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# ASSESSMENT OF THE CONTENT OF MACRO, MICRO AND POTENTIALLY TOXIC ELEMENTS IN THE SOIL OF THE SERBIAN MOUNTAINS BY MULTIVARIATE ANALYSIS

*Jelena BOŽOVIĆ[1]*, Snežana STAJIĆ[1], Ilija ĐORĐEVIĆ[1], Bojan KONATAR[1], Goran ČEŠLJAR[1], Dragana ŽIVOJINOVIĆ[2]*

**Abstract:** *The goal of this investigation was to assess the presence, content and limit concentrations of macro elements of plant nutrituion, trace elements, and potentially toxic elements in the soil. The research was carried out in Kopaonik, Crni Vrh and Mokra Gora during the period 2020-2022 on the different depths. Samples were prepared by microwave digestion with mixture of mineral acids. Concentration of extractedelements were measured by Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES). The method of sample preparation is very important for the successful determination of elements because it is a very complex matrixChemometric approach was applied to explain the distribution of elements and potentially toxic elements in the soil by location and sampling depth. Principal Component Analysis and Cluster Analysis have proven to be excellent tools for reducing the number of measurements and for grouping data by parameters and by sampling location. Research has shown that there was no major soil contamination with toxic metals in the selected areas.*

**Keywords:** soil, microwave digestion, trace metals, ICP-OES, PCA, HCA

# PROCENA SADRŽAJA MAKRO, MIKRO I TOKSIČNIH ELEMENATA U ZEMLJIŠTU SRPSKIH PLANINA MULTIVARIJANTNOM ANALIZOM

**Sažetak:** *Cilj ovog istraživanja bio je da se proceni prisustvo, sadržaj i granične koncentracije makroelemenata ishrane biljaka, elemenata u tragovima i potencijalno toksičnih elemenata u zemljištu. Istraživanja su vršena na Kopaoniku, Crnom Vrhu i Mokroj Gori u periodu 2020-2022. godine na različitim dubinama. Uzorci su pripremljeni mikrotalasnom digestijom sa mešavinom mineralnih kiselina. Koncentracija ekstrahovanih elemenata je merena induktivnospregnutom plazmom optičkomemisionom spektroskopijom (ICP-OES). Metoda pripreme uzorka je veoma važna za uspešno određivanje elemenata jer se radi o veoma složenoj matrici. Primenjen je hemometrijsk ipristup da se objasni distribucija elemenata i potencijalno toksičnih elemenata u zemljištu po lokaciji i dubini uzorkovanja. Analiza glavnih komponenti i klaster analiza su se pokazale kao odlični alati za smanjenje broja merenja i za grupisanje podataka po parametrima i lokaciji uzorkovanja.*

[1]Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
[2]Faculty of Technology and Metallurgy, Karnegijeva 4, 11120 Belgrade, Serbia
*Corresponding author. E-mail: jelena.bozovic@forest.org.rs

*Istraživanja su pokazala da na odabranim područjima nije bilo većeg zagađenja zemljišta toksičnim metalima.*

**Ključne reči:** zemljište, mikrotalasnadigestija, metali u tragovima, ICP-OES, PCA, HCA

## 1. INTRODUCTION

Forest ecosystems contain pools of microelements, as well as toxic elements in virtually all forest compartments: forest floor, vegetation (trees, shrubs, ground vegetation), fauna, micro-organisms, soil and soil solution. Fluxes of these trace metals cycle along with carbon and nutrients and water (e.g. leaching). This labor focuses on macroelements, microelements (essental, and useful) and toxic elements concentrations and stocks in the forest soil, i.e. the mineral and organic layer.

The objective of this experiment was to assess the presence, content and limit concentrations of trace elements and potentially toxic elements in the soil. The research was carried out in Kopaonik, Crni Vrh and Mokra Gora, sampling and soil analysis.

## 2. MATERIAL AND METHODS

In 2020 on Kopaonik, in 2021 on Crni Vrh and in 2022 on Mokra Gora, soil sampling was carried out and laboratory analyzes of physical and chemical parameters were carried out according to ICP Forests Forest Soil Co-ordinating Centre methodology (Cools, De Vos 2020).

Sampling was performed on the observation plot established for soil analysis. It was performed using a probe at 30 different spots and making average samples. Probing was performed at depths of 0-10 cm, 10-20 cm and 20-40 cm.

The surface soil layer of 0–10 cm depth was sampled from 30 pits, and the deeper layers from 30 individual samples collected using a probe. An average sample was made for each layer. There were three average samples each composed of 10 individual samples. The following parameters were determined in the samples:

- ✓ Macro elements of plant nutrition (calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P))
- ✓ Microelements of plant nutrition
  - Essential microelements (copper (Cu), zinc (Zn)
  - Useful elements (manganese (Mn), iron (Fe), aluminum (Al))
- ✓ Toxic elements (lead (Pb), cadmium (Cd)).

Samples for soil analysis were prepared in the Testing Laboratory of the Department of Soil, Plant Material and Water Analysis of the Institute of Forestry.

## 2.1. Methods

Elements that are soluble in aqua regia are processed by wet digestion. Wet digestion is carried out in the Microwave Digestion System - Milestone Ethos LEAN, EASY in a mixture of nitric acid (HNO3) and hydrochloric acid (HCl). A sample weighing about 0.2 grams of air-dry soil was poured with 7.5 ml of HCl and 2.5 ml of HNO3. The resulting extract was filtered through filter paper into a normal vessel and filled up to 50 ml. The amounts of the macroelements of plant nutrition (K, P, Ca, Mg,), essential microelements (Cu, Zn) usefull elements (Mn, Fe, Al), and toxic elements (Pb, Cd) were determined by VARIAN VISTA PRO ICP-OES spectrometer and converted to an absolutely dry sample. (Madrid L. et al. 2006)

Statistical analyzes of the test results were performed using by the IBM SPSS Statistics Version 20 software.

## 3. RESULTS AND DISCUSSION

In Table 1 shows the results of average values of concentration microelements and potentional toxic elements from Kopaonik.

**Table 1.** *Concentrations of plant nutrients and potential toxic elements in soil at Kopaonik*

| | **Macro elements** | | | | **Essential micro elements** | | | | **Useful elements** | **Toxic elements** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | Ca | Mg | K | P | Mn | Cu | Zn | Fe | Al | Pb | Cd |
| cm | mg/kg | | | | | | | | | | |
| -4.5-0 | 625.11 | 70.09 | 46.76 | 104.62 | 121.36 | 3.39 | 3.11 | 1238.86 | 69.3 | 22.29 | < 0.1 |
| 0-10 | 106.10 | 139.98 | 51.64 | 80.48 | 44.21 | 5.07 | 3.30 | 2621.39 | 637.50 | 23.95 | 0.19 |
| 10-20 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| 20-40 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| Limit value | - | - | - | - | - | 36.00 | 3.00 | - | - | 85.00 | 0.80 |
| Remediation value | - | - | - | - | - | 190.00 | 200.00 | - | - | 530.00 | 12.00 |

Of the acid cations is dominated by aluminum and manganese. Of the base cations, calcium is the most abundant, followed by potassium. Their presence is highest in the organic layer, followed by the surface soil layers. As very important, macronutrients, they depend on the content of organic matter. With the depth of the soil, the amount of exchangeable forms of these elements decreases. Of the micronutrients extracted in the aqua regia, manganese, iron, copper and zinc were determined. The amounts of iron and manganese are high, but these two elements do not have defined limit and remediation values, because there are always sufficient amounts of these elements in the soil, and their high concentrations do not affect plants. Copper and zinc are essential microelements, which are necessary for plant nutrition.(Baldi E. et al. 2021) However, in very high concentrations they can be harmful to plants. In none of the collective samples, the amounts of copper and zinc do not exceed the remediation value, i.e. there are sufficient quantities of these elements in the soil, but not in high concentrations that would be harmful to plants. Of the potentially toxic nutritional elements extractable in Aqua regia mercury, cadmium, lead, arsenic and chromium.(Borůka Lj. et al. 2005) The amounts of mercury, arsenic and chromium are extremely low and were below the detection limit, both in the organic layer and in the soil layer of 0-10 cm depth. In the horizon of organic layer, the amount of cadmium were below the detection limit. Small amounts of cadmium were found in the surface layer of the soil 0-10 cm thick, however, they are far below than the remediation value and even the lower limit value.This means that the amounts of this toxic element do not endanger plants on the sample plot. Small amounts of lead were found, both in the organic layer and in the surface layer of 0-10 cm of soil. However, the concentrations of this element are far below the remediation value, and also below the lower limit value, which means that they are far below the toxic concentrations.

In Table 2 shows the results of microelements and potentional toxic elements from Mokra Gora.

**Table 2.** *Concentrations of plant nutrients and potential toxic elements in soil at Mokra Gora*

| | **Macro elements** | | | | **Essential micro elements** | | | | **Useful elements** | **Toxic elements** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | Ca | Mg | K | P | Mn | Cu | Zn | Fe | Al | Pb | Cd |
| cm | mg/kg | | | | | | | | | | |
| -4.5-0 | 7074.43 | 8324.40 | 497.50 | 1374.23 | 497.50 | 5.13 | 32.50 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| 0-10 | 1671.20 | 40135.97 | 330.30 | 333.60 | 330.30 | 8.13 | 28.67 | 10.97 | 11.40 | < 0.1 | < 0.1 |
| 10-20 | 1519.57 | 40907.30 | 296.83 | 349.37 | 296.83 | 8.33 | 31.70 | 18.80 | 13.80 | < 0.1 | < 0.1 |
| 20-40 | 1837.13 | 42572.50 | 325.10 | 343.13 | 325.10 | 16.90 | 53.87 | 18.80 | 9.60 | < 0.1 | < 0.1 |
| Limit value | - | - | - | - | - | 36.00 | 3.00 | - | - | 85.00 | 0.80 |
| Remediation value | - | - | - | - | - | 190.00 | 200.00 | - | - | 530.00 | 12.00 |

The most abundant element on Mokra Gora in the extract in aqua regia is magnesium. Its concentrations are the lowest in the organic horizon, but they sharply increase with the transition to the organomineral part of the solum. Its highest concentrations are in in the organic horizon, which is the result of biological accumulation. Potassium extracted in aqua regia is also significantly more abundant in the organic horizon than in the organomineral parts of the soil. The increased presence of potassium in the organic layer compared to the deeper parts of the soil is also a result of the biological accumulation of this nutrient macroelement. Manganese content in Mokra Gora is the lowest in the organic horizon, and increases strongly with depth. The amount of phosphorus in Mokra Gora is extremely low. It is the largest in the organic horizon, but it decreasesstrongly in the organomineral part of the soil. Copper soluble in aqua regia is poorly represented on Mokra Gora, both in the organic horizon and in the surface soil layers. The amount of lead and cadmium in the organic horizon and in the deeper layers of the soil on Mokra Gora are below the detection limit. The predominance of iron over aluminum is understandable because serpentinites are ferromagnesian silicates. In this case, there are no visible changes in iron concentrations at greater depths. The lowest concentrations of aluminum were found in the surface layers, but they slightly increase with the depth of the soil. ( Albanese S. et al. 2023)

In Table 3 shows the results of microelements and potentional toxic elements from Crni vrh.

**Table 3.** *Concentrations of plant nutrients and potential toxic elements in soil at Crni Vrh*

| | **Macro elements** | | | | **Essential micro elements** | | | | **Useful elements** | **Toxic elements** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | Ca | Mg | K | P | Mn | Cu | Zn | Fe | Al | Pb | Cd |
| cm | mg/kg | | | | | | | | | | |
| -4.5-0 | 1061.92 | 625.98 | 474.89 | 31.93 | 178.26 | 25.04 | 3031.58 | 4614.93 | 3031.58 | < 0.1 | < 0.1 |
| 0-10 | 1250.67 | 653.89 | 487.77 | 24.16 | 164.62 | 26.44 | 3222.2 | 4866.96 | 3222.2 | 25.04 | < 0.1 |
| 10-20 | 983.23 | 692.19 | 528.96 | 32.82 | 190.05 | 18.47 | 136.42 | 3127.1 | 136.42 | 26.44 | < 0.1 |
| 20-40 | 1061.92 | 625.98 | 474.89 | 31.93 | 178.26 | 25.04 | 3031.58 | 4614.93 | 3031.58 | 18.47 | < 0.1 |
| Limit value | - | - | - | - | - | 36.00 | 3.00 | - | - | 85.00 | 0.80 |
| Remediation value | - | - | - | - | - | 190.00 | 200.00 | - | - | 530.00 | 12.00 |

The most abundant elements extracted in aqua regia are aluminum and iron, which is understandable because it is an acidic brown soil. The second most abundant element extracted in aqua regia are the alkaline earth elements calcium and magnesium. The amounts of toxic elements in the soil extracted in aqua regia – mercury, cadmium are below the detection limit. Only certain amounts of lead were found, but they are also less the lower limit values.

### 3.1. Chemometric approach to the distribution of microelements and potentially toxic elements in the soil

The results of the correlation analysis showed that in the Pearson correlation matrix there are not many correlation factors that are greater than 0.8, which indicates a very high degree of correlation between the elements. The strongest correlation was observed between Mn, Pb, Fe, Al and Mg, then between Cu, Fe and Al, then Ca and P.

**Table 4.** *Correlation Matrix*

| | | Ca | Mg | K | Mn | P | Cu | Pb | Cd | Zn | Fe | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Correlation | **Ca** | 1.000 | .099 | .208 | .190 | .984 | -.255 | -.494 | -.036 | .243 | -.487 | -.290 |
| | **Mg** | .099 | 1.000 | -.398 | .988 | .140 | -.306 | -.781 | .013 | .513 | -.795 | -.596 |
| | **K** | .208 | -.398 | 1.000 | -.336 | .118 | .285 | .198 | -.598 | -.082 | .180 | .368 |
| | **Mn** | .190 | .988 | -.336 | 1.000 | .221 | -.312 | -.815 | -.002 | .496 | -.822 | -.597 |
| | **P** | .984 | .140 | .118 | .221 | 1.000 | -.313 | -.544 | .003 | .288 | -.538 | -.363 |
| | **Cu** | -.255 | -.306 | .285 | -.312 | -.313 | 1.000 | .396 | .033 | .045 | .645 | .861 |
| | **Pb** | -.494 | -.781 | .198 | -.815 | -.544 | .396 | 1.000 | -.037 | -.456 | .823 | .643 |
| | **Cd** | -.036 | .013 | -.598 | -.002 | .003 | .033 | -.037 | 1.000 | .021 | .161 | .056 |
| | **Zn** | .243 | .513 | -.082 | .496 | .288 | .045 | -.456 | .021 | 1.000 | -.401 | -.162 |
| | **Fe** | -.487 | -.795 | .180 | -.822 | -.538 | .645 | .823 | .161 | -.401 | 1.000 | .873 |
| | **Al** | -.290 | -.596 | .368 | -.597 | -.363 | .861 | .643 | .056 | -.162 | .873 | 1.000 |

By applying PCA analysis, a strong correlation was established between most of the examined elements. However, the grouping of elements according to their appearance at different depths in the soil was made into three main components, of which most of the elements are in the first component (PC1), which includes the largest part of the variance, as shown in Figure 1.

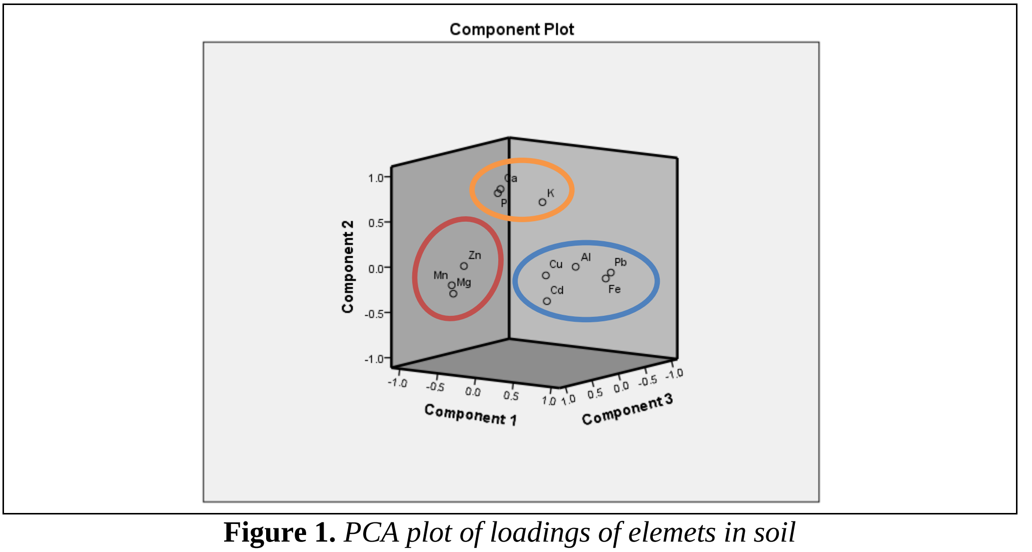


**Figure 1.** *PCA plot of loadings of elemets in soil*

Using hierarchical cluster analysis (HCA), the samples were grouped according to the sampling location and on the basis of the measured concentrations of elements. Three clusters can be seen on the dendrogram, the first two of which are Crni Vrh and Kopaonik at a very close Euclide distance and continue to connect into one cluster. Mokra Gora is a special cluster (Figure 2).

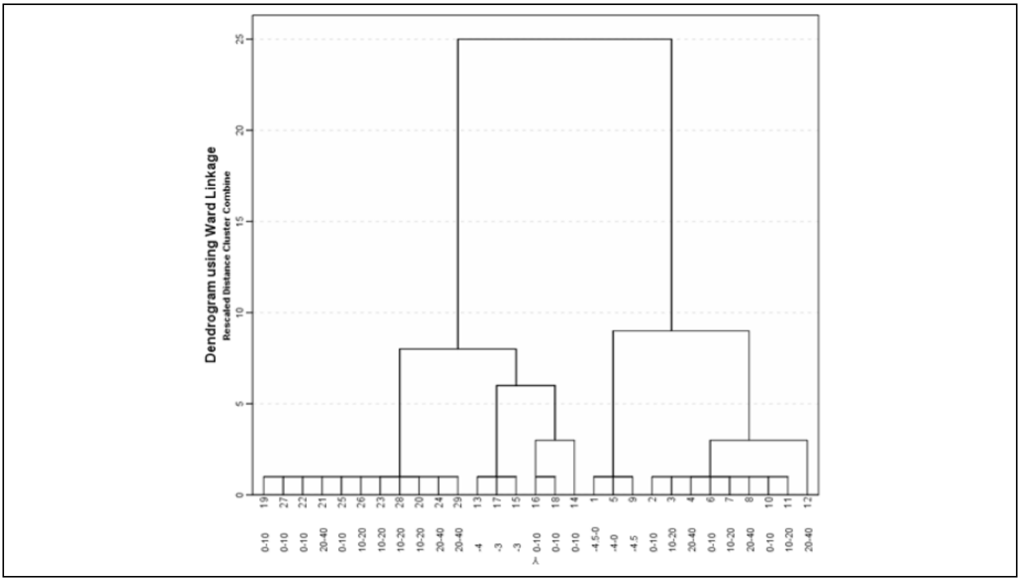


**Figure 2.** *Dendrogram of soil samples grouped by location*

## 4. CONCLUSION

Research has shown that there was no major soil contamination with toxic metals in the selected areas. As for the grouping of elements, three groups were distinguished using the PCA method: I (Fe, Al, Cu, Cd i Pb), II (Mn, Mg i Zn) and III (K, P i Ca), while the cluster analysis grouped the samples by location and depth of sampling in two clusters.

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## ASSESSMENT OF THE CONTENT OF MACRO, MICRO AND TOXIC ELEMENTS IN THE SOIL OF THE SERBIAN MOUNTAINS BY MULTIVARIATE ANALYSIS

*Jelena BOŽOVIĆ, Snežana STAJIĆ, Ilija ĐORĐEVIĆ, Bojan KONATAR,Goran ČEŠLJAR, Dragana ŽIVOJINOVIĆ*

### Summary

In this research, the content of microelements and potentially toxic elements in the soil sampled on the terrain of the Serbian mountains:Kopaonik, Crni Vrh and Mokra Gora during the period 2020-2022 at different depths was examined. Preparation by microwave digestion using mineral acids was applied, and the measurement was performed using the ICP-OES technique. Using chemometric methods of multivariate analysis, correlation between elements was performed, samples were grouped according to similarity in the composition of elements by depth, elements were grouped into three main components.

## PROCENA SADRŽAJA MAKRO, MIKRO I TOKSIČNIH ELEMENATA U ZEMLJIŠTU SRPSKIH PLANINA MULTIVARIJANTNOM ANALIZOM

*Jelena BOŽOVIĆ, Snežana STAJIĆ, Ilija ĐORĐEVIĆ, Bojan KONATAR,Goran ČEŠLJAR, Dragana ŽIVOJINOVIĆ*

### Rezime

U ovom istraživanju ispitivan je sadržaj mikroelemenata i potencijalnotoksičnih elemenata u zemljištu uzorkovanom na terenima srpskih planina Kopaonika, Crnog Vrha i Mokre Gore u periodu 2020-2022 na različitim dubinama. Primenjena je priprema mikrotalasnom digestijom pomoću mineralnih kiselina, a merenje je obavljeno ICP-OES tehnikom. Korišćenjem hemometrijskih metoda multivarijacione analize izvršena je korelacija između elemenata, uzorci su grupisani prema sličnosti u sastavu elemenata po dubini, elementi su grupisani u tri glavne komponente.

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Original scientific paper

# DETERMINATION OF CHROMIUM, ARSENIC AND NICKEL CONTENT IN THE AGRICULTURAL LAND OF THE MUNICIPALITY OF TOPOLA

*Sonja BRAUNOVIĆ[1]*, Saša EREMIJA[1], Sabahudin HADROVIĆ[1], Filip JOVANOVIĆ[1], Natalija MOMIROVIĆ[1], Jovana CVETKOVIĆ[1], Zoran MILETIĆ[1]*

**Abstract:** *The content of potentially toxic elements chromium (Cr), arsenic (As) and nickel (Ni), in the agricultural land of the municipality of Topola was examined in this paper, with a presentation of geographic and natural characteristics of the municipality and the land use of agricultural land. The municipality has a central position in Serbia and it is characterized by favourable conditions for growing agricultural cultures. The content of Cr in the land in most cases is between the minimum limit value (MLV) and remediation value (RV), while the content of As on 87% of the examined areas is lower than the MLV, and the content of Ni on 94% of the areas is between the values of the MLV and the RV. It is necessary to take measures of prevention of the use of agricultural land for non-agricultural purposes and fragmentation of arable agricultural land as well as implementing the control of soil fertility.*

**Keywords:** agricultural land, potentially toxic elements, Cr, As, Ni, the municipality of Topola

# UTVRĐIVANJE SADRŽAJA HROMA, ARSENA I NIKLA U POLJOPRIVREDNOM ZEMLJIŠTU OPŠTINE TOPOLA

**Sažetak:** *U radu je ispitan sadržaj potencijalno toksičnih elemenata, hroma (Cr), arsena (As) i nikla (Ni), u poljoprivrednom zemljištu opštine Topola, uz prikaz geografskih i prirodnih karakteristika opštine i strukture korišćenja poljoprivrednog zemljišta. Opština ima centralan položaj u Srbiji i odlikuje se povoljnim uslovima za gajenje poljoprivrednih kultura. Sadržaj Cr u zemljištu u najvećem broju slučajeva je između granične minimalne vrednosti (GMV) i remedijacione vrednosti (RV), dok je sadržaj As na 87% ispitivanih površina manji od GMV, a sadržaj Ni na 94% površina među vrednostima GMV i RV. Potrebno je preduzimanje mera na sprečavanju korišćenja poljoprivrednog zemljišta u nepoljoprivredne svrhe, sprečavanju usitnjavanja obradivog poljoprivrednog zemljišta i sprovođenje kontrole plodnosti zemljišta.*

**Ključne reči:** poljoprivredno zemljište, potencijalno toksični elementi, Cr, As, Ni, opština Topola

[1]Institute of Forestry, Kneza Višeslava 3, 11000 Belgrade, Serbia
*Corresponding author. E-mail: sonja.braunovic@forest.org.rs

# 1. INTRODUCTION

The greatest pressures on land in the Republic of Serbia represent decrease of content of organic matter, pollution and the change of way of land use, erosion processes and occurrence of landslides. Special problem is contamination of soil and increase of content of potentially toxic elements above remediation value (Ministarstvo zaštite životne sredine – Agencija za zaštitu životne sredine, 2020).

Soil resources contribute significantly to the provision of essential ecosystem goods and services. The presence of potentially toxic elements in agricultural land has become a significant global concern (Bigalke, 2017). Environmental contamination shows increasing tendencies, and monitoring of potentially toxic elements needs to be continuous to protect human public health.

Toxicity of potentially toxic elements is directly related to their accumulation in food. High amounts of these elements generate numerous health issues (Scutarașu & Trincă, 2023). Therefore, the quality of soil is directly related to human health.

The metal content found in soils stems from a combination of human activities and natural processes (Marrugo-Negrete, 2017). The contribution of metals from human activities is much greater than from natural processes (Desaules, 2012; Li et al., 2012; Teng et al., 2014).

High concentrations of potentially toxic elements in the soil represent great risk for agroecosystem, since they are very resistant. Remediation techniques of the soil polluted in such way are still very time-consuming and expensive, and due to the danger of potentially toxic elements entering the food chain via cultivated plants, the contaminated areas require a special way of land use as well as exclusion from primary plant production (Ninkov & Banjac, 2016).

Several studies on this subject have been published for the territory of Serbia (e.g., Belanović Simić et al., 2022; Gajic et al., 2012; Ministarstvo zaštite životne sredine – Agencija za zaštitu životne sredine, 2013, 2018; Ninkov et al., 2012), including the wider area of Šumadija administrative district (Ninkov et al., 2015; Ninkov & Banjac, 2016); however, with no particular reference to the area of the municipality of Topola.

Thus, the objective of this paper is to determine content of potentially toxic elements, chromium, arsenic and nickel in the agricultural land of the municipality of Topola (central Serbia, Šumadija administrative district).

The territory of the municipality of Topola is divided into 29 cadastral municipalities (CM) (Table 2). The research covered 28 cadastral municipalities, except the CM Topola (Varošica), because the land of all cadastral plots of the said CM belongs to urban development land. Location of the municipality of Topola is presented in Figure 1.

