problem is the fact that the concepts of forest cover, green spaces, and tree canopy cover cannot be used as synonyms. Therefore, it is scientifically more justified to speak of reference greening targets than of a single universal, optimal level of urban forest cover (UNP+, 2025; EEA, 2025).

Based on the above, a review of the relationship between the seasonal dynamics of air pollution in Belgrade, meteorological conditions, and the state of urban forests and greenery can provide a relevant basis for an interdisciplinary understanding of this issue, while at the same time taking into account the limitations of the available data and the complexity of the urban system itself (Venter et al., 2024; European Environment Agency, 2025).

2. AIMS OF THE STUDY AND RESEARCH QUESTIONS

The aim of this paper is, based on a review of the available literature and publicly available data, to examine the seasonal dynamics of air pollution in Belgrade during 2025, to consider the significance of meteorological conditions in the formation and dispersion of pollution episodes, and to assess the potential of urban forests, tree avenues, and green infrastructure as complementary measures for reducing population exposure to polluted air (Venter et al., 2024; SEPA, 2025; UNP+, 2025).

A specific aim of the paper is to critically consider to what extent the available literature supports the contribution of urban forests and green infrastructure to air pollution mitigation, and whether it is scientifically justified, in the case of Belgrade, to speak of a single optimal level of forest cover, or whether it is more appropriate to use the concept of reference greening targets, taking into account local climatic, spatial, and urban planning specificities (Venter et al., 2024; Islam et al., 2024; EEA, 2025).

The following research questions were considered in the paper:

1. What is the seasonal dynamics of air pollution in Belgrade during 2025, as observed through the available monthly and annual air quality indicators (SEPA, 2025)?
2. To what extent do meteorological conditions, especially wind and air ventilation, influence the intensity and spatial manifestation of air pollution episodes in Belgrade (Milošević Pantović et al., 2024)?
3. What does the contemporary literature show about the role of urban forests, green spaces, tree avenues, and tree canopy cover in mitigating pollutant concentrations in cities, and which vegetation traits and commonly used tree genera may be relevant for reducing exposure to particulate pollution

(Rodríguez-Santamaría et al., 2022; Gaglio et al., 2022; Venter et al., 2024; Islam et al., 2024)?

4. Can one speak of a single optimal level of forest cover for Belgrade, based on the available data on urban greenery and the literature on urban tree cover, or is it scientifically more justified to speak of indicative and locally adapted greening targets (UNP+, 2025; EEA, 2025)?
5. To what extent can urban forests and green infrastructure represent a realistic complementary measure for mitigating air pollution in Belgrade, given that they cannot replace emission reductions at the source (Venter et al., 2024)?

3. MATERIAL AND METHODS

This paper was conceived as a literature review with elements of publicly available secondary data analysis. Such an approach was chosen because it enables the integration of official air quality data, data on urban greenery, and contemporary literature on the role of urban forests and green infrastructure in mitigating air pollution (Grant & Booth, 2009; Snyder, 2019).

The analysis was based on publicly available data and documents. To assess the seasonal dynamics of air pollution, monthly reports of the Serbian Environmental Protection Agency on detected exceedances of air pollutant limit values during 2025 were used, with particular emphasis on data for the Belgrade area. To examine the state of urban greenery and forests, available data and descriptions from the Urban Nature Plans Plus platform were used, as well as relevant European sources referring to indicators of green infrastructure and tree canopy cover (SEPA, 2025; Urban Nature Plans Plus, 2025; European Environment Agency, 2025). Additional information on the maintained tree avenues and park forests in Belgrade was obtained from the official pages of JKP "Zelenilo-Beograd", while planning aspects of Belgrade's green infrastructure were interpreted using published analyses of the Belgrade green space system and green infrastructure planning (Marić et al., 2015; JKP "Zelenilo-Beograd", n.d.a, n.d.b).

In addition to official sources, contemporary scientific literature was also used, addressing four key thematic areas: the seasonal dynamics of air pollution in urban environments, the influence of meteorological conditions on the dispersion of air pollutants, the role of urban forests and greenery in improving air quality, and species- or trait-related differences in particulate matter retention by urban trees. Particular attention was paid to recent papers and review studies indicating that the effects of urban greenery depend on spatial scale, urban form, local climatic conditions, and leaf and crown traits (Rodríguez-Santamaría et al., 2022; Gaglio et al., 2022; Venter et al., 2024; Islam et al., 2024).

In the analytical part of the study, seasonal patterns of air pollution in Belgrade were first identified on the basis of the available monthly reports for 2025. These patterns were then interpreted in light of the literature on meteorological factors, particularly wind and air ventilation, and in relation to the existing state of urban forests and greenery in Belgrade. Special consideration was given to the fact that the concepts of forest cover, green spaces, tree avenues, and tree canopy cover do not represent the same category and cannot be directly equated (European Environment Agency, 2025; JKP "Zelenilo-Beograd", n.d.a, n.d.b).

A limitation of this approach is that the paper is not based on original field measurements or spatially explicit modelling, but rather on the interpretation of secondary data and available literature. Nevertheless, such a methodological framework is suitable for a review paper whose aim is to synthesize existing knowledge and point out the main patterns and limitations in considering the relationship between air pollution, meteorological conditions, and urban greenery in Belgrade (Snyder, 2019).

4. SEASONAL DYNAMICS OF AIR POLLUTION IN BELGRADE DURING 2025

The seasonal dynamics of air pollution in Belgrade during 2025 show a clear annual pattern, with episodes of suspended particles being more pronounced during the colder part of the year, while ground-level ozone episodes become more important during the warmer part of the year. Such a pattern corresponds to the general characteristics of urban air pollution in temperate climatic conditions, where winter is dominated by emissions from heating and traffic combined with less favorable dispersion conditions, whereas in summer photochemical processes in the atmosphere become more important (World Health Organization, 2021).

Official monthly reports of the Serbian Environmental Protection Agency for 2025 confirm this pattern for the Belgrade area as well. Separate monthly reports for 2025 are available on the SEPA website, containing information on exceedances of hourly and daily limit values for SO2, NO2, PM10, CO, and ground-level ozone.

In January 2025, exceedances of the daily limit value for PM10 were recorded at several Belgrade monitoring sites, with 11 days of exceedance at the Belgrade Mostar station and 5 days at the Belgrade Zeleno brdo station. In July 2025, the pattern was different: 1 exceedance of PM10 was recorded at the Belgrade Mostar station, while 14 days with exceedance of O3 were recorded at the Belgrade Zeleno brdo station. With the onset of late autumn, the problem of suspended particles became more pronounced again, so in November 2025, 6 days with PM10 exceedances were recorded at the Belgrade Mostar station and 1 day at the Belgrade Zeleno brdo station. These data confirm that the problem of suspended particles is more pronounced during winter and late autumn, whereas the importance of ground-level ozone increases during the summer months.

To illustrate spatial differences in the seasonal dynamics of air pollution within Belgrade, Table 1 presents the monthly number of days with exceedances of the limit/target values for PM10 and O3 at the Belgrade Mostar and Belgrade Zeleno brdo stations during 2025 (SEPA, 2025).

Table 1. *Comparative overview of the monthly number of days with exceedances of the daily limit value for PM10 and the target value for O3 at the Mostar and Zeleno brdo stations during 2025*

Month 2025	Mostar – PM_{10}	Zeleno brdo – PM_{10}	Mostar – O_3	Zeleno brdo – O_3
January	11	5	0	0
February	11	6	0	0
March	10	1	0	0
April	0	0	0	0
May	0	0	0	3

Month 2025	Mostar – PM_{10}	Zeleno brdo – PM_{10}	Mostar – O_3	Zeleno brdo – O_3
June	3	0	0	11
July	1	0	0	14
August	0	0	0	11
September	0	0	0	1
October	5	1	0	0
November	6	1	0	0
December	13	9	0	0
Total	**60**	**23**	**0**	**40**

The results show that a considerably higher number of days with PM10 exceedances was recorded at the Mostar monitoring station, indicating a greater burden of suspended particles at this central, traffic-intensive location. In contrast, at the Zeleno brdo station, a higher number of days with exceedances of the target value for O3 was recorded during the warmer part of the year. This pattern indicates that spatial differences in air quality within Belgrade cannot be explained solely by the presence of greenery, but also by the type of pollutant, traffic intensity, the location of the monitoring station, and local meteorological conditions. Therefore, this comparison should be regarded as an illustration of the spatial variability of air pollution in urban conditions, rather than as direct evidence of the influence of forest cover or greenery on pollutant concentrations.

Such a seasonal shift in dominant pollutants shows that air pollution in Belgrade is not a single, uniform problem, but rather a set of seasonally variable phenomena with different origins. The winter period is primarily burdened by suspended particles, whereas during summer the importance of secondary photochemical pollutants becomes more pronounced. This dynamic indicates that air quality in Belgrade must be viewed as the result of the interaction between emission sources, atmospheric processes, and meteorological conditions, which provides an important basis for further consideration of the role of wind, dispersion, and the potential contribution of urban forests and greenery.

5. METEOROLOGICAL CONDITIONS AND THE DISPERSION OF AIR POLLUTANTS IN BELGRADE

In addition to emission intensity, air quality in Belgrade also depends to a large extent on meteorological conditions, particularly wind, atmospheric stability, and the possibility of pollutant dispersion. This means that episodes of air pollution cannot be interpreted solely through the presence of emission sources, but also through the atmosphere’s ability to dilute and transport these pollutants. In urban areas, low wind speeds and stable conditions favor the accumulation of suspended particles, whereas stronger winds most often contribute to the reduction of their concentrations (Đurić et al., 2020; Davidović et al., 2021).

In this respect, the Košava wind is especially important for Belgrade. It is a regionally characteristic wind that represents one of the significant natural factors of ventilation of the urban atmosphere. In domestic and regional studies, Košava is described as a wind that can significantly influence air exchange and the dispersal of pollution, particularly during episodes when it blows for several consecutive days. As a result, more favorable dispersion of air pollutants is often recorded in Belgrade under Košava conditions than during calm and stable weather (Milošević Pantović et al., 2024).

The relationship between wind speed and pollution levels has also been confirmed in studies analyzing winter air pollution episodes in Belgrade. Đurić et al. (2020) showed that wind speed is an important predictor of the air pollution index, while Davidović et al. (2021) found that stronger winds alter the composition of local air pollution and contribute to a reduction in the concentration of the fine particle fraction. Such findings indicate that meteorological conditions do not act merely as an accompanying factor, but rather as an important regulator of the intensity and duration of air pollution episodes in the city.

In the context of this study, this is particularly important because it shows that the relationship between air pollution and urban forests in Belgrade cannot be considered in isolation from local ventilation conditions. In other words, the potential of greenery to contribute to reducing exposure to pollution must be interpreted together with specific meteorological conditions, with Košava representing one of the important modulators of air quality in Belgrade. It can therefore be regarded as a significant local factor that mitigates part of the adverse effects of air pollution, although it does not affect the emission sources themselves (Đurić et al., 2020; Milošević Pantović et al., 2024).

6. URBAN FORESTS, GREEN SPACES, AND TREE CANOPY COVER IN BELGRADE

Considering the role of urban forests and greenery in mitigating air pollution in Belgrade first requires a clear distinction between several terms that are often confused in practice: forest cover, green spaces, tree avenues, and tree canopy cover. These indicators are not identical and do not describe the same spatial or functional category. In its urban assessments, the European Environment Agency specifically distinguishes tree cover as a separate indicator based on Urban Atlas data, and it cannot be directly equated with the area under forests or with total green spaces. Therefore, these terms must be used carefully and consistently in the analysis of Belgrade (European Environment Agency, 2025).

Available sources indicate that Belgrade possesses significant green resources, although they are unevenly distributed in spatial terms. According to the Urban Nature Plans Plus platform, approximately 16% of the city's territory is covered by forests and around 15% by green spaces, confirming that natural and semi-natural vegetation represents an important component of the urban environment (Urban Nature Plans Plus, 2025; https://interlace-hub.com/urban-nature-plan-plus/belgrade-serbia). These data, however, do not provide sufficient information on the distribution of greenery within the compact urban tissue, nor on the degree to which its effects are available to the population in the most polluted and densely built-up zones.

Additional information on the maintained urban greenery is provided by JKP "Zelenilo-Beograd". According to this source, the enterprise maintains 56,513 trees in street avenues in 743 streets of Belgrade. The tree avenues include about 50 tree species and around 28 genera, with the most represented genera being Acer, Platanus, Aesculus, Tilia, and Fraxinus. The same source states that one avenue tree corresponds to approximately 20 inhabitants of Belgrade, and that the largest number of avenue trees is located in the municipality of Novi Beograd, while fewer are found in Rakovica, Vračar, and Čukarica (JKP "Zelenilo-Beograd", n.d.a; https://www.zelenilo.rs/delatnosti/odrzavanje-zelenih-povrsina/drvoredi).

In addition to avenue trees, JKP "Zelenilo-Beograd" maintains about 400 ha of park forests, including 16 ha of protective belts. The maintained park-forest areas include Milićevo brdo, Zvezdara, Crveni breg, Banjički vis, Lisiciji potok, Hajd park, parts of Topčider, Rejsova padina, Jajinci, Šumice, Kijevo-Kneževac, Petlovo brdo, Repište, and Bežanijska kosa (JKP "Zelenilo-Beograd", n.d.b; https://www.zelenilo.rs/delatnosti/odrzavanje-zelenih-povrsina/odrzavanje-suma). These data show that Belgrade's green system is composed not only of compact forests and large parks, but also of linear elements, small green spaces, protective belts, and tree avenues.

The importance of such a networked approach is also supported by the planning literature. Marić et al. (2015) note that the Master Plan of Belgrade introduced the concept of an urban green space system that includes suburban forests, private forests and shrubs, urban forests, urban gardens, urban parks, and tree avenues. The same authors emphasize that the Belgrade Green Regulation project was based on the principles of connectivity, multifunctionality, accessibility, biodiversity preservation, and improvement of the state of the environment. Therefore, the issue of greenery in Belgrade should be interpreted not only through total area, but also through connectivity, continuity of green corridors, and the position of trees in relation to traffic corridors and zones of high exposure.

For the subject of this paper, it is particularly important that the state of greenery in Belgrade cannot be reduced to the simple question of whether there is enough of it or not. Scientifically, it is more precise to say that the total amount of greenery and forest cover represents only one part of the picture, while for air quality equally important factors are likely to include spatial distribution, connectivity, the presence of tree lines and smaller green areas in zones of highest population exposure, species composition, crown density, and the relationship between vegetation and urban ventilation. For this reason, in the further analysis Belgrade cannot be assessed solely through the total percentage of forest cover, but rather through the broader concept of urban green infrastructure.

7. THE ROLE OF URBAN FORESTS AND GREEN INFRASTRUCTURE IN MITIGATING AIR POLLUTION

Contemporary literature generally confirms that urban greenery can contribute to the mitigation of air pollution, while at the same time showing that this effect is neither simple nor universal. Vegetation can influence air quality through several mechanisms, including the deposition and retention of suspended particles on leaf surfaces, changes in local turbulence, reductions in temperature, and modifications of microclimatic conditions. However, recent studies warn that the actual effect is most often moderate and that its magnitude depends on spatial scale, urban form, vegetation type, and leaf and crown traits (Rodríguez-Santamaría et al., 2022; Gaglio et al., 2022; Venter et al., 2024; Sun et al., 2024).

It is particularly important that the positive effects of urban greenery are not equally expressed at all spatial levels. Venter et al. (2024) conclude that greening may contribute to improved air quality at the level of a neighborhood or an entire city, but that this contribution is generally limited, whereas at street level the effects may even be unfavorable, especially if vegetation obstructs ventilation. This means that simply increasing the amount of greenery does not automatically guarantee a proportional reduction in pollution in every urban context.

Species selection is nevertheless important because particulate matter retention differs among tree species and is influenced by traits such as leaf area, leaf surface roughness, waxes, trichomes, canopy density, phenology, and tolerance to urban stress. Review studies emphasize that broad leaf area and complex leaf surfaces may increase particle capture, while evergreen and coniferous species can provide longer seasonal retention, although their use in streets must be balanced with drought tolerance, allergenic potential, maintenance needs, and the need to preserve ventilation (Rodríguez-Santamaría et al., 2022; Gaglio et al., 2022).

In Belgrade, the most represented avenue genera are Acer, Platanus, Aesculus, Tilia, and Fraxinus (JKP "Zelenilo-Beograd", n.d.a). These genera can therefore be considered relevant not only because they are already established in the city, but also because they include broadleaved trees with relatively large crowns and substantial leaf area, which can be useful for shading and particle deposition when properly placed and maintained. However, no single genus should be recommended universally. Planting should be adapted to street width, underground infrastructure, available rooting space, exposure to de-icing salt, drought risk, pest susceptibility, and the need for air flow through narrow urban canyons.

From the perspective of reducing exposure to air pollution, the most suitable practical approach for Belgrade would be to combine: (i) large-crowned shade trees in parks, squares, schoolyards, and wider boulevards; (ii) continuous but well-spaced tree avenues along traffic corridors where ventilation is not obstructed; (iii) shrub and hedge belts or mixed vegetation barriers between traffic lanes and pedestrian zones where space allows; and (iv) coniferous or evergreen elements primarily in park forests, protective belts, and wider open spaces where they can contribute to year-round filtration without worsening street-canyon ventilation. Such recommendations should be interpreted as planning guidelines rather than as a fixed list of mandatory species.

In addition, some studies indicate that a certain threshold of green space coverage is probably needed for a clearer effect on suspended particles. Islam et al. (2024) state that at least about 27% green space within the land cover structure could be associated with a more significant reduction in PM10 fluxes, while at the same time emphasizing that this threshold is not universal and depends on the local climatic and urban context. This finding is important because it supports the idea that one should not speak of a single fixed optimal value, but rather of indicative reference targets that require local verification.

One of the main limitations of the action of urban greenery relates to densely built-up areas and so-called street canyons. Under such conditions, trees and other vegetation may reduce air flow velocity and hinder the dispersion of air pollutants, so the local effect may be opposite to what is expected. For this reason, an increasing number of studies emphasize that the influence of urban forests on air quality must be considered together with urban morphology, street width, building height, vegetation permeability, and ventilation corridors, rather than separately from them (Buccolieri, 2021; Venter et al., 2024).

For the purposes of this study, the most important point is that the literature does not support the oversimplified thesis that greater forest cover by itself will solve the problem of air pollution. It is scientifically much more justified to conclude that urban forests, tree avenues, and green infrastructure may represent complementary measures for reducing population exposure to pollution, but that their effect depends on local conditions and cannot replace emission reduction at the source. In other words, the potential of urban greenery is real, but it is contextual, spatially conditioned, and as a rule smaller than is often assumed in public discourse (Venter et al., 2024; Sun et al., 2024).

8. LIMITATIONS OF THE APPLICATION OF THE CONCEPT OF OPTIMAL FOREST COVER IN THE URBAN CONDITIONS OF BELGRADE

The concept of optimal forest cover in urban conditions should be used with great caution, because contemporary literature and planning practice do not provide a single, universally applicable value that would be valid for all cities. The reason is primarily methodological: indicators of land under forests, green spaces, and tree canopy cover do not describe the same category and cannot be directly equated. The European Environment Agency treats urban tree cover as a separate indicator based on Copernicus/Urban Atlas data, which in itself shows that the question of how much greenery is enough cannot be reduced to a single simple figure.

In addition, recent literature indicates that the effect of urban greenery on air quality depends on spatial scale and urban context. Venter et al. (2024) conclude that greening may contribute to improved air quality at the level of a neighborhood or an entire city, but that this effect is generally moderate and may even be unfavorable at street level if vegetation interferes with ventilation. This means that even a high proportion of greenery does not by itself guarantee an optimal effect on air pollution.

Similarly, Islam et al. (2024) indicate that more significant effects of green spaces on PM10 reduction may be expected only above a certain threshold of coverage, with their analysis suggesting that around 27% green space cover could be associated with a more pronounced effect. However, the same authors emphasize that this threshold depends on local urban and climatic conditions and should therefore not be interpreted as a universal optimal value.

In the case of Belgrade, an additional problem is that available sources describe the state of urban greenery through different indicators. Urban Nature Plans Plus states that Belgrade has approximately 16% of its territory under forests and around 15% under green spaces, while JKP "Zelenilo-Beograd" provides operational data on maintained street avenues and park forests, including 56,513 avenue trees in 743 streets and about 400 ha of maintained park forests (Urban Nature Plans Plus, 2025; JKP "Zelenilo-Beograd", n.d.a, n.d.b). These indicators do not provide the same type of information and do not fully describe tree canopy continuity, crown condition, age structure, connectivity, or exposure reduction in the most densely built-up parts of the city. For this reason, the overall percentage of forest cover cannot serve as a sufficient criterion for assessing whether the situation is optimal from the point of view of air quality and population exposure.

For all these reasons, under the urban conditions of Belgrade it is scientifically more justified to speak of locally adapted greening targets than of a single optimal forest cover. Such an approach makes it possible to take into account the climatic characteristics of the city, the role of wind and ventilation, the distribution of traffic corridors, building density, and the actual accessibility of greenery to the population. In this sense, the concept of optimal forest cover may be useful as a planning and research framework, but not as an exact, predefined value that could be directly applied to Belgrade.

9. DISCUSSION

The available data for 2025 show that air pollution in Belgrade follows a clear seasonal pattern, with exceedances of PM10 being more pronounced during the colder part of the year, while ground-level ozone episodes become more important during the warmer period. Such dynamics are consistent with the official SEPA monthly reports for 2025, which present exceedances of PM10, O3, and other pollutants for each month, as well as with the general health and environmental framework emphasizing the importance of suspended particles and ozone in urban environments (SEPA, 2025; WHO, 2021).

At the same time, this pattern confirms that the problem of air quality in Belgrade cannot be interpreted solely through the presence of emission sources. Local meteorological conditions, especially wind and air ventilation, represent important regulators of the intensity and duration of pollution episodes. Under Belgrade conditions, this is particularly important because of the Košava wind, which can contribute to more efficient dispersion of air pollutants and to the mitigation of pollutant accumulation. For this reason, the seasonal dynamics of air pollution must be viewed as the result of the combined action of emissions, atmospheric chemistry, and meteorological conditions, rather than as the consequence of a single factor (Milošević Pantović et al., 2024).

The available literature also shows that urban forests and greenery may have a positive effect on air quality, but that this effect is generally moderate and strongly dependent on spatial scale and urban context. Venter et al. (2024) indicate that greening may contribute to improved air quality at the neighborhood or city level, but that the effects are mostly moderate and may even be unfavorable at street level if vegetation interferes with ventilation. Similarly, Islam et al. (2024) report that a more significant effect of green spaces on PM10 reduction may be associated with a higher proportion of green space cover, with an estimated indicative value of around 27%, while clearly emphasizing that this threshold depends on local conditions and is not universally applicable.

In the case of Belgrade, an additional methodological complexity arises from the fact that the state of urban greenery is described through different indicators. SEPA monthly reports provide an overview of exceedances of air pollutants, whereas the EEA uses urban tree cover as a separate indicator, Urban Nature Plans Plus for Belgrade reports approximately 16% of the territory under forests and around 15% under green spaces, and JKP “Zelenilo-Beograd” reports operational data on maintained tree avenues and park forests. Since these indicators do not represent the same category, it is not scientifically justified to translate them directly into a single optimal level of forest cover for the city. It is much more precise to speak of locally adapted greening and green infrastructure improvement targets than of one universal optimal value for Belgrade.

Based on all of the above, it can be concluded that urban forests and green infrastructure in Belgrade have real potential as complementary measures for reducing population exposure to air pollution, but they cannot replace emission reduction at the source. The most useful contribution can be expected from spatially planned combinations of park forests, connected green zones, tree avenues, shade trees, and vegetation barriers, with species selection based on tolerance to urban stress and on leaf and crown traits relevant for particulate matter retention. Their contribution should be considered together with local meteorological conditions, the distribution of traffic corridors, building density, and the existing spatial distribution of greenery. For this reason, the most scientifically defensible approach for Belgrade is to treat the issue of optimal forest cover as a planning and research concept, rather than as a predefined and universally valid figure.

10. CONCLUSION

Based on the available data and the reviewed literature, it can be concluded that air pollution in Belgrade during 2025 exhibited a pronounced seasonal pattern, with suspended particle episodes being more dominant during the colder part of the year, while ground-level ozone episodes became more important during the warmer period (SEPA, 2025; WHO, 2021). This pattern confirms that air quality in the city cannot be interpreted solely through emission intensity, but also through the action of meteorological factors, especially wind and the dispersion of air pollutants. In this respect, the Košava wind represents an important local factor that can mitigate the intensity of air pollution episodes, although it does not affect the emission sources themselves (Milošević Pantović et al., 2024).

A review of the contemporary literature shows that urban forests and green infrastructure can contribute to mitigating population exposure to air pollution, but that their effect is generally moderate and strongly dependent on spatial scale, urban form, and local climatic conditions. Therefore, it is not scientifically justified to reduce the issue of air quality in Belgrade to the simple assumption that greater forest cover will automatically lead to a proportional reduction in pollution (Venter et al., 2024; Islam et al., 2024).

At the same time, the available data on the state of urban greenery in Belgrade indicate that the concepts of forest cover, green spaces, tree avenues, park forests, and tree canopy cover cannot be used as synonyms, which is why the concept of optimal forest cover in urban conditions must be applied with caution. The available operational data show that Belgrade has a substantial but uneven green system, including maintained avenue trees and park forests, with Acer, Platanus, Aesculus, Tilia, and Fraxinus among the most represented avenue genera (JKP “Zelenilo-Beograd”, n.d.a, n.d.b). In the case of Belgrade, it is scientifically more justified to speak of locally adapted greening and green infrastructure improvement targets than of a single optimal value that would be universally applicable (EEA, 2025; UNP+, 2025).

Overall, urban forests and green infrastructure in Belgrade should be regarded as important complementary measures in mitigating the effects of air pollution, but not as a substitute for emission reduction at the source. In practical terms, priority should be given to maintaining existing park forests and tree avenues, improving connectivity between green zones, and selecting site-appropriate shade trees and mixed vegetation barriers in locations where they reduce exposure without obstructing air circulation. The practical significance of such an approach lies in the fact that it opens space for an integrated consideration of air quality, urban planning, and green infrastructure, while taking into account the local specificities of the city.

Acknowledgement: *This study was supported by the Republic of Serbia, Ministry of Education, Science and Technological Development, under Agreement No. 451-03-33/2026-03/200027, dated 5 February 2026.*

REFERENCES

Balkan Green Energy News. (2024, November 8). Belgrade prepares draft Green Infrastructure Strategy. https://balkangreenenergynews.com/belgrade-prepares-draft-green-infrastructure-strategy/

Buccolieri, R. (2021). Urban obstacles influence on street canyon ventilation: A brief review. Engineering Proceedings, 8(1), 11.

Gaglio, M., Pace, R., Muresan, A.N., Maisto, G., & Manes, F. (2022). Species-specific efficiency in PM2.5 removal by urban trees: From leaf measurements to improved modeling estimates. Science of the Total Environment, 844, 157131. https://doi.org/10.1016/j.scitotenv.2022.157131

Grant, M.J. & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. Health Information and Libraries Journal, 26(2), 91-108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Davidović, M., Savić, S., Stojić, A., Kumar, P., Bartonova, A., Gramsch, E., Singh, V., Lanki T., Karttunen, A., Niemi, J.V., Hämeri, K., & Kerminen, V.-M. (2021). Diurnal, temporal and spatial variations of main air pollutants in a developing megacity: The case of Belgrade, Serbia. Applied Sciences, 11(3), 1212.

Đurić, M., Tričković, G., Šećerov, I., & Lalić, B. (2020). Short-term forecasting of air pollution index in Belgrade, Serbia. Meteorological Applications, 27(6), 1946.

European Environment Agency. (2022). Percentage of total green infrastructure, urban green space and tree cover in selected European cities.

European Environment Agency. (2025). Urban tree cover dashboards.

Islam, A., Pattnaik, N., Moula, M.M., Rötzer, T., Pauleit, S., & Rahman, M.A. (2024). Impact of urban green spaces on air quality: A study of PM10 reduction across diverse climates. Science of the Total Environment, 955, 176770. https://doi.org/10.1016/j.scitotenv.2024.176770

JKP “Zelenilo-Beograd”. (n.d.a). Drvoredi. https://www.zelenilo.rs/delatnosti/odrzavanje-zelenih-povrsina/drvoredi

JKP “Zelenilo-Beograd”. (n.d.b). Održavanje šuma. https://www.zelenilo.rs/delatnosti/odrzavanje-zelenih-povrsina/odrzavanje-suma

Marić, I., Crnčević, T., & Cvejić, J. (2015). Green infrastructure planning for cooling urban communities: Overview of the contemporary approaches with special reference to Serbian experiences. Spatium, 33, 55-61. https://doi.org/10.2298/SPAT1533055M

Milošević Pantović, A., Ignjatović, Z. & Stevanović, V. (2024). Air quality evaluation: Insights from case studies in Belgrade. Advanced Technologies, 13 (2), 67-75.

National Ecological Association. (2026). Air 2025. (In Serbian: Nacionalna ekološka asocijacija. (2026). Vazduh 2025.)

Obradović, J., Obradović, M., & Onjia, A. (2024). Air quality assessment in Belgrade: Spatial and temporal variations. In 17th International Conference on Fundamental and Applied Aspects of Physical Chemistry: Proceedings, Volume II (pp. 451-454). https://doi.org/10.46793/Phys.Chem24II.451O

Rodríguez-Santamaría, K., Chica, E.J., & Sánchez, J. (2022). Macro-morphological traits of leaves for urban tree selection for air pollution biomonitoring: A review. Biosensors, 12(10), 812. https://doi.org/10.3390/bios12100812

Serbian Environmental Protection Agency. (2025). Information on detected exceedances of hourly and daily limit values for air pollutants: Monthly reports for 2025. (In Serbian: Agencija za zaštitu životne sredine Republike Srbije. (2025). Informacije o detektovanim prekoračenjima satnih i dnevnih grančnih vrednosti (GV) zagađujućih materija u vazduhu – mesečni izveštaji za 2025. godinu)

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sun, Y., Guan, Y., Zhang, B., Zhou, Y., Du, L., & Zhu, C. (2024). Air PM10 and PM2.5 removal by urban green space under urban realistic stressors. Atmosphere, 15(12), 1443.

Urban Nature Plans Plus. (2025). Belgrade, Serbia. https://interlace-hub.com/urban-nature-plan-plus/belgrade-serbia

Venter, Z.S., Hassani, A., Stange, E., Schneider, P., & Castell, N. (2024). Reassessing the role of urban green space in air pollution control. Proceedings of the National Academy of Sciences, 121(6), e2306200121.

World Health Organization. (2021). WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.

Serbian Environmental Protection Agency (2025). Air quality. (In Serbian: Agencija za zaštitu životne sredine Republike Srbije. (2025). Kvalitet vazduha.)

AIR QUALITY IN BELGRADE DURING 2025: SEASONAL DYNAMICS, METEOROLOGICAL CONDITIONS, AND THE POTENTIAL OF URBAN FORESTS AND GREENERY IN MITIGATING AIR POLLUTION

Miroslava MARKOVIĆ, Goran ČEŠLJAR, Bojan KONATAR, Katarina MLADENOVIĆ

Summary

Air pollution is one of the most serious environmental and public health problems in contemporary urban areas, and Belgrade has long stood out as a city where this problem is particularly pronounced. The aim of this paper was, based on a review of the available literature and an analysis of publicly available data, to examine the seasonal dynamics of air pollution in Belgrade during 2025, as well as to consider the significance of meteorological conditions and the potential of urban forests and green infrastructure in mitigating population exposure to pollution.

The paper was conceived as a literature review with elements of secondary data analysis, with official monthly reports on exceedances of limit values for air pollutants being used to assess seasonal dynamics, while available data on urban forests, green spaces, and tree canopy cover were used to examine greenery and forest cover.

The results indicate pronounced seasonal variability in air quality in Belgrade. During the colder part of the year, episodes of suspended particles were dominant, which is associated with more intensive emissions from heating and traffic, as well as with less favorable dispersion conditions, whereas during the warmer part of the year ground-level ozone episodes became more important. The analysis showed that the problem of air pollution in Belgrade cannot be interpreted solely through emission intensity, but also through the action of meteorological factors, particularly wind and air ventilation. In this sense, the Košava wind has particular importance as a local factor that can contribute to the dilution of air pollutants and the mitigation of smog episodes, although it does not affect the emission sources themselves.

A review of the contemporary literature shows that urban forests and green infrastructure can contribute to reducing population exposure to air pollution, but that their effect is generally moderate and strongly dependent on spatial scale, urban form, vegetation distribution, and local climatic conditions. Additional information on Belgrade’s greenery indicates that the maintained tree avenues include about 50 tree species and around 28 genera, with Acer, Platanus, Aesculus, Tilia, and Fraxinus among the most represented genera. It is particularly emphasized that the concepts of forest cover, green spaces, tree avenues, and tree canopy cover cannot be used as synonyms, which is why the concept of optimal forest cover in urban conditions requires cautious and critical application. In the case of Belgrade, it is scientifically more justified to speak of locally adapted greening and green infrastructure improvement targets than of a single optimal value.

Overall, the paper shows that urban forests and green infrastructure represent an important complementary measure in mitigating the effects of air pollution, but they cannot replace emission reduction at the source, which is why the issue of air quality in Belgrade requires an integrated approach linking environmental protection, urban planning, and the improvement of the city’s green systems.

KVALITET VAZDUHA U BEOGRADU TOKOM 2025. GODINE: SEZONSKA DINAMIKA, METEOROLOŠKI USLOVI I POTENCIJAL URBANIH ŠUMA I ZELENILA U UBLAŽAVANJU AEROZAGAĐENJA

Miroslava MARKOVIĆ, Goran ČEŠLJAR, Bojan KONATAR, Katarina MLADENOVIĆ

Rezime

Zagađenje vazduha predstavlja jedan od najozbiljnijih ekoloških i javnozdravstvenih problema savremenih urbanih sredina, a Beograd se već duže vreme izdvaja kao grad u kome je ovaj problem posebno izražen. Cilj ovog rada bio je da se, na osnovu pregleda dostupne literature i analize javno dostupnih podataka, sagleda sezonska dinamika aerozagađenja u Beogradu tokom 2025. godine, kao i da se razmotri značaj meteoroloških uslova i potencijal urbanih šuma i zelene infrastrukture u ublažavanju izloženosti stanovništva zagađenju.

Rad je koncipiran kao pregled literature sa elementima analize sekundarnih podataka, pri čemu su za sagledavanje sezonske dinamike korišćeni zvanični mesečni izveštaji o prekoračenjima graničnih vrednosti zagađujućih materija u vazduhu, dok su za razmatranje zelenila i šumovitosti korišćeni dostupni podaci o urbanim šumama, zelenim površinama i pokrovu krošnji.

Rezultati ukazuju na izraženu sezonsku promenljivost kvaliteta vazduha u Beogradu. Tokom hladnijeg dela godine dominantne su epizode suspendovanih čestica, što je povezano sa intenzivnijim emisijama iz grejanja i saobraćaja, kao i sa nepovoljnijim uslovima disperzije, dok tokom toplijeg dela godine veći značaj dobijaju epizode prizemnog ozona. Analiza je pokazala da se problem aerozagađenja u Beogradu ne može tumačiti samo kroz intenzitet emisija, već i kroz delovanje meteoroloških faktora, naročito vetra i ventilacije vazduha. U tom smislu, košava ima poseban značaj kao lokalni faktor koji može doprineti razređivanju zagađujućih materija i ublažavanju smog epizoda, iako ne utiče na same izvore emisije.

Pregled savremene literature pokazuje da urbane šume i zelena infrastruktura mogu doprineti smanjenju izloženosti stanovništva aerozagađenju, ali da je njihov efekat uglavnom umeren i snažno zavisan od prostorne razmere, urbanog oblika, rasporeda vegetacije i lokalnih klimatskih uslova. Dodatni podaci o beogradskom zelenilu ukazuju da održavani drvoredi obuhvataju oko 50 vrsta drveća i oko 28 rodova, pri čemu su među najzastupljenijim rodovima Acer, Platanus, Aesculus, Tilia i Fraxinus. Posebno je naglašeno da se pojmovi šumovitosti, zelenih površina, drvoreda i pokrova krošnji ne mogu koristiti kao sinonimi, zbog čega pojam optimalna šumovitost u urbanim uslovima zahteva opreznu i kritičku primenu. U slučaju Beograda naučno je opravdanije govoriti o lokalno prilagođenim ciljevima ozelenjavanja i unapređenja zelene infrastrukture nego o jedinstvenoj optimalnoj vrednosti.

U celini posmatrano, rad pokazuje da urbane šume i zelena infrastruktura predstavljaju važnu dopunsku meru u ublažavanju posledica aerozagađenja, ali ne mogu zameniti smanjenje emisija na izvoru, zbog čega pitanje kvaliteta vazduha u Beogradu zahteva integrisan pristup koji povezuje zaštitu životne sredine, urbanističko planiranje i unapređenje zelenih sistema grada.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 93, 2026 ZBORNIK RADOVA 93, 2026

UDK: 630*22: 582.632.2(497.11)=111
DOI: 10.5937/SustFor2693063L
Original scientific paper

STRUCTURAL CHARACTERISTICS OF MIXED BEECH STANDS IN THE AREA OF MAJDANPEK IN EASTERN SERBIA

Nemanja LAZAREVIĆ[1], Miloš RAČIĆ[1], Aleksandar POPOVIĆ[2], Ivana RAČIĆ[1], Katarina MARINKOVIĆ[1], Danilo FURTULA[1], Nikola MARTAĆ[1]*

Abstract: *This paper analyzes structural characteristics of mixed stands of beech in the territory of Eastern Serbia. The research was carried out on three experimental fields by applying classic stand inventory parameters and structural indices (Gini coefficient, Stand Density Index, Hart-Becking Index), with additional analysis of spatial structure of trees. A special contribution of the paper is the application of an innovative approach in the analysis of the spatial distribution of trees. Due to limited applicability of Hart–Becking Index in heterogeneous stands, Delaunay triangulation, which enables defining real neighboring trees was applied in the paper and thereby the stated limitation was overcome. The established differences in structural characteristics between the researched stands can be related to combined effect of habitat conditions and silvicultural treatments carried out in the past. Also, the obtained results indicate the importance of application of comprehensive and combined approach in defining the structural build of the stand, which can serve as a reliable tool in the process of defining silvicultural measures aimed at achieving the target stand structure.*

Keywords: beech, stand structure, Gini coefficient, Stand Density Index, Hart-Becking Index.

STRUKTURNE KARAKTERISTIKE MEŠOVITIH SASTOJINA BUKVE NA PODRUČJU MAJDANPEKA U ISTOČNOJ SRBIJI

Abstract: *U radu su analizirane strukturne karakteristike mešovitih sastojina bukve na području istočne Srbije. Istraživanje je sprovedeno na tri ogledna polja primenom klasičnih taksacionih pokazatelja i savremenih strukturnih indeksa (Gini koeficijent, indeks gustine sastojine, Hart–Becking-ov indeks), uz dodatnu analizu prostorne strukture stabala. Poseban doprinos rada predstavlja primena inovativnog pristupa u analizi prostornog rasporeda stabala. Zbog ograničene primenljivosti Hart–Becking-ovog indeksa u heterogenim sastojinama, u radu je primenjena Delaunay triangulacija, kojom je omogućeno definisanje realnih susednih stabala i time je prevaziđen navedeno ograničenje. Utvrđene razlike u strukturnim karakteristikama između ispitivanih sastojina mogu se dovesti u vezu sa kombinovanim delovanjem stanišnih uslova i uzgojnih tretmana sprovedenih u prošlosti.*

[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: nemanja94.lazarevic@gmail.com

© 2026 The Authors. Published by Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

Takođe, dobijeni rezultati ukazuju na značaj primene sveobuhvatnog i kombinovanog pristupa u definisanju strukturne izgrađenosti sastojine, koji može poslužiti kao pouzdan alat u postupku definisanja uzgojnih mera u cilju postizanja ciljne strukture sastojine.

Keywords: bukva, struktura sastojine, Gini koeficijent, indeks gustine sastojine, Hart–Becking-ov indeks

1. INTRODUCTION

The range of distribution of beech (*Fagus spp.*) includes a wide belt of the northern hemisphere, whereby on European continent this species is absent only in the furthermost northern and southern parts (Velkovski et al., 2023). Based on the morphological and ecological characteristics, ten different species of the genus *Fagus spp.* have been identified in the world (Jovanović, 2000). In addition to wide spectrum of environmental conditions in which genus *Fagus spp.* occurs on a global level, significant variations in habitat conditions at the local level were also manifested, which additionally makes the ecological and typological diversity of beech forests more complex. In Serbia, beech occurs on ten types of soil, from acidic silicate to basic carbonate substrates (Knežević, 2003), which results in great typological diversity of beech forests. An area located not far away from the object of the research, that is the area of Djerdap National Park where as many as sixteen types of pure and mixed beech stands were identified, with mixed stands having special importance, can serve as an example of this diversity (Medarević et al., 2001).

Considering the wide ecological gradient of the *Fagus spp.* species and its pronounced adaptability to different habitat conditions, it is expected for beech to occupy a dominant place in the forest growing stock of Serbia. With the increase in the importance of a certain tree species in the growing stock, the need for collection of as precise and quantified as possible information about the structure of the stands that form it also grows. The collected information contributes to better understanding of the system, while its larger scope improves readiness for decision making (MacKay, 1969).

Habitat and stand conditions affect the growth of trees with different intensity, whereby different growth courses of individual trees lead to their differentiation in terms of thickness, height, and other structural elements, by which a stand structure is formed. In forest management it includes the living horizontal and vertical arrangement of trees within the forest canopy, and it is subject to changes due to growth, disturbances and application of forest management measures (Medarević, 2006). At the same time, it can be seen as the result of a dynamic system of interaction between growth factors and habitat conditions, which continuously change and shape its structure (Stajić and Vučković, 2023). A more detailed analysis of the stand structure, in addition to the classic understanding of durability which includes the durability of production, yield and income (Medarević, 2006), represents a basis for establishment of ecological sustainability and application of forest management that is close to nature.

Research and analysis of forest structure enable better understanding of the past, current state and future development of forest ecosystems (Pretzsch et al., 2017;

Franklin et al., 2002). Therefore, detailed knowledge of the relationship between different plant species in forest and their environment, as well as the law of growth, regeneration and succession of forests is of exceptional importance. In addition, the results of research and their analysis provide a theoretical basis for scientifically founded defining of forest management measures (Hui et al., 2019). Certain traditional approaches in determining the stand structure were based on a limited number of variables, most often related to production of wood volume (Martać et al., 2022). On the other hand, considering the complexity of forest ecosystems, for a comprehensive and reliable overview of the stand structure, it is necessary to apply several different methods and indicators, which enable the analysis of both basic structural elements and mutual relationships between them (Becagli et al., 2013). Proceeding from the above, in this paper, in addition to the traditional analysis of basic elements of stand structure, the method of defining of stand structural form based on the homogeneity of the inventory that forms it is presented, as well as the spatial analysis of that inventory, on the basis of which the type of mixedness and density of the stand were determined, with the aim of a more complete understanding of structural build of the researched stands.

The study of the structure of beech stands in Serbia is of particular importance, considering their large representation in total forest growing stock, as well as pronounced diversity of habitat conditions in which they occur. The stand structure directly reflects processes of growth, competition, stability and regeneration and represents the basis for understanding of functioning and future development of these forest ecosystems. In this context, the application of several different methods and approaches in this paper enables more comprehensive perception of build of beech stands and it represents reliable basis for defining scientifically based forest management goals.

2. MATERIAL AND METHODS

2.1 The object of research

The research was carried out in Eastern Serbia, in the territory of the Forest Estate “Severni Kučaj” Kučevo (Figure 1). In order to study structural characteristics of stands, three beech stands were singled out during the field trip, within which three experimental fields (EF) of square shape were established.

Experimental field I (EF I) of the area of 0.5 ha (x = 577713; y = 4923124, WGS 84 / UTM zone 34N) is located at the altitude of 664 m, on the northwestern exposure. There is a tall mixed stand of beech of closed canopy in the experimental field.

Experimental field II (EF II) of the area of 0.25 ha (x = 578101; y = 4923230, WGS 84 / UTM zone 34N) is located at the altitude of 691 m, also on the northwestern exposure. There is a tall mixed stand of beech of closed canopy in the experimental field.

Experimental field III (EF III) of the area of 0.25 ha (x = 578184; y = 4923686, WGS 84 / UTM zone 34N) is located at the altitude of 710 m, on the southwestern exposure. There is a tall mixed stand of beech of dense canopy in the experimental field.

Considering the small distance between the experimental fields, climatic and pedological-geological characteristics are presented jointly for the whole researched area. The average mean annual temperature amounts to 11.6°C, while average annual precipitation amounts to 807 mm. Parent rock consists of limestone, and the soil is medium deep (16–40 cm).

On all experimental fields numeration of trees was carried out, whereby all the trees whose diameter at breast height was greater than 10.0 cm were included. The diameter at breast height, total height and length of a stem were measured for all the numerated trees, and their positioning in the field was carried out. The data collected were processed using software MS Excel and RStudio (R 4.5.1.).

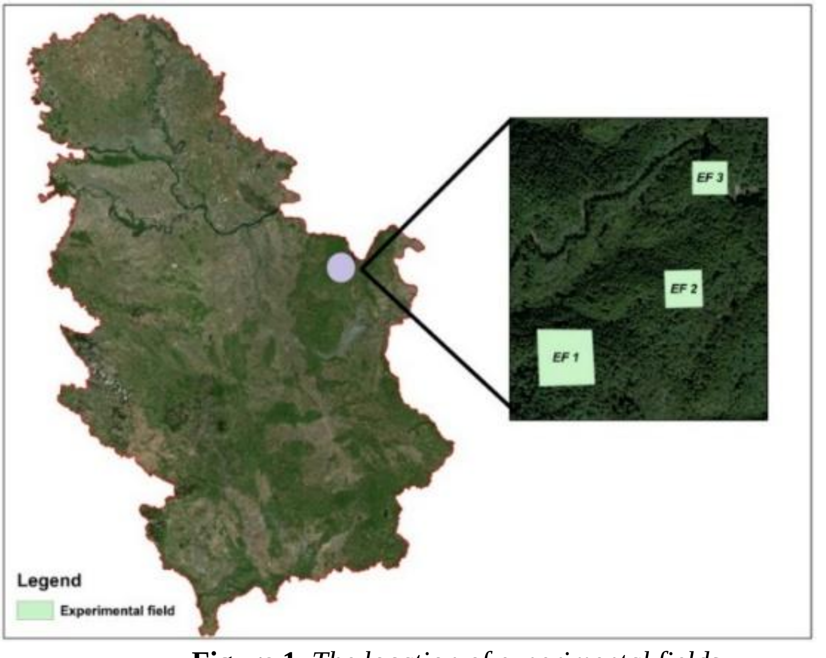


Figure 1. *The location of experimental fields*

2.2 Data processing

Stand inventory parameters were calculated using standard dendrometric methods (Banković and Pantić, 2006). The positioning of trees was carried out using theodolite. The measuring was started from vertex I (Figure 2), whereby the theodolite was placed so that the reading of “0” on the limb of the theodolite was always in the direction of the arrow on the sketch. All visible trees were covered from vertex I, and the same procedure was applied also from vertices II, III and IV. After the collection of data on positions of the trees in the field, their calculation was carried out; the example of calculation for the field of 0.25 ha (50x50 m) is presented in Table 1.

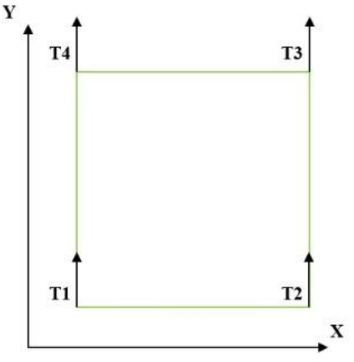


Figure 2. *Experimental field 50x50 (m)*

Table 1. Determining the position of trees on the experimental field

A	B	C	D	E	F	G
Vertex	Angle (gradians)	Angle (degrees) (B*0.9)	Angle (radians) (C*(3.14/180))	Distance (meters)	Coordinate X (meters) (E*SIN(D))	Coordinate Y (meters) (E*COS(D))
1		(B*0.9)	(C*(3.14/180))		(E*SIN(D))	(E*COS(D))
2		(B*0.9)	(C*(3.14/180))		(E*SIN(D))+50	(E*COS(D))
3		(B*0.9)	(C*(3.14/180))		(E*SIN(D))+50	(E*COS(D))+50
4		(B*0.9)	(C*(3.14/180))		(E*SIN(D))	(E*COS(D))+50

* in the column "Angle" enter the measured angle from the vertex toward the tree, in the column "Distance" enter the distance measured from the vertex toward the tree

The homogeneity and structural build of the researched stands was examined using the Gini coefficient, stand density index (SDI according to Reineke), relative distance between trees (the Hart-Becking Index), average distance between neighboring trees (Delaunay triangulation), minimal average distance between trees, spatial distribution of trees at the level of species (the Winkelmass Index).

The homogeneity of tree volume in the stand was evaluated using the Gini coefficient, whereby the volumes of individual trees were ranked in ascending order in accordance with the procedure of its application (Genèev, 2019).

$$GC(x1 \ldots . xn) = \frac{2\sum_{i=1}^{n} ix_i}{n\sum_{i=1}^{n} ix_i} - 1 - \frac{1}{n}$$

i – the reference rank number for the associated tree volume;
x_i – tree volume belonging to the reference rank;
n – total number of ranks.

Stocking percent of the stand was expressed through the index according to *Reineke* (*SDI*) (Reineke, 1933) which was primarily developed as a measure for describing even-aged structural forms of a stand, whereby with certain adaptation it is also used for uneven-aged stands (Stage, 1986; Long and Daniel, 1990; Shaw, 2000; Woodall et al., 2005; Popović, 2023).

For even-aged structural form it is determined using the following formula (Long, 1985):

$$SDI = N * (\frac{dg}{25})^{1,6}$$

For uneven-aged structural form it is determined using the following formula (Shaw, 2000):

$$SDI = \sum_{i=1}^{n}(\frac{d_i}{25})^b$$

N – total number of trees per hectare;

dg – mean diameter of the stand per basal area in (cm);

di – diameter of reference (observed) tree in (cm).

Relative distance between trees (*RS*), i.e. *Hart-Becking Index* was obtained using the following formula (Stajić and Vučković, 2023):

$$RS = \frac{\sqrt{10000/N}}{Hdom} * 100\ (\%)$$

N – total number of trees per hectare;

Hdom – average height of 20% of the tallest trees.

The Hart–Becking Index of relative distance between the trees was applied for evaluation of stand density, whereby number of trees per hectare and upper stand height were used as input parameters. This index was primarily developed for even-aged stands, where a relatively uniform distribution of trees in space is assumed (Gadow, 2003). It is difficult to apply Hart – Becking Index in more heterogeneous stand forms due to the fact that more heterogeneous stand forms such as uneven-aged and selection stands have a significantly more heterogeneous arrangement of trees in space, in terms of the distance between neighboring trees, so the upper part of the formula representing the average distance between trees per hectare ($\sqrt{10000/N}$) is not applicable in uneven-aged stands.

To adapt the index for uneven-aged stands, Delaunay triangulation of tree positions based on the In-Circle predicate (Guibas and Stolfi, 1985) was carried out in this paper (Figure 3), thus enabling the definition of real neighboring trees and calculation of "real" distance between them.

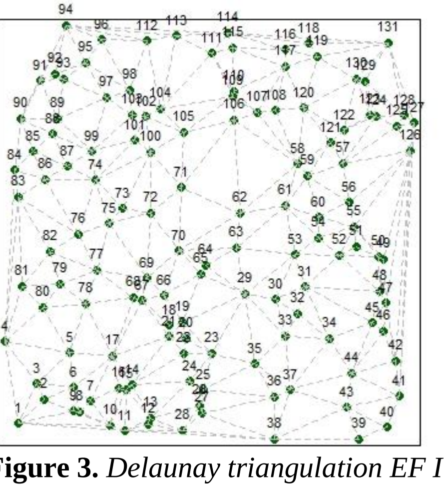


Figure 3. *Delaunay triangulation EF I*

Minimum average distance between trees was obtained based on determining the distance of 4 closest neighboring trees, whereby the sum of all averages was divided by the number of trees on the experimental field.

The information based on mutual relations of trees, such as single-tree and group arrangement of trees, the mixture that these trees make and differentiation of trees according to dimensions, can be used for providing a comprehensive description of spatial structure of the stand (Gadow and Hui, 2002). Therefore, spatial distribution of trees was analyzed in this research.

Defining the type of spatial distribution of trees at the level of tree species (single-tree, group, sporadic) was determined based on the *Winkelmass Index*. The Winkelmass index describes regularity or irregularity of spatial distribution of trees closest to the reference (observed) tree (Gadow and Hui, 2002).

Winkelmass Index was obtained using the following formulas (Gadow and Hui, 2002):

$$W = \frac{1}{N}\sum_{i=1}^{N} W_i$$

$$W_i = \frac{1}{4}\sum_{j=1}^{4} v_j$$

W – average value of *Winkelmass Index;*

W_i – *Winkelmass Index* of the *i – th* reference tree;

N – number of reference trees;

v_j – binary variable.

3. RESULTS AND DISCUSSION

Since the analysis was focused on the structure of the researched stands, numerical indicators (Tables 2-4) relate to the level of stand, i.e. they do not relate to tree species.

Table 2. *Numerical indicators for EF I*

N/ha	G/ha	dg (cm)	dg max (cm)	hg (m)	hg max (m)	h dom 20% (m)	Gini coefficient	V m^3/ha
262	38.7	43.4	59.4	29.5	32.3	33.1	0.393	572.8
Stand Density Index SDI according to Reineke			Relative distance between the trees RS, the Hart-Becking Index (%)				Average minimum distance between trees (m)	
305.41			23.11				5.53	

*The Hart-Becking Index was determined by conducting Delaunay triangulation, whereby the average distance was 7.65 m

Table 3. *Numerical indicators for EF II*

N/ha	G/ha	dg (cm)	dg max (cm)	hg (m)	hg max (m)	h dom 20% (m)	Gini coefficient	V m^3/ha
496	42.2	33.0	44.4	25.2	28.4	30.3	0.319	618.0
Stand Density Index SDI according to Reineke			Relative distance between the trees RS, the Hart-Becking Index (%)				Average minimum distance between trees (m)	
774.47			14.82				4.24	

Table 4. *Numerical indicators for EF III*

N/ha	G/ha	dg (cm)	dg max (cm)	hg (m)	hg max (m)	h dom 20% (m)	Gini coefficient	V m^3/ha
692	47.4	29.8	39.8	25.6	27.7	28.1	0.317	607.8
Stand Density Index SDI according to Reineke			Relative distance between the trees RS, the Hart-Becking Index (%)				Average minimum distance between trees (m)	
916.62			13.53				3.44	

On EF I the smallest number of trees was recorded (262 trees/ha). The total volume amounts to 572.8 m³/ha. On this EF the highest values of medium and dominant stand trees were recorded per basal area (dg = 43.4 cm; hg = 29.5 m; dg_{max} = 59.4 cm; hg_{max} = 32.3 m). The value of the Gini coefficient (0,393) shows a more pronounced structural unevenness i.e. greater differentiation of trees by dimensions. The value of SDI (305.41) and values of the Hart-Becking Index (RS = 23.11) confirm lower stand density, while greater minimum average distance between trees (5.53 m) indicates weaker mutual competition compared to other two fields.

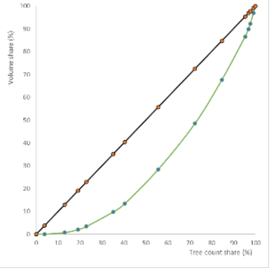
On EF II a larger number of trees is observed (496 trees/ha) with a decrease in the average size of the trees (dg = 33.0 cm; hg = 25.2 m; dg_{max} =44.4 cm; hg_{max} = 28.4 m). The volume reaches maximum value (618.0 m³/ha) compared to other two fields. The Gini coefficient (0.319) is lower than for the field I, which indicates greater structural homogeneity. The value of SDI (774.47) and presence of the Hart-Becking Index (RS = 14.82) confirm higher stand density and more pronounced competition. Minimum average distance between trees (4.24 m) confirms the results obtained.

EF III is characterized by the highest density (692 trees/ha) and the smallest average dimensions of trees (dg = 29.8 cm; hg = 25.6 m dg_{max} =39.8 cm; hg_{max} = 27.7 m). Although the basal area is (47.4 m²/ha), volume (607.8 m³/ha) is somewhat lower than on the field II. The lowest Gini coefficient (0.317) indicates even more uniform structure in terms of dimensions. The highest value of SDI (916.62) as well as minimum average distance between trees (3.44 m) indicate the highest density and confirm a high degree of competition.

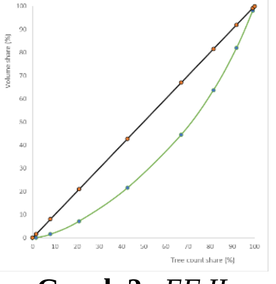
The values of Gini coefficient for even-aged structural forms of a stand range from 0.15 to 0.30, while for uneven-aged stands it amounts to 0.37 – 0.54. (Lee et al., 1999; Bravo-Oviedo et al., 2018; Popović et al., 2021*)*. The obtained value of Gini coefficient on EF I corresponds to a given interval for uneven-aged stands, while the values obtained on the other two experimental fields approximate the upper limit for even-aged structural form.

Considering the values of SDI on the one hand and numerical indicators on the other hand, it is evident that a significantly better balance has been established between the use of space for the growth of trees and other stand inventory parameters on EF I, compared to the stands of EF II and III.

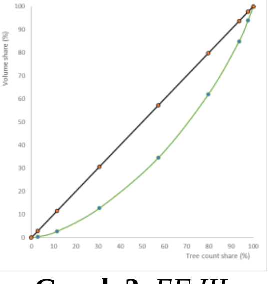
The cumulative ratio of the percentage of the number of trees and the percentage of the volume that the trees make up in the stand, is presented graphically in the form of a Lorenz curve (Graphs 1-3). Deviation of the volume homogeneity of inventory that builds the stand is possible to observe if the differences in volume per certain diameter degrees are presented graphically in the form of Lorenz curve. If the stand is more heterogeneous in terms of the volume of trees that make it up, Lorenz curve will deviate more from the reference line that represents ideal homogeneity in the volume of all trees in the stand (Kramer, 1988). Based on the presented graphs (1 – 3) heterogeneity of the inventory that makes up the volume of the stand of EF I can be clearly observed compared to more homogeneous inventory on the other two experimental fields.



Graph 1. *EF I*

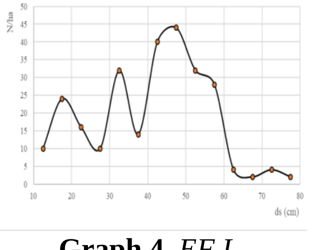


Graph 2. *EF II*

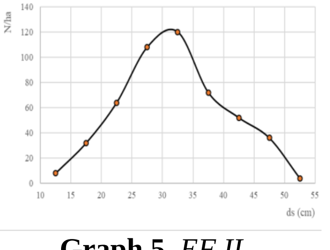


Graph 3. *EF III*

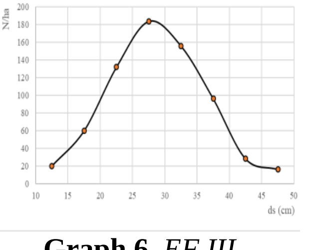
By observing diameter structure (Graphs 4-6) a clear difference in distribution of number of trees by diameter degrees can be observed between EF I (Graph 4) and EF II and III (Graphs 5 and 6). Diameter variation width for EF I, EF II and EF III amounts to 67.6 cm, 39.5 cm and 36.4 cm, respectively. More pronounced tree diameter variation width on EF I compared to the other two fields confirms more heterogeneous structure on EF I.



Graph 4. *EF I*



Graph 5. *EF II*



Graph 6. *EF III*

The values of W Index (Tables 5-7) differ depending on spatial distribution of trees. In accordance with the 72° standard angle required to yield an average of 0.5 for random distributions, values lower than 0.475 are considered for the regular arrangement of trees in the space, while those higher than 0.517 indicate a clumped arrangement (Gadow and Hui, 2002).

Single-tree and group tree arrangement was noted in all experimental fields depending on the tree species (Figures 4-6), whereby only on the EF II the dominant species (beech) is represented in group tree arrangement, while in other two fields beech is represented in single-tree arrangement.

Table 5. *The Winkelmass Index for EF I*

Tree species	W Index	Arrangement	Share in volume (%)
Beech	0.491	Single-tree	85.54
Sycamore maple	0.594	Group	9.96
Norway maple	0.607	Group	4.49

Table 6. *Winkelmass Index for EF II*

Tree species	W Index	Arrangement	Share in volume (%)
Beech	0.520	Group	95.54
Sycamore maple	0.536	Group	3.6
European hornbeam	/	Sporadic	0.85

Table 7. *Winkelmass Index for EF III*

Tree species	W Index	Arrangement	Share in volume (%)
Beech	0.512	Single-tree	85.35
Sycamore maple	0.554	Group	10.39
Norway maple	/	Sporadic	2.21
Large-leaved linden	/	Sporadic	1.16
Scots elm	/	Sporadic	0.90

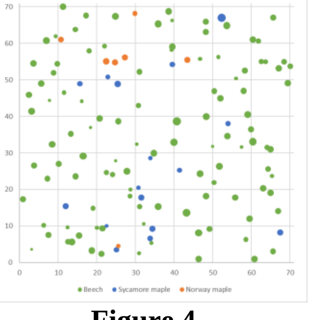


Figure 4.
Tree positions in EF I

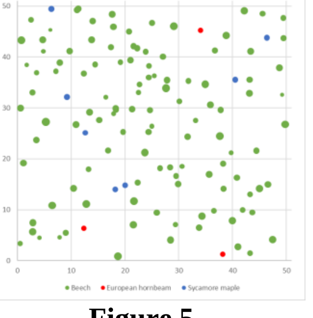


Figure 5.
Tree positions in EF II

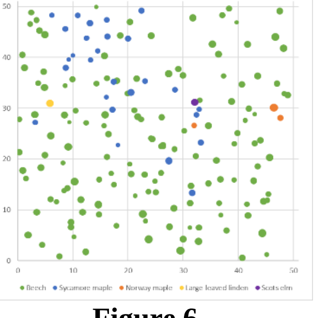


Figure 6.
Tree positions in EF III

4. CONCLUSION

The results of the research can be related to the joint influence of habitat factors and applied forest management treatments in the past, which is reflected in the build, density, degree of tree differentiation and spatial distribution of trees in the stand. The analysis of three experimental fields showed clear differences in structural characteristics, whereby EF I stands out for its more pronounced structural heterogeneity, while experimental fields II and III are characterized by higher degree of homogeneity and more pronounced competitiveness due to increased density.

An approach based on the simultaneous analysis of several interrelated elements, enables a more reliable and comprehensive overview of stand build, because individual indicators alone cannot always fully describe the complexity of forest ecosystems. The results indicate that structural heterogeneity cannot be observed exclusively through one aspect, but it is necessary to analyze simultaneously several structural components, including their mutual relations.

Additional contribution of the presented results is reflected in the analysis of the stand spatial structure, which enables more detailed perception of spatial distribution of trees and their mutual relations. By applying the Winkelmass Index, the type of spatial distribution of trees has been determined, whereby the presence of single-tree and group arrangement was recorded, with clear differences between experimental fields. It is particularly important to point out that the way of overcoming limitations of classical methods for determining the relative distance between trees in the process of defining spatial structure is presented in this paper. Given that the Hart–Becking Index in its basic form is based on the assumption of even distribution of trees, its application in heterogeneous stands is limited. By applying Delaunay triangulation, defining real neighboring trees and calculation of real mutual distances is enabled, which gave a more realistic picture of stand density and spatial arrangement of trees within it. In this way, one of the key limitations in the analysis of stand spatial structure which relates to the reliable defining of mutual distance between trees in heterogeneous stands has been overcome, which represents significant methodological contribution.

The results of the research confirm the significance of application of integral approach in the analysis of stand structure, which implies simultaneous consideration of several structural elements and their spatial relationships, which ensures a more reliable and comprehensive overview of forest stand structure. The obtained results represent a reliable tool in the process of defining silvicultural measures depending on the previously defined target stand structure, because they enable a clear overview of existing structural condition and relationships between trees within the stand.

Acknowledgement: *This study was carried out under the Agreement on realization and funding of scientific research activity of scientific research organizations in 2026, funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, no. 451-03-33/2026-03/200027 and 451-03-33/2026-03/200169 of February 5, 2026.*

REFERENCES

Banković S., Pantić D. (2006). Dendrometry, University of Belgrade – Faculty of Forestry, Belgrade, 556 (Original title: Dendrometrija. Univerzitet u Beogradu – Šumarski fakultet, Beograd)

Becagli, C., Puletti, N., Chiavetta, U., Cantiani, P., Salvati, L., & Fabbio, G. (2013). Early impact of alternative thinning approaches on structure diversity and complexity at stand level in two beech forests in Italy. *Annals of silvicultural research*, *37*(1), 55-63. http://dx.doi.org/10.12899/ASR-802

Bravo-Oviedo, A., Pretzsch, H., del Río, M. (2018). Dynamics, Silviculture and Management of Mixed Forests. In Growth and Structure in Cham, Switzerland, Volume 31, pp. 131–184

Franklin, J. F., Spies, T. A., Van Pelt, R., Carey, A. B., Thornburgh, D. A., Berg, D. R., ... & Chen, J. (2002). Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest ecology and management*, *155*(1-3), 399-423. https://doi.org/10.1016/S0378-1127(01)00575-8

Gadow, K. (2003). Waldstruktur und Wachstum. Universitätsverlag Göttingen.

Gadow, K., Hui, G. Y. (2002). Characterizing forest spatial structure and diversity. Sustainable Forestry in Temperate Regions; Proc. of an international workshop, University of Lund, Sweden, 20–30.

Genèev, M. (2019). A note on a property of the Gini coefficient. Communications in Mathematics, Volume 27, Issue 2, pp. 81–88. DOI: 10.2478/cm-2019-0008.

Guibas, L., Stolfi, J. (1985). Primitives for the manipulation of general subdivisions and the computation of Voronoi diagrams. ACM Transactions on Graphics (TOG), 4(2), 74–123. doi.org

Hui, G., Zhang, G., Zhao, Z., & Yang, A. (2019). Methods of forest structure research: A review. *Current Forestry Reports*, *5*(3), 142-154. https://doi.org/10.1007/s40725-019-00090-7

Jovanović, B. (2000). Dendrology, Faculty of Forestry of the University of Belgrade, Belgrade (Original title: Dendrologija. Šumarski fakultet Univerziteta u Beogradu, Beograd).

Knežević, M. (2003). The soils in beech forests of Serbia, Journal Forestry (Original title: Zemljišta u bukovim šumama Srbije. Časopis Šumarstvo), 1-2, 97-112.

Kramer, H. (1988). Waldwachstumslehre: Ökologische und anthropogene Einflüsse auf das Wachstum des Waldes, seine Messung und seine Steuerung. Paul Parey, Hamburg and Berlin.

Lee,W.K., Gadow, V.K., Akca, A. (1999). Forest structure and Lorenz model. Allg. ForstJagdztg., 170, 220–223.

Long, J.N. (1985). A practical approach to density management. For.

Long, J.N., Daniel, T.W. (1990). Assessment of growing stock in uneven-aged stands. Western Journal of Applied Forestry, 5(3), 93-96. Doi: 10.1093/wjaf/5.3.93

MacKay, D. M. (1969). Information, Mechanism and Meaning. MIT Press.

Martać, N., Čokeša, V., Stajić, S., Furtula, D., Pavlović, B., & Račić, M. (2022). Characteristics of structure and production in Vinatovača virgin forest. Sustainable Forestry: Vol 85-86, pp 157-167.

Medarević, M. (2006): Forest Management Planning, University of Belgrade, Faculty of Forestry, Belgrade, (Original title: Planiranje gazdovanja šumama. Univerzitet u Beogradu, Šumarski fakultet, Beograd)

Medarević, M., Jovanović, B., Banković, S., Karadžić, D. (2001). Djerdap Forests (Monograph), Donji Milanovac: PE National Park Djerdap; Belgrade: Ekolibri (Original title: Šume Đerdapa (Monografija). Donji Milanovac: JP „Nacionalni park Đerdap“; Beograd: „Ekolibri“).

Popović, A. (2023). Assessment of the ecological, structural and production characteristics of Serbian spruce, Macedonian pine and Bosnian pine from the aspect of protection and preservation of their habitats (Doctoral dissertation), University of Belgrade – Faculty of Forestry, Belgrade, (Original title: Ocena ekoloških, strukturnih i proizvodnih karakteristika

Pančićeve omorike, molike i munike sa aspekta zaštite i očuvanja njihovih staništa (Doktorska disertacija). Univerzitet u Beogradu – Šumarski fakultet, Beograd).

Popović, A., Pantić, D., Medarević, M., Šljukić, B., Obradović, S. (2021). Impact of Mixing on the Structural Diversity of Serbian Spruce and Macedonian Pine Endemic to Relict Forest Communities in the Balkan Peninsula. Forests, 12(8), 1065. Doi: 10.3390/f12081065

Pretzsch, H., Zenner, E. K. (2017). Toward managing mixed-species stands: from parametrization to prescription. Forest Ecosystems, 4(1), 19. https://doi.org/10.1186/s40663-017-0105-z

Reineke, L.H. (1933). Perfecting a stand-density index for even-aged forests. Journal of Agricultural Research, 46, 627-638.

Shaw, J.D. (2000). Application of stand density index to irregularly structured stands. Western Journal of Applied Forestry, 15(1), 40-42. Doi: 10.1093/wjaf/15.1.40

Stage, A.R. (1968). A tree-by-tree measure of site utilization for grand fir related to stand density index. USDA Forest Service Research Note INT-77.

Stajić, B., Vučković, M. (2023). Forest growth and productivity. University of Belgrade – Faculty of Forestry, Belgrade, (Original title: Rast i proizvodnost šuma. Univerzitet u Beogradu – Šumarski fakultet, Beograd).

Velkovski, N., Govedar, Z., Hristovski, S., Najdovski, B. (2023). Sustainable development and management of tall beech forests, (Original title: Održivi razvoj i upravljanje visokim bukovim šumama). Sustainable Development and Management of Forest Ecosystems, Vol. 5(5), 537-576. Doi: 10.7251/EORU2305537

Woodall, C., Miles, P., Vissaage, J. (2005). Determining maximum stand density index in mixed species stands for strategic-scale stocking assessments. Forest Ecology and Management, 216, 367-377. Doi: 10.1016/j.foreco.2005.05.022

STRUCTURAL CHARACTERISTICS OF MIXED BEECH STANDS IN THE AREA OF MAJDANPEK IN EASTERN SERBIA

Nemanja LAZAREVIĆ, Miloš RAČIĆ, Aleksandar POPOVIĆ, Ivana RAČIĆ, Katarina MARINKOVIĆ, Danilo FURTULA, Nikola MARTAĆ

Summary

This paper analyzes structural characteristics of mixed stands of beech in the territory of Eastern Serbia with the aim of more complete understanding of them through application of several complementary methods. The research was carried out on three experimental fields, whereby, in addition to classical stand inventory parameters, modern structural indices which enable more detailed analysis of tree differentiation, density and mutual relationships within the stand are applied, too. Special attention was paid to the analysis of spatial structure, where the application of Delaunay triangulation improved the determination of the mutual distances of trees, which enabled a more realistic observation of the structure in heterogeneous stands.

The obtained results indicate pronounced differences in structural characteristics between the examined stands, which can be related to the combined action of habitat conditions and silvicultural treatments carried out in the past. At the same time, the results confirm that the stand structure cannot be reliably evaluated based on individual indicators

but requires the application of an integrated approach that comprises several structural elements and their spatial relationships.

As such, the applied approach enables more reliable observation of the existing structural condition of the stand and can serve as a significant basis for defining silvicultural measures in accordance with predefined target structure and long-term forest management goals.

STRUKTURNE KARAKTERISTIKE MEŠOVITIH SASTOJINA BUKVE NA PODRUČJU MAJDANPEKA U ISTOČNOJ SRBIJI

Nemanja LAZAREVIĆ, Miloš RAČIĆ, Aleksandar POPOVIĆ, Ivana RAČIĆ, Katarina MARINKOVIĆ, Danilo FURTULA, Nikola MARTAĆ

Rezime

U radu su analizirane strukturne karakteristike mešovitih sastojina bukve na području istočne Srbije sa ciljem njihovog potpunijeg sagledavanja kroz primenu više komplementarnih metoda. Istraživanje je sprovedeno na tri ogledna polja, pri čemu su, pored klasičnih taksacionih pokazatelja, primenjeni i savremeni strukturni indeksi koji omogućavaju detaljniju analizu diferencijacije stabala, gustine i međusobnih odnosa unutar sastojine. Posebna pažnja posvećena je analizi prostorne strukture, gde je primenom Delaunay triangulacije unapređeno određivanje međusobnih rastojanja stabala, čime je omogućeno realnije sagledavanje strukture u heterogenim sastojinama.

Dobijeni rezultati ukazuju na izražene razlike u strukturnim karakteristikama između ispitivanih sastojina, koje se mogu dovesti u vezu sa kombinovanim delovanjem staničnih uslova i uzgojnih tretmana sprovedenih u prošlosti. Istovremeno, rezultati potvrđuju da se struktura sastojine ne može pouzdano oceniti na osnovu pojedinačnih pokazatelja, već zahteva primenu integrisanog pristupa koji obuhvata više strukturnih elemenata i njihove prostorne odnose.

Kao takav, primenjeni pristup omogućava pouzdanije sagledavanje postojećeg strukturnog stanja sastojine i može poslužiti kao značajna osnova za definisanje uzgojnih mera u skladu sa unapred definisanom ciljnom strukturom i dugoročnim ciljevima gazdovanja.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD
SUSTAINABLE FORESTRY COLLECTION 93, 2026
ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 93, 2026

UDK: 630*188:630*422.1(497.11)=111
DOI: 10.5937/SustFor2693077P
Original scientific paper

THE EFFECT OF STAND CHARACTERISTICS ON THE OCCURRENCE OF ICE BREAKAGE AND UPROOTED TREES BY ICE IN EASTERN SERBIA

Branka PAVLOVIĆ[1], Vlado ČOKEŠA[1], Violeta BABIĆ[2], Snežana STAJIĆ[1], Zoran PODUŠKA[1], Branko KANJEVAC[2], Ljiljana BRAŠANAC-BOSANAC[1]*

Abstract: *The subject of this paper is the analysis of the influence of stand characteristics on the damage caused by the cold wave in the winter of 2014/2015 in the area of Eastern Serbia. The research is focused on the areas where, due to the high degree of damage, clear felling was carried out after the ice breakage, and therefore it was not possible to carry out assessment of damage at the level of individual trees. For that reason, the degree of damage was observed indirectly, through the scope of area covered by clear felling as a remedial measure in cases of permanently impaired stand stability. The research was carried out within forest management units in Moravian Forest Area, where the stands with the most severe consequences of the ice breakage were recorded. Key stand forms that affect their sensitivity to extreme weather events were identified through analysis of stand characteristics. The results indicate that mixed and structurally uneven-aged stands are more resistant to ice breakage compared to pure even-aged untended stands, and above all artificially established stands of conifers. The research results can contribute to better understanding of action mechanisms of ice breakage, as well as the improvement of forest management measures in order to increase forest resistance to increasingly frequent extreme climatic events.*

Keywords: ice breakage, uprooted trees by ice, stand characteristics, Eastern Serbia.

UTICAJ SASTOJINSKIH KARAKTERISTIKA NA POJAVU LEDOLOMA I LEDOIZVALA U ISTOČNOJ SRBIJI

Sažetak: *Predmet ovog rada jeste analiza uticaja sastojinskih karakteristika na oštećenja izazvanih ledenim talasom u zimu 2014/2015. godine na području istočne Srbije. Istraživanje je usmereno na površine na kojima je, usled visokog stepena oštećenja, nakon ledoloma sprovedena čista seča, zbog čega nije bilo moguće izvršiti procenu oštećenja na nivou pojedinačnih stabala. Iz tog razloga, stepen oštećenja posmatran je posredno, kroz obim površina obuhvaćenih čistom sečom kao merom sanacije u slučajevima trajno narušene stabilnosti sastojina. Istraživanje je sprovedeno u okviru gazdinskih jedinica u Moravskom*

[1] Institute of Forestry, Kneza Viseslava 3, 11030 Belgrade, Serbia
[2] Faculty of Forestry, University of Belgrade, Kneza Viseslava 1, 11030 Belgrade, Serbia
*Corresponding author. E-mail: brankas700@gmail.com

© 2026 The Authors. Published by the Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

šumskom području, gde su evidentirane sastojine sa najtežim posledicama ledoloma. Analizom sastojinskih karakteristika identifikovani su ključni sastojinski oblici koji utiču na njihovu osetljivost na ekstremne vremenske nepogode. Rezultati ukazuju da mešovite i strukturno raznodobne sastojine imaju veću otpornost na ledolome u odnosu na čiste, jednodobne i nenegovane sastojine, a pre svega veštački podignute sastojine četinara. Rezultati istraživanja mogu doprineti boljem razumevanju mehanizama delovanja ledoloma, kao i unapređenju mera gazdovanja šumama u cilju povećanja njihove otpornosti na sve učestalije ekstremne klimatske događaje.