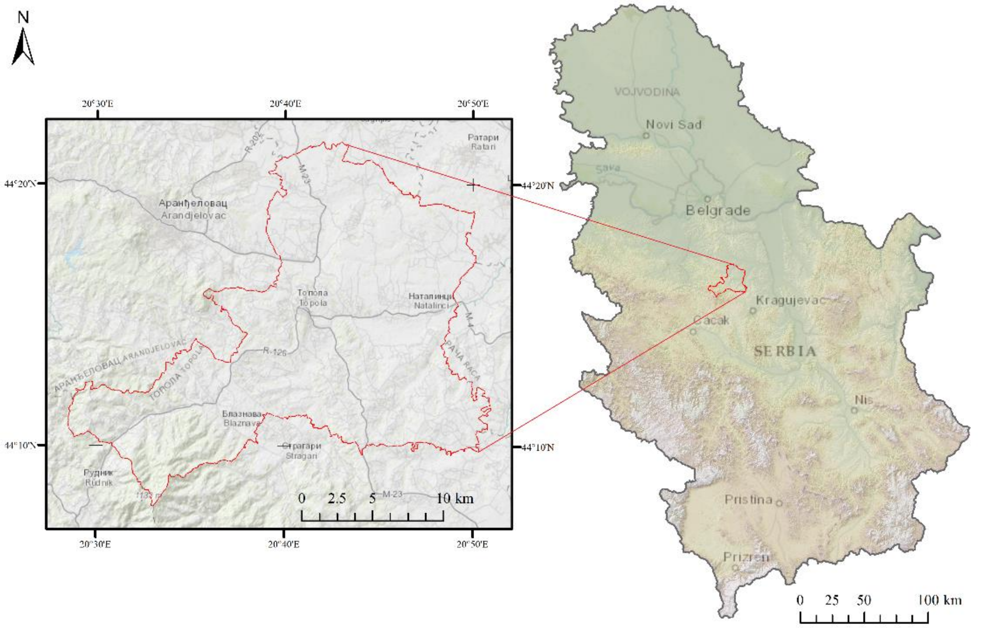


**Figure 1.** *Location of the municipality of Topola*

## 2. MATERIAL AND METHODS

Data from literature and statistical data on position and natural conditions of the municipality of Topola (relief, climatic characteristics, soil types, structure of agricultural land, etc.) (Agromedia, 2023; Opština Topola, 2017; J.P. Službeni glasnik SO Topola, 2017; Geosrbija, 2019) are collected and analysed in this paper.

Geographic and natural characteristics of the municipality of Topola are presented in Table 1. The municipality of Topola has a central position in the Republic of Serbia, it is located about 75 km from Belgrade and administratively belongs to Šumadija administrative district (Agromedia, 2023). It is characterized by favourable climatic, orographic, geological and pedological conditions for the development of forest vegetation and production of agricultural cultures (Opština Topola, 2017; J.P. Službeni glasnik SO Topola, 2017; Geosrbija, 2019).

According to the Annual Program of Protection, Arrangement and Use of Agricultural Land in the Territory of Topola Municipality for 2017 (Republički geodetski zavod, 2023), agricultural land spreads over 28,402.1817 ha. The largest part consists of arable land which occupies 70.82%. Orchards cover 18.23% of total agricultural area, meadows 6.44%, vineyards 4.50%. Pastures comprise 3.84% of total agricultural area, while other land occupies 2.31% (Table 2).

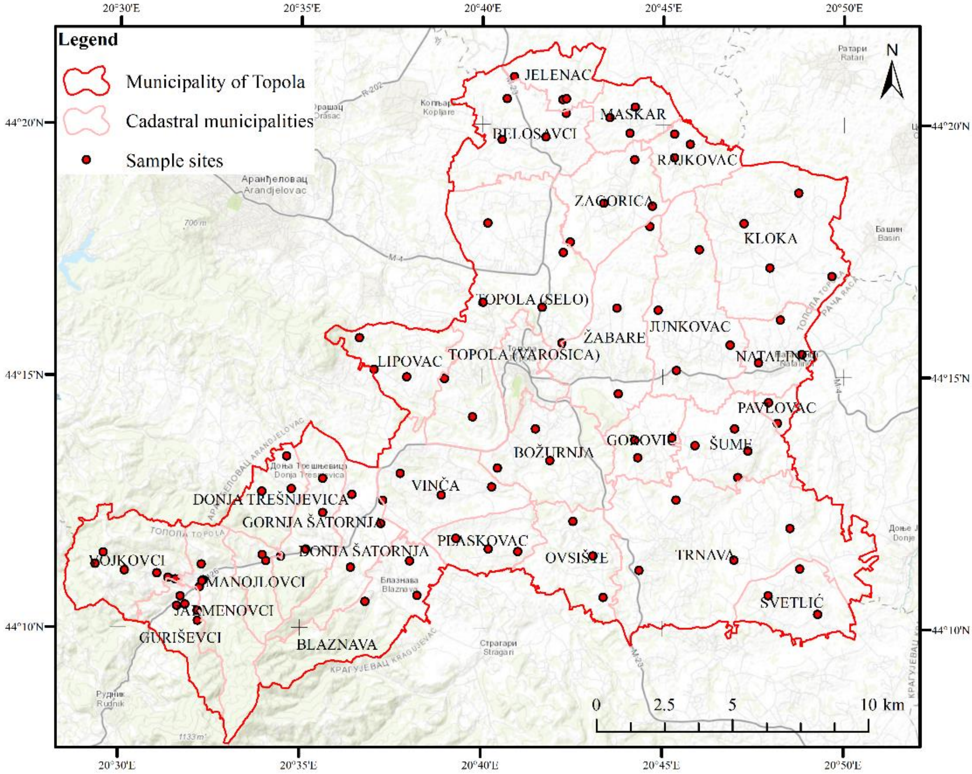


**Figure 2.** *Locations of soil sampling at CM in the municipality of Topola*

**Table 1.** *Geographical and natural characteristics of the municipality of Topola*

| No. | Characteristics | Description |
|---|---|---|
| 1 | Position | Central Serbia, Šumadija administrative district. The distance from Belgrade is about 75 km[1]. |
| 2 | Climate | Temperate continental climate. Mean annual air temperature is 11°C, Total annual precipitation is 721.3 mm, average annual relative humidity is 72%, and mean annual cloud cover is 5.2 tenths[2]. |
| 3 | Relief | The lowland stretches along the middle course of the Jasenica and the Kubršnica rivers, and mountainous relief consists of the slopes of Rudnik and Venčac. Karst forms of relief are represented (saucer-shaped and funnel-shaped sinkholes and limestone pavements)[2]. |
| 4 | Altitude range | The lowland of up to 200 m of absolute altitude occupies 36.2% of the territory of the municipality, altitude range from 200 to 500 m occupies 56.4%, hilly and mountainous relief from 500 to 1000 m occupies 6.4%, and only 1% of the territory of the municipality is higher than 1000 m of absolute altitude [2]. |
| 5 | Slope | Terrains with the slope of up to 5% occupy about 38% of the area of the municipality; slope from 5 to 20% occupies 43%, and slope exceeding 20% occupies 19% of the area of the municipality[2]. |
| 6 | Geological substrate | Serpentinites and serpentinized peridotites; Alevrolites, sandstones, marls; Clastic, pelitic and carbonatic formations; Deluvial sediments[4]. |
| 7 | Types of soil | Alluvial soils (fluvisols), vertisols, eutric cambisols, acidic brown soils (dystric cambisols) and luvisols. Vertisol occupies the largest area of the total arable land of the municipality, followed by medium acidic and very acidic soils[3]. |

**Source:** *[1]Agromedia (2023); [2] Opština Topola (2017); [3] J.P. Službeni glasnik SO Topola (2017); [4] Geosrbija (2019).*

Ploughland dominates over other ways of use of the agricultural land. 52 cadastral plots with arable land of different classes were analysed. Second most common way of use are orchards. Soils under orchards were analysed on 29 plots. Soils covered with meadows were analysed on 13 plots, with vineyards on 4 plots and soils under pastures on 2 plots. (Table 2).

Agricultural land from 100 cadastral plots was analysed through field work on the territory of the municipality of Topola. (Figure 2). Changes of land use were determined by field inspection during the soil sampling and recorded on 28 cadastral plots planned for analysis, in relation to data from electronic cadastre of real estate (Republički geodetski zavod, 2023).

**Table 2.** *Overview of the areas of agricultural land according to CM and cultures*

| No. | Cadastral municipality | Agricultural land (ha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Arable agricultural land (ha) | | | | | Pastures | Other land | Total |
| | | Ploughland | Orchards | Vineyards | Meadows | Total | | | |
| | | 1 | 2 | 3 | 4 | 5(1+2+3+4) | 6 | 7 | 8(5+6+7) |
| 1 | Belosavci | 1081.25 | 134.18 | 22.35 | 112.36 | 1350.14 | 4.21 | 24.68 | 1379.03 |
| 2 | Blaznava | 477.91 | 207.86 | 50.67 | 16.74 | 753.17 | 58.35 | 21.69 | 833.21 |
| 3 | Božurnja | 720.79 | 183.55 | 86.90 | 27.62 | 1018.87 | 69.80 | 26.04 | 1114.70 |
| 4 | Vinča | 581.88 | 495.88 | 72.35 | 35.88 | 1186.00 | 6.86 | 30.23 | 1223.08 |
| 5 | Vojkovci | 373.69 | 94.61 | 8.44 | 121.72 | 598.46 | 197.56 | 14.24 | 810.27 |
| 6 | Gornja Šatornja | 470.20 | 150.83 | 30.34 | 40.77 | 692.14 | 38.57 | 17.90 | 748.61 |
| 7 | Gorovič | 460.66 | 67.34 | 26.61 | 25.64 | 580.24 | 8.53 | 9.66 | 598.43 |
| 8 | Guriševci | 92.87 | 62.39 | 3.52 | 83.76 | 242.55 | 74.86 | 5.71 | 323.12 |
| 9 | D. Trešnjevica | 243.58 | 104.31 | 14.90 | 51.17 | 413.96 | 36.53 | 10.46 | 460.96 |
| 10 | Donja Šatornja | 428.63 | 171.52 | 52.88 | 26.56 | 679.59 | 43.54 | 18.78 | 741.91 |
| 11 | Žabare | 1100.22 | 173.40 | 97.65 | 28.30 | 1399.56 | 63.87 | 33.04 | 1496.47 |
| 12 | Zagorica | 647.00 | 134.83 | 41.49 | 159.91 | 983.23 | 30.07 | 17.22 | 1030.52 |
| 13 | Jarmenovci | 164.35 | 129.10 | 10.80 | 62.23 | 366.48 | 81.11 | 14.22 | 461.81 |
| 14 | Jelenac | 428.11 | 81.49 | 6.58 | 7.12 | 523.31 | 1.99 | 10.10 | 535.40 |
| 15 | Junkovac | 1299.39 | 254.73 | 49.56 | 61.93 | 1665.61 | 17.70 | 30.23 | 1713.54 |
| 16 | Kloka | 1795.06 | 208.64 | 54.52 | 63.50 | 2121.72 | 27.06 | 30.97 | 2179.75 |
| 17 | Lipovac | 456.41 | 120.32 | 85.68 | 8.39 | 670.81 | 20.68 | 23.77 | 715.26 |
| 18 | Manojlovci | 89.07 | 73.13 | 6.35 | 23.55 | 192.09 | 39.80 | 6.80 | 238.70 |
| 19 | Maskar | 456.92 | 43.83 | 5.40 | 81.23 | 587.38 | 2.84 | 9.51 | 599.74 |
| 20 | Natalinci | 490.51 | 64.27 | 2.68 | 77.61 | 635.07 | 5.16 | 33.09 | 673.31 |
| 21 | Ovsište | 543.29 | 166.11 | 59.93 | 23.79 | 793.12 | 60.50 | 17.65 | 871.27 |
| 22 | Pavlovac | 81.10 | 24.48 | 7.28 | 14.30 | 127.17 | 6.21 | 4.04 | 137.42 |
| 23 | Plaskovac | 368.39 | 202.18 | 35.59 | 22.19 | 628.35 | 2.49 | 10.28 | 641.12 |
| 24 | Rajkovac | 396.57 | 50.80 | 13.22 | 75.38 | 535.97 | 1.06 | 9.81 | 546.84 |
| 25 | Svetlić | 525.72 | 135.27 | 20.26 | 48.56 | 729.81 | 15.30 | 13.30 | 758.41 |
| 26 | Topola (varoš) | 181.19 | 81.68 | 32.85 | 6.16 | 301.87 | 4.50 | 45.11 | 351.48 |
| 27 | Topola (selo) | 2013.43 | 325.44 | 121.39 | 273.73 | 2733.98 | 49.93 | 74.18 | 2858.09 |
| 28 | Trnava | 2265.51 | 729.49 | 142.92 | 90.61 | 3228.54 | 107.53 | 76.04 | 3412.10 |
| 29 | Šume | 643.56 | 188.56 | 36.12 | 46.10 | 914.35 | 15.19 | 18.10 | 947.63 |
| **ha** | | 18877.27 | 4860.23 | 1199.24 | 1716.81 | 26653.54 | 1091.81 | 656.83 | 28402.18 |
| **%** | | 70.82 | 18.23 | 4.50 | 6.44 | 93.85 | 3.84 | 2.31 | 100.00 |

**Source:** *Opština Topola (2017)*

In each analysed plot soil was sampled from two depths (0–30 cm and 30–60 cm). An average sample consisting of 20-25 individual samples was taken for laboratory analyses. Sampling of individual samples for forming the average sample was performed in a checkerboard layout or diagonally, depending of the shape of the plot. Soil sampling was done with a spade and an "Eijkelkamp" type probe. The content of potentially toxic elements, chromium (Cr), arsenic (As) and nickel (Ni) in the soil, soluble in aqua regia, was determined for each soil sample. Concentrations of harmful and dangerous substances in soil samples, after their digestion in aqua regia, were determined by means of inductively coupled plasma (ICP–OES, Vista–Pro, Varian).

The obtained numerical data was processed employing descriptive and univariate statistical methods. The soil content of potentially toxic elements in depths of 0–30 cm and 30–60 cm and for two types of land use (ploughland and other) was analyzed independently. Descriptive statistics included determining the following basic parameters: minimum value (MIN), maximum value (MAX), mean value ($\bar{X}$), standard deviation (SD) and coefficient of variation (CV%). The significance of the statistical difference between the means was determined using the Student’s t-test. Before performing the t-test, raw data was tested for the normality. The variables departed from the normality were subjected to Box-Cox transformation (Box and Cox, 1964). All statistical analyses were performed with Statgraphics Centurion (ver. XVI.I; 2009, Statpoint Technologies, Inc., Warrenton, VA).

The Regulation on the program of systematic monitoring of soil quality by means of indicators for assessing the risk of soil degradation and the methodology for the development of remediation programs (J.P. Službeni glasnik RS, 88/2010), defines the MLV and the remediation values of concentrations of dangerous and harmful substances and the values that can indicate significant soil contamination (Table 3).

**Minimum Limit Values** (MLV) define the values at which the functional properties of the soil have been fully achieved, i.e. they indicate the level at which the sustainable quality of the soil has been achieved. **Remediation values** (RV) relate to the values which indicate that the basic functions of the soil are endangered or seriously damaged and require remediation, recovery and other measures (J.P. Službeni glasnik RS, 88/2010).

**Table 3.** *Minimum limit values (MLV) and remediation values (RV) of concentrations of dangerous and harmful substances*

| | **Chromium (Cr)** | **Arsenic (As)** | **Nickel (Ni)** |
|---|---|---|---|
| | mg/kg | | |
| **MLV** | 100 | 29 | 35 |
| **RV** | 380 | 55 | 210 |

***Source:*** *J.P. Službeni glasnik RS, 88/2010*

# 3. RESULTS AND DISCUSSION

## 3.1. The Content of Cr in the Agricultural Land of the Municipality of Topola

Chromium belongs to the useless and potentially toxic elements for plants. Minimum limit value for this element in the soil is 100 mg/kg of the soil and its remediation value is 380 mg/kg.

In the territory of the Topola municipality the average value of the chromium content in the surface layer of all analysed agricultural land amounts to 128.22 mg/kg. Soil layer at the depth of 30–60 cm contains 129.93 mg/kg. In the surface layer the content of chromium in the soil of all analysed plots was ranging between 32.77 and 1157.69 mg/kg, and in the deeper analysed layer between 53.13 and 1104.25 mg/kg.

In the territory of the Topola municipality 47.0% of agricultural land areas is characterized with the content of chromium below the MLV in the surface layer 0–30 cm deep (Table 4; Figure 3), and on 51% of the areas the amount of chromium in the soil is between the MLV and the RV. In the soil layer 30–60 cm deep a content of chromium larger than the MLV is recorded on 53% of the areas, and on 45% of the areas smaller than the MLV. On 2% of the analysed areas in both analysed layers the amount of chromium in the soil exceeds RV.

In the soil under vineyards on 40% of the areas the registered amount of chromium was smaller than the MLV and on 60% of the areas between the MLV and the RV (Table 4; Figure 3).

Under orchards, on 50% of the areas the registered amount of chromium in the soil was smaller than the MLV and on 46.43% areas it was between the MLV and the RV. On 3.57% of the areas the registered amount of chromium in the soil was exceeding the RV.

In the soil of meadows on 15.38% of the areas the amount of chromium was smaller than the MLV, and on 84.62% of areas it was between the MLV and the RV. In none of the plots under the meadows were the amounts of chromium in the soil higher than the RV.

**Table 4.** *The content of chromium (Cr) in the analysed soil of the Topola municipality*

| Soil category | 0–30 cm | | 30–60 cm | |
|---|---|---|---|---|
| | Number of plots | % | Number of plots | % |
| Below the detection limit <0.1 mg/kg | 0 | 0.0 | 0 | 0.0 |
| Smaller than the MLV <100 mg/kg | 47 | 47.0 | 45 | 45.0 |
| Between the MLV and the RV 100–380 mg/kg | 51 | 51.0 | 53 | 53.0 |
| Larger than the RV >380 mg/kg | 2 | 2.0 | 2 | 2.0 |
| **Total** | 100 | 100.0 | 100 | 100.0 |

Under the ploughland, on 51.92% of the plots the registered amount of chromium in the land is smaller than the MLV and on 46.15% of the areas it is between the MLV and the RV. On 1.92 % of areas under the ploughland the amount of chromium in the soil is larger than the RV. On both analysed areas under the pastures the amount of chromium in the soil was found to be lower than the MLV (Table 5).

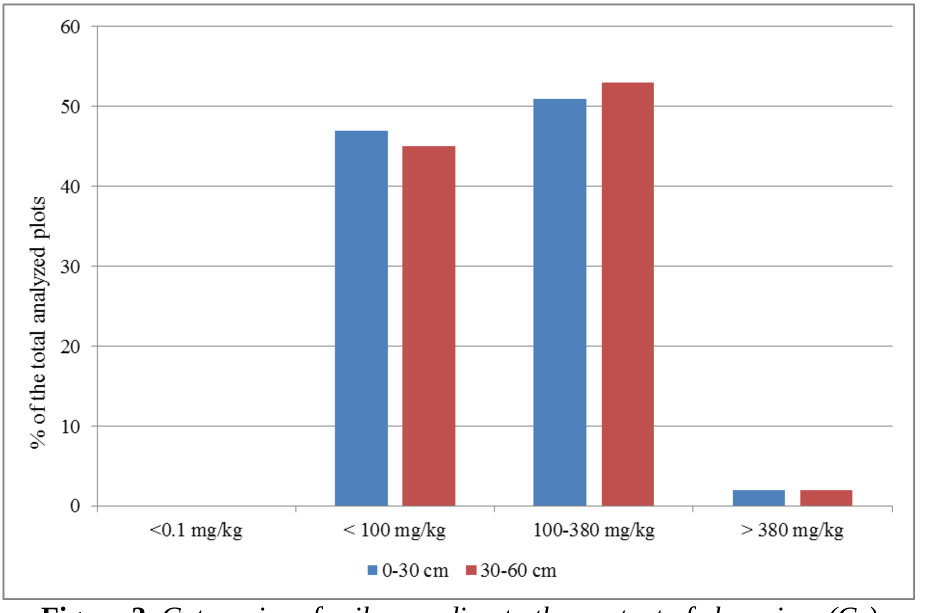


**Figure 3.** *Categories of soil according to the content of chromium (Cr) for the municipality of Topola*

**Table 5.** *Representation of soil categories according to the content of chromium (Cr) by cultures*

| Soil category | Culture | | | | |
|---|---|---|---|---|---|
| | **Vineyard** | **Orchard** | **Meadow** | **Ploughland** | **Pasture** |
| Below the detection limit <0.1 mg/kg | 0 | 0 | 0 | 0 | 0 |
| Smaller than the MLV <100 mg/kg | 2 | 14 | 2 | 27 | 2 |
| Between the MLV and the RV 100–380 mg/kg | 3 | 13 | 11 | 24 | 0 |
| Larger than the RV >380 mg/kg | 0 | 1 | 0 | 1 | 0 |
| **Total** | 5 | 28 | 13 | 52 | 2 |

### 3.2. The Content of As in the Agricultural Land of the Topola Municipality

Arsenic is a potentially toxic element whose MLV and RV in the soil amount to 29 mg/kg and 55 mg/kg, respectively. The average content of arsenic in the analysed agricultural land of the Topola municipality in the surface layer amounts to 20.87 mg/kg, and in the deeper analysed layer 20.58 mg/kg. In the surface layer (0–30 cm) the content of arsenic ranges from 6.42 to 161.44 mg/kg, and in the deeper analysed layer (30–60 cm) from 9.17 to 129.12 mg/kg.

On all analysed plots under vineyards, orchards, meadows, ploughland and pastures in the territory of the municipality of Topola, in the surface layer (0–30 cm), the amount of arsenic is smaller than the MLV (on 87 plots), while the amount of arsenic between the MLV and the RV was found on 11 plots. The amount of arsenic whose concentration exceeds the RV was found on 2 plots (Table 6; Figure 4).

Similar values appear also in the deeper analysed layer (30–60 cm). The amount of arsenic smaller than the MLV was found on 87 plots, while the amount of arsenic between the MLV and the RV was found on 12 plots. The amount of arsenic with concentrations exceeding the RV was found only on one plot.

**Table 6.** *The content of arsenic (As) in the analysed soil of the Topola municipality*

| Soil category | 0–30 cm | | 30–60 cm | |
|---|---|---|---|---|
| | Number of plots | % | Number of plots | % |
| Below the detection limit <0.1 mg/kg | 0 | 0.0 | 0 | 0.0 |
| Smaller than the MLV <29 mg/kg | 87 | 87.0 | 87 | 87.0 |
| Between the MLV and the RV 29–55 mg/kg | 11 | 11.0 | 12 | 12.0 |
| Larger than the RV >55 mg/kg | 2 | 2.0 | 1 | 1.0 |
| **Total** | 100 | 100.0 | 100 | 100.0 |

It was found that four plots under vineyards contain arsenic in the amount smaller than the MLV (< 29 mg/kg) and one plot with the content of arsenic between the MLV and the RV (29 mg/kg–55 mg/kg) (Table 7).

On 26 plots under orchards the found content of arsenic is smaller than the MLV. On one plot the content of arsenic is between the MLV and the RV and on one plot the amount of arsenic exceeds the MLV.

The content of arsenic in the amount smaller than the MLV was found in samples from 10 plots under meadows, while on three plots it was found that they contain arsenic in the amount between the MLV and the RV.

45 plots under ploughland were found to have the content of arsenic below the MLV, six with the content of arsenic between the MLV and the RV and one plot with the content of arsenic exceeding the RV. All pastures are on the soil with the amount of arsenic smaller than the MLV.

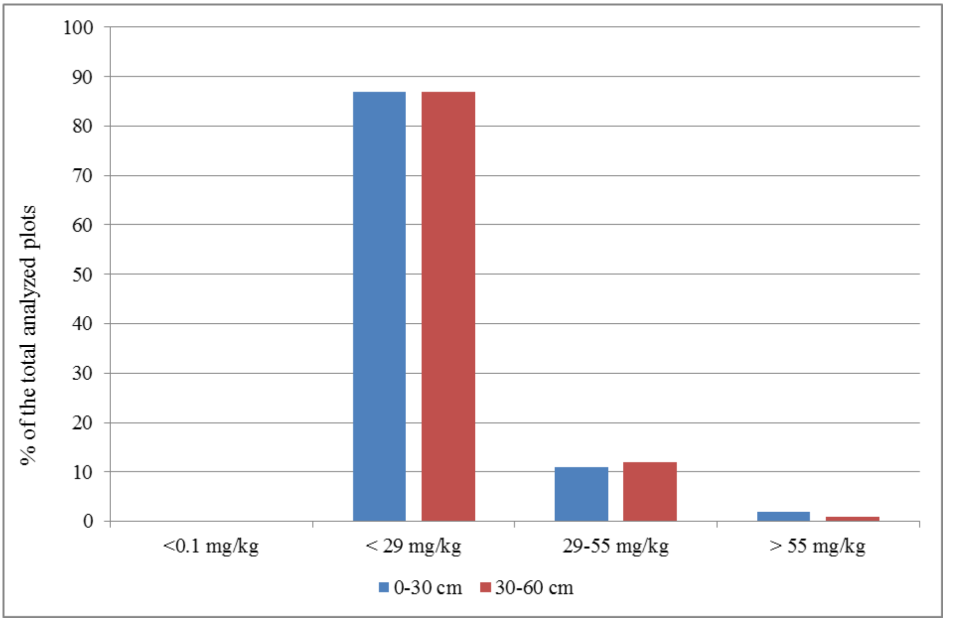

**Figure 4.** *Categories of soil according to the content of arsenic (As) for the municipality of Topola*

**Table 7.** *Representation of soil categories according to the content of arsenic (As) by cultures*

| Soil category | Culture | | | | |
|---|---|---|---|---|---|
| | Vineyard | Orchard | Meadow | Ploughland | Pasture |
| Below the detection limit <0.1 mg/kg | 0 | 0 | 0 | 0 | 0 |
| Smaller than the MLV <29 mg/kg | 4 | 26 | 10 | 45 | 2 |
| Between the MLV and the RV 29–55 mg/kg | 1 | 1 | 3 | 6 | 0 |
| Larger than the RV >55 mg/kg | 0 | 1 | 0 | 1 | 0 |
| **Total** | 5 | 28 | 13 | 52 | 2 |

### 3.3. The Content of Ni in the Agricultural Land in the Territory of the Topola Municipality

Nickel is one of the essential microelements of nutrition, i.e. plants cannot survive if there is no nickel in the soil. However, in higher concentrations it can be toxic. The minimum limit value for nickel in the soil amounts to 35.0 mg/kg of the soil, and remediation value is 210 mg/kg.