Ključne reči: ledolomi, ledoizvale, sastojinske karakteristike, istočna Srbija

1. INTRODUCTION

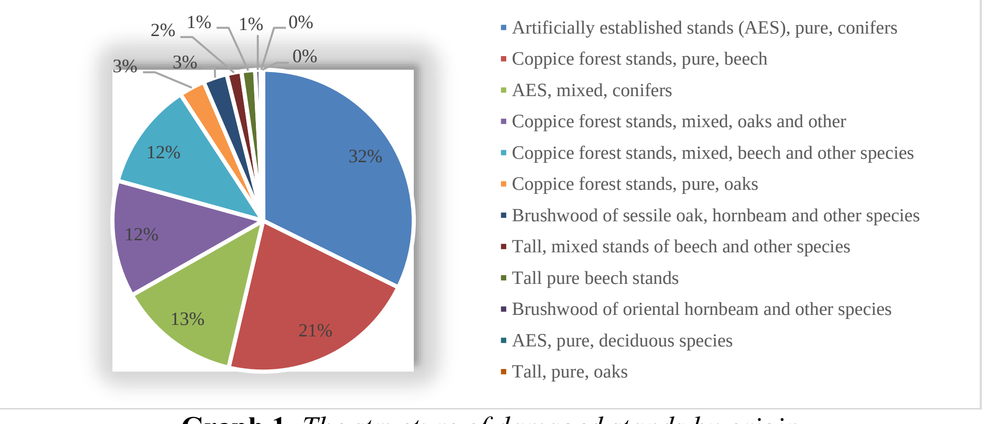
Despite numerous studies dealing with the impact of abiotic disorders on forest ecosystems, there is still insufficient knowledge about the connection between the structural characteristics of stands and the intensity of damage in conditions of extreme ice breakage, especially in the region of Southeast Europe. In recent decades, under the conditions of climate change, an increase in the frequency of extreme weather events has been observed (Seidl et al., 2017). Forest ecosystems are continuously exposed to the effect of natural disorders, whereby abiotic factors such as ice breakages, snow breakages and wind breakages have especially significant role. Given their increasing frequency, ice breakages stand out as one of the most significant forms of abiotic disorders in forest ecosystems, especially in mountainous areas. Forest ecosystems depend on their capacity to withstand and recover from natural and anthropogenic perturbations (Forzieri, G. et al., 2022). Estimates indicate that in European forests, snow breakages annually damage around 4 million m³ of wood volume, whereby the damages are most often manifested in the form of tree breaks, but also bending and fallen timber (Nykänen et al., 1997). The mechanism of damage formation is connected to the accumulation of ice in crowns, which leads to the load increase and consequent breaking of branches and trees, and in extreme cases also whole stands. The studies show that the combination of unfavorable habitat conditions and unfavorable stand structure significantly increases the probability of occurrence of such disorders (Brang et al., 2001). Long-term trends indicate the increase in frequency of natural disorders in European forests, which is related not only to climate changes, but also to changes in the structure and method of forest management. The increase in the age of stands, wood volume and total forest area contributes to their greater sensitivity to the action of abiotic factors (Schelhaas et al., 2003). According to the results of a research (Peltola et al., 1999), even-aged and dense stands of conifers, especially in the exposed and wet habitats, show increased damage risk, while the structure and the level of stand maintenance have a key role in their resistance. On the other hand, the increase in biological and structural diversity can contribute to the decrease of risk from great damages, because different species and structures react differently to disorders (Jactel et al., 2009). Ice breakages do not affect only individual trees, but also the long-term processes in forest ecosystems, including succession, changes in the composition of species and an increase in the amount of dead wood, as well as changes in microclimatic conditions. Although these processes can have positive effect on biodiversity, at the same time they increase the risk from secondary harmful factors, such as insects and pathogens. The resistance of beech stands to ice breakages depends on the combination of habitat conditions and structural characteristics, which indicates the need for adaptive forest management in the conditions of increasingly frequent extreme climatic events (Kanjevac et al., 2023). In Moravian and Timok forest areas, which were affected by ice breakages in the winter of 2014 Pavlović et al. (2022, 2023) state that the greatest damages were recorded in the stands with an unfavorable structure, above all in older and more mature stands, dense, insufficiently tended and stands with pronounced dominance of one species. Also, it was established that the intensity of the damage was largely conditioned by the combination of habitat factors (relief, exposure, altitude). Similar patterns were also recorded in other parts of Europe (Slovenia), where, for example, stands of spruce (*Picea abies*) showed increased sensitivity due to their morphological characteristics (Saje, 2014). The main meteorological conditions that lead to the occurrence of ice breakages include the occurrence of freezing rain, temperature inversions, high humidity and wind, which further increases the load on tree crowns. Bearing in mind the above, the area of Eastern Serbia, including the forests managed by Forest Estate Niš, represents an area of increased risk of these disorders, which indicates the importance of further research and the application of the adaptive approach to forest management.

2. MATERIAL AND METHODS

The research was carried out in the territory of Eastern Serbia, which was affected by intensive ice breakages during the winter of 2014. Within Morava Forest Area, the stands within Forest Management Units (FMUs) Obla glava, Kamenički vis I, Kamenički vis II, Bukovik-Mratinja, Devica, Svrljiško-Gulijanske planine and Rtanj were analyzed, where some of the stands suffered damages of such intensity that it was necessary to carry out their remediation using clear felling. The researched area is characterized by pronounced mountainous relief, frequent occurrence of temperature inversions, as well as increased frequency of freezing rain, which represents significant predisposing factor for the occurrence of ice breakages. The data on the areas on which clear felling was carried out was collected from the planning and record documentation of the forest management units. Basic structural parameters were recorded for each analyzed stand, including area, dominant tree species, origin (naturally or artificially established stands), structural form, developmental stage (age), preservation status, degree of mixedness and tendance. The data were obtained from the Forest management plans for the aforementioned Forest management units. The damage intensity was not assessed at the level of individual trees, but indirectly, based on the areas included in clear felling as a remediation measure in the stands with permanently impaired stability. Within the Morava Forest Area, clear felling was carried out on a total area of 647.85 ha. Of this, 131.29 ha were clear-felled in FMU “Bukovik–Mratinja,” 127.65 ha in “Obla glava,” 121.64 ha in “Kamenički vis I,” 101.21 ha in “Svrljiško-Gulijanske planine,” 76.19 ha in “Rtanj,” 71.43 ha in “Kamenički vis II,” and 18.44 ha in “Devica.”By reviewing the stand condition before the natural disaster, it was determined which stand forms are the most sensitive to extreme climatic influences.

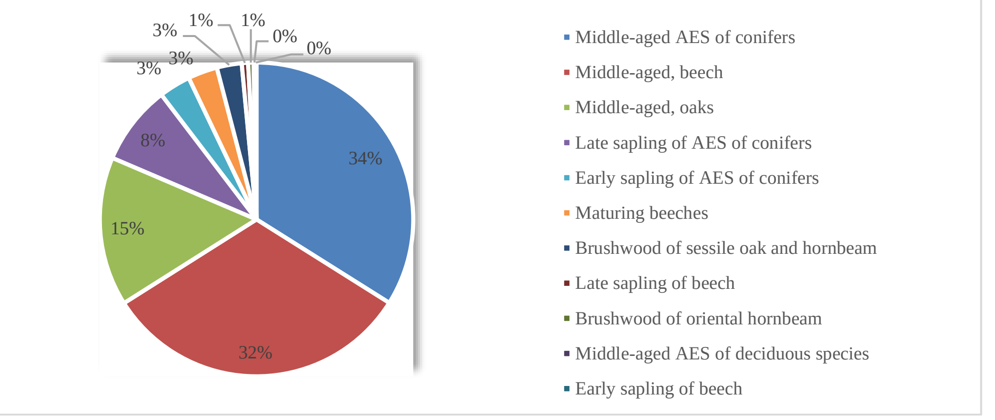
3. RESULTS AND DISCUSSION

By analyzing the collected data, it was determined that the intensity of stand damage caused by the ice breakage varies significantly depending on structural characteristics of the stands. The first thing to note is that all the stands that are affected by a natural disaster are even-aged or structurally even-aged, which means that the structure of the mensurational parameters corresponds to even-aged structure, even though they are sometimes uneven-aged. In any case, a simple even-aged structure represents a very risky and unstable stand form in relation to unfavorable abiotic influences resulting in ice breakages and uprooted trees by ice.



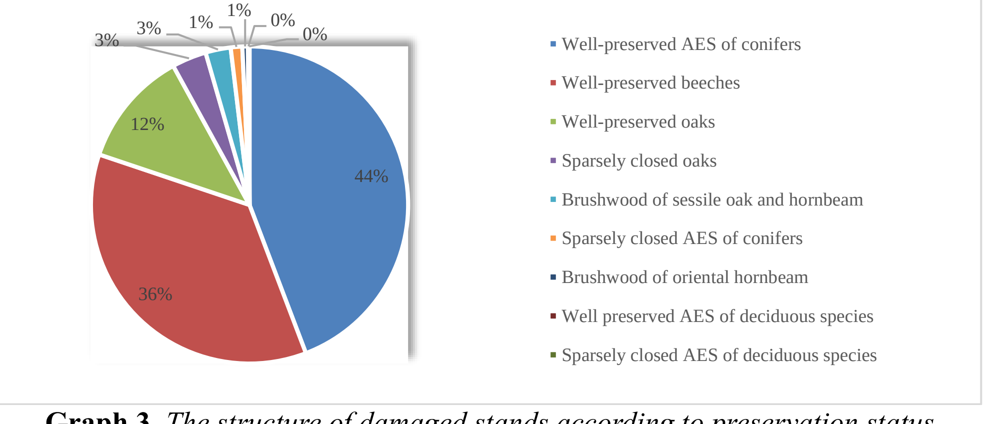
Graph 1. *The structure of damaged stands by origin*

From the Graph 1 it can be seen that pure artificially established stands of conifers on alien habitat according to area represent 1/3 of the total damaged stands. Mixed artificially established stands of conifers are somewhat more stable, but certainly with an increased risk. It can also be seen that by origin pure coppice forest stands are more endangered than mixed tall stands and that as a species beech is more endangered than oaks. Certainly, natural tall stands (especially mixed oak stands) proved to be the most resistant. Schelhaas et al., (2003) highlight that conifers, due to their dense and compact crown, are more exposed to damage than deciduous species. The lower sensitivity of mixed stands compared to monocultures confirms the hypothesis of greater stability of structurally diverse systems. Jactel et al., (2009) point out that increased biological and structural diversity reduces the risk of major damage, because different species react differently to the same stress factors, thus mitigating the overall effect of the disorder. Greater susceptibility of artificially established stands to damage can be linked to their homogeneous structure and often insufficient adaptability to local habitat conditions, which is also in accordance with the findings of other authors which indicate greater stability of natural stands (Seidl et al., 2017).



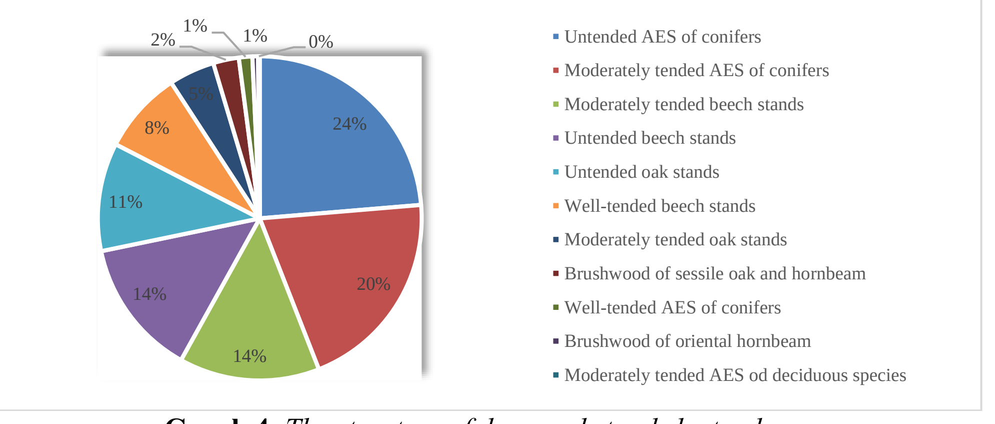
Graph 2. *The structure of damaged stands by developmental stages*

From Graph 2, it can be seen that the most endangered are middle-aged stands, and among them artificially established stands of conifers suffered the most (34%) on alien habitat, then beech (32%) and oak (15%) stands. This exception in the researched stands can be explained also by the influence of other factors on the degree of damage (position of the stand in relation to the cold wave and other environmental factors). It should also be taken into account that in terms of area the researched forest area is dominated by middle-aged stands. According to other sources (Schelhaas *et al.,* 2003), the most endangered are older stands characterized by larger tree dimensions which leads to increased load under the influence of accumulated ice. Similarly, Peltola *et al.*, (1999) indicate that the trees of larger dimensions suffer greater mechanical load under the influence of wind, snow and ice, which increases the probability of their breaking. The increased height of trees and unfavorable ratio of height and diameter (form quotient) decrease mechanical stability of trees and increase their sensitivity to ice load (Kanjevac *et al.,* 2023).



Graph 3. *The structure of damaged stands according to preservation status*

Well-preserved stands according to Graph 3 represent the highest degree of risk. This can be explained by their greater density and, therefore, higher tree form quotient, especially in artificially established stands of conifers. On the other hand, denser stands represent a greater barrier to air currents which have significantly affected breakages and fallen timber originating from trees that were burdened by larger deposits of ice. Sparsely closed stands represent less resistance to air currents. Here too, oak proved to be more resistant than beech. Preservation status and tendance are closely related stand characteristics. Untended stands should not be considered preserved, because they often have too many trees per unit area, which makes them unstable. Preserved stands should have optimal number of trees representing a stable forest ecosystem. However, in practice, stands with a larger number of trees than optimal are often declared to be preserved stands.



Graph 4. *The structure of damaged stands by tendance*

From the Graph 4 it can be seen that untended (24%) and moderately tended (20%) artificially established conifer stands are the most endangered and that together they form 44% of stands with total damage on which clear felling had to be done. The second in terms of the damage level are untended and moderately tended beech stands, which by area make up 28% of the stands with total damage from ice breakages and uprooted trees by ice. The oak stands proved to be somewhat more resistant although tendance measures influenced also the increase of their stability. Increased sensitivity of dense and insufficiently tended stands can be explained by decreased stability of individual trees, as well as by pronounced mutual influence in the conditions of a large canopy, which leads to the occurrence of chain of damage. Such results confirm findings of Brang *et al.* (2001), which emphasize the importance of stand structure in determining its response to extreme disorders.

Compared to the research conducted in Central Europe (Gardiner *et al.*, 2014), it can be concluded that there are similar sensitivity patterns, but forests of Serbia show greater spatial variability. The reason for this lies in the heterogeneity of relief, exposure, and habitat conditions. The specificity of the researched area is reflected in the combination of continental and mountain climate, as well as in frequent temperature inversions. These conditions additionally increase the risk of freezing rain and intensity of damage. From the perspective of sustainable management, the results clearly indicate the importance of increasing the structural diversity of stands. Mixed and uneven-aged stands show greater resistance thanks to better load distribution and greater stability (UNECE, FAO/2015). Also, timely application of silvicultural measures plays a significant role, above all thinning, by which canopy density is decreased and stability of trees is increased. These findings are consistent with the recommendations (UNECE, FAO/2015), which emphasize the need for adaptive approach to forest management in the conditions of climate change.

4. CONCLUSION

Based on the conducted research, it can be concluded that the highest degree of damage to forest stands due to ice breakages in the area of eastern Serbia is not accidental, but it is conditioned to a significant extent by the structural characteristics of t stands.

- Almost all totally damaged stands were even-aged or structurally even-aged;
- The most endangered are artificially established stands of conifers on alien habitat, then coppice forest stands of beech, followed by coppice forest stands of oaks. Tall natural stands showed the greatest resilience (especially oak stands);
- Pure stands are more endangered than mixed (especially artificially established stands of conifers);
- Due to smaller share of mature and maturing stands in the forest growing stock of the researched area, middle-aged stands were the most endangered, especially middle-aged artificially established stands of conifers. They were followed by middle-aged beeches, while middle-aged oak stands were less endangered;
- The stands which were declared preserved in the planning documents, nevertheless had a larger number of trees per unit area than optimal and became unstable;
- Untended artificially established stands of conifers on alien habitat proved to be the most unstable stands, and they are followed by untended coppice stands of beech.

The results of the research have a significant practical application in planning of forest management, especially in the context of climate change and increased frequency of extreme weather events. The identification of the stands with increased risk of ice breakage enables timely conducting of preventive measures, such as increase of structural diversity, adequate silvicultural interventions and selection of more resistant tree species.

Acknowledgement: *This research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-33/2026-03/200027).*

REFERENCES

Brang, P., Schönenberger, W., Ott, E. and Gardner, B. (2001) Forests as protection from natural hazards. In: The Forests Handbook, Vol. 2, pp. 53–81. https://doi.org/10.1002/9780470757079.ch3

Forzieri, G., Dakos, V., McDowell, N.G., Ramdane, A., Cescatti, A. (2022): Emerging signals of declining forest resilience under climate change. Nature 608: 534-539.

Gardiner, B. (2014): Wind and snow/ice damage to forest and the secondary impact of bark beetles. European Forest Institute. INRA, Bordeaux, France, pp. 1-41. https://www.gozdis.si/f/docs/news/4_Management_of_bark_beetles_and_Gardiner.pdf

Jactel, H., et al. (2009): Interactions between forest stands and disturbances. Annals of Forest Science, 66, 701.

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, Issue 16.

Nykänen, M.L., Peltola, H., Quine, C. (1997): Factors affecting snow damage of trees. Canadian Journal of Forest Research, 27, 193–199.

Pavlović, B., Babić, V., Čokeša, V., Martać, N., Kanjevac, B., Jović, Đ. (2022). Change in the growing stock condition of the Moravian Forest area as a consequence of ice disasters in the winter 2014. Sustainable Forestry 85-86:137-155.

https://scindeks-clanci.ceon.rs/data/pdf/1821-1046/2022/1821-10462285137P.pdf

Pavlović, B., Čokeša, V., Rakonjac, Lj., Babić, V., Poduška, Z., Martać, N., Kanjevac, B. (2023). Changes in the forest growing stock of the Timok forest area following the ice storm in winter 2014/2015. Sustainable Forestry 87-88:137-154.

https://scindeks-clanci.ceon.rs/data/pdf/1821-1046/2023/1821-10462387137P.pdf

Peltola, H., Kellomäki, S., Väisänen, H. (1999): Model computations of wind and snow damage risks. Forest Ecology and Management, 116, 273–285.

Saje, R. (2014): Žledolom v slovenskih gozdov. Gozdarski vestnik 72:204-210. https://zgds.si/wp-content/uploads/2017/01/gozdarskiVestnik2014.pdf

Schelhaas, M. J., Nabuurs, G. J., & Schuck, A. (2003). Natural disturbances in the European forests in the 19th and 20th centuries. Global Change Biology, 9(11), 1620–1633. https://doi.org/10.1046/j.1365-2486.2003.00684.x

Seidl, R., Thom, D., Kautz, M., et al. (2017). Forest disturbances under climate change. Nature Climate Change, 7, 395–402.

UNECE/FAO (2015): *Forests in the ECE Region: Trends and Challenges in Achieving the Global Objectives on Forests*. Geneva.

Forest management plan for Forest Management Unit "Obla glava" (2006–2015).

Forest management plan for Forest Management Unit "Kamenički vis I" (2007-2016).

Forest management plan for Forest Management Unit "Kamenički vis II" (2007–2016).

Forest management plan for Forest Management Unit "Bukovik-Mratinja" (2009–2018).

Forest management plan for Forest Management Unit "Devica" (2011-2020).

Forest management plan for Forest Management Unit "Svrljiško-Gulijanske planine" (2010-2019).

Forest management plan for Forest Management Unit "Rtanj" (2010–2019).

THE EFFECT OF STAND CHARACTERISTICS ON THE OCCURRENCE OF ICE BREAKAGE AND UPROOTED TREES BY ICE IN EASTERN SERBIA

Branka PAVLOVIĆ, Vlado ČOKEŠA, Violeta BABIĆ, Snežana STAJIĆ, Zoran PODUŠKA, Branko KANJEVAC, Ljiljana BRAŠANAC-BOSANAC

Summary

Based on the conducted research it can be concluded that the stand damage intensity caused by ice breakage largely depends on their structural characteristics. Given that the analysis is based on the areas where clear felling was carried out, as a final measure of remediation, the determined damage patterns indicate factors that contribute to the reduction of stand stability in conditions of extreme weather events. The research results showed that almost all totally damaged stands were even-aged or structurally even-aged. The most endangered are artificially established stands of conifers, then coppice stands of beech, and finally coppice stands of oaks. Tall natural stands showed the greatest resilience, and especially oak stands. Pure stands are more endangered than mixed stands (especially artificially established stands of conifers). Due to smaller share of mature and maturing stands, middle-aged stands were the most endangered, especially middle-aged artificially established stands of conifers. They are followed by middle-aged beeches, while middle-aged oak stands are less endangered. The stands which were declared preserved in the planning documents, had a higher number of trees per unit of area then the optimal, so they also became unstable. Untended artificially established stands of conifers on alien habitat proved to be the most unstable, followed by untended coppice forest stands of beech. The obtained results confirm that the stand structure is one of the key factors in their resistance to abiotic disorders, and indicate the need to apply appropriate forest management measures. In this sense, the timely care of stands, the increase of their structural and biological diversity, as well as the adaptation of the composition of species to habitat conditions, are of particular importance. Considering the expected increase in the frequency of extreme climate events in the future, the results of this research can contribute to improvement of forest management practice, in order to increase their stability and resistance to ice breakages and other abiotic disorders.

UTICAJ SASTOJINSKIH KARAKTERISTIKA NA POJAVU LEDOLOMA I LEDOIZVALA U ISTOČNOJ SRBIJI

Branka PAVLOVIĆ, Vlado ČOKEŠA, Violeta BABIĆ, Snežana STAJIĆ, Zoran PODUŠKA, Branko KANJEVAC, Ljiljana BRAŠANAC-BOSANAC

Rezime

Na osnovu sprovedenog istraživanja može se zaključiti da intenzitet oštećenja sastojina izazvanih ledolomom u velikoj meri zavisi od njihovih strukturnih karakteristika. S obzirom na to da je analiza zasnovana na površinama na kojima je sprovedena čista seča, kao krajnja mera sanacije, utvrđeni obrasci oštećenja ukazuju na faktore koji doprinose smanjenju stabilnosti sastojina u uslovima ekstremnih vremenskih događaja. Rezultati istraživanja pokazali su da su gotovo sve totalno oštećene sastojine bile jednodobne ili strukturno

jednodobne. Najugroženije su veštački podignute sastojine četinara, potom izdanačke bukve pa izdanačke hrastova. Visoke prirodne sastojne su pokazale najveću otpornost, a naročito sastojine hrastova. Čiste sastojine su ugroženije od mešovitih (naročito veštački podignute sastojine četinara). Usled manjeg učešća zrelih i dozrevajućih sastojina, srednjedobne sastojine su bile najugroženije, naročito srednjedobne veštački podignute sastojine četinara. Zatim slede srednjedobne bukve, dok su srednjedobne sastojne hrastova manje ugrožene. Sastojine koje su u planskim dokumentima proglašene očuvanim, imale su veći broj stabala po jedinici površine od optimalnog te su i one postale nestabilne. Kao najnestabilnije su se pokazale nenegovane veštački podignute sastojine četinara na tuđem staništu, a nakon njih nenegovane izdanačke sastojine bukve. Dobijeni rezultati potvrđuju da struktura sastojine predstavlja jedan od ključnih faktora njihove otpornosti na abiotičke poremećaje, te ukazuju na potrebu primene odgovarajućih mera gazdovanja šumama. U tom smislu, poseban značaj imaju pravovremena nega sastojina, povećanje njihove strukturne i biološke raznovrsnosti, kao i prilagođavanje sastava vrsta stanišnim uslovima. Imajući u vidu očekivani porast učestalosti ekstremnih klimatskih događaja u budućnosti, rezultati ovog istraživanja mogu doprineti unapređenju prakse gazdovanja šumama u cilju povećanja njihove stabilnosti i otpornosti na ledolome i druge abiotičke poremećaje.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 93, 2026 ZBORNIK RADOVA 93, 2026

UDK: 630*116:556(497.11)=111
DOI: 10.5937/SustFor2693087A
Original scientific paper

THE HYDROLOGICAL REGIME CHANGES ASSESSMENT ON THE ALLUVIAL-HYGROPHILOUS FOREST HABITAT AT EAST SREM FLOOD-PROTECTED AREA

*Milena ANĐELIĆ **

Abstract: *Intensive drying of single or group Q. robur L. trees at flood-protected area are connected with decreasing groundwater (GW) level and high atmospheric deficits. The study objectives are estimating GW cappillary rising, amount of avalilable water for penduculate oak and atmospheric deficit values in enclosure hunt area "Crni lug", at East Srem, the natural habitat of alluvial – hygrophilous forest. Data were collected from the observation stations of Republic Hydro-Meteorological Service of Serbia (RHMSS) for period 1992-2024 with special analysis of changes for period 2020-2024. The results reveal that all GW sesonal levels and during the vegetational period are below an average but still on favorable depth for heighest capillary rising. Soil moisture deficits indicate larger aridity in summer, and monthly, atmospheric defficits could be excessive for vegetation. Contribution of those analysis is current evaluation of available water and climatic conditions for the alluvial-higrophilous forest at flood-protected area.*

Keywords: pedunculate oak, groundwater, Sava, capillary rising, East Srem.

PROCENA PROMENE HIDROLOŠKOG REŽIMA NA STANIŠTU ALUVIJALNO-HIGROFILNIH ŠUMA U BRANJENOJ ZONI OD POPLAVA U ISTOČNOM SREMU

Sažetak: *Intenzivno sušenje pojedinačnih ili grupe stabala Q. robur L. u zoni odbrane od poplava povezuje se sa opadanjem nivoa podzemne vode (PV) i visokim atmosferskim deficitima. Cilj rada je procena kapilarnog izdizanja PV, dostupne količina vode za lužnjak i određivanje vrednosti atmosferskih deficita na primeru ograđenog lovišta "Crni lug" u istočnom Sremu koje predstavlja prirodno stanište aluvijalnih-higrofilnih šuma. Podaci su preuzeti sa osmatračnih stanica koje pripadaju Republičkom Hidro-Meteorološkom Zavodu Srbije (RHMZS) za period 1992-2024. g. sa posebnom analizom promena tokom perioda 2020-2024. g. Rezultati pokazuju da je nivo PV svih sezona i tokom vegetacionog perioda ispod prosečnih vrednosti ali još uvek na povoljnoj dubini za najveće kapilarno izdizanje. Deficit vlage u zemljištu ukazuje na veću aridnost tokom leta, a mesečno, atmosferski deficiti mogu biti ekscesivnih vrednosti za vegetaciju. Doprinos ovih analiza je trenutna procena dostupne vode i klimatskih uslova za aluvijalno-higrofilna šumska staništa u zonama koje su branjene od poplava.*

Ključne reči: lužnjak, podzemne vode, Sava, kapilarno izdizanje, istočni Srem.

*Corresponding author. E-mail: milenaandelic@hotmail.com

© 2026 The Authors. Published by Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

1. INTRODUCTION

The Pleistocene fluvial deposits of southeastern Srem, known as "Beds with *Corbicula fluminalis*" and "Makiš Deposits" by Laskarev (1938) and Stevanović (1977) are lithologically made of cyclical alternation of typical riverbed deposits (sands, gravels) and sediments of flood phase (silts and partly clays) that could be observed in many places. In some cycles flood deposits are missing and regular multi-phase gradation of material has been formed, with coarser material in the lower, and finer in the upper parts (Nenadić et al., 2015). Sandy-gravel deposits ($kf=10^{-1}$ $cm \cdot s^{-1}$) have larger and silts and clays ($kf=10^{-3}$-10^{-4}-10^{-5} $cm \cdot s^{-1}$) lower filtration values (Filipović, 2005) which affects on cappillary rising. Due to an embankment construction along the river Sava, the direct wetlands-river hydraulic connection was interrupted during period of high water. The drainage canals and wells construction next to the Sava for the needs of Belgrade's water supply probably contributed to the piezometric groundwater level decrease (Nikić, 2003).

Within the alluvial-hygrophilous complex forest types, Banković and Medarević (2003) (in: National forest inventory of Republic Serbia, 2008) indicates that penduculate oak is present in a large number of forest types whether it occurs alone as edificator or builds up two or polydominant communities, and the most common followers are narrow-leafed ash and hornbeam in various combinations. The second important specie, narrow-leafed ash in penduculate oak and narrow-leafed forest in Srem on flooded area habitat (*Fraxino – Quercetum roboris* subss. *subinundatum* Jov.et. Tom. 1980) shows a great capacity for revitalisation after an embankment has been constructed (Bobinac&Vučković, 1999). Penduculate oak and narrow-leafed ash forest at East Srem represents the most hygrophilous forest variant (Tomić, 2004). In this area hetero lithological environment influences on unevenly groundwater distribution (Nikić et al., 2010). Evapotranspiration from forest is considerably larger than from any other crop or grassland and the amount of water left for groundwater recharge is relatively low (Moricz, 2010). These parameters are specially significant during high evapotranspiration demands.

Main objective of the study is the hydrological and atmospheric conditions analysis on an example forest unit located in enclose hunt area "Crni lug" at East Srem for period 1992-2024 and 2020-2024 by using data from the observation stations of RHMSS. Reserves is replenished with high level of river Sava and low evapotranspiration, and decrease with high evapotranspiration. The results provide a contribution in more precisely perception of atmospheric and groundwater participation for hygrophilous species when the largest deficits occur.

2. MATERIAL AND METHOD

2.1. Study area and data

The East part of Srem is located between two major rivers, Sava and Danube, through which passes important Europe railways, which gives this area special importance in terms of economic development or great possibility for natural resources utilization (Vujović&Raštegorac, 2002). Forest unit (FU) „Progarska ada – Crni lug – Zidine – Drenska“ (located between 44°39'00"-44°44'00"N and

20°08'00"-20°19'00"E) stretches along the left bank of the river Sava, between villages Progar and Boljevci, at a distance of 40 km from city of Belgrade. Most of the FU (Crni lug and Zidine) is behind an embankment or flood-defended area (Dražić, 2019).

FU formes several separate forest complexes or according to the vertical distribution forest vegetation belongs to I complex forest types (72-74 m a.s.l.) which are divided on ceno-ecologycal forest type (white willows and poplar forest and penduculate oak and alder forest) and further on ceno-ecologycal units: white willows forests, white willow and black poplar forest and penduculate oak and narrow-leafed ash forest. Of the total territory, 85% is covered with forest, 15% is bare land. In this regulatory period reforestation will achive optimal forest cover, 86% of FU (Dražić, 2019).

2.2 Materials and Methods

Calculations has been conducted for period 1992-2024.yr. with special analysis of 2020-2024.yr. Selected observation station are part of RHMSS (2026) network:

1. **Hidrologycal analysis at investigation site (values are shown as absolute):**
   - **Surface water (SW)** level of river Sava: h.st. Šabac (72,61 m a.s.l.).
   - **Groundwater (GW)** level: Obrež (137), (78,44 m a.s.l.). Piezometric construction are represented in study of author Anđelić (2021).

2. **Atmospheric analysis at investigation site:** m.st. Sručin (99 m. a.s.l.; 44◦49' 20◦17') and Sremska Mitrovica (81 m a.s.l.; 45◦01' 19◦ 33') - data between those two stations are present as average:
   - **ETp Tornthwite** - corrected with coefficient (Tab. 1), (Đorović, 2001):

$$ET_P = 1{,}6\ \cdot (10 \cdot \frac{T}{I})^{\mathrm{a}};\ I = (\frac{T}{5})^{1{,}514}$$

$$\mathrm{a} = 0{,}000000675 \cdot I^3 - 0{,}000077 \cdot I^2 + 0{,}01792 \cdot I + 0{,}492$$

ETp – potentional evapotranspiration (mm); T- temperature (◦C); I- index; a-index.

Table 1. *Correction coefficient of duration day (Đorović, 2001)*

g.latitude	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
44	0.81	0.82	1.02	1.13	1.27	1.29	1.30	1.20	1.04	0.95	0.80	0.76
45	0.80	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75

- **Precipitation deficit (P-ETp)***:* arid >200 mm (Čermak&Prax, 2001).
- **Water-limited conditions ($P \cdot ETp^{-1}$):** arid ≤0,75 (Newman et al., 2006)*:*
- **Atmosphere humidity (Mayer qvotient):** arid NS<200 (Unkašević, 2005):

$$NS = \frac{\mathrm{H}}{\mathrm{E} - \mathrm{e}}$$

H-precipitation (mm); E-max. vapor pressure (kPa); e – actual vapor pressure (kPa).

- **Vapor pressure deficit –VPD** – excessive >3kPa (Tendayi, 2010): $e_a = e_s \cdot (\frac{RH}{100})$; $e_s = 0{,}6108\exp(\frac{17{,}27+T_a}{T_a+237{,}3})$

  e_S –max.vapor pressure (kPa); T*a*-temperature (◦C); e_a – actual vapour deficit (kPa), RH – relative air humidity (%).

3. RESULTS

NS aridity values (Fig. 1) for a period 1992-2024.yr. are in summer (163), monthly in April (124), Jun (112) and July (45). NS seasonal aridity for 2020-2024.yr. are: spring (160) 2020.yr., summer (178) 2021.yr., spring (137) 2022.yr, and summer (188) 2024.yr. Summer 2020.yr. (405), 2022.yr. (230), 2023.yr. (284) has more humid conditions. Monthly arid conditions for 2020-2024.yr. are: March (154), April (18), July (139), September (129), November (170) 2020.yr.; March (189), April (199), Jun (56), August (125) and September (35) 2021.yr.; January (172), February (145), March (27), May (73), Jun (174), July (122) and October (82) 2022.yr.; March (144), August (145), September (179), October (75) 2023.yr.; February (21), March (115), April (77) and August (10) 2024.yr. Excessive humidity is calculated for September 2022.yr.

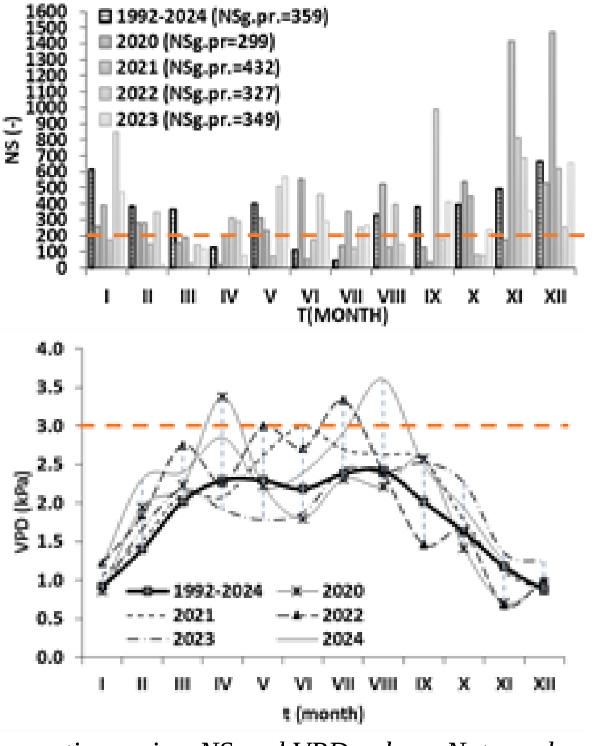


Figure 1. *Comparative review NS and VPD values. Note: colored dashed line are aridity limit (NS≤200; VPD>3kPa)*

VPD largest value (Fig.1) for 1992-2024.yr. occurs in spring (2,2 kPa) and summer (2,3 kPa), monthly April (2,3 kPa), May (2,3 kPa), July (2,4 kPa) and August (2,4 kPa). VPD seasonal largest values for 2020-2024.yr. are: spring (2,6 kPa), summer (2,1 kPa) 2020.yr.; summer (2,8 kPa), spring (2,3 kPa) 2021.yr.; summer (2,8 kPa), spring (2,7 kPa) 2022.yr.; summer (2,2 kPa), spring, autumn (2 kPa) 2023.yr.; summer (3 kPa), spring (2,5 kPa) 2024.yr. Monthly VPD largest values are: April 2020.yr. (3,4 kPa), Jun 2021.yr. (3 kPa), July 2022.yr. (3,3 kPa), September 2023.yr. (2,5 kPa) and August 2024.yr. (3,6 kPa).

Annual soil moisture (SM) deficit for 1992-2024.yr. (Fig. 2) is -120,7 mm, the largest value occurs in summer (-222,7 mm), monthly in July (-87,5 mm). Spring's deficits are lower (-25,8 mm), and surplus occurs in winter (115,5 mm) and autumn (12,3 mm). SM deficit for 2020-2024.yr. (Fig.2) are: -145 mm (2020.yr.); -6,2 mm (2021.yr.); -172,5 mm (2022.yr.), -103,8 mm (2023.yr.), -210,6 mm (2024.yr.) SM seasonal deficit for 2020-2024.yr. is predominanlty spring: 2020.yr. (-59,6 mm), 2021.yr. (-5,5 mm), 2022.yr. (-69,4 mm), 2024.yr. (-22,9 mm), (2023.yr. surplus 23,2 mm); and summer: 2020.yr. (-151,6 mm), 2021.yr. (-293 mm), 2022.yr. (-257,3 mm), 2023.yr. (-237 mm), 2024.yr. (-332,4 mm). Monthly SM largest deficits for 2020-2024.yr. are: -108,3 mm July 2020.yr., -127,9 mm Jun 2021.yr., -114,9 mm July 2022.yr., -102,6 mm August 2023.yr., -160,9 mm August 2024.yr.

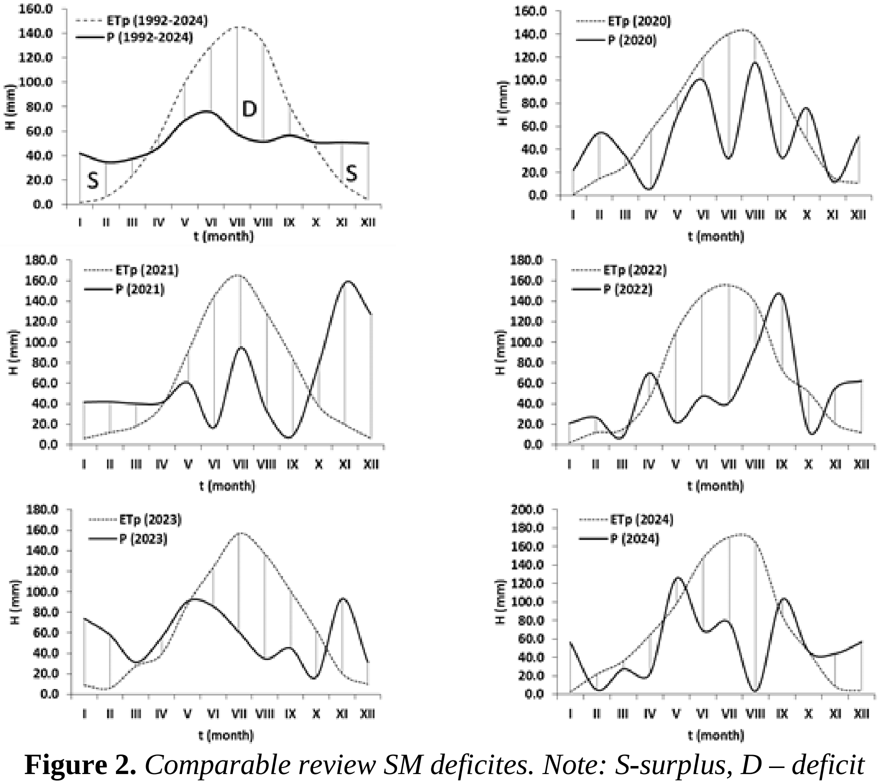


Figure 2. *Comparable review SM deficites. Note: S-surplus, D – deficit*

Water-limited conditions (WLC) lowest values ($P \cdot ET^{-1} \leq 0,75$) for 1992-2024.yr. (Fig. 2) are in summer (0,45) and April-September period (July and August has lowest values 0,4). WLC seasonal lowest values for 2020-2024.yr. are: spring (0,65) and summer (0,62) 2020.yr.; only summer (0,33) 2021.yr.; spring (0,59) and summer (0,41) 2022.yr.; only summer (0,43) 2023.yr.; only summer (0,31) 2024.yr. Monthly WCL lowest values for 2020-2024.yr. are: April (0,11) 2020.yr.; September (0,11) 2021.yr.; May (0,20) 2022.yr.; August (0,25) 2023.yr.; August (0,02) 2024.yr.

Annual highest and lowest surface-water (SW) level of river Sava for 1992-2024.yr. (Fig.3) is 75,12 m a.s.l. (April) and 72,36 m a.s.l. (August), respectively, and those two paramethers difference value are 2,76 m. SW seasonal highest level occurs in spring (74,84 m a.s.l.), and lowest in summer (72,94 m a.s.l). Highest and lowest groundwater (GW) level is 74,55 m a.s.l. (May) and 74,13 m a.s.l. (November) respectively and difference value is 0,43 m. GW seasonal highest and lowes level is spring (74,47 m a.s.l.) and autumn (74,19 m a.s.l.). Annual precipitation is 622,2 mm, the largest amount is summer (184,6 mm), Jun 75,7 mm.