The average content of nickel in the analysed agricultural land of the municipality of Topola in the surface layer amounts to 97.37 mg/kg, and in the deeper analysed layer 101.60 mg/kg. In the surface layer (0–30 cm) the content of nickel ranges from 17.86 to 893.72 mg/kg, and in the deeper analysed layer (30–60 cm) from 32.33 to 980.24 mg/kg.

On all analysed plots under vineyards, orchards, meadows, ploughland and pastures in the territory of the Municipality of Topola, in the surface layer (0–30 cm), the amount of nickel smaller than the MLV, i.e. less than 35 mg/kg, was found on two plots, while the amount of nickel between the MLV and the RV was found on 94 plots. The amount of nickel with concentrations exceeding the RV was found on four plots. Similar situation is also in the deeper analysed layer (30–60 cm). The amount of nickel smaller than the MLV was found on one plot. The amount of nickel between the MLV and the RV was found on 95 plots and the amount of nickel exceeding the RV was found on 4 plots (Table 8; Figure 5).

**Table 8.** *The content of nickel (Ni) in the analysed soil of the municipality of Topola*

| Soil category | 0–30 cm | | 30–60 cm | |
|---|---|---|---|---|
| | Number of plots | % | Number of plots | % |
| Below the detection limit <0.1 mg/kg | 0 | 0.0 | 0 | 0.0 |
| Smaller than the MLV <35 mg/kg | 2 | 2.0 | 1 | 1.0 |
| Between the MLV and the RV 35–210 mg/kg | 94 | 94.0 | 95 | 95.0 |
| Larger than the RV >210 mg/kg | 4 | 4.0 | 4 | 4.0 |
| **Total** | 100 | 100.0 | 100 | 100.0 |

Analysed plots under vineyards contain nickel in the amount smaller than the MLV. One plot under orchards contains nickel in the amount smaller than the MLV, 25 plots are with the nickel content between the MLV and the RV and two plots have nickel content above the RV. The content of nickel in the amount between the MLV and the RV is determined on 12 plots under meadows, while one plot contains nickel in the amount exceeding the RV. On one plot under ploughland nickel content below the MLV was found. On 50 plots under ploughland nickel content is between the MLV and the RV and on one analysed plot the amount of nickel is exceeding the RV. Soil under pastures on all analysed plots contains the amount of nickel between the MLV and the RV (Table 9).

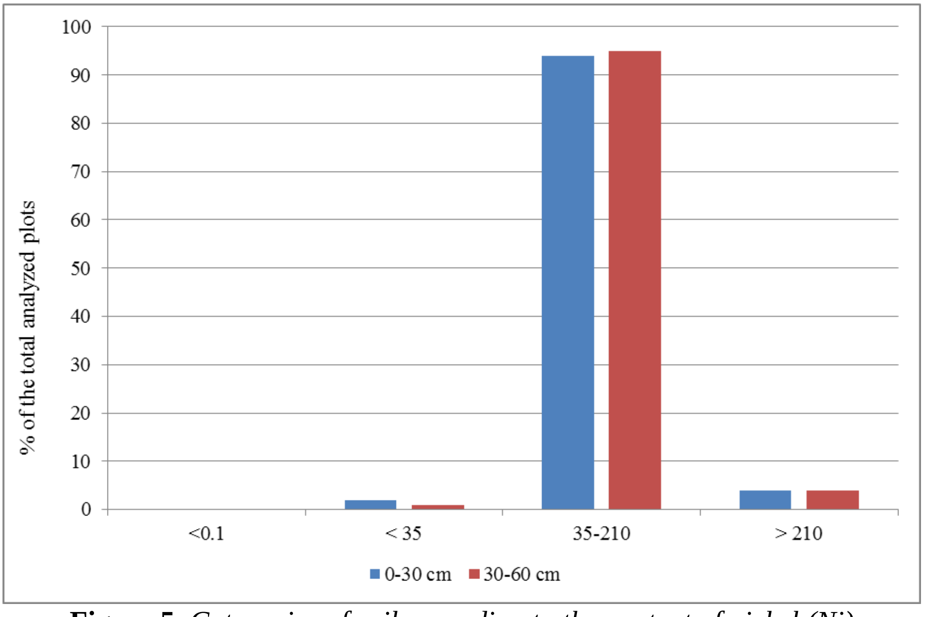


**Figure 5.** *Categories of soil according to the content of nickel (Ni) for the municipality of Topola*

In the researched area the largest part of the total agricultural area is ploughland (70.82%); 18.23% are orchards, 6.44% are meadows, 4.50% vineyards and 3.84% are pastures, while other land comprises 2.31% of the area.

**Table 9.** *Representation of soil categories according to the nickel (Ni) content by cultures*

| Soil category | Culture | | | | |
|---|---|---|---|---|---|
| | Vineyard | Orchard | Meadow | Ploughland | Pasture |
| Below the detection limit <0,1 mg/kg | 0 | 1 | 0 | 1 | 0 |
| Smaller than the MLV <35 mg/kg | 5 | 25 | 12 | 50 | 2 |
| Between the MLV and the RV 35–210 mg/kg | 0 | 2 | 1 | 1 | 0 |
| Larger than the RV >210 mg/kg | 5 | 28 | 13 | 52 | 2 |
| **Total** | 5 | 28 | 13 | 52 | 2 |

The results of the research indicate that the content of Cr in the agricultural land of the municipality of Topola in most cases is between the MLV and the RV;

the content of As is mostly smaller than the MLV and the content of Ni is usually between the MLV and the RV.

According to Ninkov et. al., 2015, the content of nickel in the agricultural land under vineyards of Šumadija district is between the MLV and the RV, which is in line with the results for the municipality of Topola.

The results of the research of agricultural land from 2012 in Zlatibor, Morava, and in smaller part of Raška district showed excess of Cr and Ni content. The amount of nickel is exceeding the RV in 16% out of 364 samples, and the amount of Cr is exceeding the RV in 12% of the analysed samples. The average content of Cr in the examined soils is 131.63 mg/kg, and the average content of arsenic is 7.51 mg/kg (Ministarstvo zaštite životne sredine - Agencija za zaštitu životne sredine, 2013). According to the results for the municipality of Topola the average content of Cr is 128.22 mg/kg, the average content of arsenic is 20.87 mg/kg (larger content is in the soils of Zlatibor, Morava and part of Raška district), the content of chromium exceeds the RV on only 2% of the samples and the content of nickel on 4% of the analysed samples.

The results of the examination of agricultural land in 2016 and 2017 (South-east Serbia) showed that the content of As was exceeding the RV in 27% of the samples and in the municipality of Topola on 2% of the samples. The content of Cr and Ni in part of south-east Serbia is between the MLV and the RV (Ministarstvo zaštite životne sredine - Agencija za zaštitu životne sredine, 2018). Similar results were obtained for Cr and Ni for the municipality of Topola.

The state of agricultural land protection in the analysed municipality requires taking measures to prevent the use of agricultural land for non-agricultural purposes, then to prevent fragmentation of arable agricultural land and to conduct control of soil fertility.

### 3.4. Statistical analysis

The results of descriptive statistics and t-test for soil content of potentially toxic elements in two soil depths and for two main types of land use are presented in Table 10. The soil content of Cr in the depth of 0–30 cm ranged from 48.73 mg/kg to 632.78 mg/kg for ploughland and from 32.71 mg/kg to 1157.69 mg/kg for other types of land use. The content of this potentially toxic element in the depth of 30–60 cm ranged from 53.13 mg/kg to 399.39 mg/kg for ploughland and from 54.39 mg/kg to 1104.25 mg/kg for other land use. On the other hand, the soil content of As in the depth of 0–30 cm ranged from 6.42 mg/kg to 61.88 mg/kg for ploughland and from 8.12 mg/kg to 161.44 mg/kg for other land use. The content of the same potentially toxic element in the depth of 30–60 cm ranged from 9.17 mg/kg to 47.68 mg/kg for ploughland and from 10.63 mg/kg to 129.12 mg/kg for other land use. Finally, the soil content of Ni in the depth of 0–30 cm ranged between 31.66 mg/kg and 302.91 mg/kg on ploughland and from 17.86 mg/kg to 893.72 mg/kg for other land use. The content of the same potentially toxic element in the depth of 30–60 cm ranged between 32.33 mg/kg and 189.75 mg/kg for ploughland and between 36.16 mg/kg and 980.24 mg/kg for other land use. As can be seen from the values of CV, all analyzed variables are characterized by very high variability. Based on the results of t-test, there is no statistical difference between the mean values of the soil content of the analyzed potentially toxic elements in two depths and for two types of land use (P > 0.05), except for Ni in the soil depth of 30–60 cm (P = 0.0397). Specifically, the results show that the mean value of Ni content in the soil depth of 30–60 cm was significantly higher for other types of land use compared to ploughland. Given that this value is lower than RV, and it is found in the deeper soil layer, it can be argued that it is a result of natural pedological factors.

**Table 10.** *Descriptive statistics and t-test for soil content of potentially toxic elements (mg/kg) in two depths and for two types of land use in the municipality of Topola*

| **Land use** | | **Cr** | | **As** | | **Ni** | |
|---|---|---|---|---|---|---|---|
| | | **Depth (cm)** | | | | | |
| | | **0–30** | **30–60** | **0–30** | **30–60** | **0–30** | **30–60** |
| Ploughland | X̄ | 116.08 | 115.66 | 19.78 | 19.12 | 82.26 | 82.87 |
| | SD | 81.16 | 54.65 | 10.17 | 8.06 | 47.86 | 39.01 |
| | CV% | 69.92 | 47.25 | 51.39 | 42.15 | 58.17 | 47.07 |
| | MIN | 48.73 | 53.13 | 6.42 | 9.17 | 31.66 | 32.33 |
| | MAX | 632.78 | 399.39 | 61.88 | 47.68 | 302.91 | 189.75 |
| Other | X̄ | 141.36 | 145.40 | 22.05 | 22.17 | 113.73 | 121.89 |
| | SD | 157.65 | 149.39 | 21.80 | 17.40 | 127.04 | 138.90 |
| | CV% | 111.52 | 102.75 | 98.84 | 78.51 | 111.70 | 113.95 |
| | MIN | 32.71 | 54.39 | 8.12 | 10.63 | 17.86 | 36.16 |
| | MAX | 1157.69 | 1104.25 | 161.44 | 129.12 | 893.72 | 980.24 |
| **t-test** | t | -1.01 | -1.50 | -0.61 | -1.10 | -1.57 | -2.08 |
| | P | 0.3132 | 0.1359 | 0.5457 | 0.2725 | 0.1203 | **0.0397** |

**Note:** *Boldfaced values denote statistically significant differences between the means at the 95% confidence level*

## 4. CONCLUSION

Based on this research it can be concluded that the largest part of total agricultural area on the researched area consists of ploughland (70.82%).

The content of chromium (Cr) in the soils of municipality of Topola is in most cases between minimum limit value (MLV) and remediation value (RV). In a large number of cases the content of Cr is lower than MLV.

The content of arsenic (As) in the soils of the municipality of Topola is lower than the MLV on 87% of the examined areas, and on 11% of the areas it is between the MLV and the RV. Only on 2% of the areas the content of this element in the soil exceeds the RV.

The content of nickel (Ni) in the soils of the municipality of Topola is between the MLV and the RV on 94% of the examined areas. On 2% of the areas it is lower than the MLV and on 4% it exceeds the RV.

The state of agricultural land protection in the municipality of Topola requires taking measures to prevent the use of agricultural land for non-agricultural purposes and fragmentation of arable agricultural land as well as to conduct control of soil fertility in this municipality.

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## DETERMINATION OF CHROMIUM, ARSENIC AND NICKEL CONTENT IN THE AGRICULTURAL LAND OF THE MUNICIPALITY OF TOPOLA

*Sonja BRAUNOVIĆ, Saša EREMIJA, Sabahudin HADROVIĆ, Filip JOVANOVIĆ, Natalija MOMIROVIĆ, Jovana CVETKOVIĆ, Zoran MILETIĆ*

### Summary

Soil pollution with the increase of potentially toxic elements content above the remediation value is a pronounced problem in the Republic of Serbia. This paper presents the results of examination of the content of potentially toxic elements, chromium (Cr), arsenic (As) and nickel (Ni), in the agricultural land of the municipality of Topola, with an overview of general and natural characteristics of the municipality and the land use of agricultural land. The objective of the research is determination of the content of potentially toxic elements, chromium, arsenic and nickel in the agricultural land of the municipality of Topola.

The research is based on the processing of the data from literature on position and natural conditions of the Topola municipality, field work on the territory of the municipality

(100 cadastre plots) with soil sampling from two depths (0–30 cm, 30–60 cm) and laboratory analyses. The Official Gazette of the Republic of Serbia (88/2010), defines minimum limit values (MLV) and remediation values (RV) of concentrations of dangerous and harmful substances, as well as the values that can indicate significant contamination of the soil.

Geographical and natural characteristics of the Topola municipality indicate that this municipality has a central position in the Republic of Serbia, it belongs to Šumadija administrative district and is characterised by favourable climatic, orographic, geological, and pedological conditions for production of agricultural cultures (Geosrbija, 2019; Opština Topola, 2017; Službeni glasnik SO Topola, 2017). The largest part of the total agricultural area on the researched area consists of ploughland (70.82%). Based on the laboratory analyses of the content of potentially toxic elements in the agricultural land of the municipality it is noted that the content of Cr is in most cases between the MLV and the RV, or lower than the MLV. The content of As is on 87% of the researched areas lower than MLV, and on 11% of the areas its values are between the MLV and the RV. The values of Ni are between the MLV and the RV on 94% of the areas.

Based on the present state of protection of agricultural land in the municipality of Topola it can be concluded that it is necessary to undertake measures of prevention of the use of agricultural land for non-agricultural purposes, and fragmentation of arable agricultural land, as well as to conduct the control of soil fertility in the territory of this municipality.

## UTVRĐIVANJE SADRŽAJA HROMA, ARSENA I NIKLA U POLJOPRIVREDNOM ZEMLJIŠTU OPŠTINE TOPOLA

*Sonja BRAUNOVIĆ, Saša EREMIJA, Sabahudin HADROVIĆ, Filip JOVANOVIĆ, Natalija MOMIROVIĆ, Jovana CVETKOVIĆ, Zoran MILETIĆ*

### Rezime

Zagađivanje zemljišta, sa povećanjem sadržaja potencijalno toksičnih elemenata iznad remedijacione vrednosti, izražen je problem u Republici Srbiji. U ovom radu su prikazani rezultati ispitivanja sadržaja potencijalno toksičnih elemenata, hroma (Cr), arsena (As) i nikla (Ni), u poljoprivrednom zemljištu opštine Topola, uz pregled osnovnih i prirodnih karakteristika opštine i strukture korišćenja poljoprivrednog zemljišta. Cilj istraživanja je utvrđivanje sadržaja potencijalno toksičnih elemenata, hroma, arsena i nikla u poljoprivrednom zemljištu opštine Topola.

Istraživanje se zasniva na obradi literaturnih podataka o geografskom položaju i prirodnim uslovima opštine Topola, terenskom radu na području opštine (100 katastarskih parcela) sa uzorkovanjem zemljišta na dve dubine (0–30 cm, 30–60 cm) i laboratorijskim analizama. Službenim glasnikom Republike Srbije (88/2010), definisane su granične minimalne vrednosti (GMV) i remedijacione vrednosti (RV) koncentracija opasnih i štetnih materija, kao i vrednosti koje mogu ukazati na značajnu kontaminaciju zemljišta.

Geografske i prirodne karakteristike opštine Topola ukazuju na to da ova opština ima centralan položaj u Republici Srbiji, pripada Šumadijskom upravnom okrugu i odlikuje se povoljnim klimatskim, orografskim, geološkim i pedološkim uslovima za proizvodnju poljoprivrednih kultura (Geosrbija, 2019; Opština Topola, 2017; Službeni glasnik SO Topola, 2017). Najveći deo ukupne poljoprivredne površine na istraživanom području čine oranice (70,82%). Na osnovu laboratorijskih analiza sadržaja potencijalno toksičnih elemenata u poljoprivrednom zemljištu opštine, zapaža se da se sadržaj Cr u najvećem broju slučajeva nalazi između GMV i RV, ili je manji od GMV. Sadržaj As je na 87% ispitivanih površina manji od GMV, a na 11% površina je u vrednostima između GMV i RV. Ni je na 94% površina u međuvrednostima GMV i RV.

Na osnovu sadašnjeg stanja zaštite poljoprivrednog zemljišta u opštini Topola može se zaključiti da je potrebno preduzeti mere na sprečavanju korišćenja poljoprivrednog zemljišta u nepoljoprivredne svrhe i sprečavanju usitnjavanja obradivog poljoprivrednog zemljišta, kao i sprovođenje kontrole plodnosti zemljišta na području ove opštine.

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# INSIGHTS INTO PH DYNAMICS, DISSOLVED OXYGEN VARIABILITY, AND ION REMOVAL EFFICIENCY IN FLOATING TREATMENT WETLAND

*Nevena ČULE[1]*, Aleksandar LUČIĆ[1], Marija NEŠIĆ[2], Ljiljana BRAŠANAC-BOSANAC[1], Ivana BJEDOV[2]*

**Abstract:** *This paper aims to analyse the dynamic responses within FTW constructed on the riverbank, focusing on pH, dissolved oxygen (DO), and the dynamics of calcium and magnesium concentrations. While some research has been carried out on Ca and Mg behavior in constructed wetlands no papers specifically addressed the removal mechanisms of these ions in FTWs have been found. Results showed that both polluted and treated water exhibited characteristics consistent with a mildly alkaline environment. Extremely low DO levels in cells with floating islands were increased after water passing through cell with algae. Ca removal efficiency in cells with floating island cells ranged from 2% to 6%, while the cell with algae achieved 23% to 49% efficiency. Modest Mg removal (1-6%) could indicate potential challenges in Mg removal processes within the FTWs. The analysis of plant responses to polluted water exposure reveals species-specific variations in Ca and Mg concentrations in shoots and roots. Ca concentration in algae tissue increased over time contrasting the marked decrease of Mg content. The study also revealed a gradual decrease of Ca and Mg concentration in stone wool corresponding to exposure duration. This research contributes to a better understanding of the complex dynamics of water treatment in FTWs, emphasizing the need for continued investigation into ion removal mechanisms, plant responses to increased Ca and Mg concentrations, and the role of algae in these biological systems.*

**Keywords:** polluted water, calcium, magnesium, macrophytes, water treatment

# UVIDI U DINAMIKU pH, VARIJABILNOST RASTVORENOG KISEONIKA I EFIKASNOST UKLANJANJA JONA U BIOLOŠKOM SISTEMU SA PLUTAJUĆIM OSTRVIMA

**Sažetak:** *Cilj ovog rada je analiza dinamičkih procesa u biološkom sistemu sa plutajućim ostrvima (FTW) konstruisanog na obali reke, sa fokusom na pH, rastvoreni kiseonik (DO) i promenu koncentracija kalcijuma i magnezijuma. Iako je manji broj istraživanja sproveden o ponašanju Ca i Mg u konstruisanim akvatičnim ekosistemima, nisu pronađeni radovi koji bi se posebno bavili mehanizmima uklanjanja ovih jona u FTW.*

[1] Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
[2] Faculty of Forestry, University of Belgrade, Kneza Višeslava 1, 11030 Belgrade, Serbia
*Corresponding author. E-mail: nevena.cule@forest.or.rs

*Rezultati su pokazali da su i zagađena i prečišćena voda imale karakteristike slabo alkalne sredine. Ekstremno nizak nivo DO u bazenima sa plutajućim ostrvima povećan je nakon prolaska vode kroz bazen sa algama. Efikasnost uklanjanja Ca u bazenima sa plutajućim ostrvima se kretala od 2% do 6%, dok je u bazenu sa algama postignuta efikasnost od 23% do 49%. Slabo uklanjanje Mg (1-6%) može da ukaže na potencijalne probleme u procesima uklanjanja Mg u FTW. Analiza reakcije biljaka na izlaganje zagađenoj vodi je pokazala varijacije specifične za vrste u koncentracijama Ca i Mg u nadzemnoj biomasi i korenu. Koncentracija Ca u tkivu algi se vremenom povećavala, dok se sadržaja Mg izrazito smanjivao. Studija je takođe ukazala na postepeno smanjenje koncentracije Ca i Mg u kamenoj vuni u skladu sa trajanjem izlaganja supstrata zagađenoj vodi. Ovo istraživanje doprinosi boljem razumevanju složene dinamike prečišćavanja vode u FTW i naglašava potrebu za kontinuiranim istraživanjem mehanizama uklanjanja jona, reakcije biljaka na povećane koncentracije Ca i Mg i uloge algi u ovim biološkim sistemima.*

**Ključne reči:** zagađena voda, kalcijum, magnezijum, makrofite, tretman vode

## 1. INTRODUCTION

Clean rivers play a crucial role in urban environments, contributing to the overall well-being of cities and their inhabitants. Rivers serve as essential water sources, providing drinking water, supporting agriculture, and sustaining diverse ecosystems. Moreover, they enhance the aesthetic appeal of urban landscapes, offering recreational spaces for residents and promoting biodiversity. However, the escalating pollution of urban rivers poses a significant threat to both the environment and public health. Contaminants such as industrial runoff, untreated sewage, and various pollutants from urban activities can compromise water quality, adversely impacting aquatic life and ecosystems. Furthermore, polluted rivers contribute to the degradation of downstream water bodies and thus affect communities beyond city limits. Addressing river pollution is imperative for ensuring sustainable urban development. Mitigating water pollution involves implementing effective waste management practices, enhancing wastewater treatment infrastructure, and promoting public awareness about the responsible disposal of pollutants.

In this context, floating treatment wetlands (FTW) emerge as a green and cost-effective technology that can help in the treatment of polluted water in urban areas. FTWs, with their innovative use of floating islands planted with vegetation, provide an eco-friendly approach to water remediation. As a crucial part of the biological system, the floating islands can be placed in existing reservoirs and cells or directly on the lake or river. By imitating natural processes, without the use of chemicals or additional energy, and due to the symbiotic relationships between plants, algae, small invertebrates, zooplankton, microorganisms, substrate, and water (Chen et al., 2017; Stottmeister et al., 2003; Yeh et al., 2015) FTWs can be used for the treatment of leachate and field runoff, stormwater, municipal, domestic, industrial, agricultural, and animal wastewater (Cule et al., 2021a; Di Luca et al., 2019; Kadlec and Wallace, 2008; Shahid et al., 2018). Integrating FTWs into urban water management strategies represents a sustainable solution to combat river pollution.

This study analyses the dynamic responses within FTW constructed on the riverbank, focusing on pH, dissolved oxygen (DO), and the dynamics of calcium and magnesium concentrations.

The pH value is an important parameter in assessing water quality, as it, like temperature, influences biological and chemical processes in water (Chapman and Kimstach, 1996). Additionally, an essential indicator of water quality is the concentration of DO, which is influenced by factors such as temperature, salinity, turbulence, atmospheric pressure, and the photosynthetic activity of algae and plants (Rajwa-Kuligiewicz et al., 2015). Calcium (Ca) and magnesium (Mg) are essential elements found in natural waters, contributing significantly to their overall chemistry, and influencing the environment and living organisms. While necessary for ecosystems, their presence in excessive amounts can pose significant challenges for both water quality. Within FTWs, Ca and Mg can play a significant role in facilitating phosphorus precipitation in anaerobic conditions and natural to the basic environment (Verhoeven and Meuleman, 1999). In that sense, the present study provides valuable insights into the dynamics of Ca and Mg within the FTW, revealing the influence of treatment cycles on Ca and Mg concentration and removal efficiency. However, it is important to acknowledge the dearth of existing research on this topic. To date, no research papers have specifically addressed the fate and removal mechanisms of these ions in FTWs. While some studies (Maine et al., 2006; Maine et al., 2009) have investigated Ca and Mg behavior in constructed wetlands, the direct comparison of results remains challenging due to construction differences in the systems.

## 2. MATERIAL AND METHODS

A floating treatment wetland (FTW) was established along the Topciderka riverbank in Belgrade, Serbia, to explore the potential of employing a nature-based solution for the effective revitalization of contaminated waters during a single vegetation period (May-October).

The FTW setup included a pump for drawing water from the river, a closed 5.0 m³ collection tank, four open rectangular cells with floating islands (3.0 m² surface area, 3.0 m³ volume each), and one open rectangular cell with algae (3.0 m² surface area, 1.5 m³ volume) (Čule et al., 2022). Water meters controlled precise water distribution from cells I-IV to cell V. With 100% cell coverage planned, anaerobic conditions were expected in cells I-IV. The inlet of cell V was positioned 50 cm above the ground to enhance oxygen introduction (Čule et al., 2017). Each of cells I-IV had three floating islands with 25 (in the first three cells) or 30 (in cell IV) seedlings, using stone wool as a substrate. Non-invasive and plants suitable for rhizofiltration (Blaylock and Huang, 2000; Cule et al., 2016; Dushenkov et al., 1995; Kumar et al., 1995; Salt et al., 1995) were selected and obtained from local nurseries. Species *Phragmites australis* (Cav.) Trin. ex Steud (PA) was planted in cell I, while *Canna indica* L. (CI) was in cell II. A mix of *P. australis* and *C. indica* seedlings was established in cell III, with planting a ratio of 12:13. A mix of *Iris pseudacorus* L. (IP; 8 seedlings), *Iris sibirica* 'Perry's Blue' (IS; 5), *Alisma plantago* - *aquatica* L. (APA; 5), *Lythrum salicaria* L. (LS; 5) and *Menyanthes trifoliata* L. (MT; 6) was planted in cell IV. This planting approach ensured consistent microclimatic conditions for each species within the FTW, facilitating their comparative analysis based on the obtained results (Čule et al., 2021). Algae were introduced directly from the river to cell V.

The FTW start-up phase lasted 45 days, involving regular water changes twice a week and the introduction of new polluted water from the river. Subsequent monitoring focused on four treatment cycles (C1, C2, C3, C4). Each cycle involved pumping water to the collection tank, gravitational transport to four cells with floating islands, 6-day retention, and simultaneous transfer to cell V for an additional 6-day polishing before release into the river. The cycles overlapped, with a new cycle beginning immediately after sampling water, plants, and substrate from the floating islands after the initial 6-day treatment.