Annual highest and lowest SW level for 2020-2024.yr. (Fig.3) are: 74,25 m a.s.l. (October) and 72,10 m a.s.l. (September), 2020.yr. (difference 2,15 m); 76,48 m a.s.l. (February) and 71,75 m n.m. (September) 2021.yr. (difference 4,73 m); 75,80 m a.s.l. (December) and 71,65 m a.s.l. (August) 2022.yr. (difference 4,15 m); 75,86 m a.s.l. (May) and 72,22 m a.s.l. (October) 2023.yr. (difference 3,64 m); 74,69 m a.s.l. (January) and 71,85 m a.s.l. (August) 2024.yr. (difference 2,84 m). SW seasonal highest and lowest levels are: winter (73,36 m a.s.l.) – summer (72,87 m a.s.l.) 2020.yr.; winter (75,84 m a.s.l.) – autumn (72,47 m a.s.l.) 2021.yr.; winter (74,46 m a.s.l.) – summer (72,10 m a.s.l.) 2022.yr.; spring (75,62 m a.s.l.) – autumn (73,17 m a.s.l.) 2023.yr.; winter (74,24 m a.s.l.) – summer (72,55 m a.s.l.) 2024.yr.

Annual highest and lowest GW level for 2020-2024.yr. (Fig.3) are : 73,32 m a.s.l. (July) and 73,01 m a.s.l. (April and December) 2020.yr. (difference 0,31 m); 73,56 m a.s.l. (Decembar) and 72,92 m a.s.l. (July) 2021.yr. (difference 0,64 m); 73,84 m a.s.l. (January and April) and 73,59 m a.s.l. (December) 2022.yr. (difference 0,25 m); 74,27 m a.s.l. (July) and 73,61 m a.s.l. (January) 2023.yr. (difference 0,66 m) - GW data for Nov. and Dec. 2023.yr. are missing in annual books of RHMSS; 73,77 m a.s.l. (April) and 73,32 m a.s.l. (December) 2024.yr. (difference 0,45 m). GW seasonal highest and lowest level are: summer (73,28 m a.s.l.) – spring (73,05 m a.s.l.) 2020.yr.; winter (73,19 m a.s.l..) – summer (72,96 m a.s.l.) 2021.yr.; spring (73,80 m a.s.l.) – summer (73,65 m a.s.l.) 2022.yr.; summer (74,23 m a.s.l.) – winter (73,65 m a.s.l.) 2023.yr.; spring (73,72 m a.s.l.) – winter and autumn (73,49 m a.s.l.) 2024.yr.

Annual precipitation for 2020-2024.yr. (Fig.3) are: 605,5 mm (2020.yr.); 743,5 mm (2021.yr.); 605,6 mm (2022.yr.); 676,6 mm (2023.yr.); 636,0 mm (2024.yr.). Seasonal largest amount is: summer 2020.yr. (247,5 mm), autumn 2021.yr. (246,2 mm), autumn 2022.yr. (213,7 mm), summer 2023.yr. (181,2 mm), autumn 2024.yr. (193,3 mm). Mountly largest amount is: August 2020.yr. (115,4 mm), November 2021.yr. (157,9 mm), September 2022.yr. (145,2 mm), November 2023.yr. (93,2 mm), May 2024.yr. (125,6 mm).

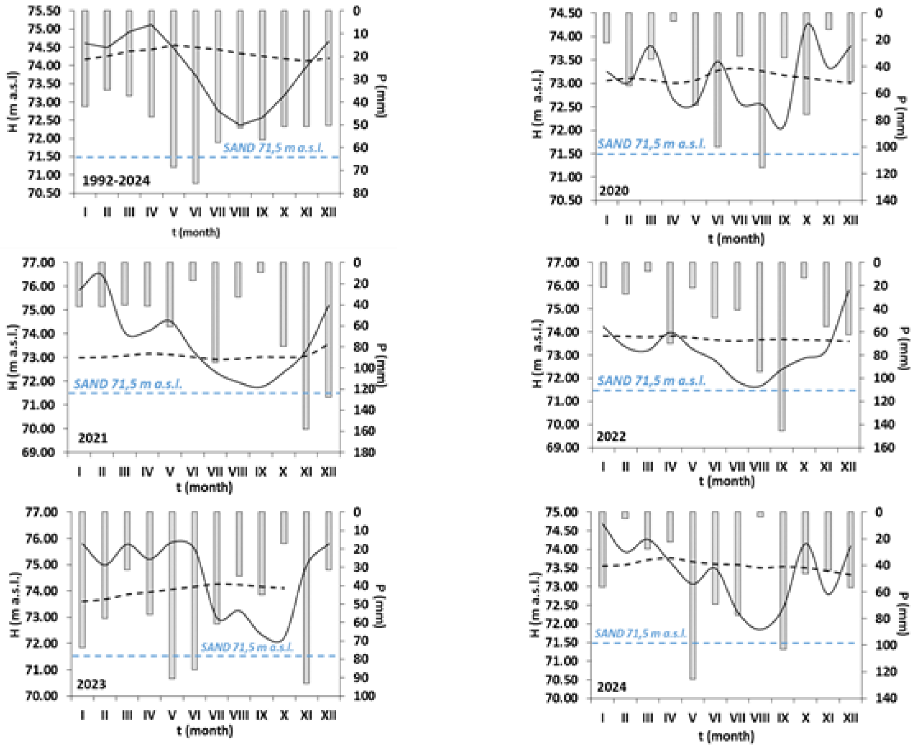


Figure 3. *Comparabile review GW, SW level and precipitations (P)*: *Legend*:- - GW; P; ━SW; *Note*: colored dashed line is a sand layer in Obrež (137) according to Anđelić (2021)

4. DISCUSSION

According to Chi et al. (2018) (in: Liu et al., 2024) ensuring the necessary water demand to support normal vegetation growth is crucial for maintaining an ecosystem’s functions, rational allocation of water resources, and coordinated development between ecological and economic water demand in river basins. A well-constructed database should accommodate identification of critical climate thresholds at which, under a given set of vegetation conditions, episodic recharge would occur (Newman et al. 2006). Süßel&Brüggemann (2021) highlight consideration of various authors that older penduculate oak trees cannot adopt their root system to changing GW supply and floodplain forests are especially prone to damage by combinations of decreased GW levels and increasing heat and drought waves (a major factor so-called “acute oak decline”). This multi-factorial phenomenon have accompany effects of abiotic and biotic stressors.

SM an average renewal occurs at the beginning (January-March) and end (October-December) of the year. SM renewal for 2020-2024.yr. are: January-March and October-December (with a November decrease) 2020.yr.; January-April and October-December (with significant increase at the end of the year) 2021.yr.; January-April (with a March decrease) and September-November (with a October decrease) 2022.yr.; January-May and November-December 2023.yr.; January and May (deficits are in February, March, April) and September-December 2024.yr.

SM annual largest decrease compared with an average (-120,7 mm) is 2024.yr. (-210,6 mm), and 2022.yr. (-172,5 mm). Favorable conditions for vegetation are 2021.yr. with the smallest annual deficit (-6,2 mm) compared to a both periods. SM spring largest values compared to an average (-25,8 mm) is 2020.yr. (-59,6 mm) and 2022.yr. (-69,4 mm), and 2023.yr. (23,2 mm) have surplus. SM summer largest values compared to an average (-222,7 mm) is 2024.yr. (-332,4 mm), 2021.yr. (-293 mm), 2022.yr. (-257,3 mm) and 2023.yr. (-237 mm), and below an average is 2020.yr. (-151,6 mm). SM autumn deficits are lower 2020.yr. (-35,2 mm) and 2023.yr. (-28,6 mm), and the largest surplus is 2021.yr. (105,3 mm). The largest SM monthly deficits for 2020-2024.yr. overcome an average (July -87,5 mm): July 2020.yr. (-108,3 mm), Jun 2021.yr. (-127,9 mm), July 2022.yr. (-114,9 mm), August 2023.yr. (-102,6 mm) and 2024.yr. (-160,9 mm).

Newman et al. (2006) reveal that arid, semiarid, and subhumid regions (sometimes collectively called drylands) are considered water limited because precipitation is typically less than ETp, such that the ratio of this variables ranges from about 0,03 to 0,75, and because extreme temporal variability results in extended periods with little to no precipitation. These environments are often sensitive and prone to change because of limitations in water and/or nutrients, which dictate fluxes and transport in the critical zone.

WLC an average spring (0,86) and summer (0,45) values indicates decrease in spring 2020.yr. (0,65) and 2022.yr. (0,59); summer 2021-2024.yr. (0,33, 0,41, 0,43, 0,31) and increase 2020.yr. (0,62) – still indicate arid conditions; autumn are below an average (1,08) in 2020.yr. (0,77) and 2023.yr. (0,84) but above the limit for aridity. Monthly lowest value WCL for period for 2020-2024.yr. indicate excessive aridity: April (0,11), July (0,23), August (0,36) 2020.yr.; May – September (0,66; 0,12; 0,58; 0,26; 0,11) 2021.yr.; March (0,51) and May-August (0,20; 0,32; 0,26, 0,68) and October (0,26) 2022.yr., Jun-October (0,69; 0,39; 0,25; 0,45; 0,27) 2023.yr., February (0,22), April (0,34), Jun-August (0,47; 0,45; 0,02), 2024.yr.

VPD serves as a critical indicator for measuring the evaporative capacity of water in the atmosphere and will increase with future temperature rise (Wang et al., 2025). Wang et al. (2025) represented other authors view that high VPD levels have high influence on plant closure stomata (minimizing water loss) consequently limiting photosynthesis and carbon uptake.

VPD spring value for 1992-2024.yr. (2,2 kPa) increased 2020.yr. (2,6 kPa), 2021.yr. (2,3 kPa), 2022.yr. (2,7 kPa), and 2024.yr. (2,5 kPa) except 2023.yr. (2 kPa). VPD summer value increased 2021.yr. and 2022.yr. (2,8 kPa) and 2024.yr. (3 kPa) until values of 2020.yr. and 2023.yr. are near to an average. VPD largest autumn increase is 2024.yr. (1,9 kPa) and 2023.yr. (2 kPa). Monthly excessive VPD values has been reached and far above an average: April (3,4 kPa) and September (2,6 kPa) 2020.yr., May – September (2,6 kPa; 3 kPa; 2,7 kPa; 2,6 kPa; 2,6 kPa) 2021.yr., March (2,8 kPa) and May-August (3 kPa; 2,7 kPa; 3,3 kPa; 2,4 kPa) 2022.yr., September (2,5 kPa) 2023.yr., April (2,9 kPa), July (2,9 kPa), August (3,6 kPa) and September (2,5 kPa) 2024.yr.

NS spring values decreased 2020.yr. (160), 2021.yr. (206), 2022.yr. (137), and 2024.yr. (253), except 2023.yr. (314) compared to an average (296). NS summer values all years (2020.yr. 405; 2021.yr. 178; 2022.yr. 230; 2023.yr. 284; 2024.yr. 188) are increased compared to an average (163), but certain years (2021.yr. and 2024.yr.) are still below the aridity limit (NS≤200). Commpared to an average (422) NS autumn value all years (except 2021-22.yr.), decreased but still above the aridity limit. NS excessive monthly values for 2020-2024.yr.: April (18) 2020.yr., Jun (56) and September (35) 2021.yr., March (27) 2022.yr., October (75) 2023.yr. and February (21) and August (10) 2024.yr.

According to Jović et al. (1989/1990) (in: Tomić&Jović, 2002) the detailed study of the forest ecosystems in Srem, forest phytosenoses succession is defined in depending on the wetting intensity or GW level and flood water from flowing to stagnant water to zonal vegetation: willow and poplar → narrow-leafed ash → penduculate oak and narrow-leafed ash → penduculate oak → penduculate oak, narrow-leafed ash and hornbeam → penduculate oak and hornbeam → zonal vegetation.

SW highest level are above an average (75,12 m a.s.l.) 2021.yr. (76,48 m a.s.l.), 2022.yr. (75,80 m a.s.l.), 2023.yr. (75,86 m a.s.l.), and below an average 2020.yr. (74,25 m a.s.l.) and 2024.yr. (74,69 m a.s.l.). SW lowest level are below an average (72,36 m a.s.l.) during all years (2020.yr. 72,10 m a.s.l.; 2021.yr. 71,75 m a.s.l.; 2022.yr. 71,65 m a.s.l.; 2023.yr. 72,22 m a.s.l.; 2024.yr. 71,85 m a.s.l.). Difference of highest and lowest SW level is above an average (2,76 m) all years (2021.yr. 4,73 m; 2022.yr. 4,15 m; 2023.yr. 3,64 m; 2024.yr. 2,84 m) except 2020.yr. (2,15 m).

SW spring level are below an average (74,84 m a.s.l.) all years (2020.yr. 73,01 m a.s.l.; 2021.yr. 74,23 m a.s.l.; 2022.yr. 73,48 m a.s.l.; 2024.yr. 73,67 m a.s.l.) except 2023.yr. (75,62 m a.s.l.). Also SW summer level are below an average (72,94 m a.s.l.) all years (2020.yr. 72,87 m a.s.l.; 2021.yr. 72,55 m a.s.l.; 2022.yr. 72,10 m a.s.l.; 2024.yr. 72,55 m a.s.l.) except again 2023.yr. (73,94 m a.s.l.). SW autumn level are below an average (73,24 m a.s.l.) all years (2020.yr. 73,23 m a.s.l.; 2021.yr. 72,47 m a.s.l.; 2022.yr. 72,83 m a.s.l.; 2023.yr. 73,17 m a.s.l.; 2024.yr. 73,12 m a.s.l.).

GW highest level is below an average (74,55 m a.s.l.) all years (2020.yr. 73,32 m a.s.l.; 2021.yr. 73,56 m a.s.l., 2022.yr. 73,84 m a.s.l.; 2023.yr. 74,27 m a.s.l., 2024.yr. 73,77 m a.s.l.). As well GW lowest level is below an average (74,13 m a.s.l.) all years (2020.yr. 73,01 m a.s.l.; 2021.yr. 72,92 m a.s.l.; 2022.yr. 73,59 m a.s.l.; 2023.yr. 73,61 m a.s.l.; 2024.yr. 73,32 m a.s.l.). GW highest and lowest level difference value are greater 2024.yr. (0,45 m), 2021.yr. (0,64 m) and 2023.yr. (0,66 m), and lower 2020.yr. (0,31 m), 2022.yr. (0,25 m).

GW level for 2020-2024.yr. compared to an average spring (74,47 m a.s.l.), summer (74,43 m a.s.l.) and autumn (74,19 m a.s.l.) are below: spring – all years (2020.yr. 73,05 m a.s.l.; 2021.yr. 73,12 m a.s.l.; 2022.yr. 73,80 m a.s.l.; 2023.yr. 73,97 m a.s.l.; 2024.yr. 73,72 m a.s.l.); summer – all years (2020.yr. 73,28 m a.s.l.; 2021.yr. 72,96 m a.s.l.; 2022.yr. 73,65 m a.s.l.; 2023.yr. 74,23 m a.s.l.; 2024.yr. 73,57 m a.s.l.); autumn – all years (2020.yr. 73,12 m a.s.l.; 2021.yr. 73,03 m a.s.l.; 2022.yr. 73,66 m a.s.l.; 2023.yr. 74,14 m a.s.l.; 2024.yr. 73,49 m a.s.l.).

5. CONCLUSION

At the East Srem area, on natural alluvial-hygrophilous forest habitat in enclosure hunt area "Crni lug" hydro-technical works changed hydrological regime and research aim is atmospheric conditions and hydrology regime review during two periods 1992-2024.yr. and 2020-2024.yr.:

- Annual atmospheric deficit (NS) indicate more humid 2021.yr. (432), more arid 2024.yr. (290) and 2020.yr. (299) and in an average (359) conditions 2022.yr. (327) and 2023.yr. (349). Vegetational period – VP (April-September) are with low values: April and August 2024.yr., at the end of VP 2023.yr., during May and summer (except August's surplus) 2022.yr, more frequent deficit presence 2021.yr., evenly distributed (April, Jun, September) deficits in VP 2020.yr. Excessive NS values are April (18) 2020.yr., Jun (56) and September (35) 2021.yr., and August (10) 2024.yr. Extreme low NS value is spring 2022.yr. (137) and 2020.yr. (160); and summer 2021.yr. (178) and 2024.yr. (188).

- VPD monthly deficits 2022.yr. are more frequent. High VPD values are specially present: 2024.yr. – during entire VP, 2023.yr. – July, August and September, 2022.yr. – entire VP except September, 2021.yr. – entire VP, 2020.yr. – entire VP except Jun. Excessive values are April (3,4 kPa) 2020.yr., Jun (3 kPa) 2021.yr., July (3,3 kPa) 2022.yr, August (3,6 kPa) 2024.yr. Summer deficits are highest 2024.yr. (3 kPa), 2022. yr. and 2021.yr. (2,8 kPa).

- SM largest annual deficit are 2024.yr. (-210,6 mm), 2022.yr. (-172,5 mm) and 2020.yr. (-145 mm), and 2021.yr. (-6,2 mm) are lower under the influence of precipitation at the end of the year. SM VP deficits are present: 2024.yr. – except May and September; 2023.yr. – except beginning of VP; 2022.yr. – except April and September; 2021.yr. - except April; 2020.yr. – entire VP. Excessive values are August 2024.yr. (-160,9 mm) and 2023.yr. (-102,6 mm), July (-114,9 mm) 2022.yr., Jun (-127,9 mm) 2021.yr., July (-108,3 mm) 2020.yr. Summer deficits are highest: 2024.yr. (-332,4 mm), 2023.yr. (-237 mm), 2022.yr. (-257,3 mm), 2021.yr. (-293 mm)-excessive aridity.

- WLC for VP are: 2024.yr. - except May and September; 2023.yr. – except April and May; 2022.yr. – except April and September; 2021.yr. – except April; 2020.yr. – except May, Jun and August. Lowest excessive values are: August (0,02) 2024.yr., August (0,25) 2023.yr., May (0,20) 2022.yr., September (0,11) 2021.yr., April (0,11) 2020.yr. WLC occures in spring 2020.yr (0,65) and 2022.yr. (0,59) and summer all years (2020.yr 0,62, 2021.yr. 0,33, 2022.yr. 0,41, 2023.yr. 0,43, 2024.yr. 0,31).

- SW spring and summer level are below an average all years of the comparable period except 2023.yr. SW autumn levels for period 2020-2024.yr. are below an average. Annual SW highest and lowest difference level value is greater than an average (2,76 m) during all years (2021.yr. 4,73 m; 2022.yr. 4,15 m; 2023.yr. 3,64 m; 2024.yr. 2,84 m) except 2020.yr. (2,15 m).

- GW spring, summer and autumn levels are below an average all years of the comparable period. Annual GW highest and lowest level difference value are greater 2024.yr. (0,45 m), 2021.yr. (0,64 m) and 2023.yr. (0,66 m), and lower 2020.yr. (0,31 m), 2022.yr. (0,25 m) compared to an average (0,43).

- GW level is all the time in clay layer which is semi-permeable or non-permeable, with highest capillary rising and longest soil moisture capturment.

Generally larger recharge soil moisture reserves are at the end of 2021.yr.; highest autumn deficits in 2020.yr.; variabile increase in 2022.yr. with higher deficient annual values; above an average recharge till May 2023.yr. with lower annual deficits than an average; lower recharge 2024.yr. with highest annual deficits.

REFERENCES

Andelić, M. (2021). *Comparable analysis atmosperic deficits and water regime during different season on alluvial flood forest habitat at East Srem.* Fresenius Enviromental Bulletin. Vol. 30.

Bobinac, M., Vučković, M. (1999). *Relationship of some exogenous factors to the variability of diameter increment of narrow-leaved ash (Fraxinus angustifolia Vahl.) future trees on an ecologically optimal site.* Ekologia No. 18 (1): 31-38.

Čermak, J., Prax, A. (2001). *Water balance of a Southern Moravian foodplain forest under natural and modified soil water regimes and its ecological consequences.* Ann.For.Sci.58.

Dražić, G. (2019). *Special forest management basis for unit „Progarska ada – Crni lug – Zidine – Drenska" for period 2020-2029.yr.* Ministry of Agriculture, Forestry and Water Management Serbia - Forest Service.

Filipović, B., Krunić, O., Lazić, M. (2005). *Regyonal hydrology of Republic Serbia. Faculty of Mining and Geology.* University of Belgrade. 1-403.

Liu, X., Alifujiang, Y., Abliz, A., Asaiduli, H., Ye, P., Nurahmat, B. (2024). *Estimation of Water demand for riparian forest vegetation based on sentinel-2 data: A case study of the Kokyar river basin.* Forests, 15, 1749.

Moricz, N. (2010). *Water balance study of a groundwater-dependent oak forest.* Acta Silv.Lign.Hung., Vol. 6. 49-66.

National forest inventory of Republic Serbia (2008). Forestry faculty, Belgrade, Ministry of Agriculture, Forestry and Water Management Serbia – Forest Service.

Newman, B.D., Wilcox, B.P., Archer, S.R., Breshears, D.D., Dahm, C.N., Duffy, C.J., McDowell, N.G., Phillips, F.M., Scanlon, B.R., Vivoni, E.R. (2006). *Ecohydrology of water-limited enviroments: A scientific vision.* Water resources research, Vol. 42, No.1-15.

Nenadić, D., Gaudenyi, T., Bogićević, K., Ganić, M. (2015). Stratigraphical position of pleistocene fluvial deposits of Southeastern Srem and the Danube terraces in Eastern Srem. Bulletin of the Natural History Museum No. 8: 7-19.

Nikic, Z. (2003). *Condition and possibilities of providing quality water for needs of hunt area "Crni lug".* Yugoslav Water Pollution Control Society. Conference Proceedings (32).

Nikić, Z., Letić, Lj., Nikolić, V., Filipović, V. (2010). *Procedure for underground water calculation regime of Pedunculata oak habitat in Plain Srem.* Bulletin of the Faculty of Forestry Vol. 101, No 125-138.

RHMSS. Republic Hydro-meteorological Service Serbia (2026). Annual books. Web: office@hidmet.gov.rs.

Süßel, F., Brüggemann, W. (2021). *Tree water relations of mature oaks in southwest Germany under extreme drought stress in summer 2018*. Plant Stress 1.

Tomić, Z. (2004). *Forest phytocenology*. University of Belgrade. Forestry faculty. Book.

Tomić, Z., Jović, N. (2002). *Recent succession of the penduculate oak and narrow-leaved ash forest in the unflooded part of Gornji Srem*. Bulletin of the Faculty of Forestry. Vol. 85, No 101-112.

Tendayi, R. (2010). *Evapotranspiration in water limited enviroments: up-scaling from the crown canopy to the eddy flux footprint.* Thesis. International institute for geo-information science and earth observation Enschede, The Netherlands. 1-81.

Unkašević, M. (2005). *Forest ecoclimatology.* University of Belgrade. Forestry faculty Belgrade. Book. 1-231.

Vujović, M., Raštegorac, Z. (2002). *Cooperative for the drying of southeastern Srem 1902-2002.* Monography. Water management company „Galovica" Zemun.

Wang, M., Hu, Z., Liu, X., Hou, W. (2025). *Vapor pressure deficit (VPD) downscaling based on multi-source remote sensing, in-situ observation, and machine learning in China*. Journal of Hydrology: Regional Studies 57.

THE HYDROLOGICAL REGIME CHANGES ASSESSMENT ON THE ALLUVIAL-HYGROPHILOUS FOREST HABITAT AT EAST SREM FLOOD-PROTECTED AREA

Milena ANĐELIĆ

Summary

At the alluvial – hygrophilous forest habitat at East Srem lithological environment is represented as a multi-phase gradation of material, with coarser material in the lower, and finer in the upper parts which affects on high of cappillary rising. At this area the direct wetlands-river hydraulic connection is interrupted during period of high water by embankment construction; drainage canals and wells contribute to the piezometric groundwater level decrease. Moisture reserves is replenished with high level of river Sava and low evapotranspiration, and decrease with high evapotranspiration. Study objective is hydrological and atmospheric conditions analyses for alluvial – higrophilous forest at East Srem during different seasons of two comparable periods 1992-2024.yr. and 2020-2024.yr., with data collected from observation station of the RHMSS network.

Results indicate that surface water (SW) spring, summer and autumn level are below an average (1992-2024.yr.) all years of the comparable period (2020-2024.yr.) except 2023.yr. (spring and summer levels). Also groundwater (GW) spring, summer and autumn levels are below an average all years of the comparable period. According to piezometric construction of Obrež (137) RHMSS, GW level is all the time in clay layer with highest capillary rising and longest soil moisture capturment. Annual SW highest and lowest difference level value is greater than an average during all years except 2020.yr. GW highest and lowest difference level value is greater during 2021.yr., 2023.yr. and 2024.yr. and lower 2020.yr. and 2022.yr. compared to an average. Atmospheric aridity indicate increase and occurance excessive values. Extreme low NS value (<200) is spring 2020.yr., 2022.yr.; and summer 2021.yr., 2024.yr. VPD (>3kPa) summer deficits are highest 2021.yr. and 2022. yr. and 2024.yr. SM (>200 mm) summer deficits are highest during 2021-2024.yr. WLC (≤0,75) occures in spring 2020.yr. and 2022.yr. and summer 2020-2024.yr.

During vegetation period, high evapotranspiration demands and groundwater capillary rising have direct impact on adaptation mechanism of higrophilous species. Precisely perception of atmospheric and groundwater participation for hygrophilous species is important when the largest deficits occurs for better planning water resources.

PROCENA PROMENE HIDROLOŠKOG REŽIMA NA STANIŠTU ALUVIJALNO-HIGROFILNIH ŠUMA U BRANJENOJ ZONI OD POPLAVA U ISTOČNOM SREMU

Milena ANĐELIĆ

Rezime

Na staništu aluvijalno-higrofilnih šuma u Istočnom Sremu litološka sredina predstavljena je kao više-fazna gradacija materijala, sa krupnozrnim materijalom u dubljim slojevima i materijalima finije granulacije u gornjim slojevima koji imaju uticaj na visinu kapilarnog izdizanja podzemnih voda. Na ovom području prekinuta je direkta veza između vlažnih terena i reke Save tokom perioda visoke vode izgradnjom nasipa; drenažni kanali i bunari doprinose opadanju pijezometarskog nivoa podzemnih voda. Rezerve vlage se obnavljaju tokom visokog nivoa reke Save i niske evapotranspiracije, a smanjuju se pod uticajem visoke evapotranspiracije. Cilj rada je analiza hidroloških i atmosferskih uslova za aluvijalno-higrofilne šume u Istočnom Sremu tokom različitih sezona dva uporedna perioda 1992-2024.g. i 2020-2024.g. na osnovu preuzetih podataka sa osmatračkih stanica RHMZS.

Rezultati ukazuju da je vodostaj (PV) reke Save tokom proleća, leta i jeseni ispod proseka (1992-2024.g.) tokom svih godina uporednog perioda (2020-2024.g.) osim 2023.g. (proleće i leto). Takođe nivo podzemnih voda (NPV) tokom proleća, leta i jeseni je ispod proseka tokom svih godina uporednog perioda. Prema pijezometarskoj konstukciji Obrež (137) RHMZS, NPV je sve vreme u sloju gline sa najvećom visinom kapilarnog izdizanja i najdužim kapacitetom za zadržavanje vlage. Godišnja razlika najveće i najmanje PV vrednosti je veća od proseka tokom svih godina osim 2020.g. Razlika najvećeg i najmanjeg NPV je veća od proseka tokom 2021.g., 2023.g., 2024.g., a manja 2020.g. i 2022.g. Atmosferska aridnost ukazuje na povećanje i prisustvo ekcesivnih vrednosti. Ekstemno niske NS (<200) vrednosti su tokom proleća 2020.g., 2022.g.; i leta 2021.g., 2024.g. VPD (>3kPa) vrednosti su tokom leta najveće 2021.g. i 2022. g. i 2024.g. SM (>200 mm) letnji deficiti su najveći tokom 2021-2024.yr. WLC (≤0,75) je zastupljen tokom proleća 2020.g. i 2022.g. i leta 2020-2024.yr.

Tokom vegetacionog perioda visoki evapotranspiracioni zahtevi i visina kapilarnog izdizanja podzemnih voda ima direktan uticaj na adaptacione mehanizme higrofilnih vrsta. Precizan uvid u učešće atmosferskih i podzemnih voda kod higrofilnih vrsta je važna kada se najveći deficiti dešavaju zbog boljeg planiranja vodnih resursa.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD
SUSTAINABLE FORESTRY COLLECTION 93, 2026
ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 93, 2026

UDK: 712:630*41(497.11)=111
DOI: 10.5937/SustFor2693101V
Original scientific paper

THE MOST FREQUENT DISEASES OF CERTAIN INTRODUCED TREE SPECIES IN PARKS, PARK FORESTS, AND TREE ROWS OF SERBIA

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

Abstract: *Various symptoms of diseases, including primarily rotting and dieback of branches were recorded on individual trees of boxelder maple (Acer negundo), honey locust (Gleditsia triacanthos), and green ash (Fraxinus pennsylvanica) during the urban forest health monitoring in the territory of Serbia. This paper presents the most frequent parasitic and saprophytic fungi related to the decline of these tree species. 14 species in total of lignicolous fungi and 1 species that causes necroses and die-back of trees were recorded. The greatest damages were recorded on boxelder maple (Acer negundo) and green ash (Fraxinus pennsylvanica) and the smallest on honey locust (Gleditsia triacanthos). The application of protection strategies should be aimed at reducing the source of inoculum for healthy trees. This can be achieved using various forestry measures, which primarily should be aimed at better phytosanitary treatments of parks and park forests of Serbia, as well as the papers aimed at production of phenotypically adequate trees.*

Keywords: introduced species, main diseases, chain damage

NAJČEŠĆE BOLESTI POJEDINIH INTRODUKOVANIH VRSTA DRVEĆA U PARKOVIMA, PARK ŠUMAMA I DRVOREDIMA SRBIJE

Sažetak: *Na pojedinačnim stablima negunda (Acer negundo), gledičije (Gleditsia triacanthos), i pensilvanijskog jasena (Fraxinus pennsylvanica) zabeleženi su različiti simptomi bolesti, prvenstveno uključujući trulež i sušenje grana tokom monitoringa zdravstvenog stanja urbanih šuma na području Srbije. U radu su prikazane najčešće parazitske i saprofitske gljive povezane sa propadanjem ovih vrsta drveća. Konstatovano je ukupno 14 vrsta lignikolnih gljiva i 1 vrsta koja prouzrokuje nekroze i odumiranje stabala. Najveće štete su zabeležene na negundu (Acer negundo) i pensilvanijskom jasenu (Fraxinus pennsylvanica) a najmanje na gledičiji (Gleditsia triacanthos). Primena strategija zaštite treba da bude usmerena u smanjenju izvora inokuluma za zdrava stabla. Ovo se može postići različitim šumarskim merama, koje prvenstveno treba da budu usmerene u boljim fitosanitarnim tretmanima parkova i park šuma Srbije, kao i radovima usmerenim prema proizvodnji fenotipski odgovarajućih stabala.*

Ključne reči: introdukovane vrste, glavne bolesti, ulančavanje šteta

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

© 20XX The Authors. Published by the Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

1. INTRODUCTION

Boxelder maple (*Acer negundo* L.), honey locust (*Gleditsia triacanthos* L.) and green ash (*Fraxinus pennsylvanica* Marsch.) represent allochthonous tree species in Serbia, often grown for decorative purposes in parks and tree rows (Cvjetićanin et al., 2016). Boxelder maple represents invasive weed species on alluvial habitats (Cvjetićanin et al., 2016). Since boxelder maple represents widely grown species, many pathogens of this tree species are present in various parts of range, whereby it occasionally represents a new host for already known pathogens (Li et al., 2020; Liu et al., 2021). In addition, new species of fungi have been discovered on boxelder maple lately (Patejuk et al., 2023). On the other hand, according to the available literature, in recent times there are no studies related to the diseases of honey locust trees.

The dieback of green ash trees deserves special attention. First of all, there is a relatively small number of studies of *Hymenoscyphus fraxineus* on green ash. One of the main causes is the fact that *Hymenoscyphus fraxineus* causes the most damage to common ash (*Fraxinus excelsior* L.) and narrow-leaved ash (*Fraxinus angustifolia* Vahl) (Enderle et al., 2019). The damages on manna ash (*Fraxinus ornus* L.) are far smaller and limited to the leaves (Schwanda and Kirisits 2015; Kirisits 2017). Also, in domestic literature, almost there are no studies that dealt with the causes of dieback of green ash trees. The obtained results will open the way to further studies of pathogens related to decay of this tree species, but above all they will enable more efficient application of protection measures in order to preserve green ash trees in urban areas of Serbia.

In accordance with all mentioned above, the objective of the research was to determine the presence of the most common and most important causative agents of decay of boxelder maple, honey locust and green ash trees. The focus of the research was on lignicolous fungi because they cause the greatest damage and danger in urban conditions.

2. MATERIAL AND METHODS

2.1 Field methods

In the period from spring 2023 to autumn 2025, an inspection of parks, park forests and tree rows in large cities of Serbia was carried out. A special focus was on the city of Belgrade, where Ada Ciganlija, Košutnjak, Šumice, Byford’s Forest, Topčider Park, Topčidersko Brdo and Bežanijska Kosa were inspected as locations with great presence of trees of introduced tree species.

The inspection of the terrain encompassed periodical monitoring of the occurrence of decay several times a year. Damaged parts of the trees, including rotting wood and fruiting bodies of macrofungi were sampled for laboratory analyses. In case of green ash, branch samples with the appearance of ash dieback were also collected; 100 branches from 10 trees were collected, i.e. 10 branches per tree.

The collected samples were packed in paper bags and transported to the laboratory for forest protection of the Institute of Forestry in Belgrade and the

Faculty of Forestry of the University of Belgrade. The samples were stored in refrigerators at the temperature of 5-10°C. Before storing in refrigerators, carpophores were dried at room temperature for 24 hours.

2.2 Laboratory methods

The isolation of fungi from the samples of wood and carpophores was carried out on malt extract agar nutrient medium (MEA, Biolab, Hungary), prepared according to the manufacturer's instructions. Before the isolation the surface of samples was sterilized by coating with 96% alcohol and exposure to flame of spirit lamp for a few seconds. The procedure was repeated 2-3 times. After the growth of the first hyphae, they were transplanted to a new MEA nutrient medium in order to obtain pure cultures.

Part of the fungi was identified based on the appearance of the fruiting bodies, i.e. carpophores based on the description of Ryvarden and Melo (2014) and Karadžić et al., (2016). The identification of fungi based on the cultures was carried out using the description of Nobles (1948, 1965), Stalpers (1978) and Kowalski (2006).

Pure cultures of lignicolous fungi were identified immediately, while the cultures of fungus morphotype isolated from green ash were previously stored at the temperature of 5-10 °C for 3 months.

3. RESULTS AND DISCUSSION

Table 1 shows an overview of the recorded species of fungi. The largest number of the mentioned species of fungi was recorded for the first time on the researched tree species in the parks of Serbia.

Table 1. *The overview of the recorded parasitic and saprophytic fungi on the researched introduced tree species*

Fungus species	Host	Part of the tree	Type of damage	Importance
Antrodia heteromorpha	Boxelder maple, green ash	Trunk	Sapwood rot	+
Auricularia auricula judae	Boxelder maple	Trunk	Dead wood rot	+
Auricularia mesenterica	Boxelder maple, green ash	Trunk	Dead wood rot	+
Bjerkandera adusta	Boxelder maple, honey locust, green ash	Trunk	Sapwood rot	++
Fomes fomentarius	Honey locust, green ash	Trunk	Central rot	+++
Ganoderma applanatum	Boxelder maple, honey locust, green ash	Root, trunk	Central rot	+++
Ganoderma pfeiferii	Boxelder maple, green ash	Root, trunk	Central rot	+++
Hymenoscyphus fraxineus	Green ash	Branches	Necrosis, dying off	+++
Inonotus hispidus	Green ash	Trunk	Sapwood rot	+++
Irpex lacteus	Boxelder maple, honey locust, green ash	Trunk	Dead wood rot	+
Laetiporus sulphureus	Boxelder maple, honey locust	Trunk	Central rot	+++

Fungus species	Host	Part of the tree	Type of damage	Importance
Meripilus giganteus	Honey locust	Root, trunk	Central rot	+++
Phylloporia ribis	Boxelder maple, green ash	Root, trunk	Central rot	+++
Schizophyllum commune	Boxelder maple, honey locust, green ash	Trunk	Sapwood rot	++
Trametes versicolor	Boxelder maple, honey locust, green ash	Trunk	Sapwood rot	++

Addendum to the table: + the fungus has little importance
++ the fungus causes damage
+++ the fungus causes great damage

Most of the present species of fungi were found in advanced and final stage of tree rot, when the fruiting bodies were visible (Figure 1). *Fomes fomentarius*, *Ganoderma applanatum*, *Ganoderma pfeiferii*, *Inonotus hispidus*, *Laetiporus sulphureus*, *Meripilus giganteus* and *Phylloporia ribis* fungi caused greatest damage. Other fungi appeared in succession after these species or on the trees which were damaged due to undefined causative agents (Figure 1).

Figure 1. *Presentation of certain fungi found: A – Antrodia heteromorpha, B – Auricularia auricula judae, C – Auricularia mesenterica, D – Bjerkandera adusta, E – Ganoderma applanatum, F – Ganoderma pfeiferii, G – Irpex lacteus, H – Laetiporus sulphureus, I – Meripilus giganteus*

The presence of a fungus *Hymenoscyphus fraxineus* was found on green ash (Figure 2). The fungus was isolated from one sample, collected from a tree in Bežanijska Kosa, i.e. from 1% of branches.

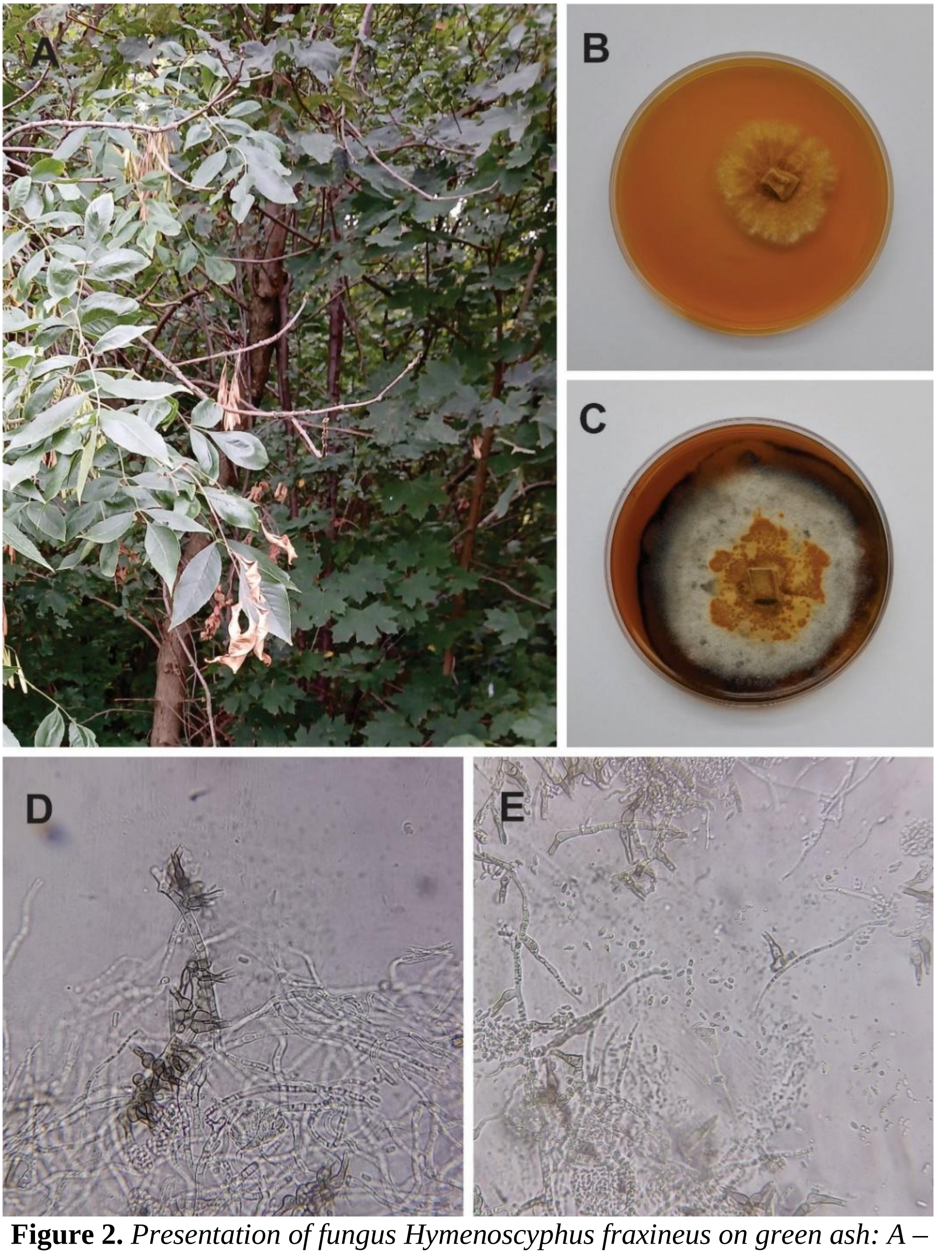


Figure 2. *Presentation of fungus Hymenoscyphus fraxineus on green ash: A – symptoms, B-C – pure cultures, D-E – phialides and conidia*

This study covers the most common causative agents of tree decay of some of the main introduced tree species in parks and other green areas in Serbia. The fact that the fungi with hard carpophores, which are more specific for natural stands, are frequently found, stands out in particular (Vasaitis 2013). The aforementioned phenomenon indicates that the trees of introduced tree species in urban conditions of Serbia reached certain age and decline in vitality, which according to Vasaitis (2013) represent the most important triggers of active development of infection by lignicolous fungi with hard fruiting bodies.

The obtained results indicate that the health status of introduced tree species in Serbia is under infection pressure of various pathogens which colonize trees. Breakages and fallen trees affected by *Fomes fomentarius*, *Laetiporus sulphureus* and *Phylloporia ribis* fungi, most likely caused by snow and wind, confirm the above statement. Such damages from abiotic factors are expected also in trees affected by other lignicolous fungi which cause the greatest damage, i.e. species *Ganoderma applanatum*, *Ganoderma pfeiferii*, *Inonotus hispidus* and *Meripilus giganteus*.

An exception to the above is boxelder maple, where a different way of observing of determined damages is recommended, and in that sense moderate application of protection measures. Boxelder maple shows a potential for intensive spreading and supression of other tree species, especially in wet habitats (Sikorska et al., 2019). In addition, due to increase in soil moisture of these habitats, a negative impact on adaptability and succession of various plant species occurs (Dubrovin et al., 2022). When implementing future protection measures in urban forests, in the case of boxelder maple trees near water bodies it is necessary to make a balance in terms of leaving a certain number of trees to harmful factors. In this way, their invasive potential and the reduction of diversity in these habitats will be reduced.

The presence of *Hymenoscyphus fraxineus* is confirmed on the green ash trees with the symptoms of dieback in urban conditions of Serbia. The symptoms are limited to certain branches i.e. parts of crown. That is, *Hymenoscyphus fraxineus* was isolated in a small percentage from symptomatic trees. However, it should be emphasized that in case of *Hymenoscyphus fraxineus* the degree of isolation should not be considered an important indicator of its harmfulness. The reason for the above may be the slow growth of the fungus, i.e. the appearance of various species of saprophytic fungi which appear in the later stages of the development of necrotic lesions, i.e. dieback of trees (Kowalski et al., 2016).

Hymenoscyphus fraxineus pathogenicity tests on green ash showed the occurrence of necrotic lesions on 5.5% of inoculated trees (Kowalski et al., 2015), while 16% of trees with necrotic lesions was recorded in nature (Gross and Sieber 2016). The above indicates that *Hymenoscyphus fraxineus* does not develop actively as on sensitive ash species (*Fraxinus* spp.). An additional difficulty in determining the frequency of ash dieback symptoms on green ash reflects in the fact that necrotic lesions caused by *Hymenoscyphus fraxineus* are small and do not differ from necroses caused by other factors (Kowalski et al., 2015; Gross and Sieber 2016). On the researched sites, dieback of branches was relatively often present, while necrotic lesions were rarely clearly visible. This phenomenon can indicate several things: that *Hymenoscyphus fraxineus* is more common on green ash trees in urban forests of the city of Belgrade but cannot be reliably confirmed at the moment, or the dieback of the crown is necessary to be attributed to other factors. Anyway, a small number of isolates of this fungus is consistent with the results of previous research.

High temperatures limit the spreading of *Hymenoscyphus fraxineus* (Grosdidier et al., 2018). In addition, the mycelium of the fungus ceases to be vital at high temperatures (Kowalski and Bartnik 2010). These studies may provide a partial explanation why the symptoms are present without the possibility of isolation of the fungus. It is possible that the fungus previously achieved infection, but quickly ceased to be vital due to high temperatures. The only confirmed finding of this fungus was in the forests on Bežanijska Kosa which were neglected due to the lack of care measures, which probably influenced more favorable conditions for the growth of the fungus.

As previously stated, dieback of certain branches or parts of the crown was noted, without the tendency of dieback of entire trees. Pastirčáková et al., (2020) state a lower degree of crown defoliation in green ash compared to the crown of common ash. In the future, it is necessary to research the connection of different characteristics of green ash trees and dieback intensity. The above data will enable better understanding of the occurrence of symptoms caused by *Hymenoscyphus fraxineus* and distinguishing it from other factors which contribute to dieback of green ash trees.

5. CONCLUSION

The carried-out study was one of the first to study diseases of introduced tree species in parks of Serbia. As such, it represents the basis for further research which will characterize in more detail dieback of each of the stated tree species. Based on the results obtained, individual conclusions were formed.

- In total, 14 species of lignicolous fungi were found on introduced tree species: boxelder maple, honey locust and green ash. The most important recorded fungi, causative agents of rot, were *Fomes fomentarius*, *Laetiporus sulphureus* and *Phylloporia ribis*.
- The majority of the recorded fungi was found for the first time on trees of introduced tree species in urban areas of Serbia.
- After the occurrence of central rot caused by fungi *Fomes fomentarius*, *Laetiporus sulphureus* and *Phylloporia ribis*, a chain damage from snow and wind is recorded.
- *Bjerkandera adusta*, *Irpex lacteus*, *Schizophyllum commune* and *Trametes versicolor* fungi were occasionally found on the damaged trees.
- Fungus *Hymenoscyphus fraxineus* was found on green ash. According to the available literature the above finding represents the first finding of *Hymenoscyphus fraxineus* on green ash in Serbia.

Acknowledgement: *This research was carried out under the Agreement on financing by the Ministry of Science, Technological Development and Innovation for 2026 No. 451-03-33/2026-03/200027.*

REFERENCES

Cvjetićanin, R., Brujić, J., Perović, M., & Stupar V. (2016). Dendrology. Faculty of Forestry, University of Belgrade (Original title: Dendrologija. Univerzitet u Beogradu, Šumarski fakultet).

Dubrovin, D.I., Rafikova, O.S., & Veselkin, D.V. (2022). Soil Moisture in Urbanized Habitats Invaded by Alien *Acer negundo*. *Russian Journal of Ecology*, *53,* 347-356. https://doi.org/10.1134/S1067413622050034

Gross, A., Sieber, & T.N. (2016). Virulence of *Hymenoscyphus albidus* and native and introduced *Hymenoscyphus fraxineus* on *Fraxinus excelsior* and *Fraxinus pennsylvanica*. *Plant Pathology*, *65(4),* 655-663. https://doi.org/10.1111/ppa.12450

Grosdidier, M., Ioos, R., & Marçais, B. (2018). Do higher summer temperatures restrict the dissemination of *Hymenoscyphus fraxineus* in France? *Forest Pathology*, 48(4), e12426.

Enderle, R., Stenlid, J., & Vasaitis, R. (2019). An overview of ash (*Fraxinus* spp.) and the ash dieback disease in Europe. *CABI Reviews*, *14(025),* 1-12. https://doi.org/10.1079/PAVSNNR201914025

Karadžić, D., Keča, N., Milenković, I., Milanović, S., & Stanivuković, Z. (2016). Forest mycology. Faculty of Forestry, University of Banja Luka (Original title: Šumska mikologija, Univerzitet u Banjoj Luci, Šumarski fakultet.).

Kirisits, T. (2017). Further Observations on the Association of *Hymenoscyphus fraxineus* with *Fraxinus ornus*. *Baltic Forestry*, *23(1),* 60-67.

Kowalski, T. (2006). Chalara fraxinea sp. nov. associated with dieback of ash (*Fraxinus excelsior*) in Poland. *Forest Pathology*, *36(4),* 264-270. https://doi.org/10.1111/j.1439-0329.2006.00453.x

Kowalski, T., & Bartnik, C. (2010). Morphological variation in colonies of *Chalara fraxinea* isolated from ash (*Fraxinues excelsior* L.) stems with symptoms of ash dieback and effects of temperature on colony growth and structure. *Acta Agrobotanica*, *63(1),* 99-106. https://doi.org/10.5586/aa.2010.012

Kowalski, T., Bilański, P., & Holdenrieder, O. (2015). Virulence of *Hymenoscyphus albidus* and *H. fraxineus* on *Fraxinus excelsior* and *F. pennsylvanica*. *PLoS ONE* 10(10), e0141592. https://doi.org/10.1371/journal.pone.0141592

Kowalski, T., Kraj, W., & Bednarz, B. (2016). Fungi on steams and twigs in initial and advanced stages of dieback of European ash (*Fraxinus excelsior*) in Poland. *European Journal of Forest Research*, *135(3),* 565-579. https://doi.org/10.1007/s10342-016-0955-x

Li., M., Dai, Y., Zheng, Z., & Chen, F. (2020). First Report of *Fusarium solani* Causing Stem Canker of Acer negundo in China. *Plant Disease*, *104(12),* https://doi.org/10.1094/PDIS-03-20-0477-PDN

Liu, C-L., Zheng X.R., & Chen F.M. (2021). Dieback and Leaf Spot in Box Elder (*Acer negundo*) Caused by *Exserohilum rostratum*. *Plant Disease, 105(10),* 2955-2963. https://doi.org/10.1094/PDIS-07-20-1424-RE

Nobles, M.K. (1948). Studies in Forest Pathology. VI. Identification of cultures of Wood-rooting fungi. *Canadian Journal of Research 26*, 281-431.

Nobles, M.K. (1965). Identification of cultures of wood-inhabiting Hymenomycetes. *Canadian Journal of Botany, 43,* 1097-1139.

Pastirčáková, K., Adamčíková, K., Barta, M., Pažitný, J., Hoťka, P., Sarvašová, I., & Kádasi Horáková, M. (2020). Host Range of *Hymenoscyphus fraxineus* in Slovak Arboreta. *Forests, 11(5),* 596. https://doi.org/10.3390/f11050596

Patejuk, K., Czachura, P., Baturo-Cieśniewska, A., Owczarek-Kościelniak, M., Pusz, W., Najberek, K., & Piątek, M. (2023). *Colletotrichum acericola* sp. nov. from seeds of the invasive alien tree species *Acer negundo* in Poland. *Plant Pathology, 72(9),* 1716-1725. https://doi.org/10.1111/ppa.13785

Ryvarden, L., & Melo, I. (2014). Poroid fungi of Europe second edition, Sinopsis fungorum 37, Fungiflora, Oslo, Norway.

Schwanda, K., & Kirisits, T. (2015). Pathogenicity of *Hymenoscyphus fraxineus* towards leaves of three European ash species: *Fraxinus excelsior*, *F. angustifolia* and *F. ornus*. *Plant Pathology, 65(7),* 1071-1083. https://doi.org/10.1111/ppa.12499

Sikorska, D., Sikorski, P., Archiciński, P., Chormański, J., & Hopkins, R.J. (2019). You Can't See the Woods for the Trees: Invasive *Acer negundo* L. in Urban Riparian Forests Harms Biodiversity and Limits Recreation Activity. *Sustainability, 11(20),* 5838. https://doi.org/10.3390/su11205838

Stalpers, J.A. (1978). Identification of Wood inhabiting Aphyllophorales in pure culture. *Studies in mycology, 16,* 1-248.

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

THE MOST FREQUENT DISEASES OF CERTAIN INTRODUCED TREE SPECIES IN PARKS, PARK FORESTS, AND TREE ROWS OF SERBIA

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

Summary

The paper presents the results of a three-year monitoring of health condition of boxelder maple (*Acer negundo*), honey locust (*Gleditsia triacanthos*) and green ash (*Fraxinus pennsylvanica*) from the point of view of pathogenic fungi. Various urban forests were inspected, including individual trees, tree rows, parks and park forests. Most of the recorded lignicolous fungi caused great damage on trees. The most important recorded abiotic damages are breakages caused by snow or wind, which often occur after damages from parasitic fungi.

Also, the results of monitoring of fungus *Hymenoscyphus fraxineus* on symptomatic trees of green ash are presented in the paper. The symptoms of ash dieback were recorded on several sites, while *Hymenoscyphus fraxineus* was isolated from one symptomatic tree. Dieback of green ash was limited to individual branches, without the tendency of dieback of whole trees. The isolate was characterized by moderate growth, formation of phialides and conidia after three months at 5-10 °C.

The trees with the dieback symptoms were often damaged by abiotic factors or were located in unfavorable habitat conditions. According to the available data, the above results represent the first finding of *Hymenoscyphus fraxineus* on green ash in Serbia. The influence of environmental factors on the occurrence of *Hymenoscyphus fraxineus* was discussed especially.

NAJČEŠĆE BOLESTI POJEDINIH INTRODUKOVANIH VRSTA DRVEĆA U PARKOVIMA, PARK ŠUMAMA I DRVOREDIMA SRBIJE

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

Rezime

U radu su prikazani rezultati trogodišnjeg monitoringa zdravstvenog stanja negunda (*Acer negundo*), gledičije (*Gleditsia triacanthos*) i pensilvanijskog jasena (*Fraxinus pennsylvanica*) sa stanovišta patogenih gljiva. Pregledane su različite urbane šume, uključujući pojedinačna stabla, drvoredi, parkovi i park šume. Najveći broj konstatovanih lignikolnih gljiva je izazvao velika oštećenja na stablima. Najvažnija konstatovana abiotička oštećenja su lomovi uzrokovani snegom ili vetrom, koja se često pojavljuju posle šteta od parazitskih gljiva.

Takođe, prikazani su rezultati monitoringa gljive *Hymenoscyphus fraxineus* na simptomatičnim stablima pensilvanijskog jasena. Simptomi odumiranja jasena su konstatovani na više lokaliteta, dok je *Hymenoscyphus fraxineus* izolovana iz jednog simptomatičnog stabla. Sušenje pensilvanijskog jasena je bilo ograničeno na pojedinačne grane, bez tendecije odumiranja celih stabala. Izolat se karakterisao umerenim rastom, formiranjem fijalida i konidija posle 3 meseca na 5-10 °C.

Stabla sa pojavom simptoma odumiranja su često bila oštećena od abiotičnih faktora ili se nalazila u nepovoljnim stanišnim uslovima. Prema dostupnim podacima, navedeni rezultati predstavljaju prvi nalaz *Hymenoscyphus fraxineus* na pensilvanijskom jasenu (*Fraxinus pennsylvanica*) u Srbiji. Uticaj ekoloških faktora na pojavu *Hymenoscyphus fraxineus* je posebno diskutovan.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY COLLECTION 93, 2026
ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 93, 2026

UDK: 630*45:582.746.56(497.11)=111
DOI: 10.5937/SustFor2693111M
Original scientific paper

THE FIRST RECORD OF TETRANYCHIDAE AND PHYTOSEIIDAE (ACARI) ON *AESCULUS HIPPOCASTANUM* (SAPINDACEAE) IN SERBIA

Katarina MLADENOVIĆ[*1], *Danilo FURTULA*[1], *Jelena BOŽOVIĆ*[1], *Miroslava MARKOVIĆ*[1], *Jovana CVETKOVIĆ*[1]

Abstract: *Three species of spider mites from two genera one subfamily: Eotetranychus pruni, Eotetranychus tiliarium and Schizotetranychus garmani as well as two species of predatory mites Euseius finlandicus and Phytoseius echinus from two genera two subfamilies were recorded for the first time on the horse-chestnut in Serbia. The species S. garmani is the first record in the world found on Aesculus hippocastanum. The research was carried out on a large number of urban and semi-urban sites in central Serbia and Vojvodina. The collecting of samples encompassed the period of six growing seasons.*

Keywords: biodiversity, spider mites, predatory mites, horse-chestnut tree.

PRVI NALAZ TETRANYCHIDAE I PHYTOSEIIDAE (ACARI) NA *AESCULUS HIPPOCASTANUM* (SAPINDACEAE) U SRBIJI

Sažetak: *Na divljem kestenu u Srbiji su prvi put zabeležene tri vrste grinja paučinara iz dva roda jedne potfamilije Eotetranychus pruni, Eotetranychus tiliarium i Schizotetranychus garmani kao i dve vrste predatorskih grinja Euseius finlandicus i Phytoseius echinus iz dva roda dve potfamilije. Vrsta S. garmani je prvi nalaz u svetu zabeležen na Aesculus hippocastanum. Istraživanja su obavljena na većem broju urbanih i semiurbanih lokalita u centralnoj Srbiji i Vojvodini. Sakupljanje uzoraka je obuhvatilo period šest vegetacijskih sezona.*

Ključne reči: biodiverzitet, grinje paučinari, predatorske grinje, divlji kesten.

1.INTRODUCTION

The species *Aesculus hippocastanum* L. (Sapindales: Sapindaceae) is a tertiary relict, present in Central Europe before the Ice Age (Jovanović 2000). It is an endemic species for a limited area of the Balkan Peninsula: North Macedonia, Greece, Albania and Bulgaria (Aas and Riedmiller 1992; Ball 1968; Boratynski et al. 1992; Greuter et al. 1986; Heldreich 1980; Polunin 1997; Strid and Tan 2000). In Serbia, the horse-chestnut is an allochthonous species to which the growing

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

© 2026 The Authors. Published by Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

conditions of the oak and warmer beech forest belt are suitable, and it reaches the height up to 30 m with diameter at breast height of 1m. It is resistant to frost down to –30^{0}C, and it is mesophilic, mesotrophic, mesothermal and sciophilous species for which deep humus soils are suitable (Cvjetićanin et al. 2016; Vukićević 1996). Nowadays, it is widely cultivated in the temperate climate zone as an ornamental and landscape tree due to its appearance and strong resistance to environmental conditions (Walas et al. 2019; Wilczynski and Podlaski 2007). The horse-chestnut is significant for pollinators (Somme et al. 2016). *Aesculus hippocastanum* seeds have been used since ancient times as a medicine for horses which is where its folk name horse-chestnut comes from (Jovanović 2000). Medical significance of horse-chestnut is reflected in treatment of venous insufficiency, coronary disease, diarrhea and hemorrhoids (Busia 2016). The horse-chestnut research in recent years has been focused more and more on chemical properties and to characterize different compounds in specific parts of fruits and assessment of their bioactivity and to test the stability in food, cosmetic, and pharmaceutical formulations (Dridi et al. 2023).

City parks and urban forests include diverse bushy and woody autochthonous and allochthonous vegetation that serves as nourishment, shelter and substrate for a large number of organisms among which arthropods are dominant (Brown and Freitas 2002; Ebeling et al. 2018). Phytophagous species such as insects and mites can lead to significant physiological, biochemical and anatomical changes on ornamental woody plants which directly influences the condition and decorative value (Hrubik et al. 2008). Herbivorous arthropods, i.e. their density and composition on woody and bushy species are regulated by the presence of carnivores and omnivores (Ebeling et al. 2018) both in natural and in anthropogenic ecosystems. Beneficial arthropods among which are many phytoseiid mites are important predators to numerous small arthropods, especially to tetranychid mites where their importance is manifested in preventing outbreaks (McMurtry et al. 2013).

Spider mites (Acari: Tetranychidae) are the most significant harmful mites in agriculture, forestry and horticulture. 1364 valid species on 4139 different plants have been recorded worldwide to date, while 13 tetranychid mites from six genera have been found on *A. hippocastanum*, of which in Europe two species each were recorded in Hungary and Poland, and one species each in Lithuania and Georgia (Migeon and Dorkeld 2026). Numerous papers indicate that tetranychid mites lead to significant economic damage on the ornamental plants (Jeppson et al. 1975, Ripka et al. 2005; Yesilayer and Cobanoglu 2015 etc.). So far, 47 species of tetranychid mites have been recorded in Serbia (Stojnić et al. 2026) of which a smaller number was determined on horticultural woody plant species.

Predatory mites (Acari: Phytoseiidae) represent an important group of predatory mites which inhabit herbaceous, bushy and woody plant species. To date, 2707 valid species have been recorded worldwide (Demite et al. 2026). According to Kopačka and Zemek (2023) horse-chestnut is an important reservoir of phytoseiid mites in city parks and urban forests. In the Czech Republic, 8 species of phytoseiid mites were found on *A. hippocastanum*, 4 species in Greece, 3 in Finland, 8 in Slovenia (Kopačka and Zemek 2023; Kopačka et al. 2018, Kreiter et al. 2020; Tuovinen 1994; Tuovinen and Rokx 1991), and in Neartic two species (de Moraes et al. 1986; Prasad 2012). So far, 51 species of phytoseiids have been determined in Serbia (Stojnić et al. 2023).

Our research provides the first overview of the species diversity of epiphilic species of two groups of phytophagous and predatory mites on horse-chestnut in Serbia.

2. MATERIAL AND METHOD

Plant material was collected on eight sites on urban and semi-urban areas in Serbia (Belgrade and surroundings, Goč, Vršac, Bečej and surroundings) during 6 vegetation seasons from 2019 to 2024. Plant samples contained 50 horse-chestnut leaves each, which were packed in plastic bags. The samples were exposed to the effect of ethyl acetate for 30 minutes (Stojnić et al 2021; Mladenović et al. 2025). The selection of adult individuals for the purposes of determination was carried out using Leica Wild M3Z stereo microscope. The selected individuals were illuminated in fixative 1:5 of lactic acid and ethanol after which permanent preparations were made in Hoyer medium (Baker and Wharton 1964; Evans and Browing 1955; Krantz and Walter 2009).

The determination of mite species was carried out using phase-contrast microscope, Olympus BX53 with the use of appropriate keys, catalogues and databases relevant for both researched groups of mites (Baker and Tuttle 1994; Begljarov 1981; Bolland et al. 1998; Chant and McMurtry 2007; De Moraes et al. 2004; Demite et al. 2026; Karg 1993; Migeon and Dorkeld 2026; Mitrofanov et al. 1987; Prasad 2012; Pritchard and Baker 1955; Tixier et al. 2012).

Permanent preparations are stored at Institute of Forestry, Department of Forest Protection, Belgrade and in the University of Belgrade, Faculty of Agriculture, Institute of Phytomedicine, Department of Entomology and Agricultural Zoology.

3. RESULTS AND DISCUSSION

Our research represents the first record of mites from two families: Tetranychidae Donnadieu, 1875 and Phytoseiidae Berlese 1916 on *Aesculus hippocastanum* L. in Serbia.

Three species of phytophagous mites have been determined *Eotetranychus pruni* **(**Oudemans, 1931**),** *Eotetranychus tiliarium* (Hermann, 1804) and *Schizotetranychus garmani* Pritchard & Baker, 1955 grom two genera *Eotetranychus* Oudemans, 1931 and *Schizotetranychus* Trägårdh, 1915 one subfamily *Tetranychinae* Berlese, 1913, as well as two species of predatory mites *Euseius finlandicus* (Oudemans, 1915a) and *Phytoseius echinus* Wainstein & Arutunjan, 1970 from two genera *Euseius* Wainstein 1962 and *Phytoseius ribaga* 1902 two Subfamilies Amblyseiinae Muma 1961 and Phytoseiinae Berlese 1916.

Aesculus hippocastanum was recorded for the first time as host plant for spider mite *S. garmani*.

Family	Tetranychidae Donnadieu, 1875
Subfamily	Tetranychinae Berlese, 1913
Tribe	Tetranychini Reck, 1950
Genus	*Eotetranychus* Oudemans, 1931
Species	*Eotetranychus pruni* (Oudemans, 1931
	Eotetranychus tiliarium (Hermann, 1804)
Genus	*Schizotetranychus* Trägårdh, 1915
Species	*Schizotetranychus garmani* Pritchard & Baker, 1955

Three species of tetranychidae were determined on horse-chestnut in Serbia of which one species was recorded for the first time in the world on horse-chestnut as a new host plant (Table 1).

Table 1. *Three species of spider mites recorded on horse-chestnut in Serbia and their distribution in Europe*

Tetranychid Species	Distribution on horse-chestnut in Europe	Reference
Eotetranychus pruni	Serbia*	
	Georgia Poland Hungary	Reck 1950. Soika and Łabanowski 2003. Gyenis et al. 2005.
Eotetranychus tiliarium	Serbia*	
	Latvia	Petrov 1971
Schizotetranychus garmani	Serbia*	

*** new data**

With our finding the total number of recorded spider mite species on horse-chestnut in the world increased to 14 and in Europe to 5.

During the research, species *E. pruni* and *E. tiliarium* were recorded on urban habitats, while *S. garmani* was recorded on semi-urban habitat in the immediate vicinity of the forest ecosystem.

Eotetranychus pruni commonly named apple yellow spider mites and *E. tiliarium* commonly named lime spider mites are polyphagous harmful species on numerous deciduous forest or horticultural woody and bushy species such as European hornbeam, linden, oak, willow, hazel, chestnut, ash, maple, elm and others, widely distributed in Europe (Anonymus 2026).

Schizotetranychus garmani is one of the key pests on cultivated willows (Puchalska et al. 2014; Soika and Łabanowski 2003; Tomczyk 2004) found on 13 woody forest species of 4 genera *Quercus*, *Populus*, *Salix* and *Acer*, tetranychid which is present in Europe in Hungary, Poland, Serbia and Switzerland (Migeon and Dorkeld 2026).

During our research we did not determine larger damages occurred due to nutrition of phytophagous mites on horse-chestnut leaves which corresponds to previously recorded findings (Soika and Labanowski 2003). Rarely present damage can be the result of a small number of determined individuals on researched leaf samples.

Family	Phytoseiidae Berlese 1916
Subfamily	Amblyseiinae Muma 1961
Genus	*Euseius* Wainstein 1962
Species	*Euseius finlandicus* (Oudemans, 1915a)
Subfamily	Phytoseiinae Berlese 1916
Genus	Phytoseius Ribaga 1902
Species	*Phytoseius echinus* Wainstein & Arutunjan, 1970

Euseius finlandicus is a predatory cosmopolitan species recorded on a large number of host plants (Demite et al. 2026; De Moraes et al. 1986; Prasead 2012) most commonly present on smooth leaves while it hides in domatia (Kabiček 2005, 2008). McMurtry and Croff (1979) and McMurtry et al. (2013) classified this species in Type IV generalist predator which prefer pollen but also are significant regulators of number of harmful mite species.

Phytoseius echinus predatory species is widely present in Europe and recorded on forest species (oaks, willows, wild cherry, etc.) (Demite et al. 2026; De Moraes et al. 1986, 2004; Prasead 2012).

Juvenile stages of *S. garmani* are adequate prey for *E. finlandicus* in laboratory conditions (Puchalska and Kozak 2016) so this phytoseiid is suitable as biocontrol agent for spider mite control.

During our research prey-predator complex was not determined which is probably the consequence of low number of species of spider mites found on horse-chestnut. In one sample, the cohabitation of two predatory species, *E. finlandicus* and *P. echinus,* was recorded.

5. CONCLUSION

The first record of epiphyllous mites tetranychid and phytoseiid on *A. hippocastanum* in Serbia was presented.

Phytophagous species confirmed on horse-chestnut in Serbia are *E. pruni*, *E. tiliarium* and *S. garmani.*

Predatory species recorded on horse-chestnut in Serbia are *E. finlandicus* and *P. echinus*.

Spider mite *S. garmani* was recorded for the first time in the world on a new host plant, *A. hippocastanum.*

During our research on horse-chestnut prey-predator complex was not determined, while cohabitation of two predatory species *E. finlandicus* and *P. echinus* was recorded only on one sample.

Considering our findings, the number of species of spider mites determined on horse-chestnut for the world's acarofauna increased to 14 and for European acarofauna to 5 species.

It is necessary to continue the research of diversity of horse-chestnut mites in order to determine, on the one hand, the potential harmfulness of phytophagous spider mites and on the other hand, to record the presence of predatory mites on horse-chestnut which is an important reservoir of these species in city parks and urban forests.

REFERENCES

Aas, G., Riedmiller, A. (1992): *Bäume: Laub- und Nadelbäume Europas erkennen und bestimmen* (GU Naturführer). Gräfe und Unzer Verlag, München.

Anonymus (2026). Atlas of forest pests Forest pests Europe NATIONAL FOREST CENTRE Forest Protection Service Slovakia https://www.forestpests.eu/

Baker, E. W. and Wharton, G. W. (1964): *An introduction to acarology*, Macmillan Co., N.Y. pp 465.

Baker, E.W., and Tuttle, D.M. (1994): *A guide to the spider mites (Tetranychidae) of the United States*. Indira Publishing Hous, pp. 347.

Ball P. W. (1968): Hippocastanaceae. – In: Tutin, T. G. & al. (eds), *Flora Europaea*. Vol. 2, p. 340. Cambridge Univ. Press, Cambridge.

Begljarov, G. A. (1981): *Key for identification of the predacious mites Phytoseiidae (Parasitiformes, Phytoseiidae) in the fauna of the USSR*, Information Bulletin EPS IOBC, 3: pp 141.

Bolland H.R., Gutierrez J., Flechtmann C.H.W. (1998): *World catalogue of the spider mite family (Acari: Tetranychidae)*. Leiden, Brill Academic Publishers: pp 392.

Boratynski A., Browicz K., Zieliński, J. (1992): *Chorology of Trees and Shrubs in Greece*. Sorus, Poznań/Kórnik.

Brown, K.S., Freitas, A.V.L. (2002): *Butterfly Communities of Urban Forest Fragments in Campinas, São Paulo, Brazil: Structure, Instability, Environmental Correlates, and Conservation*. *Journal of Insect Conservation* 6, 217–231. https://doi.org/10.1023/A:1024462523826.

Busia, K. (2016): *Fundamentals of Herbal Medicine: Major Plant Families, Analytical Methods, Materia Medica*; Xlibris Publishing: Bloomington, UK, Volume 2.

Chant D.A., McMurtry J.A. (2007): *Illustrated keys and diagnoses for the genera and subgenera of the Phytoseiidae of the world (Acari: Mesostigmata)*. Indira Publishing House, West Bloomfield, 219 pp.

Cvjetićanin, R., Brujić J., Perović, M., Stupar, V. (2016): *Dendrology*. University of Belgrade Facultz of Forestry, 557 pages. (Original title: *Dendrologija*. Univerzitet u Beogradu Šumarski fakultet. 557 str).

De Moraes, G.J., McMurtry, J.A., Denmark, H.A. (1986): *A catalogue of the mite family Phytoseiidae*. EMBRAPPA-DDT, Brasilia.

De Moraes, G.J., McMurtry, J.A., Denmark, H.A., Campos, C.B. (2004): *A revised catalog of the mite family Phytoseiidae*. Zootaxa 434: 1-494.

Demite, P.R., Moraes, G.J. de, McMurtry, J.A., Denmark, H.A., Castilho, R. C. (2026): Phytoseiidae Database. Available from: www.lea.esalq.usp.br/phytoseiidae (accessed 23/03/2026).

Dridi, A., Reis, F.S., Pires, T.C.S.P., Calhelha, R.C., Pereira, C., Zaghdoudi, K., Ferreira, I.C.F.R., Barros, L., Barreira, J.C.M (2023): *Aesculus hippocastanum* L.: *A Simple Ornamental Plant or a Source of Compelling Molecules for Industry*? 160. https://doi.org/10.3390/separations10030160.

Ebeling, A., Hines, J., Hertzog, D., Lange, M., Meyer, S., Simons, N., Weisser, W. (2018): *Plant diversity effects on arthropods and arthropod-dependent ecosystem functions in a biodiversity experiment*, Basic and Applied Ecology, Volume 26, Pages 50-63, ISSN 1439-1791, https://doi.org/10.1016/j.baae.2017.09.014.

Evans, G. O., Browing, E. (1955): *Techniques for the preparation of mites for study*. Ann. Mag. Nat. Hist. 8 (12): 631-635.

Greuter W., Burdet M. H., Long G. (1986): *MedChecklist. Dicotyledones. (Convolvulaceae Labiatae*). Bot. Garden & Bot. Museum, Berlin – Dahlem.

Gyenis, K., Penzes, B., Hegyi, T. (2005): *Phytophagous, predatory mites on the horse chestnut tree*. Növényvédelen, 41 (4): 143-148.

Heldreich U. (1980): *Dictionary of the Common Plant Names of Greece*. Publ. Tolides Broth., Athens

HRUBÍK., P., JUHÁSOVÁ, G., GÁPER, J., TKÁČOVÁ, S. (2008): *Protection of ornamental plants*. Slovak university of agriculture, Nitra, 155 pp. [in Slovak]

Jeppson, L.R., Keifer, H.H., Baker, E.W. (1975): *Mites Injurious to Economic Plants*. University of California Press, Berkeley, 646.

Jovanović, B. (2000): *Dendrology*. University of Belgrade, Serbia, University textbook, Book 86, 536 pages, ISBN 86-81019-86-4. (Original title: *Dendrologija*. Univerzitet u Beogradu, Srbija, Univerzitetski udžbenik, Knjiga 86, 536 str. ISBN 86-81019-86-4).

Kabiček J. (2005): *Intra-leaf distribution of the phytoseiid mites (Acari, Phytoseiidae) on several species of wild broadleaf trees*. Biologia, 60, 523–528.

Kabiček J. (2008): *Cohabitation and intra-leaf distribution of phytoseiid mites (Acari: Phytoseiidae) on leaves of Corylus avellana*. Plant Protection Science, 44, 32–36.

Karg, W. (1993): *Acari (Acarina), Milben Parasitiformes (Anactinochaeta) Cohors Gamasina Leach. Raubmilbe*. Die Tierwelt Deutschlands: 59, Second Edition, Gustav Fischer Verlag, Jena, Germany, 523 pp.

Kopačka M, Zemek R. (2023): *Species Composition and Seasonal Abundance of Predatory Mites (Acari: Phytoseiidae) Inhabiting Aesculus hippocastanum (Sapindaceae*). ***Forests***. 14(5):942. https://doi.org/10.3390/f14050942.

Kopačka, M., Stathakis, T.I., Broufas, G., Papadoulis G.Th., Zemeke, R. (2018): *Diversity and abundance of Phytoseiidae (Acari: Mesostigmata) on horse chestnut (Aesculus hippocastanum L.) in an urban environment: a comparison between Greece and the Czech Republic*. Acarologia, 58(Suppl), 83– 90.

Krantz, G.W., Walter, D.E. (2009): *A manual of acarology*. Lubbock, Texas Tech University Press, 807 pp.

Kreiter, S, Amiri, K. Douin, M., Bohinc, T., Trdan, S., Tixier, M. (2020). *Phytoseiid mites of Slovenia (Acari: Mesostigmata): new records and first description of the male of Amblyseius microorientalis* 60 2 203-242 Journal Article Acarologia - Volume: 60 Issue: 2 pages: 203-242 https://doi.org/10.24349/acarologia/20204364.

McMurtry, J.A., Croft, B. A. (1997): *Life-styles of phytoseiid mites and their roles in biological contro*l. Ann. Rev. Entomol., 42: 291-321.

McMurtry, J.A., De Moraes G,J,. Sourassou, N.F. (2013): *Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies*. Syst. Appl. Acarol. 18: 297–32.

Migeon, A., Dorkeld, F. (2026): *Spider Mites Web*: a comprehensive database for the Tetranychidae. Available from https://www1.montpellier.inrae.fr/CBGP/spmweb (Accessed 1st February 2026).

Mitrofanov, V.I., Strunkova, Z.I., Livsic, I.Z. (1987). *Opredelitelj teranihovih klesci fauni SSSR i sopredeljnih stran*. Dusanbe, 223 pp.

Petrov, V.M. (1971): *On the study of spider mites species structure and ecology in Latvia*. Vestis, 7 (288): 26-32.

Polunin, O. (1997): *Flowers of Greece and the Balkans, a Field Guide*. Oxford Univ. Press, Oxford, New York, Tokyo.

Prasad, V. (2012): *Checklist of Phytoseiidae of the world (Acari: Mesostigmata).* Indira Publishing House, West Bloomfield, Michigan, USA, 1063 pp.

Pritchard, A.E, Baker, E.W. (1955): *A revision of the spider mite family Tetranychidae*. Memoirs Series, San Francisco, Pacific Coast Entomological Society, 2: 472 p.

Puchalska, E., Kozak, M. (2016): *Typhlodromus pyri and Euseius finlandicus (Acari: Phytoseiidae) as potential biocontrol agents against spider mites (Acari: Tetranychidae) inhabiting willows: laboratory studies on predator development and reproduction on four diets*. Experimental & applied acarology. 68. 10.1007/s10493-015-9973-5.

Puchalska, E.K., Kropczynska-Linkiewicz, D, Kazmierczak, B. (2014): *Evaluation of the co-occurrence of spider mites (Acari: Tetranychidae) and phytoseiid mites (Acari: Phytoseiidae) on willows (Salix spp.) in nurseries and natural environments*. Int J Acarol 40(7):473–484. doi:10.1080/01647954.2014.956670.

Reck, G.F. (1950): *Spider mite fauna from Georgia (Tetranychidae: Acarina)*. Trudy Zoologicheskogo Instituta Akademia Nauk Gruz.S.S.R., 9: 117-134.

Ripka, G., Fain, A., Kamierski, A., Kreiter, S., Magowski, W.Ł. (2005): *New data to the knowledge of the mite fauna of Hungary (Acari: Mesostigmata, Prostigmata, and Astigmata)*. Acta Phytopathologica et Entomologica Hungarica, 40(1 2), 159 176.https://doi.org/10.1556/APhyt.40.2005.1-2.13.

Soika, G., Łabanowski, G. (2003): *Spider mites (Tetranychidae) recorded on ornamental trees and shrubs in nurseries*. Journal of Plant Protection Research, 43 (2): 105-112.

Somme, L., Moquet, L., Quinet, M., Vanderplanck, M., Michez, D., Lognay, G., Jacquemart, A.L. (2016): *Food in a Row: Urban Trees Offer Valuable Floral Resources to Pollinating Insects*. Urban Ecosyst., 19, 1149–1161.

Stojnić, B.; Mladenović, K.; Vidović, B.; Anđelković, N.; Milanović, S. (2026): First Records of *Eotetranychus libocedri* (McGregor, 1936) and *E. thujae* (McGregor, 1950) (Acari: Tetranychidae) from Serbia. *Diversity*, *18*, 371. https://doi.org/10.3390/d18060371.

Stojnić, B, Mladenović, K, Marčić, D (2023): *Overview of the predatory mite complexes (Acari: Phytoseiidae) in Serbia*. 8th Meeting of the IOBC-WPRS Working Group "Integrated Control of Plant-Feeding Mites". IOBC-WPRS Beograd: Institut za pesticide i zaštitu životne sredine Beograd: Društvo za zaštitu bilja Srbije.