Sampling, analysis, and data processing followed internal QA/QC procedures. Polluted water samples were obtained at the beginning of each treatment cycle at the pump outlet, while treated water was sampled every 6 days in cells I-IV and at the end of each treatment cycle in cell V. The composite water sample represented 1L of water collected from 5 spots within each cell (each angle and middle) at approximal 30 cm depth. Initial plant, algae and substrate sampling were done just before the beginning of water treatment (C0) to assess baseline nutrient concentrations. Subsequent plant sampling was done at the end of each cycle in cells I-IV, with roots and shoots separated, washed, dried (Campbell and Plank, 1998), and milled for chemical analysis. One composite plant sample represented one vegetative part of one plant species on one floating island within one cell. The algal samples were collected at the end of each treatment cycle and prepared for analysis according to the same methodology as for plants. The composite algal sample represented algae tissue collected from 5 spots within cell 5 (each angle and middle). The sampling of the substrate was done along with plant sampling. The composite substrate sample represented stone wool collected from 5 spots of one floating island (each angle and middle).

Microwave digestion (CEM MDS 2000, Berghof, Germany, Mod. Speedwave MWS3+) was used for the extraction of Ca and Mg from plant and algae tissue (Șenilă et al., 2011). The extraction of Ca and Mg from the air-dried substrate was done in aqua regia according to the ISO 11466:1995 method.

Temperature, pH, and dissolved oxygen (DO) were measured (HACH HQ 40d Digital Multi 2-channel Meter with automatic temperature calibration) at the beginning of each treatment cycle at the outlet of the pump and directly in cells (each angle and middle) at the end of each treatment cycle. The concentrations of Ca and Mg in water, plants, algae, and stone wool, were analyzed using ICP-OES (Varian Vista-PRO, CCD Simultaneous ICP-OES) according to standard methodology (ISO 11885:2009).

When appropriate, statistical analysis was performed using Analyses of Variance (one-way ANOVA). Significant differences between the groups were determined by a subsequent comparison using Fischer’s LSD test ($p < 0.05$). Summary statistics and ANOVA tests were carried out using Statgraphics Centurion XVI (Statpoint Technologies, Inc., Warrenton, VA, USA).

## 3. RESULTS

The results of the pH analysis of both polluted and treated water are displayed in Table 1. The influent pH ranged from 7.66 to 8.46. Following the initial six days of treatment, a decline in the pH values was observed in the effluent of all cells with floating islands, falling within the range of 7.29 to 7.91. However, upon passing through cell V with algae in all treatment cycles, the pH values of the water increased and were within the limits of 7.79 to 8.43.

**Table 1.** *pH value of polluted and treated water during experimental period.*

| Treatment cycles | | C1 | C2 | C3 | C4 |
|---|---|---|---|---|---|
| **Influent to FTW (mg/L)** | Tank | 8.46 | 8.38 | 8.29 | 7.66 |
| **Effluent of single cell (mg/L)** | Cell I | 7.61 | 7.52 | 7.68 | 7.33 |
| | Cell II | 7.85 | 7.81 | 7.91 | 7.29 |
| | Cell III | 7.52 | 7.37 | 7.42 | 7.37 |
| | Cell IV | 7.57 | 7.55 | 7.50 | 7.33 |
| | Cell V | 7.79 | 8.43 | 8.14 | 8.15 |

Each value represents the value of a composite sample taken from the tank and 5 spots in each cell. C1 - 1st treatment cycle, C2 - 2nd treatment cycle, C3 - 3rd treatment cycle, C4 - 4th treatment cycle. Cell I - *Phragmites australis* (Cav.) Trin. ex Steud., Cell II - *Canna indica* L., Cell III - *P. australis* and *C. indica*, Cell IV - *Iris pseudacorus* L., *Iris sibirica* 'Perry's Blue', *Alisma plantago - aquatica* L., *Lythrum salicaria* L. and *Menyanthes trifoliata* L.

The water temperature (t) showed two different trends during the water treatment period (Figure 1). Temperatures of the influent into the FTW were 24.0°C and 22.5°C at the end of C1 and C2, respectively. Water temperature rose above initial temperatures in cells with floating islands (26.8°C -28.3°C and 22.6 °C-23.1°C in C1 and C2, respectively) but declined again in the cell with algae (19.2°C and 15.5°C in C1 and C2, respectively) till the end of these treatment cycles. Following lower air temperatures in late September and early October, temperatures of influent were lower with values of 18.0°C and 14.5°C at the end of C3 and C4, respectively. Water temperature then further declined in cells with floating islands (16.0°C - 16.6°C and 12.1°C -12.8°C in C3 and C4, respectively) but raised above initial temperatures of influent in the cell with algae (22.5°C and 15.0°C in C3 and C4, respectively) till the end of these treatment cycles.

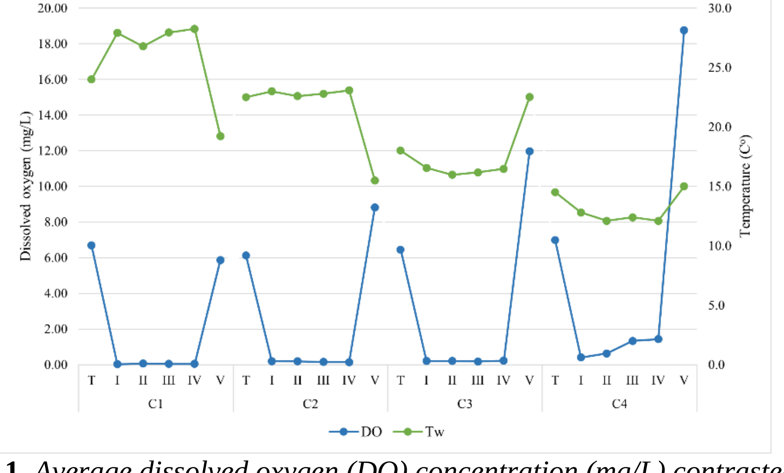


**Figure 1.** *Average dissolved oxygen (DO) concentration (mg/L) contrasted with water temperature (Tw) during water treatment.*

T - tank, C1 - 1st treatment cycle, C2 - 2nd treatment cycle, C3 - 3rd treatment cycle, C4 - 4th treatment cycle; Cell I - *Phragmites australis* (Cav.) Trin. ex Steud., Cell II - *Canna indica* L., Cell III - *P. australis* and *C. indica*, Cell IV - *Iris pseudacorus* L., *Iris sibirica* 'Perry's Blue', *Alisma plantago - aquatica* L., *Lythrum salicaria* L. and *Menyanthes trifoliata* L.; Each value represents the value of the composite sample of water taken from the tank or 5 spots in the cell.

Figure 1 further reveals that dissolved oxygen (DO) concentration maintained relatively constant in influent into the FTW with average values of 6.11-6.98 mg/L during the water treatment period. There is a clear trend of decreasing DO levels after six days of water treatment in cells with floating islands in all treatment cycles. The DO levels declined far below 1.0 mg/L resulting in anaerobic conditions in all cells except in cell III and cell IV in C4 (1.33 mg/L and 1.43 mg/L, respectively). The concentration of DO increased in cell V with algae till the end of each treatment cycle. The DO levels in cell V were higher than the initial DO in influent at the end of C2 (8.81 mg/L), C3 (11.96 mg/L), and C4 (18.77 mg/L), and slightly below in C1 (5.87 mg/L). Even water supersaturation occurred in cell V at the end of C3 and C4 with oxygen saturation of 140% and 183%, respectively.

Table 2 presents the results obtained from the analyses of Ca concentration in both polluted and treated water, alongside the Ca removal efficiency of FTW. The influent Ca concentrations entering the FTW varied from 7.61 mg/L to 8.12 mg/L. Table 2 further reveals that there was a slight increase in Ca concentration in all cells after the first six days of treatment in C1 and C2, except for cells II and III exhibiting very low Ca removal efficiency of 2% and 1%, respectively, at the end of C2. Gradual efficiency increase was noted across all cells with floating islands in C3 and C4. Throughout these treatment cycles, the Ca removal efficiency ranged from 2% to 6%, with the highest efficiency recorded in C4 in Cell II planted with *C. indica*. A significant reduction of the Ca content in the water occurred only in the cell with algae (Cell V) at the end of all treatment cycles (C1-C4). The calcium concentrations in the FTW effluent ranged from 3,99 to 6.22 mg/L resulting in 23% to 49% FTW Ca removal efficiency. The most notable reduction in Ca concentration was observed at the end of C3.

**Table 2.** *Calcium concentration in polluted and treated water and efficiency of the floating treatment wetland.*

| **Treatment cycles** | | **C1** | **C2** | **C3** | **C4** |
|---|---|---|---|---|---|
| Influent to FTW (mg/L) | Tank | 7.92 | 8.12 | 7.86 | 7.61 |
| Effluent of single cell (mg/L) | Cell I | 8.15 | 8.21 | 7.60 | 7.46 |
| | Cell II | 8.07 | 7.98 | 7.60 | 7.18 |
| | Cell III | 7.96 | 8.02 | 7.64 | 7.21 |
| | Cell IV | 8.25 | 8.21 | 7.71 | 7.48 |
| Reduction of Ca in single cell (mg/L) | Cell I | -0.23 | -0.09 | 0.25 | 0.15 |
| | Cell II | -0.15 | 0.14 | 0.26 | 0.43 |
| | Cell III | -0.04 | 0.10 | 0.22 | 0.40 |
| | Cell IV | -0.33 | -0.09 | 0.14 | 0.13 |
| Single cell efficiency (%) | Cell I | -3 | -1 | 3 | 2 |
| | Cell II | -2 | 2 | 3 | 6 |
| | Cell III | 0 | 1 | 3 | 5 |
| | Cell IV | -4 | -1 | 2 | 2 |
| Influent to Cell V (mg/L) | Cells I-IV | 8.11 | 8.10 | 7.64 | 7.33 |
| Effluent of single cell (mg/L) | Cell V | 6.13 | 6.22 | 3.99 | 4.99 |
| Reduction of Ca in single cell (mg/L) | Cell V | 1.97 | 1.88 | 3.65 | 2.34 |
| Single cell efficiency (%) | Cell V | 24 | 23 | 48 | 32 |

Each value represents the value of a composite sample taken from the tank and 5 spots in each cell. C1 - 1st treatment cycle, C2 - 2nd treatment cycle, C3 - 3rd treatment cycle, C4 - 4th treatment cycle.Cell I - *Phragmites australis* (Cav.) Trin. ex Steud., Cell II - *Canna indica* L., Cell III - *P. australis* and *C. indica*, Cell IV - *Iris pseudacorus* L., *Iris sibirica* 'Perry's Blue', *Alisma plantago - aquatica* L., *Lythrum salicaria* L. and *Menyanthes trifoliata* L.

The results of Mg concentration in both polluted and treated water, along with the Mg removal efficiency of FTW are shown in Table 3. What stands out in this table is the notable absence or low reduction rate of Mg content in all cells. The influent Mg concentrations varied from 7.61 mg/L to 8.12 mg/L. A slight increase in Mg concentration was observed in Cell I and Cell IV at the end of C1 as well as in all cells with floating islands at the end of C2. There was a slight reduction of Mg content in subsequent cycles (C3 and C4) in Cell I-IV with the Mg removal efficiencies ranging from 1% to 4%. Upon passing through the cell with algae, Mg concentrations in treated water surpassed those in the influent, reaching the highest recorded concentration of 2.66 mg/L by the end of C1. The highest Mg removal efficiency of 6% was achieved in Cell V at the end of C4.

**Table 3.** *Magnesium concentration in polluted and treated water and efficiency of the floating treatment wetland.*

| **Treatment cycles** | | **C1** | **C2** | **C3** | **C4** |
|---|---|---|---|---|---|
| Influent to FTW (mg/L) | Tank | 2.18 | 2.06 | 1.99 | 1.86 |
| Effluent of single cell (mg/L) | Cell I | 2.21 | 2.14 | 1.96 | 1.84 |
| | Cell II | 2.17 | 2.11 | 1.96 | 1.80 |
| | Cell III | 2.13 | 2.10 | 1.97 | 1.78 |
| | Cell IV | 2.33 | 2.16 | 2.00 | 1.83 |
| Reduction of Ca in single cell (mg/L) | Cell I | -0.03 | -0.08 | 0.03 | 0.02 |
| | Cell II | 0.01 | -0.05 | 0.04 | 0.06 |
| | Cell III | 0.05 | -0.04 | 0.02 | 0.08 |
| | Cell IV | -0.15 | -0.10 | 0.00 | 0.03 |
| Single cell efficiency (%) | Cell I | -1 | -4 | 2 | 1 |
| | Cell II | 1 | -3 | 2 | 3 |
| | Cell III | 2 | -2 | 1 | 4 |
| | Cell IV | -7 | -5 | 0 | 2 |
| Influent to Cell V (mg/L) | Cells I-IV | 2.21 | 2.13 | 1.97 | 1.81 |
| Effluent of single cell (mg/L) | Cell V | 2.66 | 2.21 | 2.04 | 1.75 |
| Reduction of Ca in single cell (mg/L) | Cell V | -0.45 | -0.08 | -0.06 | 0.06 |
| Single cell efficiency (%) | Cell V | -20 | -4 | -3 | 3 |

Each value represents the value of a composite sample taken from the tank and 5 spots in each cell. C1 - 1st treatment cycle, C2 - 2nd treatment cycle, C3 - 3rd treatment cycle, C4 - 4th treatment cycle; Cell I - *Phragmites australis* (Cav.) Trin. ex Steud., Cell II - *Canna indica* L., Cell III - *P. australis* and *C. indica*, Cell IV - *Iris pseudacorus* L., *Iris sibirica* 'Perry's Blue', *Alisma plantago - aquatica* L., *Lythrum salicaria* L. and *Menyanthes trifoliata* L.

The results obtained from the analysis of the effects of treatment cycles on the concentration of Ca and Mg in shoots (CaS and MgS, respectively) and roots (CaR and MgR, respectively) of selected plant species are presented in Figure 2 A-G. As evident from the data, there was no significant difference ($p>0.05$) in the Ca concentration of *P. australis* shoots (3.44-4.83 g/kg) concerning the duration of reed exposure to polluted water (Fig. 2A). The same trend was also noted in *M. trifoliata*, with Ca concentration falling within the range of 13.76-16.63 g/kg (Fig. 2G). Figure 2 further reveals that species *C. indica*, *I. pseudacorus* and *I. sibirica* 'Perry's Blue' contained significantly more Ca in their shoot at the end of C4 (15.78 g/kg, 37.78 g/kg and 25.03 g/kg, respectively) compared to treatment cycles that preceded it. At the end of C2, *A. plantago-aquatica* contained a significantly higher Ca concentration of 28.79 g/kg in shoots, while *L. salicaria* had a concentration of 44.19 g/kg at the end of C3, surpassing levels observed in other treatment cycles (Fig. 2E and Fig. 2F, respectively).

Concerning the Mg content in the shoots of selected plants, Figure 2 illustrates that there was no significant difference (p>0.05) in the Mg concentration of *I. pseudacorus* shoots (4.22-5.35 g/kg) and *A. plantago-aquatica* shoots (2.74-3.94 g/kg) concerning the period of exposure of these species to polluted water (Fig. 2C and Fig. 2E, respectively). *I. sibirica* 'Perry's Blue' was the only species that contained significantly higher Mg concentration in shoots (4.36 g/kg) at the end of C4 compared to the preceding treatment cycles (Fig. 2D). Significantly lower Ca concentrations were determined in *C. indica* shoots (4.58 g/kg) sampled at the end of C3 compared to those sampled at the beginning of the experimental period (C0) and at the end of C1 (Fig. 2B). Furthermore, there is a significant decrease in Ca content in the shoots of *P. australis*, *L. salicaria*, and *M. trifoliata* (1.20 g/kg, 3.75 g/kg, and 3.23 g/kg, respectively) at the end of C4 in contrast to the prior treatment cycles.

The present study revealed no significant difference (p>0.05) in the Ca concentration of *I. pseudacorus* and *I. sibirica* 'Perry's Blue' roots (14.92-26.88 g/kg and 18.16-27.50 g/kg, respectively) concerning the duration of species exposure to polluted water (Fig. 2C and Fig. 2D, respectively). Moreover, across the experimental period (C1-C4), there was no significant difference (p>0.05) in the Ca concentration of *P. australis* roots (15.47-20.47 g/kg) (Fig. 2A). However, these Ca concentrations were significantly higher compared to the Ca concentrations in roots (5.15 g/kg) sampled before the beginning of the experiment (C0) (Fig. 2A). *C. indica* roots contained significantly higher Ca concentrations (35.55 g/kg) at the end of the experimental period (C4) compared to all other treatment cycles (Fig. 2B). Conversely, significantly lower Ca concentrations were detected in *A. plantago-aquatica* roots (25.43 g/kg) compared to other treatment cycles (Fig. 2E). Calcium concentrations in the roots of *L. salicaria* significantly increased toward the end of the experiment compared to the Ca concentrations in roots (19.99 g/kg) sampled before the experiment began (C0) (Fig. 2F). In contrast, Ca content in *M. trifoliata* roots (16.72 g/kg) significantly decreased at the end of C4 compared to C1 (Fig. 2G).

Similar to the Ca content, there was no significant difference (p>0.05) in the Mg concentration of *I. pseudacorus* and *I. sibirica* 'Perry's Blue' roots (14.92-26.88 g/kg and 18.16-27.50 g/kg, respectively) concerning the duration of species exposure to polluted water (Fig. 2C and Fig. 2D, respectively). The same trend was also noted for Mg concentration in *P. australis* roots (3.39-4.13 g/kg) (Fig. 2A). A significant decrease in Mg concentration in *C. indica* roots at the end of C1, C2, and C3 was observed when compared to the Mg content in roots (9.85 g/kg) sampled before the beginning of the experiment (C0) (Fig. 2B). However, at the end of the experimental period (C4), there was no significant difference (p>0.05) in root Mg concentration compared to C0 (Fig. 2B). Species *A. plantago-aquatica* contained significantly higher Mg concentration in roots (6.73 g/kg) at the end of C4 compared to C3 (Fig. 2E). Significantly lower Mg concentrations were detected in roots of *L. salicaria* and *M. trifoliata* (2.60 g/kg and 2.12 g/kg, respectively) at the end of C4 compared to the first treatment cycle (C1) (Fig. 2F and Fig. 2G).

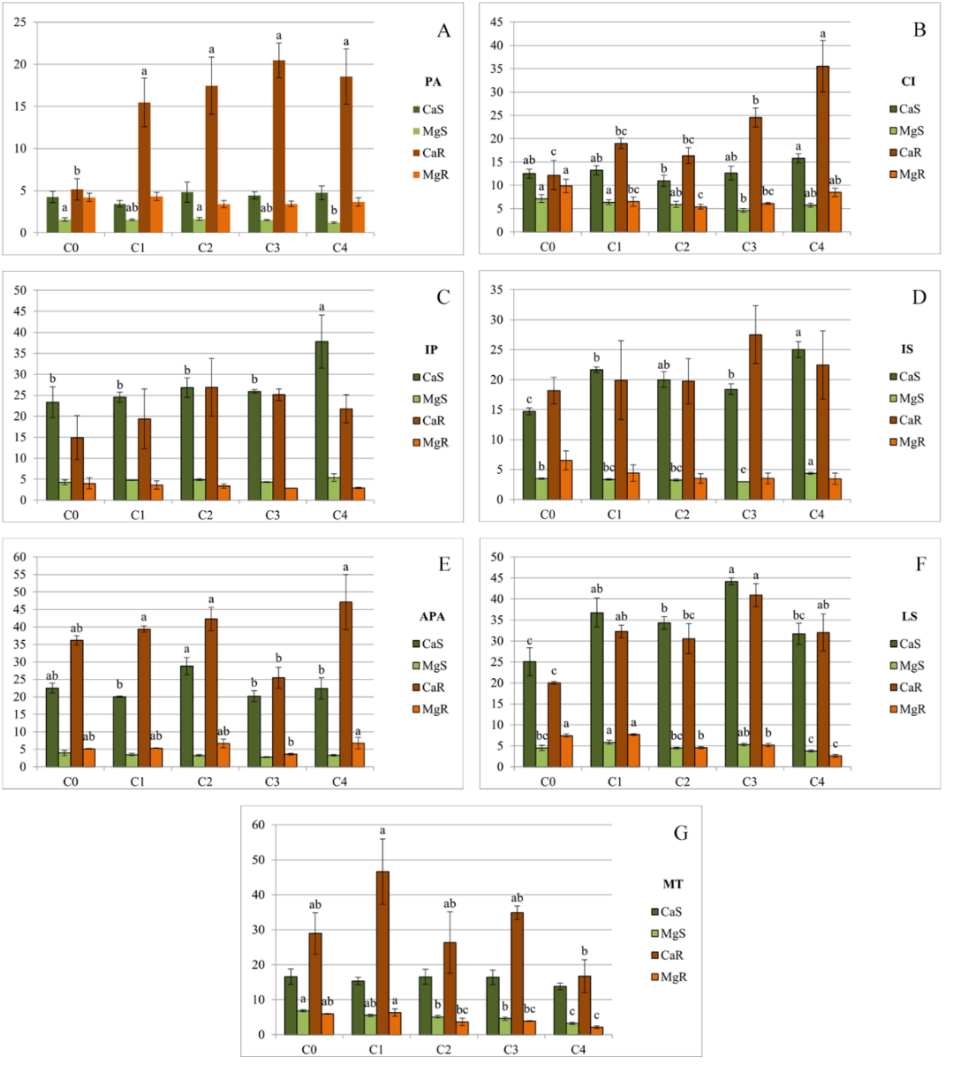


**Figure 2 A-G** *The concentration of Ca and Mg in shoots and roots (g/kg) of selected plant species in relation to treatment cycle.*

One-way analysis of variance (ANOVA I). Factor treatment cycle with 5 levels: C0 - the beginning of the experiment, C1 - 1st treatment cycle, C2 - 2nd treatment cycle, C3 - 3rd treatment cycle, C4 - 4th treatment cycle; plant species: PA - *Phragmites australis* (Cav.) Trin. ex Steud., CI - *Canna indica* L., IP - *Iris pseudacorus* L., IS - *Iris sibirica* 'Perry's Blue', APA - *Alisma plantago-aquatica* L., LS - *Lythrum salicaria* L., MT - *Menyanthes trifoliata* L.; CaS - concentration of Ca in the shoot, MgS - concentration of Mg in the shoot, CaR - concentration of Ca in the root, MgR - concentration of Mg in the root. Each value represents the mean value ± SE; Within each series mean values with a different letter are significantly different ($p<0.05$).

Table 3 presents the results obtained from the analysis of Ca and Mg concentrations in algae of the genus *Cladophora* sp. across different treatment cycles. There is a noticeable increase in Ca concentration in *Cladophora* sp. corresponding to the duration of exposure to polluted water. The highest Ca concentration, reaching 255.00 g/kg, was observed in C1. Conversely, a marked decrease in Mg concentration in algal tissue was observed from one treatment cycle to the next. At the end of the experimental period (C4), *Cladophora* sp. had the lowest Mg content of 2.67 g/kg.

**Table 3.** *Concentration of Ca and Mg in algae in relation to treatment cycle.*

| Treatment cycles | C0 | C1 | C2 | C3 | C4 |
|---|---|---|---|---|---|
| Ca concentration (g/kg) | 186.45 | 255.00 | 234.84 | 197.27 | 252.80 |
| Mg concentration (g/kg) | 6.96 | 6.30 | 5.06 | 3.39 | 2.67 |

Each value represents the value of a composite sample taken from 5 spots in Cell V. C0 - the beginning of the experiment, C1 - 1st treatment cycle, C2 - 2nd treatment cycle, C3 - 3rd treatment cycle, C4 - 4th treatment cycle.

Table 4 provides the results obtained from the analysis of Ca and Mg concentrations in stone wool in relation to the treatment cycle. As data reveals there has been a gradual decrease in both Ca and Mg concentrations in substrate concerning the period of exposure to polluted water. Stone wool sampled just before the beginning of the experiment (C0) contained significantly higher Ca and Mg than substrate sampled at the end of the treatment cycles C3 and C4.

**Table 4.** *Concentration of Ca and Mg in stone wool in relation to treatment cycle.*

| Treatment cycles | Ca concentration (g/kg) | Mg concentration (g/kg) |
|---|---|---|
| C0 | 130,75±3,657ab | 51,66±1,356a |
| C1 | 149,06±11,056a | 57,21±1,922a |
| C2 | 129,41±4,080ab | 50,99±2,239a |
| C3 | 115,32±5,721c | 39,57±3,646b |
| C4 | 100,17±8,647c | 37,51±3,529b |
| | $^{A}F_{4,54}$=6,38* | $F_{4,54}$=9,71* |

One-way analysis of variance (ANOVA I). Factor treatment cycle with 5 levels: C0 - the beginning of the experiment, C1 - 1st treatment cycle, C2 - 2nd treatment cycle, C3 - 3rd treatment cycle, C4 - 4th treatment cycle. Each value represents the mean value ± SE; Within each series mean values with a different letter are significantly different ($p<0.05$). $^{A}$= *F*-test indicator with a number of degrees of freedom; ns = not significantly different ($p>0.05$); * = significantly different ($p<0.05$).

## 4. DISCUSSION

The observed changes in pH values throughout the FTW provide valuable insights into the water treatment process. The presented results indicate that both polluted and treated water exhibited characteristics consistent with a mildly alkaline environment. The influent pH established the initial conditions of the water under study. The observed decline in pH values within the effluent of all cells with floating islands during the initial six days of treatment suggests a dynamic response to the introduced phytoremediation processes. These results reflect those of White and Cousins (2013) who also observed lower pH in planted FTWs in their experiments. The decrease in pH values indicates the removal of alkaline substances from the polluted water. This could be attributed to various factors associated with the treatment mechanisms, such as microbial activity, plant uptake, or chemical reactions occurring within the floating treatment wetlands. According to Gao et al. (2017), one of these mechanisms involves nitrification, where the conversion of ammonium to nitrate by nitrifying bacteria results in proton consumption, ultimately causing a decrease in pH. Additionally, the breakdown of organic matter releases protons, augmenting the decline in pH (Ijaz et al., 2015). This alteration may also be attributed to the discharge of $CO_2$ and acidic exudates during plant root system respiration (Iamchaturapatr et al., 2007). Lastly, Sharma et al. (2021) propose that floating islands host diverse microorganisms capable of exchanging cations (e.g., $H^+$ for $Ca^{2+}$ or $Mg^{2+}$) with the surrounding water, potentially leading to a reduction in pH. The subsequent increase in pH values upon passing through cell V with algae in all treatment cycles indicates the potential role of algae in modifying water chemistry. Algae are known to influence pH through photosynthetic activity, where carbon dioxide uptake during photosynthesis can elevate pH levels (Kadlec and Wallace, 2008). Also, algae utilize various nutrients from the water, including bicarbonate ions (Gao, 2021). Removal of these ions can shift the carbonate equilibrium towards the less acidic forms, increasing pH. The pH values ranging from 7.79 to 8.43 demonstrate the buffering effect of algae within the treatment system, contributing to the restoration of a more neutral pH range.