Stojnić B, Mladenović K, Vidović B. (2021): Rapid techniques of isolation of and preparation forming for mites. XVI Symposium on Plant Protection, Zlatibor 22-25.11.2021. ISBN-978-86-83017-37-9, COBISS.SR-ID. (Original title: Stojnić B, Mladenović K, Vidović B. (2021): Brze tehnike izdvajanja i izrade preparata grinja. XVI Simpozijum o zaštiti bilja, Zlatibor 22-25.11.2021. god. ISBN-978-86-83017-37-9, COBISS.SR-ID).

Strid, A., Tan Kit. (2000): *Flora and Phytogeography of NW Greece (Epirus and W. Macedonia)*. Report of a Student Excursion from the University of Copenhagen 20 May–2 June 1999. Bot. Inst., Univ.of Copenhagen.

TixieR, M.S., Baldassar, A., Duso, C., Kreiter, S. (2012): *Dichotomous key to species of Phytoseiidae mites in European vine fields*. http://www1.montpellier.inra.fr/CBGP/phytoseiidae/sitewebvineyards2/index.htm. Accessed 10 March 2026.

Tomczyk, A. (2004): *Diseases and pests of cultivated willows. In: Grzybek A (ed) Willow: cultivation and processing technologies* [Choroby i szkodniki upraw wierzbowych. Wierzba energetyczna: uprawa I technologie przetwarzania]. Wy_zsza Szkoła Ekonomii i Administracji w Bytomiu. ISBN 83-88587-71-4.

Tuovinen, T. (1994): *Influence of Surrounding Trees and Bushes on the Phytoseiid Mite Fauna on Apple Orchard Trees in Finland*. Agric.Ecosyst. Environ. 50, 39–47.

Tuovinen, T., Rokx, J.A.H. (1991): *Phytoseiid Mites (Acari: Phytoseiidae) on Apple Trees and in Surrounding Vegetation in Southern Finland*. Densities and Species Composition. Exp. Appl. Acarol., 12, 35–46.

Vukićević, E. (1996): Decorative dendrology, Faculty of Forestry of the University of Belgrade, Belgrade, 581 pages (Original title: *Dekorativna dendrologija*, Šumarski fakultet Univerziteta u Beogradu. Beograd, 581 str).

Walas, Ł., Dering, M., Ganatsas, P., Pietras, M., Pers-Kamczyc, E., Iszkuło, G. (2018): *The present status and potential distribution of relict populations of Aesculus hippocastanum L. in Greece and the diverse infestation by Cameraria ohridella Deschka & Dimić*. Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology. 152. 1-11. 10.1080/11263504.2017.1415991.

Wilczynski, S.; Podlaski, R. **(2007):** *The effect of climate on radial growth of horse chestnut (Aesculus hippocastanum L.) in the ´Swi˛etokrzyski National Park in central Poland*. J. For. Res. 12, 24–33.

Yeşilayer A., Çobanoğlu S., (2015): *Tetranychidae (Acari: Prostigmata) species from parks, ornamental plants in Istanbul, Turkey*. Gaziosmanpaşa Bilimsel Araştırma Dergisi, 11: 90-98.

FIRST RECORD OF TETRANYCHIDAE AND PHYTOSEIIDAE (ACARI) ON *AESCULUS HIPPOCASTANUM* (SAPINDACEAE) IN SERBIA

Katarina MLADENOVIĆ, Danilo FURTULA, Jelena BOŽOVIĆ,
Miroslava MARKOVIĆ, Jovana CVETKOVIĆ

Summary

Three species of spider mites *Eotetranychus pruni* (Oudemans, 1931**),** *Eotetranychus tiliarium* (Hermann, 1804) and *Schizotetranychus garmani* Pritchard & Baker, 1955 as well as two species of predatory mites *Euseius finlandicus* (Oudemans, 1915a) and *Phytoseius echinus* Wainstein & Arutunjan, 1970 are recorded for the first time on horse-chestnut in Serbia. Phytophagous species *S. garmani* was recorded for the first time in the world on horse-chestnut as the host plant. All three species of spider mites are present in Europe. Considering our findings, the number of species of spider mites determined on horse-chestnut for the world's acarofauna increased to 14, and for European to 5 species. During the research, species *E. pruni* and *E. tiliarium* were recorded on urban habitats while *S. garmani* was recorded on semi-urban habitat in the immediate vicinity of forest ecosystem. Predatory species *E. finlandicus* is cosmopolitan, while *P. echinus* is present in Europe. Prey-predator complex was not determined during our research on horse-chestnut, while cohabitation of two predatory species was recorded only in one sample. The research was carried out on a large number of urban and semi-urban sites in central Serbia and Vojvodina. The collecting of samples encompassed the period of six growing seasons. During the research, we did not find any significant damage as a result of the feeding of the recorded species of spider mites. Horse-chestnut is an important reservoir of phytoseiid mites in city parks and urban forests, so it is necessary to continue further research of mite diversity on this frequently present horticultural species in our parks and urban greenery.

PRVI NALAZ TETRANYCHIDAE I PHYTOSEIIDAE (ACARI) NA *AESCULUS HIPPOCASTANUM* (SAPINDACEAE) U SRBIJI

Katarina MLADENOVIĆ, Danilo FURTULA, Jelena BOŽOVIĆ,
Miroslava MARKOVIĆ, Jovana CVETKOVIĆ

Rezime

Na horse-chestnut u Srbiji su prvi put zabeležene tri vrste spider mites *Eotetranychus pruni* (Oudemans, 1931**),** *Eotetranychus tiliarium* (Hermann, 1804) i *Schizotetranychus garmani* Pritchard & Baker, 1955 kao i dve vrste predatorskih grinja *Euseius finlandicus* (Oudemans, 1915a) i *Phytoseius echinus* Wainstein & Arutunjan, 1970. Fitofagna vrsta *S. garmani* je u svetu prvi put zabeležena na divljem kestenu kao biljci hraniteljki. Sve tri vrste spider mites su prisutne u Evropi. Našim nalazom broj vrsta spider mites utvrđen na divljem kestenu za svetsku acaro faunu je povećan na 14 a za Evropsku na 5 vrsta. Vrste *E. pruni* i *E. tiliarium* tokom istraživanja zabeležene su na urbanim dok je *S. garmani* zabeležen na semiurbanom staništu u neposrednoj blizini šumskog ekosistema. Predatorska vrsta *E. finlandicus* je kosmopolit dok je *P. echinus* prisutan u Evropi. Tokom naših istraživanjanja, na divljem kestenu, nije utvrđen prey-predator complex dok je kohabitacija dve predatorske vrste zabeležena samo u jednom uzorku. Istraživanja su obavljena na većem broju urbanih i semiurbanih lokalita u centralnoj Srbiji i Vojvodini. Sakupljanje uzoraka je obuhvatilo period šest vegetacijskih sezona. Tokom istraživanja nismo utvrdili značajnija oštećenja kao rezultat ishrane zabeleženih vrsta

spider mites. Horse-chestnut je važan rezervoar fitoseidnih grinja u gradskim parkovima i urbanim šumama tako da je neophodno nastaviti dalja istraživanja diverziteta grinja na ovoj često prisutnoj hortikulturnoj vrsti u našim parkovima i urbanom zelenilu.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY COLLECTION 93, 2026

ODRŽIVO ŠUMARSTVO ZBORNIK RADOVA 93, 2026

UDK: 528.74:582.685.4=111
DOI: 10.5937/SustFor2693123S
Original scientific paper

INTEGRATED ASSESSMENT OF TREE HEALTH AND STRUCTURAL STABILITY USING UAV MULTISPECTRAL IMAGING, 3D PHOTOGRAMMETRY, VTA AND ACOUSTIC TOMOGRAPHY: A CASE STUDY OF A LIME TREE

Nenad ŠURJANAC[1], Aleksandar LUČIĆ[1], Ivana ŽIVANOVIĆ[1]*

Abstract: *Accurate assessment of the physiological and mechanical condition of trees in urban environments represents a key component of risk management and the planning of protection measures. This study presents the integration of four methodological approaches – multispectral UAS (drone) analysis, a photogrammetrically generated 3D model, Visual Tree Assessment (VTA) and acoustic tomography (Arbotom) – applied to an old lime tree (*Tilia platyphyllos*) located in the courtyard of the Bishop's Palace of the Šabac Eparchy. Multispectral analysis was used to calculate the NDRE index of physiological activity, while the 3D trunk model was employed for precise positioning of the Arbotom sensors. Tomographic measurements performed at heights of 40 cm and 200 cm identified degradation zones with a reduction in load-bearing cross-sectional area of 27–39% (lower section) and 43–52% (upper section). The NDRE index indicated localized areas of reduced physiological activity within the crown, while the VTA method confirmed the presence of fungi of the genus* Ganoderma*. The integrated results indicate that the tree currently maintains a stable mechanical structure, with localized degradation zones that do not yet affect its static stability. The presented multi-sensor approach is highlighted as an efficient tool for detection, evaluation, and risk management in urban forestry, however as this research was conducted on a single Tillia platyphyllos specimen, the findings should be interpreted as a case study and methodological demonstration rather than as results directly generalizable to a broader population of urban trees.*

Keywords: Remote sensing, UAS, multispectral, Arbotom, sonic tomography, non-destructive assesement.

INTEGRISANA PROCENA ZDRAVSTVENOG STANJA I STRUKTURNE STABILNOSTI STABALA PRIMENOM UAV MULTISPEKTRALNOG SNIMANJA, 3D FOTOGRAMETRIJE, VTA METODE I AKUSTIČNE TOMOGRAFIJE: STUDIJA SLUČAJA LIPE

Sažetak: *Precizna procena zdravstvenog i mehaničkog stanja stabala u urbanom okruženju predstavlja ključnu komponentu upravljanja rizicima i planiranja mera zaštite. U*

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

© 20XX The Authors. Published by the Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

ovom radu prikazana je integracija četiri metodološka pristupa – multispektralne UAS (dron) analize, fotogrametrijski generisanog 3D modela, vizuelne procene stabla (VTA) i zvučne tomografije (Arbotom) – primenjenih na staro stablo lipe (Tilia platyphyllos Scop.) koje se nalazi u dvorištu Vladičanskog dvora Eparhije šabačke. Multispektralna analiza korišćena je za izračunavanje NDRE indeksa fiziološke aktivnosti, dok je 3D model debla upotrebljen za precizno pozicioniranje Arbotom senzora. Tomografska merenja sprovedena na visinama od 40 cm i 200 cm identifikovane su zone degradacije sa redukcijom nosive površine poprečnog preseka od 27–39 % (donji presek) i 43–52 % (gornji presek). NDRE indeks ukazao je na lokalizovane zone smanjene fiziološke aktivnosti u krošnji, dok je VTA metodom potvrđeno prisustvo gljiva roda Ganoderma *sp. Integrisani rezultati ukazuju da stablo trenutno poseduje stabilnu mehaničku strukturu, uz lokalizovane zone degradacije koje za sada ne utiču na njegovu statičku stabilnost. Predstavljeni multisenzorski pristup ističe se kao efikasan alat za detekciju, evaluaciju i upravljanje rizikom u urbanom šumarstvu, pri čemu treba naglasiti da obzirom na to da je istraživanje sprovedeno na jednom stablu vrste Tilia platyphyllos, rezultate treba tumačiti kao studiju slučaja i metodološku demonstraciju, a ne kao nalaze koji se mogu neposredno generalizovati na širi skup urbanih stabala.*

Ključne reči: daljinska detekcija, UAS, Arbotom, zvučna tomografija, nedestruktivna procena.

1. INTRODUCTION

Urban trees provide important ecological and social benefits, but in densely inhabited areas they may also represent a safety risk when affected by physiological decline, internal decay, or mechanical instability. Therefore, reliable assessment of tree condition is essential for informed decision-making in urban forestry and risk management, particularly where tree failure could threaten people or nearby structures (Živanović et al., 2023).

Visual Tree Assessment (VTA) is widely used for recognizing external symptoms of decline, but visual inspection alone often cannot detect internal structural defects or early physiological stress. In this context, acoustic tomography is a valuable non-destructive method for assessing the internal condition of standing trees, because it enables detection of decay and weakened wood through analysis of stress-wave propagation (Deflorio et al., 2008; Živanović et al., 2020). At the same time, UAV-based multispectral sensing provides detailed insight into canopy physiological condition through vegetation indices. Among them, the NDRE index is particularly suitable for detecting subtle changes in chlorophyll-related activity and stress in mature vegetation (Gitelson & Merzlyak, 1994; Delegido et al., 2011).

The integration of multispectral UAV analysis, photogrammetric 3D modeling, VTA, and acoustic tomography offers a comprehensive framework for simultaneous assessment of physiological condition and internal structural integrity. The aim of this study was to demonstrate such an integrated approach on a mature urban tree in order to improve diagnostic accuracy and support tree risk evaluation in urban environments.

2. AIM OF THE STUDY

The aim of this study is to develop and demonstrate an integrated multi-sensor methodology for the assessment of health status, internal structural integrity, and mechanical stability of mature urban trees (Živanović et al., 2020; Živanović et al., 2023). Specifically, the study seeks to combine multispectral UAV-based vegetation indices, photogrammetrically derived 3D trunk geometry, and acoustic tomography to enable precise detection and spatial localization of physiological stress and internal wood degradation which should supplement and provide more insight over the traditional VTA method.

Figure 1. *Location of the linden tree and nearby house*

For the purpose of testing the multi-sensor approach a single linden tree (*Tillia platyphyllos*) was selected, at location of Bishop's Palace near Šabac (19°38'35.21" E; 44°44'21.56" N WGS 84). Height of the tree was ~17m. The selected tree represents a single case-study specimen; therefore, the obtained results describe the condition of this individual tree and cannot be directly generalized without additional testing on a larger sample and control trees.

Figure 2. *Linden tree (Tillia platyphillos) in courtyard of Bishop's palace*

The vicinity of the to the nearby domicile of the bishop made the accuracy of the assessment of utmost importance due to the risk of damaging the house and endangerment of life for people living and working in and round the house (Živanović et al., 2023) (Figure 1; Figure 2).

By applying this approach to a mature *Tilia platyphyllos* specimen, the study aimed to improve the accuracy of tree risk evaluation and to support informed decision-making in urban forestry management through non-destructive, data-driven analysis (Živanović et al., 2023). The purpose of the study is therefore primarily methodological, while future research should include a larger number of trees and control specimens to evaluate the broader applicability of the approach.

3. METHODOLOGY

3.1 Remote Sensing

Data acquisition was performed using a quadcopter multirotor unmanned aerial system (UAS) equipped with a 20-megapixel RGB camera and a MicaSense RedEdge-M multispectral sensor (Figure 3a) The flight was conducted under sunny and cloud-free conditions, at a flight height of 50 above ground level, capturing RGB and multispectral data simultaneously. The RedEdge-M sensor records reflectance in five narrow spectral bands centered at 475 nm (blue), 560 nm (green), 668 nm (red), 717 nm (red-edge), and 840 nm (near-infrared), enabling detection of subtle variations in vegetation spectral response associated with chlorophyll concentration, leaf cellular structure, and physiological activity (Hunt et al., 2013; Zarco-Tejada et al., 2013). Spectral bands of multispectral sensor are presented in Figure 4.

a b c

Figure 3. *a) MicaSense RedEdge M multispectral sensor, b) DLS, c) calibrated panel*

Radiometric calibration of multispectral imagery was conducted using a calibrated reflectance panel (CRP) shown on Figure 3c. prior and after each flight mission. Simultaneously, incident solar irradiance was continuously recorded during the flight using the integrated Downwelling Light Sensor (DLS) (Figure 3b), allowing correction of radiometric inconsistencies caused by changing illumination conditions during image acquisition. The combined use of CRP-based calibration and irradiance measurements enables conversion of raw digital number values into surface reflectance data, thereby improving the comparability and quantitative reliability of vegetation indices derived from UAS imagery (Turner et al., 2014; Aasen et al., 2018). Radiometric calibration was performed using the Downwelling Light Sensor (DLS / sun sensor) and a calibrated reflectance panel. The calibration panel was imaged before and after the flight mission, while incident illumination was recorded continuously by the sun sensor during acquisition. The calibration procedure and the application of radiometric corrections were carried out within the software environment according to the internal processing algorithms and predefined software workflow.

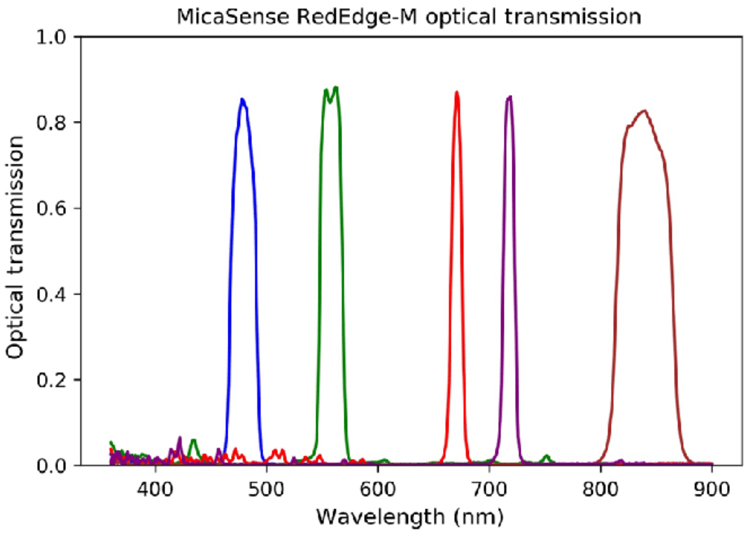


Figure 4. *Narrow bands of multispectral sensor*

Calibrated multispectral data were subsequently used to calculate the NDRE (Normalized Difference Red Edge) vegetation index, which utilizes reflectance in the red-edge and near-infrared spectral regions. NDRE is particularly sensitive to variations in chlorophyll content and canopy physiological condition, allowing detection of plant stress before visible symptoms become apparent (Gitelson & Merzlyak, 1994; Delegido et al., 2011). UAV-based multispectral sensing thus provides an effective means of quantifying spatial variability in canopy physiology and identifying early indicators of stress or decline in tree vitality (Zarco-Tejada et al., 2018).

Photogrammetric processing of the acquired data was processed in professional photogrammetry software Agisoft Metashape Pro. The result of the processing was RGB and multispectral orthomosaics with 1.5cm/pixel for RGB and 4cm/pixel resolution for multispectral orthomosaic. The resolution provided sufficient level of detail for assessment of the physiological activity of parts of the single tree through application of vegetation indices. Image alignment, calibration and orthomosaic generation were performed as software-defined internal processing steps in Agisoft Metashape Pro. Photograph overlap and the photogrammetric processing settings of aerial imagery was not treated as a relevant output parameter for the final orthomosaic in this study.

Multispectral UAV analysis provided detailed information on the physiological condition of the tree canopy. Physiological activity is quantified through application of vegetation indices which represent values based on levels of reflectance of different wavelengths from vegetation and provide rapid, scalable and interpretable insights into vegetation health (Vidican et al., 2023). Reflectance distribution of different wavelengths is presented in figure 5. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Red Edge Index (NDRE) are among the most widely used spectral vegetation indices for assessing plant physiological condition based on reflectance characteristics in the red, red-edge, and near-infrared (NIR) regions of the electromagnetic spectrum. Although NDVI is the most widely used vegetation index so for this purpose the NDRE vegetation index is used due to its sensitivity in late season physiology assessment.

NDVI is calculated using reflectance in the red and NIR spectral bands and is primarily sensitive to chlorophyll absorption and vegetation biomass:

$$NDVI=(NIR-Red)/(NIR+Red)$$

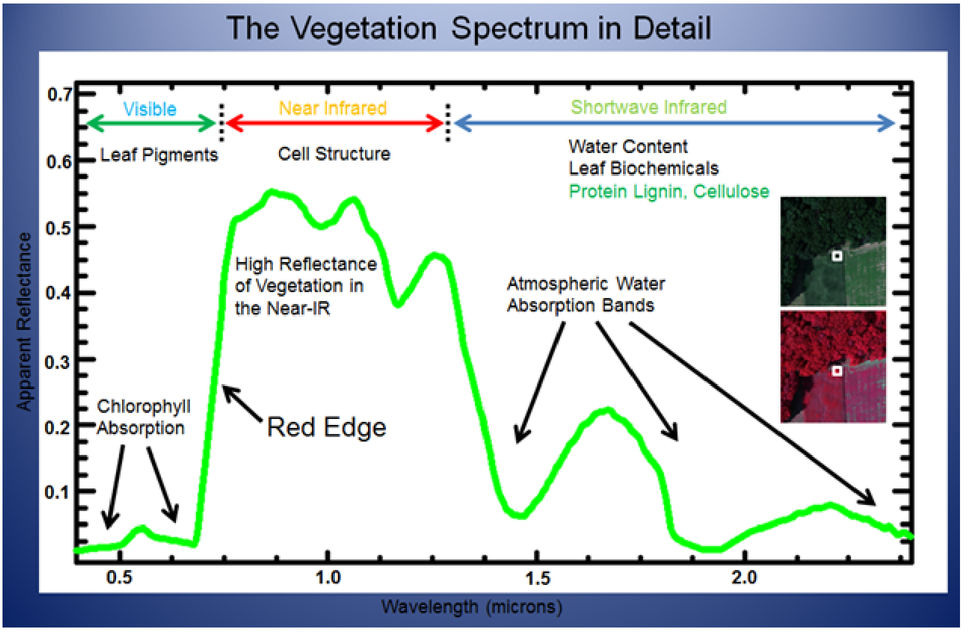


Figure 5. *Distribution of light reflectance from vegetation*

NDVI is effective for general vegetation detection, biomass estimation, and monitoring of canopy density and greenness (Rouse et al., 1974; Tucker, 1979). However, NDVI tends to saturate in dense vegetation canopies, limiting its sensitivity to physiological variability in mature or structurally complex tree crowns (Gitelson, 2004). This saturation effect reduces its effectiveness in detecting subtle stress conditions in high-leaf-area-index environments such as urban trees or forest stands.

NDRE incorporates reflectance from the red-edge region instead of the red band:

$$NDRE=(NIR-RedEdge)/(NIR+RedEdge)$$

The red-edge spectral region is particularly sensitive to variations in chlorophyll concentration and leaf internal structure, making NDRE more responsive to early physiological stress and nutrient deficiencies that may not yet produce visible structural changes in the canopy (Delegido et al., 2011; Gitelson & Merzlyak, 1994). Unlike NDVI, NDRE maintains sensitivity across higher biomass levels and is therefore better suited for monitoring mature vegetation and detecting sub-canopy stress in woody species (Sims & Gamon, 2002).

3.2 Sonic Tomography

Internal structural condition of the trunk was assessed using acoustic (sonic) tomography with the Arbotom® system. The method is based on the principle of stress-wave propagation through woody tissue, where the velocity of sound transmission is directly related to the material density and mechanical stiffness of the wood. Sound waves propagate more rapidly through intact, structurally sound wood and are significantly slowed in areas affected by decay, cavities, or fungal degradation due to reduced density and disrupted cellular structure (Gilbert & Smiley, 2004; Deflorio et al., 2008).

Measurements were conducted at two trunk heights, the first at 40 cm (Figure 6.) and the second at 200 cm above ground level using a circumferential arrangement of evenly spaced sensors. After mechanical impulse excitation, the travel time of stress waves between individual sensor pairs was recorded and used to reconstruct a two-dimensional tomographic image of internal trunk structure. The resulting tomograms represent spatial distribution of acoustic wave velocities, where low-velocity zones correspond to degraded or compromised wood tissue, while high-velocity zones indicate structurally sound material (Nicolotti et al., 2003).

Figure 6. *Arbotom sensors at height of 40cm with data receiver*

This approach allows for non-destructive detection and localization of internal defects that are not externally visible, including advanced fungal decay and loss of load-bearing capacity (Živanović et al., 2020). Quantification of the residual wall thickness and effective load-bearing cross-sectional area provides a biomechanical basis for assessing the remaining structural integrity of the trunk and its capacity to withstand mechanical loads such as wind stress (Smiley & Gilbert, 2003; Wang et al., 2007).

Sonic tomography has been shown to be particularly effective in detecting early-stage internal decay associated with wood-decaying fungi, enabling improved evaluation of tree stability and failure risk in urban environments where preservation of mature trees is often required (Deflorio et al., 2008, Živanović et al., 2020). In this study, tomographic results were interpreted in conjunction with Visual Tree Assessment (VTA) to improve diagnostic reliability and reduce uncertainty associated with singular assessment methods.

In addition to qualitative identification of internal decay, the tomographic analysis enabled quantitative assessment of residual wall thickness and effective load-bearing capacity of the trunk cross-section. The structural integrity of hollow or decayed tree stems is commonly evaluated using the ratio between the thickness of the remaining intact wood wall (t) and the overall radius of the trunk (R), expressed as the t/R ratio. This parameter has been widely applied as an indicator of mechanical stability and failure risk in standing trees (Mattheck & Breloer, 1994; Mattheck et al., 2006).

According to established biomechanical models, a residual wall thickness of approximately 30% of the trunk radius ($t/R \geq 0.3$) is generally considered sufficient to maintain structural stability under typical loading conditions, whereas lower values may indicate increased susceptibility to mechanical failure due to bending or buckling stresses (Mattheck & Bethge, 1998). Sonic tomography enables indirect estimation of this parameter by delineating zones of compromised wood tissue and identifying the remaining ring of structurally sound material.

Figure 7. *Photogrammetric 3D model of tree trunk*

In order to precisely measure and position the sensors in Arbotom software the close-range photogrammetric survey of the tree trunk was performed using RGB imagery to generate a high-resolution three-dimensional model through Structure-from-Motion (SfM) processing (Figure 7.). The resulting 3D geometry enabled accurate spatial positioning, through simulating the changes of topography of tree trunk, and allowed better assessment of the distance between sensors which further increased the precision of acoustic tomography sensors for internal structural assessment (Figure 8). The 3D model of the trunk was produced in the same photogrammetric software Agisoft Metashape Pro, which was used for aerial imagery. Images for 3D model were acquired with handheld DSLR camera Nikon D5300, and fixed AF-S DX Nikkor 35mm f/1.8G lens. The images were captured by multistation-multidirectional approach. Trunk was imaged from multiple points around the tree with every point being used to capture multiple different segments of the trunk. Size calibration and scaling was done by using the same measuring tape positioned around the trunk for sonic tomography. Building of textured 3D model was performed through internal processing algorithms of photogrammetric software, through depth maps filtering and 3D mesh building.

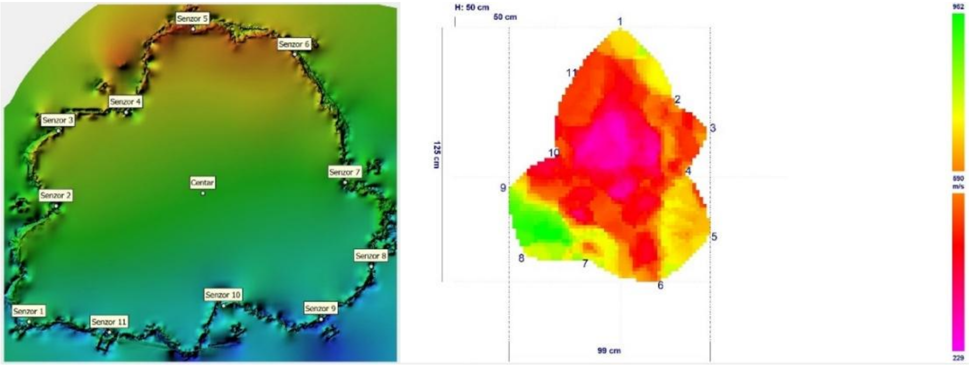


Figure 8. *Cross-section of 3D model of a tree trunk with resulting model in Arbotom software*

4. RESULTS

The NDRE vegetation index revealed clear spatial heterogeneity, with several localized zones of reduced physiological activity detected within the crown. Figure 9. shows the color-coded image with values of NDRE index distributed from Red (low values) to Green (high values). These areas suggest reduced photosynthetic efficiency and potential stress, likely linked to internal structural or biological factors. Due to the time of the year when imaging was done, the lower values of the NDRE vegetation index may be under the influence of natural autumn senescence, however the majority of the senescing was primarily localized to the one side of the crown. The high spatial resolution of the UAV data enabled precise identification of affected crown segments, supporting targeted interpretation of tree health.

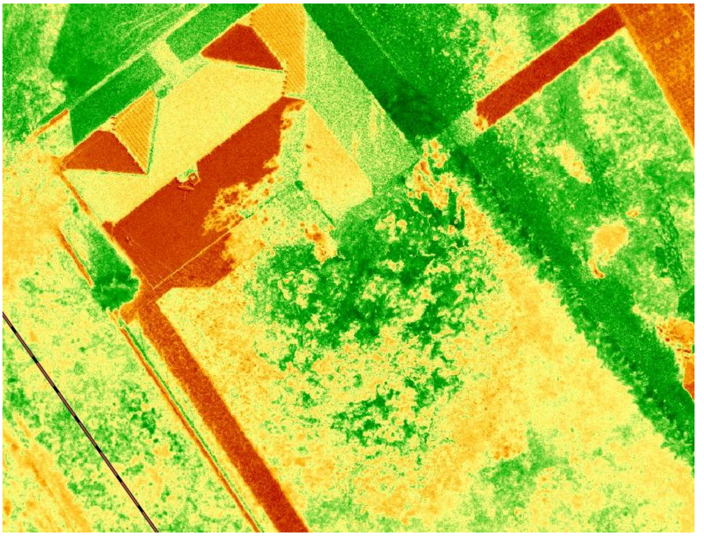


Figure 9. *Color-coded presentation of values of NDRE vegetation index of linden tree*

During further analysis of the multispectral orthomosaic, the NDRE (Normalized Difference Red Edge) vegetation index was applied to quantify the physiological activity of phytopigments, thereby indicating the physiological condition of the vegetation, in this case the assessed linden tree. The obtained results show a reduction in physiological activity in the upper part of the crown on the side facing the courtyard. Localized weakening of physiological activity was also observed in the crown section oriented toward the house.

It should be noted that the survey was conducted during the last week of October, when a decrease in physiological activity in deciduous vegetation and leaf senescence is expected. Therefore, physiological decline cannot be determined with certainty, although similar stress was not detected in the majority of the crown. For a more reliable distinction between seasonal senescence and physiological stress, repeated acquisitions during different phenological phases are recommended.

In the present study, tomographic cross-sections obtained at both measurement heights revealed the presence of continuous residual sound wood despite localized degradation. The spatial distribution of intact peripheral tissue suggests that the remaining load-bearing structure is capable of sustaining mechanical loads under current environmental conditions. The interpretation of residual wall thickness was further supported by Visual Tree Assessment (VTA), which provided external indicators of fungal decay consistent with tomographic findings.

The sensors were positioned at 10 locations along the circumference of the trunk cross-section, with their arrangement aligned to the geometry obtained from the 3D photogrammetric trunk model.

At a height of 40 cm, the tomogram revealed a pronounced zone of central and marginal wood degradation, with a reduction in load-bearing cross-sectional area of 32–50%.

Zones of reduced sound transmission velocity were observed along the west–east axis, corresponding to the location of external damage and the presence of fungal activity.

At a height of 200 cm, a similar pattern was obtained, with a reduction in load-bearing cross-sectional area ranging from 43–52%.

Sound transmission velocities in healthy wood (green–yellow zone) ranged between 1600–2800 m/s, while values below 600 m/s indicated zones of advanced internal decay.

Visual Tree Assessment confirmed the presence of wood-decaying fungi of the genus *Ganoderma*, supporting the tomographic findings (Figure 10). Despite the detected internal decay, the combined results indicate that the remaining sound wood provides sufficient structural integrity, and the tree currently exhibits stable mechanical behavior without immediate risk to static safety.

The bark is locally thickened, with the presence of minor longitudinal cracks and signs of physiological aging.

Several dead branches were observed in the inner part of the crown, along with the occurrence of lichens and moss in the root collar zone and lower sections of the trunk.

Fruiting bodies of fungi of the genus *Ganoderma* sp. (Figure 10.) were identified on the northern side of the trunk, indicating a localized white rot process in the lower part of the stem.

Figure 10. *Ganoderma sp. fruiting bodies*

Table 1. *Results of tomographic analyses of linden tree – lower cross-section*

Parameter	**Value**
Tree species	*Tilia platyphyllos* (Lime)
Measurement height	40 cm
Number of sensors	10
Velocity range	580 – 2750 m/s
Estimated cross-sectional reduction	≈ 32 – 45 %
Minimum load-bearing area	≈ 60 – 68 %
Note	Central and marginal wood degradation localized along the W–E axis; correlation with external damage and presence of *Ganoderma* sp. fruiting bodies

Table 2. *Results of tomographic analyses of linden tree – upper cross-section*

Parameter	Value
Tree species	*Tilia platyphyllos* (Lime)
Measurement height	200 cm
Number of sensors	10
Velocity range	620 – 2800 m/s
Estimated cross-sectional reduction	≈ 43 – 52 %
Minimum load-bearing area	≈ 55 – 62 %
Note	Linear degradation zone in the upper part of the cross-section; sound peripheral tissue with stable acoustic velocities

By comparing the obtained values with reference data for healthy wood of deciduous species (Dackermann et al., 2014), it was observed that the measured values fall within the expected range for partially degraded but structurally stable wood.

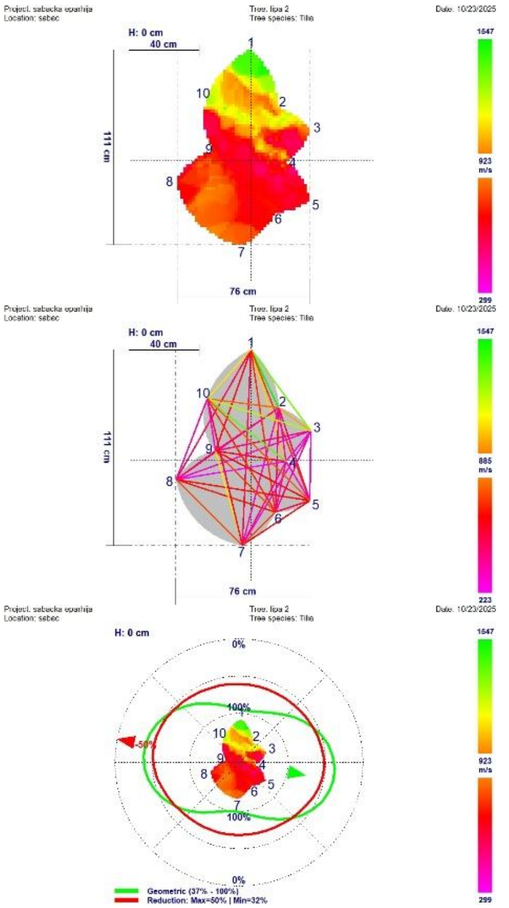


Figure 11. *Tomographs of linden tree – lower cross-section*

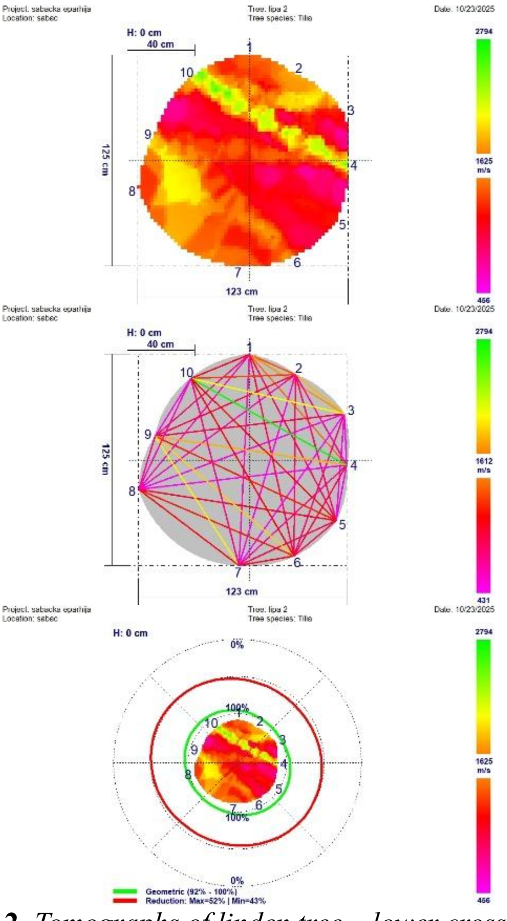


Figure 12. *Tomographs of linden tree – lower cross-section*

5. DISCUSSION AND CONCLUSION

The results obtained in this study demonstrate the applicability and complementary value of integrating multispectral UAV analysis with acoustic tomography for comprehensive assessment of urban tree condition (Živanović et al., 2023). Multispectral analysis based on the NDRE vegetation index enabled spatially explicit evaluation of canopy physiological activity, identifying localized areas of reduced photosynthetic performance within the crown. Given that NDRE is sensitive to chlorophyll concentration and internal leaf structure, its use allows for detection of early physiological stress that may not yet be expressed through visible morphological symptoms (Gitelson & Merzlyak, 1994; Delegido et al., 2011). However, it must be emphasized that data acquisition was performed in late October, during the period of natural senescence in deciduous species, which may influence reflectance-based physiological indicators and complicate interpretation of stress signals. The late-October acquisition represents an important limitation of the NDRE interpretation; therefore, the observed spatial pattern should be validated through multi-seasonal or temporally repeated UAV surveys.

Acoustic tomographic measurements revealed internal structural degradation within the trunk at both investigated heights, with a reduction in load-bearing cross-sectional area ranging from 32–50% at 40 cm and 43–52% at 200 cm. The spatial distribution of low acoustic velocity zones corresponded with the position of externally observed fungal fruiting bodiesof the genus *Ganoderma*, suggesting an ongoing localized decay process consistent with white rot development. Despite this internal degradation, tomographic cross-sections indicated the presence of a continuous peripheral ring of structurally sound wood.

Biomechanical interpretation based on residual wall thickness suggests that the trunk retains sufficient load-bearing capacity to withstand mechanical loading under current environmental conditions. According to established failure criteria, trees may maintain structural stability even in the presence of internal cavities provided that the residual wall thickness remains above critical thresholds relative to trunk radius (Mattheck & Breloer, 1994). The measured sound transmission velocities within intact wood tissue were consistent with reference values reported for structurally functional hardwood species (Dackermann et al., 2014), further supporting the interpretation that the observed decay does not currently compromise static stability.

The integration of canopy-level physiological indicators with internal structural diagnostics provides a more robust basis for tree risk assessment than either method applied independently. While multispectral UAV analysis enables early detection of physiological stress and spatial mapping of canopy vitality, acoustic tomography provides direct insight into internal mechanical integrity. This multisensor approach is therefore particularly valuable in urban environments where preservation of mature trees must be balanced with safety considerations. The results are limited by the case-study design, the assessment of a single tree, the late-season timing of multispectral acquisition, and the absence of independent validation of tomographic results. Future work should include larger samples, control trees, repeated seasonal surveys, and additional diagnostic validation.

Acknowledgement: *This study was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract No. 451-03-33/2026-03/200027, from 05.02.2026.*

REFERENCES

Aasen, H., Honkavaara, E., Lucieer, A., & Zarco-Tejada, P. J. (2018). Quantitative remote sensing at ultra-high resolution with UAV spectroscopy: A review of sensor technology, measurement procedures, and data correction workflows. *Remote Sensing*, *10*(7), 1090. https://doi.org/10.3390/rs10071090

Dackermann, U., Li, J., Crews, K., & Riordan, J. (2014). Acoustic testing for evaluation of standing timber: A review. Construction and Building Materials, 65, 1–10. https://doi.org/10.1016/j.conbuildmat.2014.04.117

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, 117–132. https://doi.org/10.1007/s00226-007-0172-4

Delegido, J., Verrelst, J., Alonso, L., & Moreno, J. (2011). Evaluation of Sentinel-2 red-edge bands for empirical estimation of green LAI and chlorophyll content. Sensors, 11(7), 7063–7081. https://doi.org/10.3390/s110707063

Gilbert, E. A., & Smiley, E. T. (2004). Picus sonic tomography for the quantification of decay in white oak and hickory. Journal of Arboriculture, 30(5), 277–281.