The presented results provide valuable insights into the dissolved oxygen (DO) dynamics within the floating treatment wetland. The dissolved oxygen content in water depends on water temperature, salinity, turbulence, atmospheric pressure and photosynthetic activity of algae and plants (Chapman and Kimstach, 1996). The solubility of oxygen in water decreases with increasing salinity and temperature (Marks, 2008). Looking at Figure 1, there is no clear evidence that water temperature had a decisive influence on DO levels in cells with floating islands. A possible explanation for extremely low DO levels is a lack of aeration and free water surface in these cells. These results reflect those of (Chance and White, 2018) who also found that DO level in non-aerated FTW was less influenced by temperature but more by cell coverage percent. The higher the cell coverage percent, the more atmospheric diffusion is restricted by vegetation, and therefore the DO concentration is lower (Pavlineri et al., 2017). It can thus be suggested that 100% coverage of cells with floating islands, as well as the high consumption of oxygen during the decomposition of organic matter (Radwan et al., 2003), led to extremely low DO levels. Chance and White (2018) further suggested that as temperatures declined DO in non-aerated FTW appeared to be more influenced by temperature. This fact can explain the higher DO concentration in cell III and cell IV in the last treatment cycle (C4) when the water temperature was below 15°C. Another possible explanation for this is that at temperatures below 15°C, the activity of microorganisms that decompose organic matter slows down (Kumarathilaka et al., 2017), so the consumption of oxygen is lower. Treated water was enriched with additional amounts of oxygen after passing polishing treatment in cell V. Several factors can explain this fact. In addition to removing various pollutants, algae can enhance oxygen levels in water through photosynthesis (Kadlec and Wallace, 2008) and the most oxygen is released during the period of rapid algal growth (Marks, 2008). Algal biomass was not monitored during the water treatment. However, based on the photo documentation from the beginning and the end of the treatment period, it can be stated that the algae had a significant increase in biomass. Even lower water and air temperatures in early October did not hinder the algae growth resulting in the highest DO levels in this period. It is also possible that higher DO levels occurred as a result of water inlet construction which led to good aeration of cell V. Furthermore, the large free water surface could also enable the additional introduction of oxygen into this cell through the creation of numerous opportunities for contact between water and air (Wu et al., 2001). Taken together, these factors simultaneously with the influence of lower temperature can explain the occurrence of supersaturation in the last two treatment cycles (C3 and C4).

The findings of this study provide insights into the dynamics of Ca and Mg within the FTW, illustrating the influence of treatment cycles on the concentration and efficiency of Ca and Mg removal. It is worth noting that limited knowledge exists regarding the fate and removal mechanisms of these ions in FTWs. Additionally, direct comparisons with the behavior of Ca and Mg in constructed wetlands are not meaningful due to fundamental differences in the systems. Constructed wetlands typically employ a substrate of gravel, sand, or soil to support plant growth and microbial activity. However, FTWs utilize floating islands with plant roots directly submerged in the water column. This distinct configuration likely influences the processes and pathways associated with Ca and Mg removal.

The influent Ca concentrations establish the starting point for evaluating the treatment efficiency. The initial observation of a slight increase in Ca concentration across all cells after the first six days of treatment in C1 and C2 could indicate a potential adjustment phase in the FTW. Notably, cells II and III show low Ca removal efficiency, emphasizing the need for further investigation into the specific factors affecting these cells. A positive trend emerges in subsequent treatment cycles (C3 and C4), with a gradual increase in Ca removal efficiency across all cells with floating islands. The range of 2% to 6% efficiency indicates an improving trend, culminating in the highest efficiency recorded in C4, particularly in Cell II planted with *C. indica*. This could underscore the influence of plant species on enhancing the removal of Ca from water. An interesting finding is the significant reduction in Ca content observed exclusively in the cell with algae (Cell V) at the end of all treatment cycles (C1-C4). This emphasizes the unique contribution of algae to Ca removal, potentially through biological interactions or specific biochemical processes. In contrast to Ca, the results for Mg reveal a notable absence or low reduction rate in all cells. A slight reduction in Mg content is noted in C3 and C4 in cell I-IV, with Mg removal efficiencies ranging from 1% to 4%. This modest reduction could suggest challenges or limitations in Mg removal within the FTW. The highest Mg removal efficiency of 6% is achieved in Cell V at the end of C4, indicating the potential efficacy of algae in Mg removal. Despite the limited research, this study demonstrates the potential of FTWs for Ca removal, achieving overall efficiencies ranging from 23% to 48%, with the most significant reduction observed at the end of C3. The findings suggest that microbial activity, plant uptake, and algal bioremediation all contribute to this removal process. However, Mg removal efficiency remained significantly lower, ranging from 1% to 6%, highlighting the need for further research to improve Mg removal in FTWs.

The analysis of the effects of treatment cycles on the concentration of Ca and Mg in the shoots and roots of selected plant species provides valuable insights into the response of these plants to exposure to polluted water over different treatment periods. The results revealed significant variations in the concentrations of both elements across different plant species and treatment cycles.

*P. australis* and *M. trifoliata* exhibited a consistent Ca concentration in shoots throughout the exposure, suggesting resilience to the duration of exposure to polluted water. Conversely, *C. indica*, *I. pseudacorus*, and *I. sibirica* 'Perry's Blue' displayed a significant accumulation of Ca in their shoots by the end of C4, signifying a potential adaptive response or physiological adjustment (Barker and Pilbeam, 2006) to prolonged exposure. *A. plantago-aquatica* demonstrated a spike in shoot Ca concentration at the end of C2. Similarly, *L. salicaria* exhibited a substantial increase in Ca concentration at the end of C3, surpassing levels observed in other treatment cycles. These differences underscore the dynamic nature of plant responses to water quality conditions and varying rates of Ca supply, with different species manifesting unique adaptations (Loneragan and Snowball, 1969). The roots of *I. pseudacorus* and *I. sibirica 'Perry's Blue'* maintained consistent Ca levels across the treatment cycles, emphasizing a stable response to polluted water exposure. In contrast, *P. australis* roots exhibited a significant increase in root Ca concentration throughout C1-C4, indicating an efficient uptake mechanism. *C. indica* roots displayed a notable accumulation of Ca at the end of C4, suggesting a potential role in the remediation process. Conversely, *A. plantago-aquatica* roots showed a decline in Ca concentration, possibly indicating a dynamic response unique to this species. *L. salicaria* roots exhibited an increase in Ca content toward the end of the experiment, emphasizing the species-specific dynamics of root ion accumulation (Barker and Pilbeam, 2006).

Turning to Mg concentrations, the study found consistent levels in *I. pseudacorus* and *A. plantago-aquatica* shoots, highlighting their stability in the face of varying exposure periods. A notable increase in Mg concentration was observed only in *I. sibirica* 'Perry's Blue' shoots at the end of C4, signifying a species-specific response (Barker and Pilbeam, 2006; Schwab et al., 2000). *C. indica* shoots exhibited a decline in Mg concentration at the end of C3, suggesting a potential influence of treatment cycles on Mg dynamics. The observed decrease in Mg content in the shoots of *P. australis*, *L. salicaria,* and *M. trifoliata* at the end of C4 could also indicate a dynamic species-specific response to prolonged exposure. Regarding this, prior studies have highlighted that the uptake and accumulation of magnesium can vary across distinct phases of physiological development (Schwab et al., 2000; Mills and Scoggins, 1998). Additionally, these processes can be influenced by an antagonistic relationship between magnesium ions and other cations, including hydrogen, ammonium, calcium, potassium, aluminum, or sodium (Mills and Jones, 1996). The investigation into Mg concentrations in roots revealed consistent levels in *P. australis*, *I. pseudacorus* and *I. sibirica* 'Perry's Blue'. *A. plantago-aquatica* roots displayed an increase in Mg concentration at the end of C4, indicating a distinct pattern in root ion uptake dynamics. Conversely, *C. indica* roots exhibited a decrease in Mg content at the end of C1-C3, emphasizing the variability in root responses. *L. salicaria* and *M. trifoliata* roots showed a decline in Mg concentration at the end of C4, signifying a nuanced response to prolonged exposure. The observed species-specific patterns in root Mg accumulation highlight the complex interplay between plant physiology and environmental conditions (Barker and Pilbeam, 2006).

The results of this study highlight the contrasting dynamics of Ca and Mg accumulation in algae belonging to the genus *Cladophora* sp. exposed to polluted water for different durations. *Cladophora* sp. exhibited an increase in Ca concentration over time, with the highest content of 255.00 g/kg observed in the first treatment cycle (C1). This suggests a rapid uptake and accumulation of Ca by the algae, as algae are known to exhibit rapid responses to their environmental conditions. The reasons for this increased Ca accumulation could include active uptake, passive adsorption, and precipitation. Although algae, unlike plants, need calcium only as a micronutrient (Knight et al., 1973) *Cladophora* sp. may actively take up Ca for various metabolic processes, such as cell wall formation and calcium carbonate precipitation (Barker and Pilbeam, 2006). Also, Ca ions in the polluted water may bind to the surfaces of *Cladophora* sp. cells through passive adsorption processes or precipitate on the surface of algae cells due to changes in water chemistry or biological processes within the algae (Chen et al., 2023). In contrast to Ca, *Cladophora* sp. displayed a marked decrease in Mg concentration throughout the experiment. This finding was unexpected, and the lowest Mg content of 2.67 g/kg was observed at the end of the final treatment cycle (C4).

The presented results offer insights into the dynamics of Ca and Mg concentrations in stone wool concerning different treatment cycles. The data indicates a significant reduction in both Ca and Mg concentrations within the substrate corresponding to the duration of exposure to polluted water. Specifically, stone wool sampled at the beginning of the experiment (C0) exhibited significantly higher concentrations of both Ca and Mg compared to samples taken at the end of treatment cycles C3 and C4. It could be argued that the observed decrease in Ca and Mg concentrations in stone wool could be attributed to either the leaching of these elements into the water or the reduced concentration in the substrate resulting from the uptake of these elements by plants. However, drawing a definitive conclusion from the findings of this study proves challenging.

## 5. CONCLUSION

This study provided a comprehensive examination of the dynamic responses within a floating treatment wetland, focusing on pH, dissolved oxygen, and the dynamics of calcium and magnesium concentrations.

The observed changes in pH values reflect the influence of phytoremediation processes on water quality. The initial decline in pH within the effluent of FTW cells with floating islands during the early treatment days suggests active remediation processes, potentially involving microbial activity, plant uptake, and chemical reactions. The subsequent increase in pH values upon passing through cells with algae highlights the buffering effect of algae, contributing to the restoration of a more neutral pH range. The dissolved oxygen dynamics reveal the complex interaction of various factors, including temperature, cell coverage, and organic matter decomposition. The low DO levels in cells with floating islands and full coverage indicate challenges in oxygen diffusion. The increase in DO after passing through the cell with algae underscores the role of algae in enhancing oxygen levels through photosynthesis and nutrient uptake. The investigation into the dynamics of Ca and Mg concentrations in both water and selected plant species sheds light on the complexities of ion removal within the FTW. The study identifies a lack of research on Ca and Mg removal in FTWs, emphasizing the need for further exploration in this area. The observed increase in Ca removal efficiency across treatment cycles suggests an adaptive phase in the FTW, with notable contributions from plant species (particularly in Cell II planted with *C. indica*) and algae. However, Mg removal efficiency remains modest, indicating potential challenges in Mg removal processes within the FTWs. The analysis of plant responses to polluted water exposure reveals species-specific variations in Ca and Mg concentrations in shoots and roots. The study highlights the resilience of certain species to varying exposure periods, while others exhibit dynamic adjustments in ion accumulation. The unique patterns in root ion uptake underscore the complex interaction between plant physiology and environmental conditions. Notably, the research into algae belonging to the genus *Cladophora* sp. demonstrates a rapid uptake and accumulation of Ca, suggesting active processes such as metabolic utilization or passive adsorption. The unexpected decrease in Mg concentration in *Cladophora* sp. prompts further inquiry into the mechanisms involved in Mg dynamics within algae exposed to polluted water. The study also explores changes in Ca and Mg concentrations in stone wool, revealing a gradual decrease corresponding to exposure duration. However, the exact mechanisms leading to this reduction, whether leaching or plant uptake, remain inconclusive.

This research contributes to a better understanding of the complex dynamics of water treatment in FTWs, emphasizing the need for continued investigation into ion removal mechanisms, plant responses, and the role of algae in these biological systems. The findings provide a foundation for future research aiming to optimize FTWs for enhanced water treatment efficacy.

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# INSIGHTS INTO PH DYNAMICS, DISSOLVED OXYGEN VARIABILITY, AND ION REMOVAL EFFICIENCY IN FLOATING TREATMENT WETLAND

*Nevena ČULE, Aleksandar LUČIĆ, Marija NEŠIĆ, Ljiljana BRAŠANAC-BOSANAC, Ivana BJEDOV*


## Summary

The escalating pollution of urban rivers poses a significant threat to both the environment and public health. Addressing river pollution is imperative for ensuring sustainable urban development. In this context, floating treatment wetlands (FTW) emerge as a green and cost-effective technology that can help in the treatment of polluted water in urban areas. The aim of this paper is to analyse the dynamic responses within FTW constructed on the riverbank, focusing on pH, dissolved oxygen (DO), and the dynamics of calcium and magnesium concentrations. The pH value is an important parameter in assessing water quality, as it, like temperature, influences biological and chemical processes in water. Additionally, an essential indicator of water quality is the concentration of DO, which is influenced by factors such as temperature, salinity, turbulence, atmospheric pressure, and the photosynthetic activity of algae and plants. Calcium (Ca) and magnesium (Mg) are essential elements found in natural waters. While necessary for healthy ecosystems, their presence in excessive amounts can pose significant challenges for both water quality and life. While some studies have investigated Ca and Mg behavior in constructed wetlands, no research papers have specifically addressed the fate and removal mechanisms of these ions in FTWs. Results showed that both polluted and treated water exhibited characteristics consistent with a mildly alkaline environment. Decline of pH values within all cells with floating islands was noted. The subsequent increase in water pH values upon passing through cell with algae, ranging from 7.79 to 8.43, indicated the important role of algae. Extremely low DO levels of 0.03 mg/L - 1.43 mg/L were detected in cells with floating islands. Treated water was enriched with additional amounts of oxygen after passing polishing treatment in cell with algae resulting in DO concentrations of 5.87 mg/L - 18.77 mg/L. Calcium removal efficiency ranged from 2% to 6% in cells with floating islands. A significant reduction of the Ca content in the water occurred in the cell with algae resulting in 23% to 49% FTW Ca removal efficiency. The modest FTW Mg removal efficiency of 1-6% could indicate potential challenges in Mg removal processes within the FTWs. The analysis of plant responses to polluted water exposure reveals species-specific variations in Ca and Mg concentrations in shoots and roots. The research highlights the resilience of certain species to exposure periods, while others exhibit dynamic adjustments in ion accumulation. Algae demonstrated a rapid uptake and accumulation of Ca, with the increase Ca concentration in algae tissue over time. However, an unexpected decrease in Mg concentration occurred. The study also revealed a gradual decrease of Ca and Mg concentration in stone wool corresponding to exposure duration. The exact mechanisms leading to this reduction, whether leaching or plant uptake, remain inconclusive. This study offers valuable insights into the dynamics of FTW water treatment, demonstrating the need for continued research on ion removal mechanisms, plant-pollutant interactions, and the role of algae.

# UVIDI U DINAMIKU pH, VARIJABILNOST RASTVORENOG KISEONIKA I EFIKASNOST UKLANJANJA JONA U BIOLOŠKOM SISTEMU SA PLUTAJUĆIM OSTRVIMA

*Nevena ČULE, Aleksandar LUČIĆ, Marija NEŠIĆ, Ljiljana BRAŠANAC-BOSANAC, Ivana BJEDOV*

## Rezime

Sve veće zagađenje urbanih reka predstavlja značajnu pretnju i životnoj sredini i zdravlju. Rešavanje problema zagađenja reka je imperativ za osiguranje održivog urbanog razvoja. U tom kontekstu, biološki sistemi sa plutajućim ostrvima (FTW) se pojavljuju kao zelena i isplativa tehnologija, koja može da pomogne u tretmanu zagađene vode u urbanim područjima. Cilj ovog rada je analiza dinamičkih procesa u FTW konstruisanog na obali reke, sa fokusom na pH, rastvoreni kiseonik (DO) i promenu koncentracija kalcijuma i magnezijuma. pH vrednost je važan parametar u proceni kvaliteta vode, jer kao i temperatura, utiče na biološke i hemijske procese u vodi. Takođe, značajan indikator kvaliteta vode je koncentracija DO, na koju utiču faktori kao što su temperatura, salinitet, turbulencija, atmosferski pritisak i fotosintetička aktivnost algi i biljaka. Kalcijum (Ca) i magnezijum (Mg) su esencijalni elementi, koji se nalaze u prirodnim vodama. Iako su neophodno za održivost ekosistema, njihovo prisustvo u prevelikim koncentracijama može da predstavlja značajne izazove za kvalitet vode. Iako su neke studije istraživale ponašanje Ca i Mg u konstruisanim akvatičnim ekosistemima, nijedna se nije posebno bavila mehanizmima uklanjanja ovih jona u FTW. Rezultati su pokazali da i zagađena i prečišćena voda pokazuju karakteristike slabo alkalne sredine. Uočen je pad pH vrednosti u svim bazenima sa plutajućim ostrvima. Naknadno povećanje pH vrednosti vode pri prolasku kroz bazen sa algama, u rasponu od 7,79 do 8,43, ukazuje na značajnu ulogu algi. Ekstremno nizak nivo DO od 0,03 mg/L - 1,43 mg/L detektovan je u bazenima sa plutajućim ostrvima. Tretirana voda je obogaćena dodatnim količinama kiseonika nakon prolaska tretmana poliranja u bazenu sa algama što je rezultiralo koncentracijom DO od 5,87 mg/L - 18,77 mg/L. Efikasnost uklanjanja Ca kretala se od 2% do 6% u bazenima sa plutajućim ostrvima. Do značajnog smanjenja sadržaja Ca u vodi došlo je u bazenu sa algama, što je rezultiralo efikasnošću uklanjanja Ca od 23% do 49% u FTW. Mala efikasnost uklanjanja Mg u FTW od 1-6% mogla bi da ukaže na potencijalne probleme u procesima uklanjanja Mg unutar ovih bioloških sistema. Analiza odgovora biljaka na izlaganje zagađenoj vodi otkriva varijacije specifične za vrste u koncentracijama Ca i Mg u izdancima i korenu. Istraživanje naglašava otpornost određenih vrsta na dužinu izlaganja zagađenoj vodi, ali i dinamička prilagođavanja drugih vrsta u akumulaciji jona. Alge su pokazale brzo usvajanje i akumulaciju Ca, uz povećanje koncentracije Ca u tkivu algi tokom vremena. Međutim, došlo je do neočekivanog smanjenja koncentracije Mg. Istraživanje je takođe pokazalo postepeno smanjenje koncentracije Ca i Mg u kamenoj vuni u skladu sa trajanjem izlaganja. Tačni mehanizmi koji dovode do ovog smanjenja, bilo da se radi o ispiranju ili usvajanju od strane biljke, ostaju nejasni. Ova studija daje uvid u dinamiku tretmana vode u FTW, ukazujući na potrebu za kontinuiranim istraživanjem mehanizama uklanjanja jona, interakcija biljaka i zagađivača i uloge algi.

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# FLORISTIC DIVERSITY OF ARTIFICIALLY ESTABLISHED STANDS OF DIFFERENT CONIFEROUS SPECIES IN THE AREA OF KOSMAJ (SERBIA)

*Snežana STAJIĆ[1]*, Vlado ČOKEŠA[1], Saša EREMIJA[1], Zoran MILETIĆ[1], Ljubinko RAKONJAC[1], Nikola MARTAĆ[1], Jelena BOŽOVIĆ[1]*

**Abstract:** *One of the causes of decrease of species diversity of forest ecosystems could be inadequate selection of tree species for afforestation and ameliorations. It is known that by establishing new forest ecosystem habitat conditions change, and thus, edaphic and hydrological conditions and light regime also change, which directly or indirectly reflects on plant species. The research included four artificially established stands (pure or mixed) in the area of Kosmaj, where various coniferous species were introduced in the process of substitution of autochthonous forests of Hungarian oak and Turkey oak. The largest total number of plant species was recorded in artificially established stand of common spruce, Atlas cedar, and Douglas-fir (41). The highest Shannon-Wiener diversity index was recorded in stand of Douglas-fir (3.22), and the lowest in pine stands (2.95-2.97). It was determined by cluster analysis that stand of Austrian pine and stand of Austrian pine and Scots pine have the largest degree of mutual floristic similarity.*

**Keywords:** Substitution, plant diversity, floristic similarity, Kosmaj, Serbia

# FLORISTIČKI DIVERZITET VEŠTAČKI PODIGNUTIH SASTOJINA RAZLIČITIH VRSTA ČETINARA NA PODRUČJU KOSMAJA (SRBIJA)

**Sažetak:** *Jedan od uzroka smanjenja specijskog diverziteta šumskih ekosistema može biti neadekvatan izbor vrsta drveća za pošumljavanje i melioracije. Poznato je da se uspostavljanjem novog šumskog ekosistema menjaju stanišni uslovi, a samim tim bivaju promenjeni edafski i hidrološki uslovi i režim svetlosti, što se neposredno ili posredno manifestuje na biljne vrste. Istraživanjem su obuhvaćene 4 veštački podignute sastojine (čiste ili mešovite) na području Kosmaja, gde su u postupku supstitucije autohtonih šuma sladuna i cera unešene različite vrste četinara. Najveći ukupan broj vrsta biljaka registrovan je u veštački podignutoj sastojini smrče, atlaskog kedra i duglazije (41). Najveći Shannon-Wiener indeks diverziteta konstatovan je u veštački podignutoj sastojini duglazije (3.22), a najmanji u sastojinama borova (2.95-2.97). Klaster analizom je utvrđeno da najveći stepen međusobne florističke sličnosti imaju veštački podignuta sastojina crnog bora i sastojina crnog i belog bora.*

**Ključne reči:** Supstitucija, diverzitet biljaka, floristička sličnost, Kosmaj, Srbija

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[1]Institute of Forestry, Kneza Viseslava 3, 11030 Belgrade, Serbia
*Corresponding author. E-mail: snezanastajic@yahoo.com

## 1. INTRODUCTION

The previous criteria for introduction of various coniferous species in the belt of oak and beech forests in the territory of Serbia, in the middle of last century were largely based on the strategy of introduction of coniferous species. Introduction of coniferous species into conditions most frequently inadequate for them, influenced the resistance of these stands to various disturbances, such as extreme weather disasters, insects, fungi, and the like, thus also occurrence of die-back and decline of these cultures. Die-back of coniferous cultures in Serbia is recorded especially in the period following 2011, and the most affected were artificially established stands of Scots pine, Austrian pine, common spruce, Douglas-fir and fir, whereby the causes of die-back were very complex and include a large number of biotic and abiotic factors. (Tabaković-Tošić et al., 2016).

By changing tree species in the amelioration procedures of coppice and degraded forests, the habitat conditions are changed simultaneously. That reflects directly or indirectly on plant species, so in the majority of cases a change and significant decrease of number of species of ground vegetation occur, i.e. decrease of species diversity. At the same time, in some cases a number of invasive species increases. Changes that occur are very fast especially in the first years after the felling. In reforested forests the intensity of light is increased (Levine & Feller, 2004), and also the influence of anthropogenic factor (Decker et al., 2012) as well as the quantity of nutrients in the soil caused by accelerated decomposition of litterfall (Huebner and Tobin, 2006). In such changed conditions, in the first steps of succession increase of species diversity takes place, and only after prolonged action of negative factors significant decrease of number of species occurs in the newly created ecosystems (Lakušić, 2005).

The proper selection of tree species in afforestation or amelioration of degraded forests, along with the adequate management methods, provides the improvement of biological diversity, and simultaneous preservation of endangered and rare plant species. Therefore, the object of this paper is to determine to what extent the establishing of coniferous plantation in the researched area of Kosmaj had an impact on their floristic composition, mutual differences and diversity of these forests in general.

## 2. MATERIAL AND METHODS

Kosmaj is low and in terms of area relatively small mountain situated 40 km southeast from Belgrade. Larger part of this mountain has been protected as an area of outstanding natural landscape since 2005. In the protected area of Kosmaj in amelioration procedures of coppice forest various species of conifers were used in the previous period. They were most frequently planted in different combinations, sometimes mixed with deciduous trees and on very small areas.

This research includes four artificially established stands of various species of conifers:

a) common spruce (*Picea abies* (L.) Karst), Atlas cedar (*Cedrus atlantica* (Endl.) Carrière) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco);

b) Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco);

c) Austrian pine (*Pinus nigra* Arnold);
d) Austrian pine *(Pinus nigra* Arnold) and Scots pine (*Pinus sylvestris* L.)

For the analysis of the floristic composition of the researched stands relevés were made according to the standard method of Braun Blanquet (Braun–Blanquet,1964). Initial phase in the statistical processing of phytocoenological data was presented by conversion of values for relative abundance and coverage of the species in stands from alphanumeric Braun-Blanquet scale to numeric Van Der Maarel scale (1979). For calculation of diversity index (*Shannon-Wiener* diversity index) and evenness index (*Evenness*) program for data processing in phytocoenology Juice 7.0 (Tichý, 2002) was used. The cluster analysis was done by means of a program package for ecological research Biodiversity Pro (McAleece et al., 1997), where the similarity in floristic composition between the researched stands of conifers was determined using hierarchical classification analysis and the Bray-Curtis similarity index.

## 3. RESULTS

The researched artificially established stands of conifers are located in similar environmental conditions – on elevations from 360 to 462 m, on different exposures and slopes from 11 to 19º (Table 1). The parent rock are flysch formations, and the soil is eutric cambisol in all cases. Based on the analysis of floristic composition it has been determined that all of them are established on the habitat of Hungarian oak and Turkey oak - *Quercetum frainetto-cerridis* Rudski 1949.