Gitelson, A. A. (2004). Wide dynamic range vegetation index for remote quantification of vegetation fraction. Remote Sensing of Environment, 92(3), 318–327. https://doi.org/10.1016/j.rse.2004.06.016

Gitelson, A. A., & Merzlyak, M. N. (1994). Spectral reflectance changes associated with autumn senescence of Acer platanoides leaves. Journal of Plant Physiology, 143(3), 286–292.

Hunt, E. R., Hively, W. D., Fujikawa, S. J., Linden, D. S., Daughtry, C. S. T., & McCarty, G. W. (2013). Acquisition of NIR–green–blue digital photographs from unmanned aircraft for crop monitoring. Remote Sensing, 5(2), 674–688. https://doi.org/10.3390/rs5020674

Mattheck, C., & Bethge, K. (1998). Failure criteria for trees. Arboricultural Journal, 22(2), 123–137. https://doi.org/10.1080/03071375.1998.9747228

Mattheck, C., & Breloer, H. (1994). The body language of trees: A handbook for failure analysis. HMSO.

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

Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. Proceedings of the Third Earth Resources Technology Satellite-1 Symposium (NASA SP-351), 309–317.

Sims, D. A., & Gamon, J. A. (2002). Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. Remote Sensing of Environment, 81(2–3), 337–354.

Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment, 8(2), 127–150. https://doi.org/10.1016/0034-4257(79)90013-0

Turner, D., Lucieer, A., & Watson, C. (2014). Development of an unmanned aerial vehicle (UAV) for hyper-resolution vineyard mapping based on visible, multispectral, and thermal imagery. Remote Sensing, 4(12), 349–365.

Vidican, R.; Mălinaș, A.; Ranta, O.; Moldovan, C.; Marian, O.; Ghețe, A.; Ghișe, C.R.; Popovici, F.; Cătunescu, G.M. Using remote sensing vegetation indices for the discrimination and monitoring of agricultural crops: A critical review. Agronomy 2023, 13, 3040

Wang, X., Wiedenbeck, J., & Ross, R. J. (2007). Acoustic evaluation of wood quality in standing trees. Forest Products Journal, 57(5), 28–34.

Zarco-Tejada, P. J., González-Dugo, V., & Berni, J. A. J. (2013). Fluorescence, temperature and narrow-band indices acquired from a UAV platform for water stress detection. Remote Sensing of Environment, 117, 322–337. https://doi.org/10.1016/j.rse.2011.10.007

Zarco-Tejada, P. J., Camino, C., Beck, P. S. A., Calderón, R., Hornero, A., Hernández-Clemente, R., Kattenborn, T., Montes-Borrego, M., Susca, L., Morelli, M., & others. (2018).

Previsual symptoms of Xylella fastidiosa infection revealed in spectral plant-trait alterations. Nature Plants, 4, 432–439.

Živanović, I., Todorović, N., Rakonjac, L., & Jovanović, F. (2020). Potentials of the assessment of the wood quality in standing trees by applying acoustic methods. Sustainable Forestry, 81–82, 121–132.

Živanović, I., Todorović, N., Šurjanac, N., Kabiljo, M., & Jovanović, F. (2021). Physical and mechanical properties of northern red oak. Sustainable Forestry, 83–84, 93–105.

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

INTEGRATED ASSESSMENT OF TREE HEALTH AND STRUCTURAL STABILITY USING UAV MULTISPECTRAL IMAGING, 3D PHOTOGRAMMETRY, VTA AND ACOUSTIC TOMOGRAPHY: A CASE STUDY OF A LIME TREE

Nenad ŠURJANAC, Aleksandar LUČIĆ, Ivana ŽIVANOVIĆ

Summary

This paper presents an integrated approach to the assessment of the physiological and mechanical condition of urban trees, based on the combined use of multispectral UAV imagery, photogrammetric 3D modeling, Visual Tree Assessment (VTA), and acoustic tomography (Arbotom). The methodology was applied to a mature lime tree (*Tilia platyphyllos*) located in the courtyard of the Bishop's Palace of the Šabac Eparchy, with the aim of obtaining a more reliable assessment of canopy vitality, internal trunk condition, and overall structural stability.

The NDRE index derived from multispectral imagery indicated localized areas of reduced physiological activity within the crown. Acoustic tomography identified zones of internal wood degradation at two measurement heights, while the 3D photogrammetric model of the trunk improved the accuracy of sensor positioning and cross-sectional interpretation. Visual inspection further supported the findings by confirming the presence of fruiting bodies of *Ganoderma* sp., indicating an ongoing localized decay process. Because the multispectral survey was performed in late October, the NDRE results should be treated as indicative spatial patterns and not as conclusive proof of physiological decline without repeated seasonal monitoring.

Although internal defects were detected, the results showed that the tree still retains a continuous ring of sound peripheral wood and sufficient load-bearing capacity under current conditions. The study indicates that the integration of canopy-level physiological indicators with internal structural diagnostics can improve the reliability of tree condition assessment and provide a stronger basis for decision-making in urban tree management and risk evaluation. The findings remain limited to a single case-study tree and should be further tested on larger samples, control trees and through additional validation of tomographic outputs.

INTEGRISANA PROCENA ZDRAVSTVENOG STANJA I STRUKTURNE STABILNOSTI STABALA PRIMENOM UAV MULTISPEKTRALNOG SNIMANJA, 3D FOTOGRAMETRIJE, VTA METODE I AKUSTIČNE TOMOGRAFIJE: STUDIJA SLUČAJA LIPE

Nenad ŠURJANAC, Aleksandar LUČIĆ, Ivana ŽIVANOVIĆ

Rezime

U radu je prikazan integrisani pristup proceni fiziološkog i mehaničkog stanja urbanih stabala, zasnovan na kombinovanoj primeni multispektralnog UAV snimanja, fotogrametrijskog 3D modelovanja, vizuelne procene stabla (VTA) i akustične tomografije (Arbotom). Metodologija je primenjena na starom stablu lipe (*Tilia platyphyllos*) u dvorištu Vladičanskog dvora Eparhije šabačke, sa ciljem da se pouzdanije sagledaju vitalnost krošnje, unutrašnje stanje debla i ukupna strukturna stabilnost stabla.

Vrednosti NDRE indeksa, dobijene iz multispektralnih snimaka, ukazale su na lokalizovane zone smanjene fiziološke aktivnosti u krošnji. Akustična tomografija je registrovala zone unutrašnje degradacije drveta na dve merne visine, dok je fotogrametrijski 3D model debla omogućio preciznije pozicioniranje senzora i pouzdaniju interpretaciju poprečnih preseka. Nalazi su dodatno potvrđeni vizuelnom procenom, kojom je utvrđeno prisustvo plodnih tela gljiva roda *Ganoderma* sp., što ukazuje na lokalizovan proces truleži. Pošto je multispektralno snimanje obavljeno krajem oktobra, rezultate NDRE indeksa treba tumačiti kao indikativne prostorne obrasce, a ne kao konačnu potvrdu fiziološkog opadanja bez ponovljenih sezonskih snimanja.

Iako su unutrašnja oštećenja utvrđena, rezultati pokazuju da stablo i dalje poseduje kontinualni prsten očuvanog perifernog drveta i dovoljnu nosivost u postojećim uslovima. Dobijeni nalazi ukazuju da povezivanje pokazatelja fiziološkog stanja krošnje sa dijagnostikom unutrašnje strukture debla može doprineti pouzdanijoj proceni stanja stabla i pružiti čvršću osnovu za donošenje odluka u upravljanju urbanim zelenilom i proceni rizika. Nalazi su ograničeni na jedno stablo kao studiju slučaja i potrebno ih je proveriti na većem uzorku, uz kontrolna stabla i dodatnu validaciju tomografskih rezultata.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD
SUSTAINABLE FORESTRY ODRŽIVO ŠUMARSTVO
COLLECTION 93, 2026 ZBORNIK RADOVA 93, 2026

UDK: 004.652.2:574=111
DOI: 10.5937/SustFor2693141I
Original scientific paper

PSYCHOSOCIAL PREDICTORS OF PROACTIVE ENVIRONMENTAL BEHAVIOR: A HIERARCHICAL MODEL OF THE CONTRIBUTION OF PERSONAL RESOURCES AND ENVIRONMENTAL SELF-EFFICACY

Miroljub IVANOVIĆ[1]*, Milivoje ĆOSIĆ*[2]

Abstract: *The aim of this study was to identify key psychosocial determinants of proactive environmental behavior among adolescents using a hierarchical model of predictors. The study was conducted on a convenience sample of N = 260 participants of both genders, aged 18 to 65 (M = 30.46, SD = 9.05). A hierarchical regression analysis in four steps was applied to examine the contribution of demographic factors (gender and age), subjective quality of life, anticipated pessimism, and environmental self-efficacy. The final model explains 31% of the variance in proactive environmental behavior. The introduction of environmental self-efficacy in the final step contributed an additional 19% of explained variance, distinguishing this variable as the strongest individual predictor (β = 0.29, p ≤ 0.01). Among demographic factors, gender showed a stable contribution (β = -0.20, p ≤ 0.05), while age demonstrated increasing significance (β = 0.18, p ≤ 0.05). Quality of life emerged as a stable positive predictor (β = 0.16, p ≤ 0.05), whereas anticipated pessimism showed a statistically negligible contribution (β = 0.03, p ≥ 0.05). The findings indicate that belief in one's own effectiveness (self-efficacy) is a significantly stronger driver of proactivity than environmental concern or pessimism about the future. The results emphasize the importance of strengthening personal psychological resources and well-being in promoting environmental activism.*

Keywords: proactive environmental behavior, environmental self-efficacy, quality of life, adolescents, hierarchical regression.

PSIHOSOCIJALNI PREDIKTORI PROAKTIVNOG EKOLOŠKOG PONAŠANJA: HIJERARHIJSKI MODEL DOPRINOSA LIČNIH RESURSA I EKOLOŠKE SAMOEFIKASNOSTI

Izvod: *Cilj istraživanja je bio identifikovanje ključnih psihosocijalnih determinanti proaktivnog ekološkog ponašanja adolescenata primenom hijerarhijskog modela prediktora. Istraživanje je sprovedeno na prigodnom uzorku od N = 260 ispitanika oba pola, starosti od 18 do 65 godina (M = 30,46, SD = 9.05). Primenjena je hijerarhijska regresiona analiza u četiri koraka kako bi se ispitao doprinos demografskih faktora (pol i uzrast), subjektivnog kvaliteta života, anticipiranog pesimizma i ekološke samoefikasnosti. Finalni model*

[1] Serbian Academy of Innovation Sciences, Višnjička 91a, 11060 Belgrade, Serbia
[2] Institute of Forestry, Kneza Viseslava 3, Belgrade, Serbia
*Corresponding author. E-mail: miroljub.ivanovic@gmail.com

© 2026 The Authors. Published by Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

objašnjava 31% varijanse proaktivnog ekološkog ponašanja. Uvođenje ekološke samoefikasnosti u poslednjem koraku doprinelo je sa dodatnih 19% objašnjene varijanse, čime se ova varijabla izdvojila kao najsnažniji pojedinačni prediktor ($\beta = 0.29$, $p \leq 0.01$). Među demografskim faktorima, pol ostvaruje stabilan doprinos ($\beta = -0.20$, $p \leq 0.05$), dok uzrast beleži rastući značaj ($\beta = 0.18$, $p \leq 0.05$). Kvalitet života se pokazao kao stabilan pozitivan prediktor ($\beta = 0.16$, $p \leq 0.05$), dok je anticipirani pesimizam ostvario statistički zanemarljiv doprinos ($\beta = 0.03$, $p \geq 0.05$). Nalazi ukazuju na to da je uverenje u sopstvenu delotvornost (samoefikasnost) znatno značajniji pokretač proaktivnosti od ekološke zabrinutosti i pesimizma u pogledu budućnosti. Rezultati naglašavaju važnost jačanja ličnih psiholoških resursa i blagostanja u podsticanju ekološkog aktivizma.

Ključne reči: proaktivno ekološko ponašanje, ekološka samoefikasnost, kvalitet života, adolescenti, hijerarhijska regresija.

1. INTRODUCTION

Contemporary environmental challenges and the increasingly pronounced climate crisis impose the need for a deeper understanding of the psychological mechanisms that shape individuals' relationships with the environment. In this context, examining factors such as environmental self-efficacy and anticipated pessimism becomes crucial for predicting how people process environmental threats and make decisions about pro-environmental behavior. Previous research suggests that individual differences, primarily in terms of gender and age, significantly modify the perception of quality of life under conditions of disrupted ecological balance, thereby opening space for analyzing the complex interaction of these predictors (Nagpal & Kumari, M2026).

Existing scientific findings indicate that the perception of quality of life is no longer exclusively linked to socio-economic status, but is increasingly grounded in environmental quality and the subjective sense of control over environmental outcomes. In this sense, environmental self-efficacy – as an individual's belief in their ability to take actions that contribute to environmental protection – represents a key protective factor against passivity (Madera et al., 2024; Pigott & Gray, 2026). However, when this sense of competence is low and environmental risks are high, anticipated pessimism often emerges. This psychological phenomenon not only undermines emotional well-being but can also modify the evaluation of personal quality of life, particularly across different demographic groups such as men and women of different ages.

In the global literature, research on proactive environmental behavior is increasingly moving away from an exclusive focus on socio-demographic variables, shifting instead toward complex psychological models such as the Theory of Planned Behavior (TPB) and the Value–Belief–Norm (VBN) theory (Hachana et al., 2025; Vannam, 2025). Contemporary global trends indicate that personal factors, such as life satisfaction and assertiveness, play a significant role in bridging the gap between environmental awareness and concrete action. Although studies in developed economies often confirm a positive correlation between well-being and "green" practices, the results remain inconsistent, pointing to the importance of context-specific research (Tiring & Çakır, 2026). In this light, the present study uses hierarchical regression analysis to determine the extent to which these factors explain the variance in proactive environmental behavior within our social context, enabling direct comparison with globally recognized patterns.

A special focus of this study is directed toward identifying key determinants that contribute to individuals' proactive environmental behavior. Starting from the assumption that environmental activism is not an isolated act, but rather the result of the interaction between personal characteristics and overall well-being, the study applies hierarchical regression analysis. This approach allows for the stepwise examination of the contributions of different groups of factors – from socio-demographic characteristics, through general life satisfaction, to specific personality dimensions such as assertiveness. In this way, the study aims to determine not only which factors are statistically significant predictors, but also the extent of their partial and combined contributions in explaining the variance of environmentally responsible behavior.

Given the complexity of factors that shape environmental responsibility, this study applies hierarchical regression analysis to examine the incremental contribution of different groups of predictors. Starting from socio-demographic characteristics as control variables, the focus shifts toward psychological constructs – life satisfaction and assertiveness. This approach enables a more precise understanding of the contribution of personal well-being and social skills in explaining the variability of **proactive** environmental behavior, which directly leads to defining the subject and directions of this research.

Contemporary global trends suggest that individual factors, such as life satisfaction and assertiveness, play a relevant role in bridging the gap between environmental awareness and concrete action. Previous findings (Gkargkavouzi & Halkos, 2026; Chung et al., 2026) indicate that individuals with higher levels of subjective well-being more frequently display proactive environmental habits, because they possess a greater capacity for concern for collective goods. In this light, the present study uses hierarchical regression analysis to determine the extent to which these factors explain the variability of proactive environmental behavior in our social context.

Based on theoretical assumptions and previous findings, the general *aim of this study* is to examine the predictive power of demographic and psychological characteristics in explaining the variance of proactive environmental behavior. In accordance with the stated aim and the structure of the analysis, the following research *hypotheses* were formulated:

• H_1: It is assumed that demographic characteristics (gender and age) will make a relevant contribution to explaining proactive environmental behavior, with gender expected to have a stronger initial contribution.

• H_2: It is assumed that subjective quality of life will have a stable and positive contribution in predicting environmental proactivity, independent of demographic factors.

• H_3: It is expected that environmental self-efficacy, as a specific psychological resource, will represent the strongest individual predictor and significantly improve the explanatory power of the overall regression model.

• H_4: It is assumed that the final model, which integrates demographic and psychological factors, will explain a statistically significant proportion of the variance in proactive environmental behavior.

2. MATERIAL AND METHOD

2.1 Participants

The sample was a pertinent sample and included 260 participants (*N* = 260) of both genders, aged 18 to 65. The average age of participants was 30.46 years (*SD* = 9.05). Given the mean age, the sample was predominantly composed of individuals in early and middle adulthood. The study included 126 men (48.46%) and 134 women (51.54%). The sample comprised residents from different regions of the Republic of Serbia, with a predominance of participants from urban areas. The inclusion criteria were adulthood and voluntary consent to participate. Although the study was conducted online, a satisfactory level of gender and age diversity within the sample was achieved. In terms of educational structure, participants with secondary education (142; 54.62%) and higher education (118; 45.38%) were predominant. Such a structure of the sample is expected given the online method of data collection and the nature of the research topic, which often attracts individuals with higher levels of formal education. These individuals are more likely to have access to information about environmental crises, which can directly influence their environmental self-efficacy, as they possess the capacity for a better understanding of the problems and ways to address them.

2.2 Assessment of Quality of Life (Present and Future)

• *Subjective quality of life (present):* The standard *Satisfaction With Life Scale* (SWLS; Pavot & Diener, 2008) was used to measure the cognitive component of subjective well-being. The scale consists of five items (e.g., "The conditions of my life are excellent"), and in this study it demonstrated high reliability (α = 0.85).

• *Anticipatory pessimism (future):* This construct was operationalized through a temporal adaptation of the SWLS, based on the model of the *Temporal Satisfaction with Life Scale* (TSWLS; Pavot, & Diener, 2008). The items were modified to refer to a future time frame (e.g., "The conditions of my life will be excellent"). A high score on this scale after recoding (i.e., lower expectations) was interpreted as a measure of anticipatory pessimism. The reliability of this adapted version was α = 0.82.

2.3 Environmental Self-Efficacy Scale – ESES

To assess participants' beliefs about their ability to take effective actions aimed at environmental protection, the *Environmental Self-Efficacy Scale* (ESES; Huang, 2016) was used. The instrument consists of four items (e.g., "I believe that my actions can contribute to solving environmental problems"), to which participants responded using a five-point Likert scale (from 1 – *strongly disagree* to 5 – *strongly agree*). A higher total score indicates a stronger perceived competence in engaging in pro-environmental behaviors. In the present sample, the scale demonstrated high internal consistency reliability (*Cronbach's* α = 0.83).

2.4 General Environmental Behavior Questionnaire – GEB

Proactive environmental behavior was operationalized using a questionnaire adapted from the General Environmental Behavior model (GEB; Kaiser & Shimoda, 1999). The instrument includes 10 items referring to specific ecological practices (e.g., "I buy local products or locally produced food"). For the purposes of this study, the original scale, which primarily assesses intention, was adapted into a measure of actual behavioral frequency. Participants assessed the frequency of their behaviors on a five-point Likert scale (from 1 – *never* to 5 – *almost always*). A higher total score indicates a higher frequency of proactive environmental behavior. In this sample, satisfactory internal consistency of the scale was confirmed (Cronbach's $\alpha = 0.78$).

2.5 Statistical Analysis

Data were processed using SPSS (version 21) by applying descriptive statistics (normality indicators), Pearson correlation coefficients to examine bivariate relationships, and hierarchical regression analysis in four steps to test the predictive model of proactive environmental behavior.

3. RESULTS

3.1 Descriptive analysis

Table 1 shows the descriptive parameters of all variables.

Table 1. *Descriptive statistical parameters and indicators of normality of distribution of research variables*

Variables	*M*	*SD*	*Sk*	*Ku*	*Sk SE*	*KuSE*	*K-S*
Quality of life	30.01	4.96	0.22	0.74	0.10	0.36	0.87**
Anticipatory pessimism	16.17	5.02	0.80	0.43	0.10	0.36	0.60**
Environmental self-efficacy	17.20	3,58	0.35	0.61	0.10	0.36	0.45**
Proactive environmental behavior	28.34	7.63	0.56	0.92	0.10	0.36	0.32**

Annotation. *M* = arithmetic mean; *SD* = standard deviation, *Sk* = Skewness; *Ku* = Kurtosis; *SkSE* = standard error of skewness; *KuSE* = standard error of kurtosis; *K-S* = Kolmogorov-Smirnov test.
$p \geq 0.05$ (the distribution does not deviate significantly from normal at the 95% confidence level).

The results of the Kolmogorov–Smirnov test, as well as the inspection of skewness (Sk) and kurtosis (Ku) coefficients, indicate that the distributions of all variables do not significantly deviate from normality. Given that the values of skewness and kurtosis fall within the recommended range of -1 to 1, it was confirmed that the necessary statistical assumptions for the application of parametric statistical procedures, primarily correlation and regression analyses, were met (Field, 2013).

An inspection of the mean values shows that participants exhibit a moderately high level of proactive environmental behavior (M = 28.34). Among the psychological resources, environmental self-efficacy is the most pronounced (M = 17.20), while the values of anticipatory pessimism (M = 16.17; SD = 5.02) and overall quality of life (M = 30.01; SD = 4.96) are stable and in line with expectations for a general population sample.

3.2 Correlation analysis

Prior to testing the proposed hierarchical model, a correlation analysis was conducted to examine the direction and strength of bivariate relationships between proactive environmental behavior and the identified psychosocial predictors (Table 2).

Table 2. *Intercorrelations of the examined variables*

Variables	1	2	3	4	5	6	7	8
1. Proactive environmental behavior	1	0.15 *	-0.05	0.37**	-0.30**	0.14 *	0.02	0.10
2. Quality of life		1	-0.72**	0.03	0.01	-0.17 *	0.02	0.05
3. Anticipatory pessimism			1	0.05	0.01	-0.16 *	0.02	0.03
4. Environmental self-efficacy				1	-0.29**	0.01	-0.04	0.14 *
5. Gender					1	0.03	-0.19 *	0.37**
6. Age						1	-015 *	-0.48**
7. Population size in the place of residence							1	0.09
8. Place of residence								1

Legend. ** $p \leq$ 0,01; * $p \leq$ 0,05.

The intercorrelation analysis (Table 2) indicates that the strongest correlates of proactive environmental behavior are environmental self-efficacy (r = 0.37, $p \leq$ 0.01) and gender (r = -0.30, $p \leq$ 0.01), while quality of life and age showed significant but weaker positive associations with the criterion. In contrast, anticipatory pessimism did not show a significant relationship with proactivity (r = -0.05), despite being very strongly correlated with lower quality of life (r = -0.72, $p \leq$ 0.01). This suggests that more negative expectations about the future are associated with lower subjective well-being, although pessimism itself does not have a significant direct relationship with proactive behavior. The results further reveal a specific demographic distribution of the sample through the association of place of residence with age (r = -0.48, $p \leq$ 0.01) and gender (r = 0.37, $p \leq$ 0.01), supporting the justification for testing environmental self-efficacy as a key psychological resource within the proposed regression model.

3.3 Regression analysis

In order to examine the contribution of different predictors in explaining the variance of the criterion variable proactive environmental behavior a multiple regression analysis was conducted (Table 3).

Table 3. *Results of hierarchical regression analysis for the criterion proactive environmental behavior*

Predictors	Step 1 *β* (SE)	Step 2 *β* (SE)	Step 3 *β* (SE)	Step 4 *β* (SE)	t
Gender	-0.30 (0.01)	-0.32 (0.04)	-0.31 (0.07)	-0.20 (0.02)	-3.10
Age	0.12 (0.05)	0.09 (0.03)	0.16 (0.02)	0.18 (0.03)	5.33
Quality of life		0.17 (0.01)	0.15 (0.04)	0.16 (0.03)	5.76
Anticipatory pessimism			-0.05 (0.10)	0.03 (0.09)	5.80
Environmental self-efficacy				0.29 (0.04)	-3.15.
R^2 adj	0.10	0.02	0.00	0.09	
R^2	0.10	0.12	0.12	0.19	

Legend. β = standard beta coefficient; R^2 = coefficient of determination; R^2adj = corrected coefficient of determination, SE = standard error of the β coefficient; t = t value. ** $p \leq 0,01$, * $p \leq 0,05$.

An inspection of the regression results reveals a gradual increase in explained variance across the stages of the analysis. In the first step, the block of demographic variables (gender and age) explains 10% of the variance in the criterion. With the introduction of the second and third blocks of variables (quality of life and anticipatory pessimism), the percentage of explained variance increases to 12.4%. The key moment in the analysis occurs in the fourth step, where the inclusion of environmental self-efficacy leads to a significant increase in the model's predictive power by an additional 19%. The final model explains a total of 31.4% of the variance in participants' proactive environmental behavior, indicating high relevance and solid explanatory power of the proposed model.

The partial contributions of the variables reveal the following trends: the predictor gender shows a significant negative contribution in the first step (β = -0.30), which remains relatively stable until the final step, where its intensity decreases to (β = -0.20). This finding suggests that initial gender differences are partly mediated by the psychological factors included in the model. Age shows a stable and increasing positive trend across all steps of the analysis (final β = 0.18), indicating that as participants mature, their level of environmental engagement increases. The predictor subjective quality of life, introduced in the second step, maintains a stable and statistically significant positive contribution (final β = 0.16). This confirms that individuals who perceive their lives as higher in quality possess greater personal resources for environmental proactivity. The results for anticipatory pessimism show a change in the direction of its effect; from an initial negative value (β = -0.05), it reaches a slightly positive but marginal contribution in the final model (β = 0.03). Such a low contribution suggests that fear of the future is not a relevant motivator of environmental action among participants. The predictor environmental self-efficacy, introduced in the final step, emerges as the strongest partial predictor (β = 0.29). This factor is the key driver that accounts for the largest portion of explained variance, confirming that belief in one's own effectiveness is crucial for proactive behavior.

The obtained regression findings clearly indicate that proactive environmental behavior is not merely a product of demographic frameworks, but is primarily driven by specific psychological resources, particularly environmental self-efficacy and overall life well-being.

Based on the obtained results of the hierarchical regression analysis, it can be concluded that all proposed *research hypotheses are fully confirmed*, given the statistically significant contribution of the predictors and the high percentage of explained variance in the criterion.

4. DISCUSSION

The aim of this study was to identify key predictors of proactive environmental behavior through an integrated model of demographic and psychological variables. The results of the hierarchical regression analysis showed that the final model explains a significant proportion of the variance in the criterion, thereby fully confirming the fourth hypothesis (H_4). This finding supports the validity of a holistic approach to studying environmental activism, confirming that proactive behavior is best understood as the result of the interaction between basic demographic positions and specific personal resources (Khanna & Kaur, 2026; Owusu et al., 2025).

The analysis of the contribution of demographic factors (H_1) showed that gender and age make a relevant contribution to the model, with the assumption of a stronger initial contribution of gender being confirmed (β = -0.30, $p \leq 0.01$). The results suggest that women are more inclined toward proactive behavior, which is consistent with findings (Chung et al., 2026) that attribute gender differences to a stronger ethic of care and socialization toward altruism. Our findings are also comparable with more recent studies (Pan et al., 2023; Zabih-Allah et al., 2026), which confirm that this "eco-gender gap" is consistent across different social contexts.

The second hypothesis (H_2) regarding the stable contribution of subjective quality of life was also confirmed ($\beta = 0.16$, $p \leq 0.01$). This finding implies that well-being represents an important foundation for social engagement, as individuals who are more satisfied with their lives possess a "psychological surplus for addressing broader social issues. This trend supports the thesis of "sustainable happiness (Peng et al., 2026), according to which pro-environmental behavior and quality of life form a positive reinforcement spiral, as also documented in the study (Asamoah-Gyawu et al. (2026). The most significant contribution of the study, predicted by the third hypothesis (H3), is reflected in the dominant role of environmental self-efficacy (β = 0.29, $p \leq 0.01$), whose inclusion in the final step contributed an additional 19% of explained variance. In contrast, anticipatory pessimism showed a statistically negligible effect ($\beta = 0.03$, $p \geq 0.05$). This clearly demonstrates that mere awareness of negative outcomes does not motivate action as strongly as an individual's belief in their own effectiveness. Our findings are fully aligned with recent research (Özer et al., 2026; Solanki et al., 2026), which emphasizes that without high self-efficacy, awareness of environmental problems leads to ecological paralysis. Similarly, authors (Koolen et al. (2026) and Malecki et al. (2026)) warn that catastrophic scenarios, similar to those reflected in our pessimism variable, tend to distance individuals from the problem rather than engage them.

The obtained results carry relevant *practical implications* for the development of environmental policies and educational programs. Given that self-efficacy emerges as the primary motivator (or predictor), environmental communication strategies in Serbia should shift from a "fear-based rhetoric" toward education focused on concrete, measurable actions that empower individuals. Strengthening the belief that individual contributions matter, while simultaneously linking environmental goals with improvements in quality of life, represents the most reliable path toward increasing overall environmental activism among adolescents.

Despite the significant findings, this study has certain *methodological limitations* that should be considered when generalizing the results. Primarily, the study relies on self-report instruments, which carry the risk of bias due to socially desirable responding. Additionally, the correlational design does not allow for strict causal inferences. Future research should include larger and more representative samples, as well as more objective measures of actual (rather than self-reported) environmental behavior.

5. CONCLUSION

The conducted study confirmed that proactive environmental behavior is a complex phenomenon primarily determined by individuals' psychological resources. The results of the hierarchical regression analysis clearly indicate that the sense of environmental self-efficacy represents the strongest predictor and the key internal motivator for undertaking concrete actions aimed at environmental protection. By confirming all proposed hypotheses, the study demonstrated that, in addition to demographic characteristics such as gender and age, subjective quality of life and belief in one's own effectiveness form the core of environmental proactivity. A particularly important conclusion is that anticipatory pessimism does not contribute to activism, suggesting that fear-based, catastrophic messaging is not an effective strategy for mobilizing young people. The final model, which explains nearly one-third of the variance in behavior, provides a solid foundation for the development of future environmental programs focused on strengthening personal capacities and fostering optimism through effective action.

REFERENCES

Allam, I. M. A. (2026). *Comprehensive Collinearity Diagnostic Tool: Implementation and Statistical Analysis*. Khartoum: University of Khartoum.

Al-Busaidi, S., Al-Mahrouqi, T., Al-Omrani, S., Al-Hajri, F., Al-Salahi, A., Jose, S., & AlAdawi, S. (2025). Body Image Dissatisfaction and Its Associated Factors among Female Students at Sultan Qaboos University, Oman: A Cross-sectional Study. *Saudi Journal of Medicine & Medical Sciences, 13*(2), 106–113. https://doi.org/10.4103/sjmms.sjmms_728_24

Alkahazraji,R.(2025).Beyondthescreen:theroleofsocialmediaandfamilyinfluenceinshapingbodyimageandeatingbehaviors.*MiddleEastCurrentPsychiatry,32(*1), 34–42. https://doi.org//10.1186/s43045-025-00527-9

Alessandri, G., De Longis, E., Golfieri, F., & Crocetti, E. (2021). Can self-concept clarity protect against a pandemic? A daily study on self-concept clarity and negative affect during the COVID-19 outbreak. *Identity*, *21*(1), 6–19. https://doi.org/10.1080/15283488.2020.1846538

Al Riyami, Y. S., Al Senani, I. H., Al Brashdi, A. S., Al Balushi, N. I., Almarabheh, A. J., & Ahmed, J. (2024). Young females experience higher body image dissatisfaction associated with a high social media use: A cross-sectional study in Omani university students. *Middle East Current Psychiatry, 31*(1), 85. https://doi.org/10.1186/s43045024-00477-8

Asamoah-Gyawu, J., Badu, S. O., Abdulai, B. B., Anane, H., Takyi, S., & Baluwie, S. (2026). Impact of personality traits and pro-environmental behaviours on eco-anxiety among university students. *European Journal of Psychology and Educational Research, 9*(1), 21-34. https://doi.org/10.12973/EJPER.9.1.21

Bakhtawar, L., Zoya, R., Faisal, A., Muddassir, K., Maham, F., Ghulam, D., & Zainab, B. (2026). Assessing photo-specific social media, body dissatisfaction, anxiety, and depression: a nationwide cross-sectional study on adolescents and young adults. *Annals of Medicine & Surgery, 88*(2), 1311–1317, 10.1097/MS9.0000000000004535

Carter, J. J., & Vartanian, L. R. (2022). Self-concept clarity and appearance-based social comparison to idealized bodies. *Body Image*, *40*, 124–130. https://doi.org/10.1016/j.bodyim.2021.12.001

Chen, S., Li, X., & Ye, S. (2024). Self-concept clarity and meaning in life: A daily diary study in a collectivistic culture. *Journal of Happiness Studies*, *25*(6), 59. https://doi.org/10.1007/s10902-024-00775-2

Chong, YH. (2026). Online Social Comparison and Body Dissatisfaction among Young Adults: The Role of Self-Esteem. *PsychBehav*, *2*(1), 1–6. https://doi.org/10.64229/v8xn0317

Cooper, P. J., Taylor, M. J., Cooper, Z., & Fairbum, C. G. (1987). The development and validation of the Body Shape Questionnaire. *International Journal of Eating Disorders*, *6*(4), 485–494. https://doi.org/10.1002/1098-108X(198707)6:4<485::AID-EAT2260060405>3.0.CO;2-O

Chung, Y., Kim, S., & Lee, J. (2026). Psychological barriers and facilitators of pro-environmental behavior: The mediating roles of life satisfaction and personal agency. Journal of Environmental Psychology, 108, Article 102950 https://doi.org/10.1016/J.JENVP.2026.102950

Filosa, L., Sommovigo, V., Tavolucci, S., Rosa, V., Alivernini, F., … Baiocco, R. (2025). Daily associations between global self-esteem and self-concept clarity and their relationships with subjective well-being in a sample of adult workers. *Journal of Personality*, 93(2), 361–377. https://doi.org/10.1111/jopy.12934

Ghulam, A., Syeda, M., & Niaz, A. (2024). Body Image Dissatisfaction is the Predictor of Social Physique Anxiety and Self- Esteem. *Journal of Policy Research, 10*(3), 117–122. https://doi.org/10.61506/02.00326

Gkargkavouzi, A., & Halkos, G. E. (2026). Psychological Resilience to Climate Change: The Role of Self-Efficacy, Mindfulness, Perceived Nature Restorativeness, and Subjective Well-Being. *Sustainable Development, 34*(S2), 1435-1457. https://doi.org/10.1002/SD.70401

Gray, T., & Pigott, F. (2026). Reconnecting urban youth to nature in a place-based program for wellbeing and pro-environmental behaviour: A qualitatively driven mixed-methods pilot study. Journal of Sustainability Research, 8(1), Article e260008. 10.20900/jsr20260008

Fatima, M., Hafeez, I. N., Tariq, Z., & Rehman, F. (2026). Appearance-Related Social Media Use, Social Physique Anxiety, and Body Esteem Among Young Adults: The Role of social Media Usage and Sociodemographic Factors. *Qlantic Journal of Social Sciences and Humanities*, *7*(1), 11–19. https://doi.org/10.55737/qjssh.vii-i.26413

Hani, U. I., Umar, S., Jabbar, I., Asim, M. (2026). Charisma Phobia as a Predictor of Mental Health and Body Dissatisfaction among Teenage Girls. (2026). *Research Consortium Archive*, *4*(1), 468–478. https://www.rcresearcharchive.com/index.php/Journal/article/view/573

Hadeel, S. (2025). *Examining the Relationship Between Body Image Dissatisfaction, Social Anxiety, and Lifestyle Factors Among Female Undergraduate Students*. [Doctoral dissertation]. Jedah: Ffat university college of humanities, department of clinical psychology.

Hart, E. A., Leary, M. R., & Rejeski, W. J. (1989). Tie measurement of social physique anxiety. *Journal of Sport and Exercise Psychology*, *11*(1), 94–104. https://doi.org/10.1123/jsep.11.1.94

Hachana, R., Najar, T., & Ivanaj, S. (2025). The role of trust and environmental culture in household waste management: Shifting frameworks from socio-demographics to psychological determinants. *Global Environmental Change*, *91*, Article 102840. https://doi.org 10.1016 / j.gloe nvcha 2025.102840

Huang, H. (2016). Media use, environmental beliefs, self-efficacy, and pro-environmental behavior. *Journal of Business Research*, *69*(6), 2206–2212. https://doi.org/10.1016/j.jbusres.2015.12.031

Ivanović, M. (2025a). *Perfectionism and deviation from eating habits in women: predictors of exercise addiction, Journal of Economics, Business & Management,* 3(2), 304–311.

Ivanović, M., & Pantelić, V. Ćosić, I. (2025b). Determinants of prediction of new mothers' dissatisfaction with their body shape [Determinante predikcije porodilja nezadovoljstvom personalne konstitucije]. *Journal of Palliative Care Research and Reports, 2*(1), 1–7.

Kaiser, F. G., & Shimoda, T. A. (1999). Responsibility as a predictor of ecological behavior. *Journal of Environmental Psychology*, *19*(3), 243–253. https://doi.org/10.1006/jevp.1998.9123

Khanna, S., & Kaur, R. (2026). Predictors of sustainable activism among urban youth: Integrating demographic baselines and psychological capital. Journal of Environmental Studies and Sciences, 16(2), 312-327. https://doi.org 10.1007/S13412-026-01142-5

Koolen, M., van Noord, J., & de Vries, S. (2026). Overwhelmed by doom: How catastrophic climate framing induces psychological distance and behavioral paralysis. Journal of Environmental Psychology, 109, Article 103045. https://doi.org 10.1016/J.JENVP.2026.103045

López-Montón, M., Aonso-Diego, G., & Estévez, A. (2025). Body dissatisfaction in older adults: The role of social media, emotion regulation, social support, emotional distress, and coping strategies. *Personality and Individual Differences, 245*, 113–282. https://doi.org/10.1016/j.paid.2025.113282

Nagpal, P. B., & Kumari, M. (2026). Artificial Intelligence: Evaluating Its Role And Impact On Achieving Sustainable Development Goals. *International Journal of Environmental Sciences*, *14*(1), ID 5448. https://theaspd.com/index.php/ijes/article/view/5448

Madera, F., Puhakka, R., & Galambos, N. (2024). Nature and social connectedness as resources for well-being: An ecological-developmental perspective. *Journal of Environmental Psychology*, *96*, Article 102214 https://doi.org/10.1016/ j .jenvp .2026.102214

Malecki, K., Nowak, A., & Wisniewski, P. (2026). Climate pessimism and the withdrawal effect: The role of threat appraisal in environmental engagement. Global Environmental Change, 98, Article 103210. https://doi.org/10.1016/J.GLOENVCHA.2026.0321

Özer, D., Kurulur, H. S., & Bir, E. F. (2026). Hope for the future: Associations between eco-anxiety, pro-environmental behaviors, and hope among young adults in Türkiye. Public Health Nursing, 43(3), 521-532. https://doi.org/10.1111/PHN.70079

Owusu, A., Mensah, J. B., & Appiah, F. (2025). Socio-demographics and psychological determinants of pro-environmental behavior: A hierarchical regression approach. Global Environmental Change, 93, Article 102915. https://doi.org/10.1016/J.GLOENVCHA.2025.102 915

Pan, S.-L., Chang, L.-Y., & Lin, Y.-H. (2023). Unveiling the eco-gender gap: How altruistic values and gender socialization shape green purchase intentions and eco-activism. Global Environmental Change, 82, Article 102710. https://doi.org/10.1016/J.GLOENVCHA.2023 . 102710

Pavot, W., & Diener, E. (2008). The Satisfaction With Life Scale and the emerging construct of life satisfaction. *The Journal of Positive Psychology*, *3*(2), 137–152. https://doi.org/10.1080/17439760701756946

Peng, J., Wang, X., & Zhang, L. (2026). Effects of social norm types on pro-environmental behavior: Activating the moral identity for sustainable happiness. *Acta Psychologica Sinica, 58*(6), 1197-1211. https://doi.org 10.3724/S P.J.1041.2026.01197

Sadiqa, A. (2026). Social media use and family dynamics: understanding body image perceptions among married women. *Pakistan Journal of Social Science Review*, *5*(2), 12–33. https://www.pjssrjournal.com/index.php/Journal/article/view/568

Schaefer, L. M., Harriger, J. A., Heinberg, L. J., Soderberg, T., & Thompson, J. K. (2017). Development and validation of the sociocultural attitudes towards appearance questionnaire-4 Revised. *International Journal of Eating Disorders,* 50(2), 104–114. https://doi.org/10.1002/eat.22590

Shuai, J., Cai, G., & Wei, X. (2024). Social exclusion and social anxiety among Chinese undergraduate students: Fear of negative evaluation and resilience as mediators. *Journal of Psychology in Africa, 34*(1), 44–51. https://doi.org/10.1080/14330237.2023.2290432

Solanki, B., & Rao, M. K. (2026). Behavioural drivers of socially responsible adoption among retail actors: A PLS-SEM approach. International Journal of Management and Public Sector Analytics, 5(2), 142-158. https://doi.org/10.40368/IJMPSA.2026.40

Staśkiewicz-Bartecka, W., Lubojańska, J.,, Kołodziejczyk, A., Kiciak, A., Kardas, M., & Białek-Dratwa, A. (2026). Body Image Evaluation and Sociocultural Attitudes Toward One's Own Body Among Women Practicing Pole Dance. *Nutrients, 18*(5), 814–825. https://doi.org/10.3390/nu18050814

Ryan, R. M., Frederick, C. M., Lepes, D., Rubio, N., & Sheldon, K.M. (1997). Intrinsic motivation and exercise adherence. *International Journal of Sport Psychology, 28,* 335–354.