**Table 1.** *Basic ecological characteristics of the habitat*

| Artificially established stands | Age (years) | Elevation (m) | Exposure | Slope (°) | Parent rock | Soil |
|---|---|---|---|---|---|---|
| *Picea abies,*<br>*Cedrus atlantica*<br>*Pseudotsuga menziesii* | 40-45 | 462 | SW | 19 | Flysch | Eutric cambisol |
| *Pseudotsuga menziesii* | 40 | 433 | W | 16 | Flysch | Eutric cambisol |
| *Pinus nigra* | 66 | 444 | N | 12 | Flysch | Eutric cambisol |
| *Pinus nigra*<br>*Pinus sylvestris* | 65-30 | 360 | NE-E | 11 | Flysch | Eutric cambisol |

### 3.1. Floristic composition

The floristic composition of the researched stands is presented in Table 2. In the tree layer, in addition to the artificially introduced species of conifers (*Picea abies*, *Cedrus atlantica*, *Pseudotsuga menziesii*, *Pinus nigra*, *Pinus sylvestris*) and pedunculate oak (*Quercus robur* L.), 10 more woody species are present. In the shrub layer, whose coverage amounts from 0.1 to 0.3, 15 species in total can be found of various shrubs and the most represented are *Prunus avium* L., *Crataegus monogyna* Jacq. and *Fraxinus ornus* L.

The ground flora layer is relatively rich, especially in thinned stands, and the total number of ground flora species that were found amounts to 79. The coverage of ground flora in the researched stands ranges from 0.6 to 0.8.

**Table 2.** *Floristic composition of artificially established stands of conifers*

| Species | Family | *Picea abies, Cedrus atlantica, Pseudotsuga menziesii* | *Pseudotsuga menziesii* | *Pinus nigra* | *Pinus nigra Pinus sylvestris* |
|---|---|---|---|---|---|
| *Acer campestre* | *Aceraceae* | + | + | + | + |
| *Acer pseudoplatanus* | *Aceraceae* | + | + | | |
| *Acer tataricum* | *Aceraceae* | | | | + |
| *Ajuga reptans* | *Lamiaceae* | + | | | |
| *Alliaria petiolate* | *Brassicaceae* | | | | + |
| *Aremonia agrimonoides* | *Rosaceae* | | | + | |
| *Arum maculatum* | *Araceae* | + | | | |
| *Astragalus glycyphyllos* | *Fabaceae* | | + | | |
| *Betula pendula* | *Betulacea* | | + | | |
| *Bilderdykia convolvulus* | *Polygonaceae* | | | | + |
| *Brachypodium sylvaticum* | *Poaceae* | + | + | + | + |
| *Calamintha vulgaris* | *Lamiaceae* | + | + | | |
| *Campanula persicifolia* | *Campanulaceae* | | + | | |
| *Cardamine bulbifera* | *Brassicaceae* | + | | + | |
| *Carex pendula* | *Cyperaceae* | | | + | |
| *Carex sylvatica* | *Cyperaceae* | + | + | + | |
| *Cedrus atlantica* | *Pinaceae* | + | + | | |
| *Chamaecytisus supinus* | *Fabaceae* | | + | | |
| *Circaea lutetiana* | *Oenotheraceae* | + | | + | |
| *Clematis vitalba* | *Ranunculaceae* | + | + | + | |
| *Cornus mas* | *Cornaceae* | | | | + |
| *Cornus sanguinea* | *Cornaceae* | | + | + | |
| *Crataegus monogyna* | *Rosaceae* | + | + | + | + |
| *Danaa cornubiensis* | *Apiaceae* | + | | | + |
| *Dryopteris filix-mas* | *Aspidiaceae* | | + | + | |
| *Euphorbia amygdaloides* | *Euphorbiaceae* | + | | | + |
| *Fagus moesiaca* | *Fagaceae* | | + | + | |
| *Fragaria vesca* | *Rosaceae* | + | + | | |
| *Fraxinus ornus* | *Oleaceae* | | + | + | + |
| *Galeopsis speciose* | *Lamiaceae* | | | + | + |
| *Galium aparine* | *Rubiaceae* | + | | + | |
| *Galium schultesii* | *Rubiaceae* | + | | | + |
| *Geranium robertianum* | *Geraniaceae* | + | + | + | + |
| *Glechoma hirsute* | *Lamiaceae* | + | + | + | |
| *Hedera helix* | *Araliaceae* | + | + | | + |
| *Helleborus odorus* | *Ranunculaceae* | + | + | + | + |
| *Hieracium sabaudum* | *Asteraceae* | | + | | |
| *Hypericum hirsutum* | *Hypericaceae* | + | | | |
| *Inula conyza* | *Asteraceae* | | + | | |
| *Juglans regia* | *Juglandaceae* | | + | + | |
| *Lathyrus niger* | *Fabaceae* | | | | + |
| *Lathyrus venetus* | *Fabaceae* | + | | | + |
| *Ligustrum vulgare* | *Oleaceae* | | | + | + |
| *Lilium martagon* | *Liliaceae* | + | | | |
| *Lonicera caprifolium* | *Caprifoliaceae* | + | + | | + |
| *Lysimachia punctate* | *Primulaceae* | | | | + |
| *Melica uniflora* | *Poaceae* | | + | + | + |
| *Moehringia trinervia* | *Caryophyllaceae* | + | | + | + |
| *Mycelis muralis* | *Asteraceae* | + | + | + | + |
| *Ornithogalum pyrenaicum* | *Liliaceae* | + | | | |

| Species | Family | *Picea abies, Cedrus atlantica, Pseudotsuga menziesii* | *Pseudotsuga menziesii* | *Pinus nigra* | *Pinus nigra Pinus sylvestris* |
|---|---|---|---|---|---|
| *Picea abies* | *Pinaceae* | + | | | |
| *Pinus nigra* | *Pinaceae* | | | + | + |
| *Pinus sylvestris* | *Pinaceae* | | | | + |
| *Polygonatum odoratum* | *Asparagaceae* | + | + | | |
| *Potentilla reptans* | *Rosaceae* | | + | | |
| *Prunella vulgaris* | *Lamiaceae* | | + | | |
| *Prunus avium* | *Rosaceae* | + | + | + | + |
| *Prunus spinosa* | *Rosaceae* | | | + | + |
| *Pseudotsuga menziesii* | *Pinaceae* | + | + | | |
| *Quercus cerris* | *Fagaceae* | + | + | + | + |
| *Quercus farnetto* | *Fagaceae* | | | + | + |
| *Quercus petraea* | *Fagaceae* | | + | | |
| *Quercus robur* | *Fagaceae* | | | | + |
| *Rosa arvensis* | *Rosaceae* | | + | | |
| *Rubus caesius* | *Rosaceae* | | + | | |
| *Rubus hirtus* | *Rosaceae* | + | + | + | + |
| *Sambucus nigra* | *Sambucaceae* | + | + | | |
| *Scrophularia nodosa* | *Scrophulariaceae* | | | + | |
| *Scutellaria altissima* | *Lamiaceae* | | + | | |
| *Scutellaria columnae* | *Lamiaceae* | | | | + |
| *Stachys alpine* | *Lamiaceae* | + | | | |
| *Stachys sylvatica* | *Lamiaceae* | | | + | + |
| *Stellaria media* | *Caryophyllaceae* | + | | | |
| *Tamus communis* | *Dioscoreaceae* | + | + | + | + |
| *Tilia tomentosa* | *Tiliaceae* | + | | | + |
| *Ulmus minor* | *Ulmaceae* | | | + | + |
| *Vicia dumetorum* | *Fabaceae* | + | | | |
| *Viola alba* | *Violaceae* | | | + | |
| *Viola sylvestris* | *Violaceae* | + | | | |

## 3.2. Species richness and diversity

The largest species richness was found in mixed stand of common spruce, Atlas cedar and Douglas-fir (41), while slightly smaller number was found in the stand of Douglas-fir (40). In pine stands total number of species ranged from 34 to 35.

**Table 3.** *The average values of diversity parameters of the researched stands*

| Species | Species number | Shannon-Wiener diversity index | Evenness |
|---|---|---|---|
| *Picea abies, Cedrus atlantica, Pseudotsuga menziesii* | 41 | 3.19 | 0.83 |
| *Pseudotsuga menziesii* | 40 | 3.22 | 0.84 |
| *Pinus nigra* | 34 | 2.95 | 0.77 |
| *Pinus nigra, P. Sylvestris* | 35 | 2.97 | 0.78 |

The largest Shannon-Wiener diversity index was found in artificially established stand of Douglas-fir (3.22), slightly smaller in the mixed stand of common spruce, Atlas cedar and Douglas-fir (3.19), and the smallest in pine stands (2.95-2.97). Evenness index (*Evenness*) was largest also in Douglas-fir stand (0.84), and somewhat smaller in the mixed stand of common spruce, Atlas cedar and

Douglas-fir (0.83). The smallest values were recorded in artificially established stands of pine (0.77-0.78).

### 3.3. Floristic similarity

By cluster analysis according to Bray-Curtis (Figure 1) the largest degree of floristic similarity (more than 40%) is found in artificially established stand of Austrian pine and stand of Austrian pine and Scots pine.

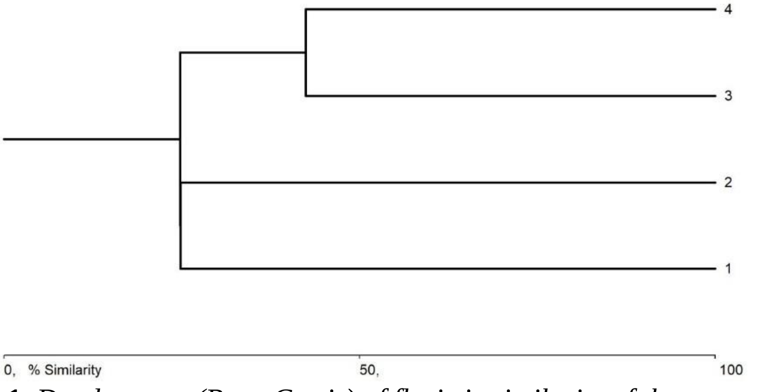


**Figure 1.** *Dendrogram (Bray-Curtis) of floristic similarity of the researched artificially established stands*

Legend: 1 – *Picea abies, Cedrus atlantica, Pseudotsuga menziesii; 2 – Pseudotsuga menziesii;3 – Pinus nigra; 4 – Pinus nigra, Pinus sylvestris*

In all other cases the degree of floristic similarity between stands of conifers is low (below 20%).

## 4. DISCUSSION

It is known that the replacement of autochthonous forest with a new tree species can reflect to ground flora and decrease of floristic diversity (Atauri et al., 2005). The artificially established stands on the researched site were exposed to different anthropogenic influence and they reacted differently to microhabitat conditions, which reflected significantly to floristic composition and diversity of these forests. Also, in recent years, there was intensive die-back of conifers in this area (Stajić, 2016). The opening of the canopy in the researched stands (due to the factors of biotic and abiotic nature) which has caused an increased inflow of light, has led to the increase of number and coverage of species, both in shrub layer and in ground flora layer. In artificially established stand of Austrian pine, as well as in mixed stand of Austrian pine and Scots pine blackberry (*Rubus hirtus* Waldst. & Kit.) formed weed coverage which indicated certain degradation of habitat, and the presence of invasive species *Alliaria petiolata* (Bieb.) Cavara & Grande was also recorded.

Species richness in natural forests of Hungarian oak and Turkey oak in this area according to a research (Stajić et al., 2021) ranged from 20 to 49 (35 in average), which was within the limits of recorded values also for the researched stands of conifers. The value of the Shannon-Wiener diversity index (H´) in autochthonous forests of Hungarian oak and Turkey oak of this area according to Stajić et al. (2021) ranged from 2.48 to 3.39 (3.04 in average). This indicated that the floristic diversity of artificially established stands of conifers slightly decreased compared to natural forests in cases where species *Pinus nigra* and *P. sylvestris* were introduced, and increased in cases of other coniferous species. Evenness index of these stands was within the limits of the values recorded for Hungarian oak and Turkey oak forests of this area (0.77 do 0.89).

Decrease of abundance and plant diversity in pine stands partly is a consequence of openning of the canopy (due to various abiotic and biotic factors), which caused certain habitat degradation and increased coverage in blackberry in ground flora layer of vegetation. The age of these stands should be taken into consideration, since the number of species and diversity decrease with the maturity of the stands.

The research of floristic diversity in artificially established stands of conifers on wider area of Serbia shows that in some cases impoverishment in floristic composition occurs, so in the stands of the species like Douglas-fir, eastern white pine, larch or common spruce many plant species characteristic of natural forests are absent (Cvjetićanin & Bjelanović, 2007; Stajić et al., 2011). At the same time, in artificially established stands of Austrian pine the increase of floristic diversity is recorded. (Novaković-Vuković *et al*., 2013). The results of the research of influence of tree species substitution on floristic diversity are quite different, both worldwide and in Serbia. What can be concluded and used as recommendation in establishing of artificially stands is partial retention and restoration of autochthonous vegetation where this is possible, as well as establishing of mixed stands using several different tree species (Horák et al., 2019).

## 5. CONCLUSION

By introducing coniferous species in the area of Kosmaj the landscape of this forest complex has been refined, not only from an aesthetic point of view, but also due to significantly wider multifunctional values, which is very significant since Kosmaj is a protected area. However, the significant participation of artificially established stands represents potentially strong threatening factor to stability of this forest complex since there has been intensive die-back of conifers in this area in recent years due to the influence of various biotic and abiotic factors.

The researched artificially established stands of conifers reacted differently on microhabitat conditions, which reflected to their floristic composition. The studies showed that the introduction of coniferous species did not have significant effect on floristic composition, plant species richness and diversity in this area. The largest *Shannon-Wiener* diversity index is registered in the artificially established stands of Douglas-fir. The decrease of diversity compared to the natural forests of this area was recorded in artificially established stand of pines. The artificially established stand of Austrian pine and a stand of Austrian pine and Scots pine showed the largest degree of floristic similarity. In other cases, this degree was low (below 20%), which was expected considering ecological-biological characteristics of introduced species.

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## FLORISTIC DIVERSITY OF ARTIFICIALLY ESTABLISHED STANDS OF DIFFERENT CONIFEROUS SPECIES IN THE AREA OF KOSMAJ (SERBIA)

*Snežana STAJIĆ, Vlado ČOKEŠA, Saša EREMIJA, Zoran MILETIĆ,*
*Ljubinko RAKONJAC, Nikola MARTAĆ, Jelena BOŽOVIĆ*

### Summary

The selection of tree species in forest management can have long-term economic and environmental consequences. By replacing the autochthonous forest with new tree species, habitat conditions change. Therefore, edaphic and hydrological conditions and light regime also change. This reflects on plant species directly or indirectly – in majority of cases change of floristic composition and plant diversity occurs. The main objective of this research has been to determine how have certain coniferous species influenced the floristic composition and diversity parameters (species richness and Shannon-Wiener diversity index) of artificially established stands in the protected area of Kosmaj (Serbia).

The research included four artificially established stands of various coniferous species: a) common spruce (*Picea abies*), Atlas cedar (*Cedrus atlantica*) and Douglas-fir (*Pseudotsuga menziesii*); b) Douglas-fir (*Pseudotsuga menziesii*); c) Austrian pine (*Pinus nigra*); d) Austrian pine and Scots pine (*Pinus nigra, Pinus sylvestris*). The stands are located in similar environmental conditions – at elevations between 360 and 462 m, different exposures and slopes from 11 to 19º. Parent rock is flysch, and soil is eutric cambisol in all cases.

The largest total number of species was recorded in the artificially established stand of common spruce, cedar and Douglas-fir (41). The highest Shannon-Wiener diversity index was recorded in the artificially established stand of Douglas-fir (3.22), and the lowest in pine stands (2.95-2.97). The cluster analysis confirmed that the artificially established stand of Austrian pine and stand of Austrian pine and Scots pine have the largest degree of mutual floristic similarity (more than 40%).

## FLORISTIČKI DIVERZITET VEŠTAČKI PODIGNUTIH SASTOJINA RAZLIČITIH VRSTA ČETINARA NA PODRUČJU KOSMAJA (SRBIJA)

*Snežana STAJIĆ, Vlado ČOKEŠA, Saša EREMIJA, Zoran MILETIĆ,*
*Ljubinko RAKONJAC, Nikola MARTAĆ, Jelena BOŽOVIĆ*

### Rezime

Izbor vrsta drveća u gazdovanju šumama može da ima dugoročne ekonomske i ekološke posledice. Zamenom autohtone šume novom vrstom drveća menjaju se stanišni uslovi, a samim tim bivaju promenjeni edafski i hidrološki uslovi i režim svetlosti. To se neposredno ili posredno manifestuje na biljne vrste – u najvećem broju slučajeva dolazi do promene florističkog sastava i diverziteta biljaka. Glavni cilj ovog istraživanja bio je da se utvrdi kako su pojedine vrste četinara uticale na floristički sastav i parametre diverziteta (species richness and *Shannon*-Wiener diversity index) veštački podignutih sastojina u zaštićenom području Kosmaja (Serbia).

Istraživanjem su obuhvaćene 4 veštački podignute sastojine različitih vrsta četinara: a) smrče (*Picea abies*), atlaskog kedra (*Cedrus atlantica*) i duglazije (*Pseudotsuga menziesii*); b) duglazije (*Pseudotsuga menziesii*); c) crnog bora *(Pinus nigra*); d) crnog i belog bora (*Pinus nigra*, *Pinus sylvestris*). Sastojine se nalaze u sličnim ekološkim uslovima-na nadmorskim visinama od 360 do 462 m, različitim ekspozicijama i nagibima od 11 do 19º. Geološka podloga je fliš, a zemljište eutrični kambisol u svim slučajevima.

Najveći ukupan broj vrsta registrovan je veštački podignutoj sastojini smrče, kedra i duglazije (41). Najveći *Shannon-Wiener* indeks diverziteta konstatovan je u veštački podignutoj sastojini duglazije (3.22), a najmanji u sastojinama bora (2.95-2.97). Klaster analizom je utvrđeno da najveći stepen međusobne florističke sličnosti (više od 40%) imaju veštački podignute sastojine crnog bora i sastojine crnog i belog bora.

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# DEGRADATION OF MOUNTAINOUS BEECH FORESTS (*Fagetum moesiacae montanum* B. Jov. 1953) IN THE SOUTHWEST SERBIA

*Ljubinko RAKONJAC[1], Vladan POPOVIĆ[1], Tatjana ĆIRKOVIĆ-MITROVIĆ[1]*, Snežana STAJIĆ[1], Vanja STOJANOVIĆ[1], Aleksandar LUČIĆ[1]*

**Abstract:** *The degradation of mountainous beech forests in various habitat conditions in the territory of southwest Serbia is presented in this paper. Various forms of degradation on limestone and acid siliceous rocks are especially highlighted. Considering the different conditions relating to the parent rock and soil characteristics, the phases of degradation differ significantly. The research area is the wider area of Peštersko-sjenički plateau with the slopes of the surrounding mountains, so it can be said that it represents southwest Serbia.*
**Keywords:** degradation, beech, habitat, southwest Serbia.

# DEGRADACIJA PLANINSKIH ŠUMA BUKVE (*Fagetum moesiacae montanum* B. Jov. 1953) U JUGOZAPADNOJ SRBIJI

**Sažetak:** *U radu je prikazana degradacija planinskih šuma bukve u različitim uslovima staništa na području jugozapadne Srbije. Posebno su istaknuti različiti oblici degradacije na krečnjacima i na kiselim silikatnim stenama. S obzirom na različite uslove koji se odnose na geološku podlogu i na karakteristike zemljišta, faze degradacije se bitno razlikuju. Oblast istraživanja je šire područje Peštersko-sjeničke visoravni sa ograncima okolnih planina, tako da se može reći da ono reprezentuje jugozapadnu Srbiju.*
**Ključne reči:** degradacija, bukva, stanište, jugozapadna Srbija.

## 1. INTRODUCTION

The vegetation succession is a long-term process, and Mišić (1962, 1964) dealt with origin, succession and degradation of forest vegetation in Serbia in the middle of the last century. Some of the research of succession of European vegetation was dealt with by Horvat et al. (1974) in the Southeast Europe, Jávorka and Csapody (1979) in Central Europe, and Tomić (1992) researched phytocoenoses in Serbia.

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

Although beech is the most abundant tree species in Serbia, and its ecological and economic importance is huge, the degradation of forests of this species is increasingly present, and the annual degree of afforestation with beech is low (Ćirković-Mitrović et al, 2022). By destroying vegetation, primarily by excessive felling, improper cultivation of steep slopes, deterioration of physical and chemical properties of the soil and the like, man has become the main factor in general degradation of the soil and the environment. Sprout forests and degraded forests are treated as an ecosystem burdened by anthropogenic influence, but the influence of some environmental factors is not excluded. By disruption of only one part of the ecosystem other segments are also disturbed in different scope and intensity. The disruption of stand canopy leads to changes and disruption of the soil solum, which has a backward effect on the state of vegetation. Furthermore, steep slopes, shallow and skeletal soils on limestone worsen the living conditions, so beech forests in such habitats are rather unstable forest ecosystems subject to degradations (Tomić, 2006).

Negative anthropogenic influences which lead to regressive succession of the ecosystem, simultaneously lead to the decrease of species diversity (Lakušić, 2005). The trend of afforestation of beech habitats by coniferous trees, which was particularly pronounced in the second half of the 20$^{th}$ century in the territory of the whole Serbia, in some cases may lead to decrease of floristic diversity and occurrence of degradation (Cvjetićanin, Bjelanović, 2007; Stajić et al., 2022).

By adopting the ecological aspect in renewal of forests, degraded forest ecosystems should return to the original state or state that is the least distant from it, which requires research of the way of origin, the estimate of current state and estimate of the trend of ecosystem development, with and without additional anthropogenic influences. The process of regressive succession of forest ecosystems is best reflected through regressive succession of vegetation. Defining the degree of degradation of certain phytocoenoses through study of degradation stages and phases is one of the most important prerequisites for the correct selection of tree species for afforestation and ameliorations (Tomić et al., 2011). In succession of vegetation, it is important to study primeval forests, completely natural ecosystems in which there were no interventions of any kind carried out by humans. The laws by which forest stands grow and regenerate are visible in them (Martać et al., 2022).

Mixed deciduous-coniferous forests and beech forests have been under great negative effects and were massively destroyed in the researched area. Beech formed with Norway spruce and fir mixed forests of the shallow karst of southwest Serbia. Nevertheless, beech forests as a member of paleogenetic forests of this area, persisted a little longer and on larger areas, although they are mostly sprout forests by origin and predominantly degraded. On limestone beech forests conquered cooler expositions, while warm sides have been degraded to meadows and pastures.

The research in this paper gives basis for determination of directions in which degradation of beech forests took place in different habitat conditions. Also, the intensities of degradation are different as a consequence of different environmental conditions and zooanthropogenic influences.

## 2. METHOD OF THE RESEARCH

The research area is the wider area of Peštersko sjenički plateau with the slopes of surrounding mountains, so it can be said that it represents southwest Serbia.

With regard to complex researches, different methods were applied in this paper for determining characteristics of climate, soil, recent forest vegetation, manner of regressive successions–degradations, as well as the reconstruction of natural potential vegetation. The study of recent forest vegetation was performed according to the principles and methodology of the French-Swiss school Braun-Blanquet (Braun-Blanquet, 1964). Potential vegetation was determined according to geographic and environmental-habitat complexes. According to these complexes for climatogenic, climatoregional, azonal, interzonal communities a scheme of its regressive succession was given through vegetation stages all the way to pasture and meadow communities. The basic method for determining the directions of degradation is applying succession series from real vegetation to barren land.

## 3. THE RESULTS OF THE RESEARCH

### 3.1 Characteristics of the Habitat

The community of mountainous beech forest *(Fagetum moesiacae montanum* Jovanović 1953) as the most represented community in the area of research has very wide ecological amplitude. In terms of elevations the stands of mountainous beech occur in the belt between 1,000 and 1,600 m above sea level. They occur also in lower elevations in the form of smaller stands and groups of trees, but in general at lower elevations around rural settlements beech forests are completely destroyed, so in progressive succession those places are occupied by pioneer tree species. The best stands that were researched were located up to around 1,280 m above sea level, which is also optimal belt of beech forests spreading for this geographic belt. On higher elevations of over 1,450 m beech occurs in the form of partially preserved stands on western, southwestern and southern exposures. In terms of slope, in this area it occurs on very different slopes and positions, on cliffs, steep slopes, plateaus but it is best preserved on longer sides of moderate slope facing north. In general, it can be said that it occurs on limestone parent rock and on acid quartz conglomerates and sandstone and diabase-chert.

Accordingly, and according to other differences which occur as a consequence of different other conditions the community is divided in two sub-communities: *calcicolum* and *silicicolum.* Beech stands on limestone occur on limestone humus and on brown limestone soil as a dominant type on which beech occurs, and on acid parent rocks on dystric cambisol.

182 species are included in the floristic composition of the researched community of mountainous beech, which indicates that the community of beech is very rich (Rakonjac *et al.*, 2014). In the first layer there are 10 tree species; 25 shrub species in the second layer and 147 species that occur in the layer of ground vegetation. The richness of certain relevés with plant species is a consequence of bad stand conditions, i.e. presence of species of grass communities due to the broken canopy.

### *3. 2. Characteristics of the community*

The canopy of the researched stands ranges from 0.5 to 0.9, which indicates that the stands are degraded or recently rejuvenated, so they have not succeeded to cover by crowns the surface of the land. Regarding the height of the trees they do not show high values and heights range from 8 to 26 m. The values of mid-diameter range from 14 to 28 cm. Average distance between trees is not large and amounts up to 4 m, bearing in mind good shoot vigour. Out of the tree species in the first layer, only slightly more significant in terms of presence degree, wild cherry (*Prunus avium*) occurs, but in form of individual trees. *Acer platanoides*, *Betula pendula*, *Carpinus betulus*, *Picea abies*, *Pyrus pyraster*, *Populus tremula*, *Salix caprea* and *Ulmus carpinifolia* occur individually in some of the relevés.

In places where the degradation is more pronounced there is a more massive occurrence of species in the shrub layer, as a response to the increased inflow of light. *Fagus sylvatica*, *Corylus avellana* and *Rosa penduline* occur in the second layer in all relevés also as a sign of degradation and greater inflow of light, and *Crataegus monogyna* occurs slightly less frequent

In **ground flora layer** *Aremonia agrimonioides* occurs with the highest degree of presence, then with the smaller degree of presence *Anemone nemorosa*, *Fragaria vesca*, *Glechoma hirsuta* and *Helleborus odorus*.