Tabancik, B. G., & Fidel, L. S. (2019). *Using Multivariate Statistics* (7th ed.). Northridge. California State University.

Tang, M. C. Y., Vartanian, L. R., & Pinkus, R. T. (2026). Momentary fluctuations in body image dissatisfaction among women: The role of self-concept clarity. *Self and Identity, 25*(2), 238–260. https://doi.org/10.1080/15298868.2026.2619136

Taylor, J., & Armes, J. (2024). Social comparisonon Instagram and itsrelations hip with self-esteem and body-esteem. *Discover Psychology,4*(1),126–138.

Tiring, O., & Çakır, M. (2026). Level and relationships of life satisfaction with cognitive flexibility, cognitive distortions, and perceived stress. Journal of Culture and Values in Education, 9(1), 225-248. https://doi.org/10.46303/JCVE.2026.10

Vannam, R., & Rao, K. S. (2025). Integrating the theory of planned behavior (TPB) and value-belief-norm (VBN) theory to explain proactive environmental behavior. Journal of Environmental Psychology, 102, Article e250912. https://doi.org/1016/J .JENVP.2025.E250912

Zabih-Allah, M., Ahmadi, A., & Karimi, S. (2026). Cross-cultural validation of the eco-gender gap: A multi-group structural equation modeling approach to sustainable behaviors. *International Journal of Environmental Sciences, 14*(2), 112-128. https://doi.org/10.64252/W PDNBP26

Zhang, Y., Wen, Z., Zhu, Y., & Guan, G.(2024). Effects of physical exercise on body esteem among females: A meta-analysis. *BMC Public Health*, *24*, 3387–3396.

PSYCHOSOCIAL PREDICTORS OF PROACTIVE ECOLOGICAL BEHAVIOR: A HIERARCHICAL MODEL OF THE CONTRIBUTION OF PERSONAL RESOURCES AND ECOLOGICAL SELF-EFFICACY

Miroljub IVANOVIĆ, Milivoje ĆOSIĆ

Summary

The main aim of this research was to identify and conduct a detailed analysis of the key psychosocial determinants of proactive ecological behavior among adults through the application of a structured four-step hierarchical regression model. The research was conducted on a convenience sample of N=260 participants of both sexes, aged 18 to 65 years (M=30.46, SD=9.05), thus encompassing the working-age and mature adult population. The

predictive system established in the study included basic demographic characteristics (gender and age), general personal resources in the form of subjective quality of life and anticipated pessimism, as well as a specific psychological resource oriented toward the ecological domain – ecological self-efficacy.

For the operationalization of constructs, the following measuring instruments with verified metric characteristics were applied:

- Questionnaire of Proactive Ecological Behavior, adapted according to the validated General Ecological Behavior model (GEB; Kaiser & Shimoda, 1999), with achieved reliability of α=0.78;
- Satisfaction With Life Scale (SWLS; Diener et al., 1985), for the assessment of the cognitive component of subjective well-being, with high internal consistency (α=0.85);
- Temporal adaptation of the SWLS scale according to the theoretical model of the Temporal Satisfaction With Life Scale (TSWLS; Pavot, Diener, & Suh, 1998), for measuring anticipated pessimism regarding future life conditions (α=0.82);
- Ecological Self-Efficacy Scale (ESES; Huang, 2016), constructed for assessing an individual's belief in their own effectiveness in solving ecological problems (α=0.83).

The results of the hierarchical regression analysis revealed a successive and statistically significant increase in the percentage of explained variance of proactive ecological behavior throughout the successive phases of the analysis. In the first step, the block of demographic variables (gender and age) explained 10% of the criterion variance. By introducing subjective quality of life in the second step and anticipated pessimism in the third step, the percentage of total explained variance slightly increased to 12.4%. The key methodological moment of the analysis was represented by the fourth step, where the introduction of ecological self-efficacy led to a sharp and robust increase in the predictive power of the model by an additional 19%. The final, completed regression model explained a total of 31.4% of the variance in participants' active ecological behavior, indicating the high relevance and solid explanatory power of the proposed theoretical framework.

The analysis of the partial contributions of individual variables in the final step identified specific trends of influence. The predictor gender achieved a stable and significant negative contribution (β=-0.20, $p \leq 0.05$), while age demonstrated a positive and increasing trend throughout all analytical steps (β=0.18, $p \leq 0.05$), clearly indicating that direct ecological engagement increases with life maturity and experience. Subjective quality of life proved to be a stable and statistically significant positive predictor (β=0.16, $p \leq 0.05$), thereby confirming the initial assumption that individuals who perceive their lives as more satisfying and stable possess greater capacity and personal resources for ecological proactivity. In contrast, anticipated pessimism achieved a statistically negligible and non-significant final contribution (β=0.03, $p \leq 0.05$), suggesting that mere fear of the future and ecological anxiety are not relevant drivers of concrete action. Ecological self-efficacy positioned itself as by far the strongest individual predictor in the model (β=0.29, $p \leq 0.01$), acting as the primary psychological lever of ecological activism. The obtained findings have direct and important practical implications for the creation of modern ecological policies, sustainable development strategies, and educational programs in the field of environmental protection and sustainable forestry in the Republic of Serbia. Strategies of ecological communication directed toward the public should urgently shift from the dominant "rhetoric of fear," catastrophic scenarios, and ecological pessimism toward structured education about concrete, measurable, and achievable steps that empower the individual. Strengthening citizens' beliefs that their individual contribution is meaningful and capable of producing real change, while simultaneously connecting ecological goals with the improvement of overall quality of life and personal well-being, represents the safest and scientifically grounded path toward increasing proactive ecological behavior within the population.

PSIHOSOCIJALNI PREDIKTORI PROAKTIVNOG EKOLOŠKOG PONAŠANJA: HIJERARHIJSKI MODEL DOPRINOSA LIČNIH RESURSA I EKOLOŠKE SAMOEFIKASNOSTI

Miroljub IVANOVIĆ, Milivoje ĆOSIĆ

Rezime

Glavni cilj ovog istraživanja bio je identifikovanje i detaljna analiza ključnih psihosocijalnih determinanti proaktivnog ekološkog ponašanja odraslih osoba, kroz primenu strukturisanog četvorostepenog hijerarhijskog regresionog modela. Istraživanje je realizovano na prigodnom uzorku od N =260 ispitanika oba pola, starosti od 18 do 65 godina (M=30.46, SD=9.05), čime je obuhvaćena radno sposobna i zrela populacija građana. Prediktivni sistem postavljen u radu obuhvatio je bazične demografske karakteristike (pol i uzrast), opšte lične resurse u vidu subjektivnog kvaliteta života i anticipiranog pesimizma, kao i specifični psihološki resurs usmeren na ekološki domen – ekološku samoefikasnost.

Za potrebe operacionalizacije konstrukata u istraživanju su primenjeni sledeći merni instrumenti sa proverenim metrijskim karakteristikama:

- Upitnik proaktivnog ekološkog ponašanja, adaptiran prema validiranom modelu opšteg ekološkog ponašanja (GEB; Kaiser & Shimoda, 1999), sa ostvarenom pouzdanošću od $\alpha = 0.78$;
- Skala zadovoljstva životom (SWLS; Diener et al., 1985) za procenu kognitivne komponente subjektivnog blagostanja, sa visokom unutrašnjom konzistentnošću ($\alpha = 0.85$;
- Vremenska (temporalna) adaptacija SWLS skale prema teorijskom modelu Temporalne skale zadovoljstva životom (TSWLS; Pavot, Diener, & Suh, 1998) za merenje anticipiranog pesimizma u pogledu budućih životnih uslova (α=0.82);
- Skala ekološke samoefikasnosti (ESES; Huang, 2016), konstruisana za procenu uverenja pojedinca u sopstvenu delotvornost u rešavanju ekoloških problema (α=0.83).

Rezultati hijerarhijske regresione analize otkrili su sukcesivan i statistički značajan porast procenta objašnjene varijanse proaktivnog ekološkog ponašanja kroz sukcesivne faze analize. U prvom koraku, blok demografskih varijabli (pol i uzrast) objasnio je 10% varijanse kriterijuma. Uvođenjem subjektivnog kvaliteta života u drugom koraku i anticipiranog pesimizma u trećem koraku, procenat ukupne objašnjene varijanse neznatno raste na 12.4%. Ključni metodološki trenutak analize predstavlja četvrti korak, gde uvođenje ekološke samoefikasnosti dovodi do naglog i robusnog skoka prediktivne moći modela za dodatnih 19%. Finalni, zaokruženi regresioni model objašnjava ukupno 31.4% varijanse u aktivnom ekološkom ponašanju ispitanika, što ukazuje na visoku relevantnost i solidnu eksplanatornu moć predloženog teorijskog okvira.

Analiza parcijalnih doprinosa pojedinačnih varijabli u finalnom koraku izdvojila je specifične trendove uticaja. Prediktor pol ostvaruje stabilan i značajan negativan doprinos (β=-0.20, $p \le 0.05$), dok uzrast beleži pozitivan i rastući trend kroz sve korake analize ($\beta = 0.18$, $p \le 0.05$), što jasno ukazuje na to da se sa životnim sazrevanjem i iskustvom povećava stepen direktnog ekološkog angažovanja. Subjektivni kvalitet života pokazao se kao stabilan i statistički značajan pozitivan prediktor (β=0.16, $p \le 0.05$), čime se potvrđuje polazna pretpostavka da pojedinci koji svoj život percipiraju kvalitetnijim i stabilnijim poseduju veći kapacitet i lične resurse za ekološku proaktivnost. Nasuprot tome, anticipirani pesimizam ostvaruje statistički zanemarljiv i beznačajan konačni doprinos (β=0.03, $p \le 0.05$), što sugeriše da puki strah od budućnosti i ekološka anksioznost nisu relevantni pokretači konkretne akcije. Ekološka samoefikasnost se pozicionirala kao ubedljivo najsnažniji pojedinačni prediktor u modelu (β=0.29, $p \le 0.01$), delujući kao primarna psihološka poluga ekološkog

aktivizma. Dobijeni nalazi imaju direktne i važne praktične implikacije za kreiranje savremenih ekoloških politika, strategija održivog razvoja i edukativnih programa u oblasti zaštite životne sredine i održivog šumarstva u Republici Srbiji. Strategije ekološke komunikacije prema javnosti morale bi se hitno pomeriti sa dominatne „retorike straha“, katastrofičnih scenarija i ekološkog pesimizma ka strukturisanoj edukaciji o konkretnim, merljivim i dostižnim koracima koji osnažuju pojedinca. Intenziviranje uverenja građana da njihov individualni doprinos ima smisla i da donosi realnu promenu, uz istovremeno povezivanje ekoloških ciljeva sa unapređenjem opšteg kvaliteta života i ličnog blagostanja, predstavlja najsigurniji i naučno utemeljeni put ka povećanju proaktivnog ekološkog ponašanja u populaciji.

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
COLLECTION 93, 2026 ZBORNIK RADOVA 93, 2026

UDK: 712.252:613.15(496.5)=111
DOI: 10.5937/SustFor2693157H
Professional paper

A PRELIMINARY ASSESSMENT OF THE RATIO BETWEEN URBAN GREENERY AND BUILT-UP AREAS AND AIR QUALITY IN THE CITY OF ELBASAN, ALBANIA

Eneida HASKA[1], Hajri HASKA[2,3], Neki FRASHERI[3], Arjan ÇUKAJ[2], Andi BUFI[2], Fatmir VODOLLARI[4], Astrit ÇEKA[5], Olsi MIRAÇI[2]*

Abstract: *The creation of cities is perhaps one of humanity's most ingenious "inventions" and solutions. Cities brought many benefits in terms of social services, but also a number of challenges, especially related to mobility and the urban environment. The demand for better living conditions increased, the pressure on natural resources intensified. On the other hand, a more overpopulated and urbanized world was emerging. Building surfaces began to dominate over natural ones and especially over greenery. Environmental components in many cases began to deteriorate, especially air. Elbasan, a city in central Albania, which also has a metallurgical plant with very outdated technology, exhibits very complex features in this sense, and is therefore included in our study. First, through semi-structured questionnaires, through a specific target group, about 16-20 people, the perception of citizens on the current construction-greening relations for the city of Elbasan and how they perceive it for the future was collected. The methodology used to select the stations where the measurements were taken was based on the use of satellite images, combined with consultations with urban greening specialists, as well as through preliminary field observations, selecting representative areas with a high construction ratio versus those with high greening ratios. Through a device with sensors, real measurements were made in Elbasan city for some air indicators. The main aim and purpose of this study is to highlight the role and importance of urban greenery and forestry in establishing and maintaining natural balances, as well as improving the livelihoods and well-being of communities in urbanized areas. A summary of some preliminary results of this data is presented in the following paper.*

Keywords: building–greenery ratio, Elbasan, air quality, urban forestry.

[1] Okan University, Instambul, Tyrkey
[2] Metropolitan University Tirana, Tirane, Albania
[3] Academy of Sciences of Albania, Tirane, Albania
[4] Elbasan County, Elbasan, Albania
[5] Directroy of Forestry, Elbasan, Albania
*Corresponding author. E-mail: eneida.haska@icloud.com

© 2026 The Authors. Published by Institute of Forestry, Belgrade.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

1. INTRODUCTION

Buildings have increasingly begun to impact the natural environment, especially on the land surface and more specifically in greenery, as a result of the population's needs for better living conditions, mainly housing and services. But also, as a result of the pressure of construction businesses for higher profits. In this context, the city of Elbasan, Albania, also presents these characteristics. On the other hand, especially in recent decades, construction entities together with scientific circles are aiming not to neglect the components of urban greenery, therefore relevant studies are being carried out to optimize construction-greening ratios. Many scientific centers and universities are involved in this challenge. In this context, a group of researchers from the Metropolitan University of Tirana (UMT) applied to the National Agency for Scientific Research, Technology and Innovation (NASRTI) with a proposal focused on the relationship between construction and greening in urban environments. The project, funded modestly by NASRTI, entitled: “Optimizing the relationship between building infrastructures and green infrastructures as one of the main elements in improving the environment and the sustainable development of urban areas. A comparative observation of these issues in some cities/neighborhoods of our country (Case study: Elbasan & Tirana) realized during 2024-2025 years.

The main aim of this project is to evaluate urban environments with different construction-greening ratios, with particular emphasis on the presence, absence, or limited presence of urban greenery-especially trees and urban forests and to examine the correlations between these and the quality of life of communities in these urban areas. The project seeks to derive conclusions about the benefits brought by urban greenery in residential centers and to formulate recommendations for improving the construction-greening ratio in favor of greening in the near future.

A primary objective is to assess community perceptions of the importance of urban greening in relation to building infrastructure and its contribution to improving environmental components and quality of life. This objective is at the core of UMT’s educational and research mission and is aligned with government strategies, where environmental problems have become increasingly significant at local, regional, and global levels (UMT, 2024).

Urban greening in cities and especially the presence of urban forestry elements such as trees and shrubs is essential for a healthy environment and for the well-being of human communities. Beatley (2012) emphasizes that we must better understand the processes by which green city innovations—and innovations in general—are embraced, adopted, and implemented. This is true for all urban centers worldwide, including those in Albania.

Various archaeological discoveries, dating back to the earliest times, in urban residential centers in Albania, have noted the presence of vegetation, trees, and shrubs (Haska, 2021; Haska, 2022).

The data collected through questionnaires and the results obtained from their processing will indicate the main directions in which future efforts should be focused, both in terms of research and in terms of policymaking and decision-making related to these pressing environmental issues. In what follows, we present several aspects of the project and some preliminary results for the city of Elbasan.

So, the aim of this paper is to highlight the construction-greening relationships in the city of Elbasan and undoubtedly the correlation between them, as well as to highlight the advantages of urban greening in the city of Elbasan in relation to air quality improvement and urban well-being

2. MATERIAL AND METHOD

2.1 Methodology and study area

All cities share similar physical structures (FAO, 2016), including: grey infrastructure: residential industrial buildings, roads, utilities, parking lots, etc.; blue infrastructure: rivers, lakes, ponds, canals, and other water bodies. Green infrastructure: trees, shrubs, grasslands, parks, forests, gardens, roadside greenery, and other vegetated areas. Optimizing interactions between these elements is essential for restructuring or building cities capable of responding to urban challenges. For the city of Elbasan, a very good and coordinated work was done in three main directions. First from the satellite image, as well as in cooperation with environmental specialists, staff of the municipality of Elbasan, forest specialists, several specific areas in the city of Elbasan were identified both on the map and in the field, about 12 of them, where 6 of them were selected with high construction coefficients and 6 with high greening coefficients. A questionnaire was drafted by the forest expert Prof. Haska and after being tested initially on 2-3 people, the final form was completed by a larger number of a specific target groups about 16-18. A completed copy of this questionnaire is attached below.

Urban forests can be defined as networks or systems that include all forests, tree groups, and individual trees located in urban and peri-urban areas. They include forests, street trees, trees in parks and gardens, and trees in abandoned or marginal spaces. Urban forests are the backbone of green infrastructure, forming a bridge between rural and urban areas and improving the urban environment. On the other hand, contemporary architecture should be guided by a vision that rethinks the relationship between construction and the environment, discovers new forms and content, and asserts that the art of building is entering a new phase that will fundamentally change the way we live, always in harmony with the “language” of nature (Haska et al., 2019).

The Study Areas for the UMT project (UMT, 2024) was the cities of Tirana and Elbasan, selected because they reflect characteristic conditions related to the project’s objectives and goals. In this paper, we present some preliminary findings for the city of Elbasan.

To make a preliminary assessment of several selected stations according to the methodology described above, i.e. based on construction–greening ratios, the project team, using a device purchased in France by project staff. Sensor apparatus with a satisfactory level of reliability, Temetop M2000, a Portable Monitor Air Quality which serves for the measurement of air quality indicators in motion, which serves for the measurement of air quality indicators in motion, with a dwell time at each station of at least 30 minutes and making real-time measurements for a duration of at least 10 minutes at the station, and at least twice a year in different seasons, carried out real field measurements of air-quality indicators in Elbasan city, which is an added value for the project because initially it was planned to collect the perception of citizens only through questionnaires.

2.2 Data about geographic and climatic characteristics of Elbasan city, Albania

The city of Elbasan is located in the Elbasan plain, on the right bank of the middle course of the Shkumbin River. It is surrounded: to the east by Krasta e Madhe and Krasta e Vogël, to the north and northwest by olive-covered hills, to the west by the Zaranika stream and to the south by the Shkumbin River. On the western side of the city flows the Zaranika stream, and on the eastern side the Manazderia stream. Elbasan lies between latitudes 41°27' N and 40°10' N and longitudes 20°34' E and 19°03' E, at an average altitude of 125 m above sea level. The region has mild, rainy winters and hot, dry summers (Municipality of Elbasan, 2024). More detailed climate data include: Average annual temperature: 15.4°C, average January temperature: 6.5°C, average August temperature: 24.1°C, average annual precipitation: 1157 mm, maximum annual precipitation: 1500 mm, minimum annual precipitation: 620 mm, annual sunshine duration: 2488 hours, average heat value: 48.48 Kcal/cm², average annual humidity: 67%, wind speed: 30–35 m/s, main wind direction: east–west, altitude: 125 m.

2.3 Assessment of Environmental and Air Quality Indicators

Assessing environmental indicators, particularly air quality, involves evaluating multiple factors that influence both ecosystems and human health. In this project, we used an approach based on key air-quality indicators, where we can mention the main ones such as:

Particulate Matter (PM):

PM_{10}: particles with a diameter of 10 micrometers or less, which can be inhaled and cause respiratory problems.

$PM_{2.5}$: fine particles with a diameter of 2.5 micrometers or less, which can penetrate deep into the lungs and enter the bloodstream, leading to serious health problems such as cardiovascular disease, lung cancer, and aggravated asthma.

Ground-Level Ozone (O_3): Formed through reactions between VOCs and NO_x in the presence of sunlight. High levels cause respiratory problems and damage vegetation and crops.

Nitrogen Dioxide (NO_2): Emitted mainly from the combustion of fossil fuels in vehicles and power plants; contributes to acid rain and smog; prolonged exposure leads to respiratory issues.

Sulphur Dioxide (SO_2): Produced by burning fossil fuels (especially coal) and industrial processes; can irritate the respiratory system and contribute to acid rain. **Carbon Monoxide (CO):** Originates from incomplete combustion of fossil fuels, especially in vehicles and industrial settings; high concentrations can be lethal, and it contributes indirectly to ground-level ozone formation.

Volatile Organic Compounds (VOCs): Emitted from vehicles, industrial processes, solvents, and paints; contribute to ozone and smog formation.

Ammonia (NH_3): Primarily from agriculture (livestock and fertilizers); contributes to particulate formation and acidification of water bodies.

Air Quality Index (AQI): A composite index (0–500) used to communicate the overall level of air pollution to the public (US-EPA, 2025). (Air Now, 2025).

2.4 Some main factors that negatively affecting air quality in Elbasan city

- Overcrowding and human respiration (CO_2 emissions)
- Transport sector (old vehicles, low-quality fuel)
- Construction activities and site dust
- Urban solid waste (at home, in bins, in landfills)
- Inert waste (dust, fine particles)
- Use of refrigerants and air conditioners (greenhouse gases)
- Urban heat island effects
- Noise pollution
- Fires and combustion (smoke and toxic gases)
- Heating and cooking with CO_2-emitting fuels
- Emissions from factories and bakeries
- Decomposition of organic matter
- Intensive technologies in residential services
- Use of pesticides and herbicides
- Smoking in public and residential spaces
- Improper disposal of hospital waste
- Specific case: emissions of BVOCs (biogenic volatile organic compounds) from certain tree species at high temperatures

Poor air quality results in health impacts such as respiratory and cardiovascular diseases and premature mortality, as well as environmental impacts including vegetation damage, soil & water pollution, and contributions to climate change.

3. RESULTS AND DISCUSSIONS

In Albanian legislation, (Law nr. 162, 2014) in Annex No. 1 describes the 13 main air pollutants, including suspended solids PM2.5 and PM 10, and the data for the city of Elbasan, which we present below, are collected around them.

3.1 Characteristics of questionnaire respondents

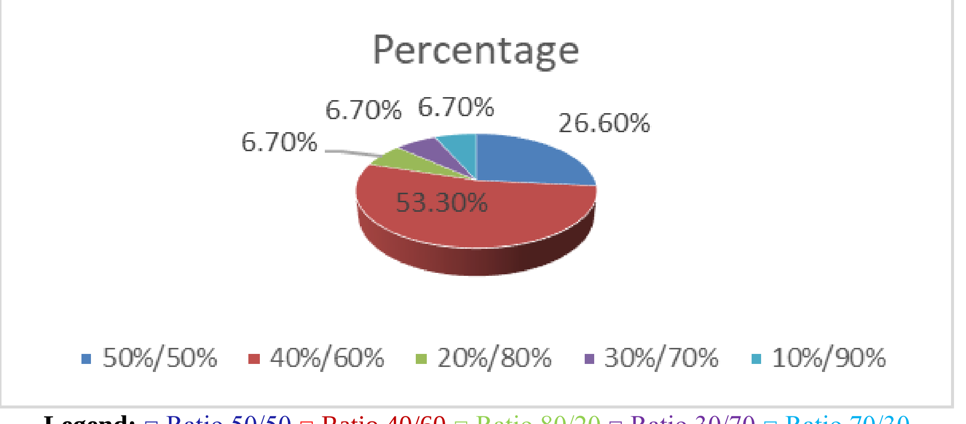
The questionnaire regarding the construction-greening relations in the city of Elbasan was compiled in four sections: the first section dealt with introductory questions such as age, education and employment. The second section–introductory questions on the issue of greening and construction in the city of Elbasan, the third section dealt with construction-greening ratio in the city of Elbasan, and the fourth section dealt with suggestions and recommendations.

So, from the processing the data, it results: regarding education: 20% with primary education, 26.7 with secondary education and 53.3 with higher education, and age: 20% up to 40 years, 13.3% over 60 years and 66.7 between 40-60 years, while employment: 6.7% self-employed, 20% pensioners, 33.3 employed in the public sector and 40% employed in the private sector (Haska et al., 2026).

Questionnaire with the focus construction-greenery ratio was drafted based in this methodology, it was initially tested in the city of Elbasan and then fulfilled completed by a considerable number of residents in this city. We are also presenting completed copies of this questionnaire above, and below we will present some relevant answer.

3.2 Public perception about ratio construction-greenery and air quality

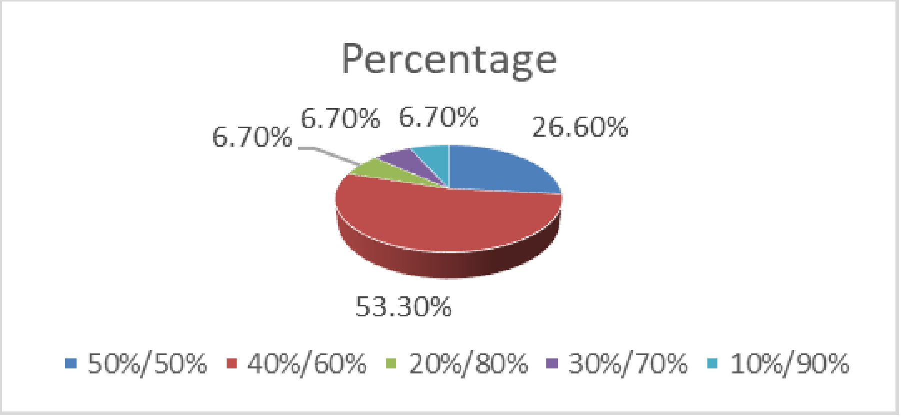
Based on the questionnaire data and a preliminary data processing, below we are graphically presenting them with answers about the construction-greening relationship as it is and as it should be according to the perceptions of the interviewees.



Legend: □ Ratio 50/50 □ Ratio 40/60 □ Ratio 80/20 □ Ratio 30/70 □ Ratio 70/30

Graph 1.

From the above data processing Graph no. 1, it is noted that regarding the question: ***According to you, in the city of Elbasan or the region where you live or work, what is the ratio, what % is construction and what % is greening (in percentage)*** - about 55.3% of respondents answered that this construction/greening ratio is 50/50 percentage, whereas 26.6 % of respondents answered that this construction/greening ratio is 40/60 percentage, 6.7 % of respondents answered that this construction/greening ratio is 80/20 percentage, as well 6.7 % other of respondents answered that this construction/greening ratio is 30/70 percentage, as some people think and answered that this construction/greening ratio is 70/30 percentage, so an interesting variety of answers, but most of them are in the 50/50 ratio.



Legend: □ Ratio 50/50 □ Ratio 40/60 □ Ratio 20/80 □ Ratio 30/70 □ Ratio 10/90

Graph 2.

From the above data processing Graph. 2, it is noted that regarding the question: ***In your opinion, what should the construction-greening ratio be in the future?*** What percentage should be construction and what % greening? About 26.6% of respondents answered that this construction/greening ratio should be 50/50 percentage, whereas 53.3 % of respondents answered that this construction/greening ratio should be 40/60 percentage, 6.7 % of respondents answered that this construction/greening ratio should be 20/80 percentage, as well 6.7% other of respondents answered that this construction/greening ratio should be 30/70 percentage, as some people think and answered that this construction/greening ratio should be 10/90 percentage in the favor of greenery. In relation of questionary for air indicators, a large proportion of respondents indicated that city centers are the most polluted areas and identified transportation and local businesses as primary sources of pollution.

3.3 Field measurements of air-quality indicators

One of the most important aspects of this modest project is that real measurements of air components were carried out based on methodologies using contemporary instruments. While the city of Tirana has several permanent air-monitoring stations, the city of Elbasan does not.

Therefore, the project team - especially the architecture specialist - decided not only to rely on questionnaires, and the perceptions given there by the interviewees, but also to conduct direct field measurements the main air quality indicators in the Elbasan city.

Figure 1. *During air measurements in terrain, Elbasan City*

Table 1: *Standards for pollutants Pm $_{2.5}$ and Pm $_{10}$*

Nr	Pollutants	Albanian standards	World Health Organization standards	European Union Standards
1	Pm $_{2.5}$	25	5	10
2	Pm $_{10}$	40	15	20

(Source: NEA 2024, WHO 2021, Chathamparambath 2025)

From the Table 1 we can see the standards for some very important pollutants, and especially for Pm $_{2.5}$ and Pm $_{10}$, where Albanian standards have some more higher value for example for Pm $_{2.5}$ till 25 and for Pm $_{10}$ till 40, while the standards are stricter from World Health Organization, respectively 5 for Pm $_{2.5}$ and 15 for Pm $_{10.}$ In relation to this standard, direct field measurements in the Elbasan city were carried out in accordance with the relevant methodology explained in the above paragraphs. The measured values are presented in the following Table 2.

Table 2. *Air Quality Measurements – Elbasan City (12.10.2024-E. Kamberi, H.Haska)*

Nr	Components Indicators		Stations							
			Station 1 (Gas station, Kastrati)	Station 2 (Globe)	Station 3 (Municip Elbasan)	Station 4 (Krasta Lower)	Station 5 (Crossing Librazhd)	Station 6 (Park Rinia)	Station 7 (Crossing Gramsh)	Station 8 (Crossing Gjinar)
1	**Pm 2.5**		9.2	9.6	11.2	12.4	10.1	**6.4**	**17.3**	9.2
2	**Pm 10**		13.4	18,8	19	21.1	18.2	**10.4**	**29.6**	16.6
3	**Particles**		1125	2250	1726	1847	1597	**952**	**2659**	1480
4	**CO2**		412	415	459	392	395	385	557	411
5	**HCHO**		0.115	0.050	0.039	0.034	0.031	0.029	0.027	0.028
6	**Temp C^0**		25.1	28	27.5	27.7	27.4	27.3	27.8	26.9
7	**Humidity %**		55.5	44,2	50	50	50.7	51.6	49.6	53.4
8	**Coordinate**	**N**	41^0 06' 01"	41^0 06' 29"	41^0 06' 40"	41^0 07' 09"	41^0 07'17"	41^0 07'04"	41^0 06' 16"	41^0 05' 45"
		E	20^0 01' 46"	20^0 04' 17"	20^0 04' 52"	20^0 06' 08"	20^0 06'12"	20^0 06' 12"	20^0 04' 54"	20^0 04' 59"
9	**TIME**		AM	AM	AM	AM	AM	AM	AM	AM

From Table 2, it is evident that: From the data, we note that the Albanian standard is not exceeded at all stations, neither for $PM_{2.5}$, nor for PM_{10}, but exceeded World Health Organization standards in all 8 stations for $PM_{2.5}$, and in 6 stations from 8 in total for PM_{10}, are also exceeded European Union Standards in 4 stations from 8 in total for $PM_{2.5}$, and in 2 stations from 8 in total for PM_{10}. We can underline that Station 7 (Crossing Gramsh) shows the worst values, especially for $PM_{2.5}$, PM_{10}, particle and CO_2. This is due to very high traffic loads: vehicles of different sizes traveling from Tirana towards Qafë Thana and the Kapshticë border, and towards Korça, Cerrik, Belsh, and Gramsh. From the other side Station 6 (Rinia Park), located near a large urban green area with many trees and relatively few buildings, has the best air-quality indicators among the monitored stations. It is very interesting to underline that and a study realized from world Bank last years, published by World Bank report on six Western Balkan countries, “Western Balkans – Regular Economic Report No. 25 | Spring 2024 – Invigorating Growth” (World Bank, 2024), shows that Elbasan has comparatively good green-space coverage, with more than 16% of its area covered by greenery in 2020 year, a relatively satisfactory value compared to many other cities in Albania, but also in the region, which present relatively low values.

3.4 Activities to increase green spaces and community participation

To ensure that the project had a tangible positive impact not only on data and analysis but also on the ground, UMT, as the implementing institution, decided to donate and plant a number of decorative saplings symbolically in the municipality of Elbasan. This aimed to contribute to nature and, at the same time, raise community awareness about the importance of a green environment. The principle applied was: **“Do it together with the community, not for the community.”** Planting trees with community participation enhances project sustainability and promotes shared responsibility. Several field visits were carried out in Elbasan to identify suitable planting sites. Approximately **60–70 decorative** saplings were procured with funding from NASRIT and UMT. There were initial difficulties because many private nurseries did not have sufficient decorative red plum stocks. Ultimately, some seedlings were secured in Tirana and others in Lushnje, and transportation was supported by UMT and the Elbasan region. The dendrometric parameters and planting operations were based on contemporary literature on urban afforestation and on the **Afforestation Manual** of the National Forestry Agency (Tabaku & Starja, 2023). After selecting a planting site near the new Elbasan Municipality building, the planting process was carried out according to proper methodology-from pit opening through to final planting and initial watering. On the promotional planting day, participants included: The Mayor of Elbasan, **Mr. Gledian Llatja, m**unicipal staff, prof. Haska, urban forestry expert from UMT, other project staff and community members. This activity served as an important additional component of the project, contributing to community awareness and active participation in expanding green areas in the urban environment.

Figure 2. *During promotional planting day, Municipality of Elbasan, Albania*

4. CONCLUSIONS AND SUGGESTIONS

From the preliminary data, while more detailed statistical processing is ongoing, we can outline several conclusions:

- **In both Elbasan & Tirana, construction dominates over green infrastructure.** In future, efforts must be made to reduce this imbalance so that cities have green spaces in sufficient quantity and quality, with benefits for both the environment and society.
- **Areas dominated by greenery show better environmental indicators.** The monitoring results and in Elbasan city clearly show better air quality near large green spaces compared to high-construction zones.
- **Urban greening specialists should be integrated into planning teams**. Urban planners, architects, and policymakers should include urban forestry experts in studies and plans.
- **Dedicated green spaces must be planned for each city.** Green areas should be intentionally designed, not merely leftover or marginal spaces. Tree species must be selected carefully. Species choice should be based on scientific criteria (tolerance, environmental benefits, allergenic potential, maintenance needs). Maintenance and services for green spaces are essential. Air-quality indicators are good in some parts of the city and unsatisfactory in others.
- **Continuous air monitoring is needed.** Air quality is a crucial indicator for both environmental and human health. Monitoring pollutants such as $PM_{2.5}$, PM_{10}, ozone, and NO_2 is essential to assessing the severity and impacts of air pollution. Particularly in Elbasan, the absence of permanent monitoring stations is a serious gap. Citizen awareness is crucial for the maintenance of urban environments. Environmental education and public engagement should be strengthened.
- **Addressing air pollution requires** a combination of stricter regulations, technological improvements, and sustainable practices across sectors. Effective action can improve public health, protect the environment, and contribute to climate-change mitigation.

In conclusion, the implementation of this modest project from the UMT, supported financially by NASRIT and in collaboration with the Municipality and Region of Elbasan, Albania, has generated important insights into the correlations between built-up surfaces and green areas in urban centers, with the main aim so that in the future, a more substantial optimization of the construction-greening ratios in these residential centers can be aimed at.

REFERENCES

AirNow. (2025). AQI – Air Quality Index (AQI) Basics: What is the U.S. Air Quality Index (AQI)? AirNow.gov.

Beatley, T. (2012). Green Cities of Europe. Global Lessons on Green Urbanism. © 2012 Island Press. ISBN 1-59726-975-1. Page 285.

Chathamparambath, P. (2025) Global Air Quality Standards of PM2.5 and PM10.https://smartairfilters.com/en/blog/global-air-quality-standards-pm2-5-pm10/ Assessed May 2026.

Haska, E., Eryildiz, H.S., & Haska, H. (2019). The sustainable intelligent building skins-façades imitating the tree process of filtering air: Biomimicry architecture. Sustainable Forestry Collection 79–80. Institute of Forestry, Belgrade.

FAO. (2016). Guidelines on Urban and Peri-Urban Forestry. F. Salbitano,S. Borelli, M. Conigliaro, & Y. Chen (Eds.).

Haska H, Frasheri N, Haska E, Miraçi O, Bufi A, Vodollari F, Çeka A. (2026). Relationship between construction-greening area and correlations with urban environment, human life and the way for their improvement. International Scientific Journal Monte (ISJM) ISSN 2661-2666 (Online), 2026.

Haska, H. (2022). Silviculture & Urban Forestry: Scripted Lessons.UBT, FSHP, Tirane, LAW No. 162/2014: On the protection of air quality in the environment, ASSEMBLY OF THE REPUBLIC OF ALBANIA

Municipality of Elbasan. (2024). Public and Urban Services Agency–Greening Sector. Data provided by Fatmir Vodollari, e-mail dated 20 November 2024.

National Environmental Agency. (2024). STATE OF THE ENVIRONMENT REPORT 2024.Tirane, Albania.

Tabaku, V., & Starja, K. (2023). Afforestation Manual. National Forestry Agency, Tirana, Albania

UMT. (2024). Optimizing the relationship between building infrastructures and green infrastructures as one of the main elements in improving the environment and the sustainable development of urban areas. A comparative observation about these issues in some cities/neighborhoods of our country (Case study from Elbasan and Tirana). Metropolitan University of Tirana, supported by AKKSHI.

US-EPA. (2025). Environmental Topics – Air Topics. United States Environmental Protection Agency. https://www.epa.gov/environmental-topics/air-topics

WHO-World Health Organization (2021). Global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021.
License: CBY/NC/SA 3.0 IGO.https://www.who.int/publications/i/item/9789240034228

World Bank. (2024). Western Balkans – Regular Economic Report No. 25 | Spring 2024 – Invigorating Growth.

Sustainable Forestry © 2024 by Institute of Forestry Belgrade is licensed under CC BY 4.0

This is an open access article distributed under the terms of the Creative Commons Attribution license (CC BY 4.0)

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