### *3.3 Regressive successions*

The community of beech on acid siliceous rocks (*Fagetum moesiacae montanum silicicolum*) occurs in the mosaic with the community *Populo-Betuletum* and pioneer community of birch (*Betuletum verrucosae*), most frequently in the belt of elevations from 1050 to1200 m. In the belt of rural settlements, the community of beech succeeded to survive in the shape of smaller woods and small rural forests. Here beech forests are degraded with significant participation of aspen, birch, and hazel. Almost there is no preserved stand which would represent real natural beech forests in their optimal conditions.

Community of aspen and birch (*Populo-Betuletum*) is a form of degradation of mountainous beech forest which has almost disappeared due to constant anthropogenic influence. It occurs on deeper soils, stagnosols, luvisols, dystric cambisols to mildly eutric, less exposed to the sun, where there is less evaporation of soil moisture. The presence of this community is pronounced in overshadowed river valleys, where there is enough moisture and favourable climatic currents, but without strong wind, while it is not present on southern slopes of smaller rivers. On very deep stagnosols the community is present also on slightly sloping warmer slopes, but as soon as you enter into the belt above river valleys and warmer conditions, shallower dystric cambisols, you enter in the area of potential community of Sessile oak and Turkey oak. On deeper soils above rivers and brooks the community of aspen and birch with significant participation of hazel represents the final stage of degradation of forest vegetation.

Degradation of community *Fagetum moesiacae montanum silicicolum* on eutric rankers, cambisols and colluviums goes over *Populo-Betuletum*, while on dystric cambisols and dystric rankers transitional stage is *Betuletum verrucosae*. The final stage of regressive successions in above-mentioned conditions are meadows and pastures of the type *Brometo-Cynosuretum*, *Nardetum strictae* and *Festuco-Chrysopogonetum grylli*, and on warmer expositions meadows and pastures of the type *Nardetum strictae* and *Festuco-Chrysopogonetum grylli* (Table 1).

This community regenerates well in favourable edaphic and climatic conditions due to great shoot vigour of aspen and birch, so the degradation does not develop to meadow and pasture communities. In the belt more significantly above river courses, on dystric soils, which are shallower than stagnosols and luvisols the degradation of beech does not stop by the community *Populeto-Betuletum*, but through hazel bush growth (*Coryletum avellanae*) goes to meadows and pastures. Meadow and pasture communities which originate from further forest degradation are communities of the type *Brometo-Cynosuretum*, *Nardetum strictae* and *Festuco-Chrysopogonetum grylli.*

**Table 1.** *Scheme of regressive succession and degradation phases of the community Fagetum moesiacae montanum*

| Devastation (opening of the canopy, leaf forage cutting, clearing) | |
|---|---|
| ↓ | ↓ |
| On overshadowed, colder, north and northeast exposures, more moist soils, stagnosols, and deep dystric cambisols stand canopy becomes opened, aspen and birch enter tree layer | On brown limestone soils, on deeper limestone humus devastation leads to mass occurrence of hazel (*Corylus avellana*) in second layer with hawthorn (*Crataegus monogyna*) and Alpine rose (*Rosa pendulina*) |
| ↓ | ↓ |
| Further devastation, removal of beech | Devastation of the first layer |
| ↓ | ↓ |
| Aspen and birch form a community **(*Populo-Betuletum*)** | Hazel conquers the entire area **Formation of hazel bush growth *Coryletum avellanae*** |
| ↓ | ↓ |
| Further devastation (opening of the canopy, grazing) | Cutting, devastation, stamping, grazing and other zooanthropogenic influences |
| ↓ | ↓ |
| Aspen is massively regenerated by means of coppice shoots, in lower positions it dominates, in middle appears with birch and hazel and in upper there is hazel bush growth | Disappearance of hazel bush growth and appearance of common juniper ***Juniperus communis*** among remaining groups of hazel |
| ↓ | ↓ |
| Formed areas with aspen, birch and hazel in lower positions, where the degradation of forests on deep acid brown soils and stagnosols ends. | **Forming of community of common juniper *Juniperetum communis*** |
| ↓ | ↓ |
| Further degradation by means of clearing, excessive grazing, and stamping and other zooanthropogenic influences in middle and higher positions of slopes | Cutting of common juniper for rural needs, grazing, stamping, burning of common juniper |
| ↓ | ↓ |
| Communities of meadows and pastures (community of the type ***Brometo-Cynosuretum*, community of *Nardetum strictae* and pastures of *Festuca* and *Chrysopogon gryllus Festuco-Chrysopogonetum grylli***) | ***Formation of pasture of the type Festucetum, Cariceto-Brometum erecti, Rhinantho - Cynosuretum cristati.*** |

Out of the rocky canyons, valleys and depressions, potential vegetation of the lower belt of this part of the plateau from 1,050 to 1,200 m above sea level and on the slopes up to 40º is *Fagetum moesiacae montanum calcicolum*. It is the area composed from limestone humus and brown limestone soils. The degradation of this community by means of excessive logging goes through beech stands with the participation of wild cherry (*Prunus avium*) and aspen (*Populus tremula*). In the second layer there is significant occurrence of *Corylus avellana*, *Rosa pendulina, Crataegus monogyna, Viburnum lantana, Euonymus verrucosus, Daphne mezereum,* etc.

By further degradation, on brown limestone soils and browned limestone humus hazel thicket appears (*Coryletum avellanae*). Due to constant negative zooanthropogenic influences a community of common juniper *Juniperetum communis* is formed from hazel thicket. Further regression to pasture occurs due to burning of juniper, grazing, cattle stamping all the way to clean poor pastures. The last stage of regression are pastures of the type *Festucetum, Danthonietum calycinae, Cariceto-Brometum erecti*, *Rhinantho-Cynosuretum cristati*.

## 4. CONCLUSION

– Degradation of beech forests in the researched area has developed by different intensity and in different directions on limestone and on acid siliceous rocks. On limestone degradation has developed faster to hazel bush growth (*Coryletum avellanae*), without any transitional phase compared to the degradation on siliceous rocks where aspen forest with birch and hazel represented the transitional stage. In upper positions hazel directly conquers areas.
– Community of beech on acid siliceous rocks (*Fagetum moesiacae montanum silicicolum*) regenerates well in favourable edaphic and climatic conditions due to great shoot vigour of aspen and birch, so the degradation does not go to meadow and pasture communities. The final stage of regressive successions in these conditions are meadows and pastures of the type *Brometo-Cynosuretum*, *Nardetum strictae*, etc.
– Since the condition of the soil is less favourable on limestone parent rock, forest degradation was more intensive here from the aspect of capability to create tree layer from aspen and birch which would protect soil from erosion. Degradation of the community *Fagetum moesiacae montanum calcicolum* by means of excessive logging goes over beech stands with the participation of wild cherry (*Prunus avium*) and aspen (*Populus tremula*) to hazel thicket (*Coryletum avellanae*). Further degradation develops to community of common juniper (*Juniperetum communis*), and then the regression continues to pasture of the type *Festucetum, Danthonietum calycinae, Cariceto-Brometum erecti, Rhinantho-Cynosuretum cristati*.

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*Ljubinko RAKONJAC, Vladan POPOVIĆ, Tatjana ĆIRKOVIĆ-MITROVIĆ, Snežana STAJIĆ, Vanja STOJANOVIĆ, Aleksandar LUČIĆ*

### Summary

Degradation of beech forests in the researched area of southwest Serbia has developed by different intensity and in different directions on limestone and on acid siliceous rocks. On limestone degradation has developed faster to hazel bush growth without any transitional phase, compared to the degradation on silicate rocks where aspen forest with birch and hazel represented the transitional stage.

This community regenerates well in favourable edaphic and climatic conditions due to great shoot power of aspen and birch, so the degradation does not go to meadow and pasture communities. The final stage of regressive successions in the above-mentioned conditions are meadows and pastures of the type *Brometo-Cynosuretum*, *Nardetum strictae*, etc.

The condition of the soil is less favourable on limestone parent rock, since forest degradation was more intensive from the aspect of capability to create tree layer from aspen and birch which would protect soil from erosion. The degradation of this community by means of excessive logging goes over beech stands with the participation of wild cherry (Prunus avium) and aspen (*Populus tremula*) to hazel bush growth (*Coryletum avellanae*). Further degradation develops to community of juniper (*Juniperetum communis*), and then the regression continues to the pasture of the type *Festucetum, Danthonietum calycinae, Cariceto-Brometum erecti, Rhinantho-Cynosuretum cristati*.

## DEGRADACIJA PLANINSKIH ŠUMA BUKVE (*Fagetum moesiacae montanum* B. Jov. 1953) U JUGOZAPADNOJ SRBIJI

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### Rezime

Degradacija bukovih šuma na istraživanom području jugozapadne Srbije odvijala se različitim intenzitetom i u različitim pravcima na krečnjacima i na kiselim silikatnim stenama. Na krečnjacima degradacija se brže odvijala do leskara, bez neke prelazne faze u odnosu na degradaciju na silikatima gde je prelaznu fazu činila šuma jasike sa brezom i leskom.

Ova zajednica se u povoljnim edafskim i klimatskim uslovima dobro obnavlja zahvaljujući velikoj izdančkoj moći jasike i breze, tako da degradacija ne ide do livadskih i pašnjačkih zajednica. Krajnji stadijum regresivnih sukcesija u napred navedenim uslovima su livade i pašnjaci tipa *Brometo-Cynosuretum, Nardetum strictae i dr*

Stanje zemljišta je nepovoljnije na krečnjačkoj geološkoj podlozi jer je degradacija šuma bila intenzivnija sa aspekta sposobnosti stvaranja sprata drveća od jasike i breze koje bi štitile zemljište od erozije. Degradacija ove zajednice putem prekomerne seče ide preko sastojina bukve sa učešćem divlje trešnje (*Prunus avium*) i jasike (*Populus tremula*) do šibljaka leske (*Coryletum avellanae*). Dalja degradacija se odvija do zajednica kleke *Juniperetum communis, a zatim* regresija se odvija do pašnjaka tipa *Festucetum, Danthonietum calycinae, Cariceto-Brometum erecti, Rhinantho-Cynosuretum cristati.*

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# THE INFLUENCE OF URBAN AND SUBURBAN ENVIRONMENTAL CONDITIONS ON THE MORPHOLOGICAL CHARACTERISTICS OF EUROPEAN BEECH LEAVES IN THE BELGRADE AREA

*Tatjana ĆIRKOVIĆ-MITROVIĆ[1]*, Ljiljana BRAŠANAC-BOSANAC[1], Sabahudin HADROVIĆ[1], Saša EREMIJA[1], Goran ČEŠLJAR[1], Bojan KONATAR[1], Filip JOVANOVIĆ[1]*

**Abstract:** *The research of morphological characteristics of leaves in urban and suburban conditions of the city of Belgrade has been carried out in this paper, in order to determine whether there is significant difference of these parameters on trees in urban and suburban zone of the city, i.e. the influence of urban and suburban environmental conditions on morphological characteristics of beech leaves in the territory of Belgrade. The research was performed on two sites in the territory of the city of Belgrade: Natural monument "Faculty of Forestry Arboretum" (urban zone) and "Area of Outstanding Natural Landscape Avala" (suburban zone). All the average values of the morphological parameters of leaves sampled in Arboretum are larger and show significant difference compared to morphological parameters of leaves sampled on Avala. This can be explained, besides the origin of the seeds, by the fact that the trees growing in Arboretum are protected from the negative anthropogenic influence and agrotechnical measures are regularly applied, in contrast to the beech trees in the natural stand of submontane beech forest on Avala, which does not have such protection.*

**Keywords:** european beech, morphological characteristics of leaves, urban and suburban environmental conditions, Belgrade

# UTICAJ GRADSKIH I PRIGRADSKIH USLOVA SREDINE NA MORFOLOŠKE KARAKTERISTIKE LIŠĆA BUKVE NA PODRUČJU BEOGRADA

**Sažetak:** *U radu su izvršena istraživanja morfoloških karakteristika lišća bukve u gradskim i prigradskim uslovima Grada Beograda, kako bi se utvrdilo da li postoji signifikantna razlika ovih parametara na stablima u urbanoj i suburbanpoj zoni grada, odnosno uticaj gradskih i prigradskih uslova sredine na morfološke karakteristike lišća bukve na području Beograda. Istraživanja su vršena na dva lokaliteta na području Grada Beograda: Spomenik prirode „Arboretum Šumarskog fakulteta" (gradska zona) i „Predeo izuzetnih odlika Avala" (prigradska zona). Sve prosečne vrednosti morfoloških parametara listova uzorkovanih u Arboretumu su veće i pokazuju signifikantno značajnu razliku u odnosu*

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

*na morfološke parametre listova uzorkovanih na Avali. Ovo se može objasniti, pored porekla semena, time što su stabla rasla u Arboretumu zaštićena od negativnog antropogenog uticaja i redovno se primenjuju agrotehničke mere, za razliku od stabala bukve u prirodnoj sastojini brdske bukove šume na Avali, koja nema takvu vrstu zaštite.*

**Ključne reči:** bukva, morfološke karakteristike listova, gradski i prigradski uslovi sredine, Beograd

## 1. INTRODUCTION

European beech (*Fagus silvatica* L.) is one of the most abundant broad-leaved tree species in Switzerland and elsewhere in Europe, and it has an important economic and environmental role in sustainable forest management (Hlásny et al., 2014).

Beech as the most widespread woody species in Serbia has a great importance in forest ecosystems. The size of a leaf is of vital importance in direct correlation with the production of total biomass and for the role in air purification (Mitrović et al., 2022). Therefore, this species is important in urban environments, both as individual tree in the parks and as a species represented in urban and suburban forests. In addition to aesthetical, its role in preserving the environment is very important.

Beech leaf morphology was studied from various aspects by researchers worldwide and in Serbia. In recent years, leaf morphological traits and leaf nutrient concentrations of European beech across a water availability gradient in Switzerland was studied by Salehi et al. (2020), leaf morphological traits of beech (Fagus sylvatica L.) along an altitudinal gradient was studied by Adamidis et al. (2021). Boutsios et al. (2021) studied leaf morphology in beech populations of South Rhodope Mountains. Morphological and phenological variability of European beech (Fagus sylvatica L.) in international provenance test in Bosnia and Herzegovina was studied by Memišević Hodžić and Ballian (2021), variability of morphological characteristics of beech leaves in Switzerland was studied by Zhu et al. (2022), the relation of morphometric characteristics and drought stress by Mathes et al. (2023) and others. In Serbia morphological characteristics of beech leaves were studied by Šijačić-Nikolić et al. (2013), Nonić (2016), Nonić et al. (2019) and others.

The research of morphological characteristics of beech leaves in urban and suburban conditions of the city of Belgrade has been carried out in this paper, in order to determine whether there is significant difference of these parameters on trees in urban and suburban zone of the city, i.e. the influence of urban and suburban environmental conditions on morphological characteristics of beech leaves in the Belgrade area.

## 2. METHODOLOGY

The analysis of morphological characteristics of leaves was carried out during the summer of 2019 on two sites in the territory of the city of Belgrade (Figure 1): Natural monument "Faculty of Forestry Arboretum" (urban zone) and "Area of Outstanding Natural Landscape Avala" (suburban zone) (Figure 1). The analysed beech trees in Arboretum are planted, while beech trees on the site on Avala are from natural population.


**Figure 1.** *Sites on the territory of the city of Belgrade*

While collecting the material primary selection was carried out in order for the sample to be as homogenous as possible, both for the samples within one tree and for all the trees of the studied species. The collection of leaves on the site was carried out by the random sampling method, in the part of growing season when these vegetative organs are completely developed. Thirty healthy undamaged leaves per tree were sampled from the trees.

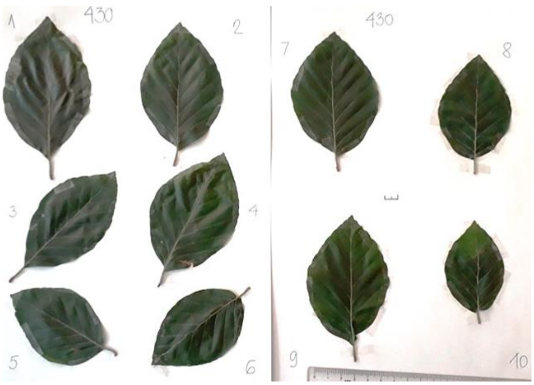


**Figure 2.** *Herbarized plant material*

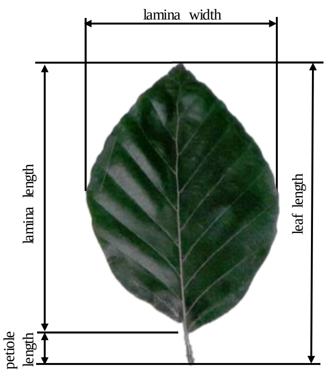



**Figure 3.** *Display of measured morphometric parameters*

The leaves were collected from the same part of the crown (outer part of the crown on the southern side) and from approximately same height (4-6 m). They were put in plastic bags and transported to the laboratory of the Institute of Forestry immediately. Leaves were then herbarized (Figure 2), and on such herbarized material measurements of morphological parameters were carried out with the precision of 0.1-1.0 mm.

Morphometric parameters on the collected samples (Figure 3), which were measured or derived, were the following: lamina length (cm), lamina width (cm), petiole length (cm), lamina thickness (mm), leaf length (cm), lamina width/lamina length ratio.

Statistical processing of the obtained data was carried out by using the software *Microsoft Office* and *Statistica 7*. The estimates of statistical importance of various factors of variation of the monitored characteristics were carried out by applying the analysis of variance (ANOVA). The basic parameters of descriptive statistics, mean value ($\bar{X}$), minimum and maximum value ($X_{min}$ and $X_{max}$), standard deviation (Sd) and coefficient of variation (CV%) were done separately for each sample. Fisher LSD test was used for confirmation of importance of differences of arithmetic means between individual measured and derived parameters. In order to determine the existence of connection between all measured morphometric parameters, a regression analysis was performed.

## 3. RESULTS AND DISCUSSION

The research was carried out on two sites: Faculty of Forestry Arboretum and Area of Outstanding Natural Landscape Avala.

Faculty of Forestry Arboretum in Belgrade represents created botanical value. Spatially and functionally it is connected into system of urban greenery. It is recognizable primarily by educational and scientific purpose, bioecological and sanitary-hygienic as well as cultural and aesthetic. Arboretum is located in urban zone of Belgrade, so it is exposed to various influences of urban functions as sources of pollution: traffic, sewerage (soil pollution by waste water as a consequence of bad infrastructure), housing (in the immediate vicinity the construction of high-rise residential objects is pronounced). The research was carried out in the specific conditions of arboretum, which stands on the habitat of former mixed autochthonous forests of Hungarian oak and Turkey oak (*Querceto-frainetto cerris* subass. *aculeatetosum* Jov. = syn. *Rusco-Quercetum frainetto-cerris* Jovanović, 1951) (Plan of management of Natural monument Faculty of Forestry Arboretum), at the elevation of 120 m.

The area of mountain Avala has experienced protection of its natural and cultural assets for a very long time. Avala is protected by the current legislation as the Area of outstanding natural landscape. This shows in the best way the importance that this natural entity has for the citizens of Belgrade as the closest mountain and forecourt of the urbanized area of capital city. The resource of preserved nature and cultural sights provides to this area a large touristic potential. However, due to such a great importance it has for the population of Belgrade, preservation of biodiversity of this area and sustainable touristic and also population development of Avala can be cited as the imperative (Bakić and Radić, 2019). The research was carried out in submontane beech forest (*Tilio-Fagetum submontanum* (Janković et Mišić 1960) Mišić 1972), at the elevation of 480 m.

Morphometric parameters of leaves from the trees of selected deciduous species (with simple leaves in terms of structure) from two sites are presented in the table.

**Table 1.** *Morphological traits of beech leaves*

| Locality | Traits | Mean | Max | Min | Range | Sd | Cv |
|---|---|---|---|---|---|---|---|
| Arboretum | **a** | 9.27 | 10.80 | 7.10 | 3.70 | 0.94 | 10.14 |
| | **b** | 5.99 | 6.80 | 4.60 | 2.20 | 0.60 | 9.99 |
| | **c** | 1.21 | 1.60 | 0.90 | 0.70 | 0.17 | 14.41 |
| | **d** | 10.48 | 12.40 | 8.00 | 4.40 | 1.08 | 10.27 |
| | **e** | 0.10 | 0.11 | 0.08 | 0.03 | 0.01 | 8.21 |
| | **f** | 0.65 | 0.70 | 0.55 | 0.15 | 0.03 | 5.09 |
| Avala | **a** | 7.80 | 9.30 | 6.40 | 2.90 | 0.79 | 10.18 |
| | **b** | 4.68 | 6.00 | 3.90 | 2.10 | 0.60 | 12.72 |
| | **c** | 0.72 | 1.00 | 0.50 | 0.50 | 0.12 | 16.62 |
| | **d** | 8.52 | 10.10 | 6.90 | 3.20 | 0.86 | 10.14 |
| | **e** | 0.08 | 0.08 | 0.07 | 0.01 | 0.00 | 6.40 |
| | **f** | 0.60 | 0.67 | 0.56 | 0.11 | 0.03 | 4.53 |

Morphological traits:
a - lamina length, b - lamina width, c - petiole length, d - leaf length, e - lamina thickness, f - lamina width/lamina length

On the site Faculty of Forestry Arboretum morphometric parameter lamina length for beech has an average value of 9.27 cm, and ranges from 7.10 to 10.80 cm. The average lamina width is 5.99 cm, the smallest measured is 4.60, and the largest 6.80 cm. The petiole length has an average value of 1.21 cm, and ranges from 0.90 to 1.60 cm. The average total length of beech leaf is 10.38 cm, and ranges from 8.00 to 12.40 cm. The average lamina thickness is 0.10 mm, the smallest measured is 0.08, and the largest 0.11 mm. The average value of the ratio of lamina width and lamina length is 0.64, ranging from 0.55 to 0.70. The value of the coefficient of variation is the highest for the petiole length parameter (17.57%), and the lowest for the ratio of lamina width and lamina length (6.44%).

On the site Avala, the average lamina length for beech is 7.90 cm, and ranges from 6.40 to 9.30 cm. The average lamina width is 4.75 cm, the smallest measured is 3.90, and the largest 5.90 cm. The average petiole length is 0.72 cm, and ranges from 0.50 to 1.00 cm. The average total length of beech leaf is 8.62 cm, and ranges from 6.90 to 10.10 cm. The average lamina thickness is 0.08 mm (0.07-0.08 mm). The average value of the ratio of lamina width and lamina length amounts to 0.60, and ranges from 0.57 to 0.63. The value of the coefficient of variation is the highest for the parameter petiole length (19.42%), and the lowest for the parameter ratio of lamina width and lamina length (3.37%).

**Table 2.** *Correlation analysis of the studied morphological characteristics*

| Arboretum | | | | | | |
|---|---|---|---|---|---|---|
| | **a** | **b** | **c** | **d** | **e** | **f** |
| **a** | 1.00 | | | | | |
| **b** | 0.86* | 1.00 | | | | |
| **c** | 0.74* | 0.53* | 1.00 | | | |
| **d** | 0.99* | 0.84* | 0.81* | 1.00 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **e** | 0.49* | 0.58* | 0.29 | 0.48* | 1.00 | |
| **f** | -0.31 | 0.21 | -0.42 | -0.34 | 0.14 | 1.00 |
| Avala | | | | | | |
| **a** | 1.00 | | | | | |
| **b** | 0.93* | 1.00 | | | | |
| **c** | 0.53* | 0.46* | 1.00 | | | |
| **d** | 0.99* | 0.92* | 0.63* | 1.00 | | |
| **e** | 0.32 | 0.39 | 0.31 | 0.34 | 1.00 | |
| **f** | 0.34 | 0.65* | 0.2 | 0.33 | 0.35 | 1.00 |
| *Marked correlations are significant at $p < 0.05$ | | | | | | |

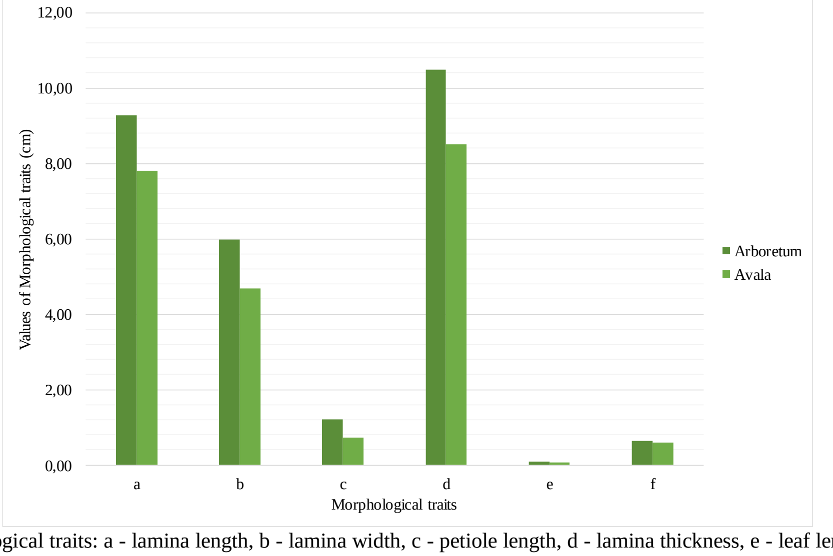
Morphological traits:
a - lamina length, b - lamina width, c - petiole length, d - leaf length, e - lamina thickness, f - lamina width/lamina length

Correlation analysis on the site Faculty of Forestry Arboretum shows that between lamina length and all other studied morphological characteristics, except the ratio of lamina width and lamina length, there is significant absolutely positive correlation. The strongest relation is with lamina length (0.99), and the weakest with the total length of the leaf (0.35). A large interdependence of lamina width and lamina thickness was recorded (0.84) and of lamina thickness and petiole length (0.68).

On the site Avala the strongest relation of lamina length is also with lamina thickness (0.99), as with leaves sampled in Arboretum. The weakest correlation of lamina length is with petiole length (0.53). A large interdependence of lamina width and lamina thickness (0.92) and lamina thickness and petiole length (0.68) was recorded also on this site.

In his research of morphological characteristics of beech leaves from the site Belgrade, Municipality Savski Venac, Dedinje – White Court, Nonić (2016) recorded average lamina length of 8.57 cm, lamina width 5.48 cm, petiole length 0.95 cm, average total leaf length of 9.52 cm, which is within the range of the values obtained during this research. The lamina width, lamina length and petiole length of beech leaves sampled on Fruška Gora and Kopaonik (Šijačić-Nikolić et al., 2013) have smaller dimensions than the leaves from the researched sites.

A comparative overview of morphometric parameters of leaves from the selected beech trees on the researched sites is presented on the graph below.




Morphological traits: a - lamina length, b - lamina width, c - petiole length, d - lamina thickness, e - leaf length, f - lamina width/lamina length

**Graph 1.** *Comparative overview of morphometric parameters of leaves from the selected beech trees on the researched sites*

**Table 3.** *Results of statistical analysis of morphological parameters of beech leaves from the researched sites*

| | a | b | c | d | e | f |
|---|---|---|---|---|---|---|
| **Arboretum** | 9.27a | 5.99a | 1.21a | 10.48a | 0.10a | 0.65a |
| **Avala** | 7.80b | 4.68b | 0.72b | 8.52b | 0.08b | 0.60b |

Morphological traits:
a - lamina length, b - lamina width, c - petiole length, d - leaf length, e - lamina thickness, f - lamina width/lamina length
Fisher's LSD (least significant difference) post-hoc comparisons test (ANOVA, $p < 0.05$) (the same letters associate parameters with no statistically significant differences)

By comparative analysis of morphological characteristics of beech leaves from two sites, it can be determined that there is statistically significant difference for all the measured and derived parameters (Table 3). The values of all the morphometric parameters of leaves sampled on the site Arboretum are higher. This difference in leaf morphology can be explained by the origin of seeds, it can be the result of the phenotypic plasticity of beech trees, but also of the adaptation of beech populations to different environmental conditions. Faculty of Forestry Arboretum is the object where mowing and watering is constantly carried out and agrotechnical measures are applied. The latter can also explain significant difference between the researched parameters. On the other hand, trees in the forest ecosystem of the Area of Outstanding Natural Landscape Avala, near Belgrade, are exposed to a higher level of human threats, due to their specific location and surroundings (Popović et al., 2022). The research of Nonić (2016) also shows that the beech leaves in urban environment have larger dimensions than the ones in natural stands. Salehi et al. (2020) in their research of morphological characteristics of beech leaves on 12 sites in the main geographical regions of Switzerland state that the length of leaves tended to decrease with the increase of elevation. Boutsios et al. (2021) state that the trend of change of morphology of leaves in the direction West-East in South Rhodope

Mountains in the territory of northeast Greece also can be the result of phenotypical plasticity of beech trees or adaptation of beech populations to different environmental conditions.

## 5. CONCLUSION

Morphological characteristics of leaves are considered to be appropriate indicators of plant functioning, such as photosynthetic and respiratory functions (Wright et al., 2004, Poorter et al., 2009). Their morphology directly affects their physiology (Fitter and Hay, 2002).

Regarding the correlation of certain morphological parameters, on both sites this correlation is strongest between the properties lamina length and leaf length. All the average values of morphological parameters of leaves sampled in Arboretum are larger and they show significant difference compared to morphological parameters of leaves sampled on Avala. This can be explained, besides the origin of the seeds, by the fact that the trees growing in Arboretum are protected from the negative anthropogenic influence and agrotechnical measures are regularly applied, in contrast to the beech trees in natural stand of submontane beech forest on Avala which does not have such protection.

Wide ecological amplitude and growth on elevations from 50 to over 2,000 m indicate great adaptability of the species to different environmental conditions. Beech trees can stand the air pollution in urban environments, in parks, where care and protection measures are constantly applied.

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*План управљања Спомеником природе „Арборетум Шумарског факултета“ 2021-2030. год.* https://www.sfb.bg.ac.rs/wp-content/uploads/2021/10/Plan_upravljanja_2021-2030_Arboretum_Sumarskog_fakulteta.pdf [Plan of management of Natural monument Faculty of Forestry Arboretum 2021-2030. год.]

## THE INFLUENCE OF URBAN AND SUBURBAN ENVIRONMENTAL CONDITIONS ON THE MORPHOLOGICAL CHARACTERISTICS OF EUROPEAN BEECH LEAVES IN THE BELGRADE AREA

*Tatjana ĆIRKOVIĆ-MITROVIĆ, Ljiljana BRAŠANAC-BOSANAC, Sabahudin HADROVIĆ, Saša EREMIJA, Goran ČEŠLJAR, Bojan KONATAR, Filip JOVANOVIĆ*

### Summary

Beech as the most widespread woody species in Serbia has a great importance in forest ecosystems. The size of the leaf is of vital importance, in direct correlation with the production of total biomass, and also has a role in air purification. (Mitrović et al., 2022). Therefore, this species is important in urban environments, both as individual tree in parks and as a species represented in urban and suburban forests. In addition to aesthetic, its role in preservation of environment is also important. The research of morphological characteristics of leaves in urban and suburban conditions of the city of Belgrade is carried out and presented in this paper, in order to determine whether there is a significant difference of these parameters on trees in urban and suburban zone of the city, i.e. influence of urban and suburban environmental conditions to morphological characteristics of beech leaves in the territory of Belgrade. The research was carried out on two sites in the territory of the city of Belgrade: Natural Monument Faculty of Forestry Arboretum (urban zone) and Area of Outstanding Natural Landscape Avala (suburban zone). Regarding the correlation of certain morphological parameters, on both sites this correlation is the strongest between the properties lamina length and leaf length. All the average values of morphological parameters of leaves sampled in Arboretum are higher and show significant difference compared to morphological parameters of leaves sampled on Avala. This can be explained, in addition to the phenotypical plasticity of beech trees or adaptation of beech populations to different environmental conditions, by the fact that the trees growing in Arboretum are protected from negative anthropogenic influence and agrotechnical measures are regularly applied, in contrast to the beech trees in the natural stand of submontane beech forest on Avala, which does not have that kind of protection.

# UTICAJ GRADSKIH I PRIGRADSKIH USLOVA SREDINE NA MORFOLOŠKE KARAKTERISTIKE LIŠĆA BUKVE NA PODRUČJU BEOGRADA

*Tatjana ĆIRKOVIĆ-MITROVIĆ, Ljiljana BRAŠANAC-BOSANAC, Sabahudin HADROVIĆ, Saša EREMIJA, Goran ČEŠLJAR, Bojan KONATAR, Filip JOVANOVIĆ*

## Rezime

Bukva kao najrasprostranjenija drvenasta vrsta u Srbiji ima veliki značaj u šumskim ekosistemima. Veličina lista je od vitalnog značaja, u direktnoj korelaciji sa proizvodnjom celokupne biomase, ali i ulogom u prečišćavanju vazduha (Mitrović et al., 2022). Zato je ova vrsta značajna u gradskim sredinama, kako kao pojedinačno stablo u parkovima, tako i kao vrsta zastupljena u gradskim i prigradskim šumama. Pored estetske, veoma je važna njena uloga u očuvanju životne sredine. U radu su izvršena istraživanja morfoloških karakteristika lišća u gradskim i prigradskim uslovima Grada Beograda, kako bi se utvrdilo da li postoji signifikantna razlika ovih parametara na stablima u urbanoj i suburbanpoj zoni grada, odnosno uticaj gradskih i prigradskih uslova sredine na morfološke karakteristike lišća bukve na području Beograda. Istraživanja su vršena na dva lokaliteta na području Grada Beograda: Spomenik prirode „Arboretum Šumarskog fakulteta“ (gradska zona) i „Predeo izuzetnih odlika Avala“ (prigradska zona). Što se tiče korelacije pojedinih morfoloških parametara, na oba lokaliteta ova korelacija je najjača između svojstava dužina liske i dužina lista. Sve prosečne vrednosti morfoloških parametara listova uzorkovanih u Arboretumu su veće i pokazuju signifikantno značajnu razliku u odnosu na morfološke parametre listova uzorkovanih na Avali. Ovo se može objasniti, pored fenotipske plastičnosti bukovih stabala ili adaptacije populacija bukve na različite uslove životne sredine, time što su stabla rasla u Arboretumu zaštićena od negativnog antropogenog uticaja i redovno se primenjuju agrotehničke mere, za razliku od stabala bukve u prirodnoj sastojini brdske bukove šume na Avali, koja nema takvu vrstu zaštite.

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# BACTERIAL TREATMENT IMPACT ON MORPHOLOGICAL TRAITS OF ONE-YEAR-OLD SESSILE OAK SEEDLINGS OF TWO SERBIAN PROVENANCES

*Sanja JOVANOVIĆ[1]*, Vladan POPOVIĆ[1], Aleksandar LUČIĆ[1], Ljubinko RAKONJAC[1]*

**Abstract:** *Plant growth promoting bacteria present a diverse group of bacteria with wide applicative potential in seedling production, especially in referring to the Green agenda concept. The effect of 2 bacterial species on one-year-old sessile oak seedling's height, root collar diameter, and their ratio was studied. Oak plants were from 2 provenances – Avala and Košutnjak. The most significant influence on measured traits in Avala had treatment with Pseudomonas koreensis, and in Košutnjak, with Viridibacillus arvi. However, a two-way analysis of variance showed no statistical significance of provenance effect and bacterial treatment on measured traits. The research needs to be repeated on a greater number of individuals in order to confirm the results since the bacteria manifested their PGP potential in vitro.*

**Keywords:** plant growth promoting bacteria, sessile oak, provenances, morphology, Serbia

## UTICAJ BAKTERIJSKIH TRETMANA NA MORFOLOŠKE OSOBINE JEDNOGODIŠNJIH SADNICA HRASTA KITNJAKA DVE SRPSKE PROVENIJENCIJE

**Sažetak:** *Bakterije koje promovišu rast biljaka predstavljaju raznovrsnu grupu bakterija koje imaju širok aplikativni potencijal u proizvodnji sadnica, naročito u skladu sa načelima zelene agende. U ovom radu ispitivan je efekat 2 bakterijske vrste na prečnik korenovog vrata, visinu, i njihov odnos kod jednogodišnjih sadnica kitnjaka 2 provenijencije – Košutnjak i Avala. Na njihove vrednosti u provenijenciji Avala najveći efekat imao je tretman bakterijom Pseudomonas koreensis, a u provenijenciji Košutnjak bakterijom Viridibacillus arvi. Međutim, dvofaktorijalna analiza varijanse pokazala je da nema statističke značajnosti između provenijeničnog efekta i bakterijskog tretmana na merene osobine. Istraživanje treba ponoviti na većem broju uzoraka kako bi se potvrdili dobijeni rezultati, s obzirom da su bakterije pokazale in vitro potencijal za promociju rasta biljaka.*

**Ključne reči:** bakterije koje promovišu rast biljaka, hrast kitnjak, provenijencije, morfologija, Srbija

[1]Institute of Forestry, Kneza Viseslava 3, 11000, Belgrade, Serbia
*Corresponding author. E-mail: sanja.jovanovic@forest.org.rs

## 1. INTRODUCTION

Bacteria present a large group of very diverse organisms with enormous potential for application. Although being more known as plant pathogens, within the domain of bacteria, there is a special group of “Plant Growth-Promoting Bacteria” (PGPB), with metabolically diverse members that promote plant growth, development, coupling with its surroundings during transplantation shock, fructification, resistance to different plant pathogens, tolerance on stressful environmental conditions, etc. These bacterial species can be found all over plant organism, and there are evidence they are being inherited as well (Abdelfattah et al., 2021). PGPB are most abundant in plant rhizosphere, where their growth and reproduction are supported by root exudates, leading to even species-specific bacteria-plant relations (Backer et al., 2018; Upadhyay et al., 2022). Nowadays, these bacteria are seen as an ecologically adequate substitution for chemical fertilizers, especially in referring to the Green agenda concept.

The forestry sector in Serbia relies on traditional methods of forest seedling production. However, the rise of ecological awareness and knowledge on environmental damage caused by chemical substances that are being used leads to more restricted lists of approved chemicals that can be used in nurseries, and proper replacements need to be found and produced. Sessile oak (*Quercus petraea* (Matt.) Liebl) is one of the most common oak species cultivated in forest seedling nurseries in Serbia (Popović et al., 2019). It is also one of the most important species in Serbian forest, in general. Its forests cover more than 173,000 ha (Banković et al., 2009), and it is highly valued as a resource for many branches of the economy. Due to many problems with its natural regeneration, artificial measures take place for which healthy and top-quality seedlings are necessary. Foresters perceived the significance of different values of seedlings attributes and their association with future transplant success and field performance since the beginning of the 20th century (Grossnickle & MacDonald 2018). Subsequently, they started examining and developing different nursery production strategies to produce as good seedlings as possible, i.e., to manipulate plant traits. In order to estimate seedling quality, foresters use various morphological and physiological plant attributes that are rapid, simple, cheap, reliable, nondestructive, quantitative, and diagnostic (Zaerr, 1985). However, in the operational level, only some of them are practiced. One of the main morphological parameters of good seedling quality are greater root collar diameter and seedling height. Greater stem diameter enables a higher chance of survival and growth by limiting susceptibility to planting stress through improved water uptake and transport to foliage, while greater height provides a competitive advantage (i.e., access to light) on sites with competing vegetation (Grossnickle & MacDonald 2018). Besides plant nursery management, seedling attributes are also influenced by the provenance effect. Different origins and life histories have selected distinct genotypes that can differ in fitness and field performance when found under the same environmental conditions.

In this research, we examined the effect of two plant growth-promoting bacterial isolates on the height, root collar diameter and their ratio of one-year-old sessile oak seedlings of two provenances from Serbia, Avala and Košutnjak, with the aim of inspecting whether the bacterial treatment is positivley affecting these plant traits.

## 2. MATERIAL AND METHODS

The two bacterial strains were isolated from soil samples of sessile oak rhizosphere from its natural forest stands in Mountain Rudnik (unpublished data) and tested *in vitro* for plant growth-promoting traits and based on the partial 16S rDNA sequence identified as *C* (Heyrman et al., 2005) Albert et al. 2007 and *Pseudomonas koreensis* Kwon et al. 2003 (unpublished data).

Sessile oak acorns used to test bacterial treatments were collected from its natural stands on Mountain Avala and Košutnjak. After seed processing, acorns were sowed in containers for broadleaved species, and the mixture of white and black peat was used as a substrate (Baltic 70/30, The Netherlands).

Within each sessile oak provenance, three groups were formed: 1) group treated with *V. arvi*, 2) group treated with *P. koreensis*, and 3) control group treated with tap water. Each treatment was conducted on ten one-year-old seedlings of sessile oak.

Treatments contained live bacterial cells of selected bacteria ($10^8$cfu/ml) in saline in 10 ml volume. Seedlings were inoculated by sterile syringe at the end of May. The procedure was repeated after 7 days.

Plants were nurtured in semicontrolled conditions in the Nursery of the Institute of Forestry in Belgrade (44°46’55” N, 20°25’21” E), in half shadow conditions. They were watered every other day, without any fertilization treatment.

At the end of the growing season, seedling height was measured by a ruler with an accuracy of 0.5 cm. The seedling root collar diameter was estimated by Vernier caliper with an accuracy of 0.1 mm. A two-way analysis of variance (ANOVA) followed by a Dunnett’s multiple comparisons post hoc test was performed to analyse the provenance and treatment effect. A P value less than or equal to 0.05 was considered statistically significant. Statistical analysis was done in Graph Pad Prism version 9.0.0. for Windows (Graph Pad Software, San Diego, California USA).

## 3. RESULTS

In table 1, descriptive statistics data of measured plant attributes is presented for Avala provenance. The minimum height value was reported in treatment with *P. koreensis*, 4.5 cm. The maximum height value was detected in the same treatment group, 21.5 cm. The root collar diameter had its minimal value in the control group, 1.96 mm, while the maximum value was recorded in treatment with *P. koreensis*, 5.36 mm. The height to root collar diameter ratio was highest in a plant from a control treatment group, 6,54, and the lowest value was detected in a plant from a treatment with *P. koreensis*, 1.73.

In table 2, descriptive statistics data is presented for the Košutnjak population. The maximum height value was detected in *V. arvi* treatment, 24 cm, while the minimum was in a control treatment, 7.5 cm. Maximum root collar diameter was reported in the control treatment, 4.61 mm, and the minimum in the *V. arvi* treatment, 2.24 mm. The height to root collar diameter ratio had the highest and lowest values in plants from *V. arvi* treatment group, 6.7 and 2.02.

**Table 1.** *Descriptive statistics for morphological traits of one-year-old sessile oak seedlings of Avala provenance in relation to bacterial treatment*

| **Treatments** | | **Height (h)** | **Root collar diameter (d)** | **h/d** |
|---|---|---|---|---|
| *Viridibacillus arvi* | Mean | *12,14* | *3,38* | *3,62* |
| | Min | *7.00* | *2.64* | *2.35* |
| | Max | *20.60* | *4.52* | *5.27* |
| | SD | *3,98* | *0,71* | *0,98* |
| | CV% | *32.76* | *20.92* | *27.03* |
| *Pseudomonas koreensis* | Mean | *13,81* | *3,66* | *3,82* |
| | Min | *4.50* | *2.37* | *1.73* |
| | Max | *21.50* | *5.36* | *5.63* |
| | SD | *5,50* | *0,91* | *1,42* |
| | CV% | *39.81* | *24.98* | *37.23* |
| Control | Mean | *12,89* | *3,19* | *4,02* |
| | Min | *6.00* | *1.96* | *2.01* |
| | Max | *21.30* | *3.70* | *6.54* |
| | SD | *6,16* | *0,54* | *1,61* |
| | CV% | *47.81* | *17.05* | *39.97* |

**Table 2.** *Descriptive statistics for morphological traits of one-year-old sessile oak seedlings of Košutnjak provenance in relation to bacterial treatment*

| **Treatments** | | **Height (h)** | **Root collar diameter (d)** | **h/d** |
|---|---|---|---|---|
| *Viridibacillus arvi* | Mean | *12,50* | *3,28* | *3,88* |
| | Min | *6.80* | *2.24* | *2.02* |
| | Max | *24.00* | *3.81* | *6.70* |
| | SD | *5,50* | *0,66* | *1.60* |
| | CV% | *43.98* | *20.16* | *41.25* |
| *Pseudomonas koreensis* | Mean | *12,14* | *3,50* | *3,52* |
| | Min | *8.00* | *2.37* | *2.42* |
| | Max | *19.50* | *4.43* | *5.03* |
| | SD | *3,48* | *0,76* | *0,84* |
| | CV% | *28.68* | *21.70* | *23.94* |
| Control | Mean | *11,41* | *3,34* | *3,42* |
| | Min | *7.10* | *2.08* | *2.44* |
| | Max | *16.00* | *4.61* | *4.67* |
| | SD | *3,74* | *0,84* | *0,76* |
| | CV% | *32.76* | *25.27* | *22.29* |

In the Avala provenance, coefficients of variation (CV) were the highest in the control treatment for plant height and height to root collar diameter ratio, while the highest CV for root collar diameter was observed in treatment with *P. koreensis*. The lowest CV was detected in control treatment for root collar diameter, while for height and height to root collar diameter ratio in *V. arvi* treatment. Based on CV, plant height was more variable trait than the root collar diameter.

In the Košutnjak provenance, CV values were highest in the group treated with *V. arvi* for height and height to root collar diameter ratio. In contrast, the highest value of CV for root collar diameter was observed in the control group. The lowest CV value for height trait was detected in the group treated with *P. koreensis*. For root collar diameter the lowest value was observed in the group treated with *V. arvi*, and for height to root collar diameter in the control group. On the basis of CV, plant height was the most variable trait in this provenance, and the least variable was root collar diameter.

**Table 3.** *Two-way analysis of variance (ANOVA) for the measured morphological characteristics of one-year-old seedlings of sessile oak from two provenances and under two bacterial treatments*

| **Parameter** | | **F (DFn, DFd)** | **p** |
|---|---|---|---|
| *Root collar diameter* | Treatment | *F (1.917, 27.80) = 1.398* | *0.2635* |
| | Provenance | *F (1, 18) = 0.01944* | *0.8907* |
| | Treatment x Provenance | *F (2, 29) = 0.4910* | *0.6170* |
| Plant height | Treatment | *F (1.803, 26.15) = 0.1601* | 0.8316 |
| | Provenance | *F (1, 18) = 0.4517* | *0.5100* |
| | Treatment x Provenance | *F (2, 29) = 0.2375* | *0.7901* |

In order to investigate provenance and bacterial treatment influence on measured plant growth attributes, two-way ANOVA was performed. The results of a two-way ANOVA are presented in Table 3. There is no statistically significant effect of provenance and bacterial treatment and their interaction on seedling height or root collar diameter.

## 4. DISCUSSION

Root collar diameter and seedling height are phenotypic plant attributes affected by many factors, such as genetics, provenance effect, climate and weather, soil properties, pathogens, and other environmental elements (Vivas et al., 2019). In this paper, we investigated the influence of bacterial treatment on these two plant traits on a one-year-old sessile oak seedlings in one growing season. Although differences in the mean values exist for each of the two measured traits, they are not statistically significant.

Popović et al. (2022) measured the same growth parameters on one-year-old sessile oak seedlings that originate from healthy acorns of selected trees of the Area of Outstanding Natural Landscape "Avala". The mean height value was 22.9 cm, which is greater than in this research (13,81 cm was the highest mean value in Avala, 12,5 cm in Košutnjak). Although both of our maximum height values were obtained from the bacterial treatment group plants, the maximum height reached in the control groups was 21.3 cm and 16 cm, respectively. Regarding the seedling root collar diameter, in the mentioned study, the mean value was 4.4 mm. In comparison, in our study, these values are 5.36 mm for the Avala population (in bacterial treatment group) and 4.61 mm (the control group) for Košutnjak. Popović et al. (2022) conducted their research on a 50 seedlings sample, that gives more reliable final results and conclusion. However, since the mother trees and acorns were selected, their results could present an above-average values.

Popović et al. (2019) investigated the same traits on one-year-old sessile oak bare root seedlings. The mean root collar diameter was 3.52, and the mean height was 14.8 cm. Seedlings originated from eastern Serbia and were produced in the same nursery as seedling for this research. These results are more similar to ours, however, the experimental seedlings were bare-rooted, while seedlings in the present study were produced in containers. Significant differences in root architecture of these two types of seedlings can affect future plant characteristics.

Avala and Košutnjak are two provenances in central Serbia, with very similar climate conditions. In both provenances, the most variable trait was seedling height, while the least variable was root collar diameter.

In Avala provenance, the higher impact on observed plant traits was achieved in treatment with *P. koreensis*. However, in population Košutnjak, treatment with *V. arvi* had higher influence on seedling traits (except for root collar diameter) based on mean, maximal, and minimal values. Bacteria *V. arvi* and *P. koreensis* are soil bacteria already described as plant growth-promoting bacteria (Gu et al., 2020; Jabborova, 2022; Lyngwi et al., 2016). *In vitro* tests confirmed their PGP potential (unpublished results). Therefore, it is possible that the conditions for experiment performance were not optimal. In unpredictable and stressful field conditions, bacterial population might have decreased its number, or couldn't express its PGP potential. In addition, a low number of oak seedlings might have affected the results, and the experiment should be investigated on a larger plant sample. Another factor that should be considered is the life span of oaks. The seedlings might be in an inappropriate stage for the evaluation of bacterial treatment efficiency. Since the scarcity of similar studies in this forest species, there is a large open space for research to be conducted in the future, where all factors can and should be tested.

## 5. CONCLUSION

The results obtained in this study do not show a statistically significant interaction between the effects of provenance and bacterial treatment on seedling height or root collar diameter. The research should be conducted on a larger sample, and more growth parameters included. Since one of the major challenges in forestry is seedling transplantation and establishment in new field conditions, in the future, it is recommended to investigate the bacterial influence on plant growth and survival after transplanting to the field.

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## BACTERIAL TREATMENT IMPACT ON MORPHOLOGICAL TRAITS OF ONE-YEAR-OLD SESSILE OAK SEEDLINGS OF TWO SERBIAN PROVENANCES

*Sanja JOVANOVIĆ, Vladan POPOVIĆ, Aleksandar LUČIĆ, Ljubinko RAKONJAC*

### Summary

Plant growth promoting bacteria present a diverse group of bacteria that have wide applicative potential in seedling production, especially in refer to Green agenda concept. One of the most producted forest species in Serbian forest nurseries is sessile oak. In this paper the effect of 2 bacterial species on one-year-old sessile oak seedling's height, root collar diameter, and their ratio was studied. Oak plants were from 2 provenances – Avala and Košutnjak.

The observed traits were estimated by a Vernier caliper and a ruler. The greatest influence on measured traits in Avala had treatment with *P. koreensis* bacteria, and in Košutnjak the one with *V. arvi*. Two-way analysis of variance showed there were no statistical significance of provenance effect and bacterial treatment on measured traits. The research needs to be repeated on greater number of individuals in order to confirm obtained results, since the bacteria manifested their PGP potential in laboratory. Since one of the major challenges in forestry is seedling transplantation and establishment in new field conditions, in future it is recommended to investigate bacterial influence on plant growth and survival after transplanting to the field.

## UTICAJ BAKTERIJSKIH TRETMANA NA MORFOLOŠKE OSOBINE JEDNOGODIŠNJIH SADNICA HRASTA KITNJAKA DVE SRPSKE PROVENIJENCIJE

*Sanja JOVANOVIĆ, Vladan POPOVIĆ, Aleksandar LUČIĆ, Ljubinko RAKONJAC*

### Rezime

Bakterije koje promovišu rast biljaka predstavljaju raznovrsnu grupu bakterija koje imaju širok aplikativni potencijal u proizvodnji sadnica, naročito u skladu sa načelima zelene agende. Jedna od šumskih vrsta koje se najviše proizvode u rasadnicima Srbije je hrast kitnjak. U ovom radu ispitivan je efekat 2 bakterijske vrste na prečnik korenovog vrata, visinu kao i njihov odnos kod jednogodišnjih sadnica kitnjaka 2 provenijencije – Košutnjak i Avala.

Posmatrane osobine merene su pomičnim kljunastim merilom i lenjirom. Na njihove vrednosti u provenijenciji Avala najveći efekat imao je tretman bakterijom *P. koreensis*, a u provenijenciji Košutnjak bakterijom *V. arvi*. Dvofaktorijalna analiza varijanse pokazala je da nema statističke značajnosti između provenijeničnog efekta i bakterijskog tretmana na izmerene osobine. Istraživanje treba ponoviti na većem broju uzoraka kako bi se potvrdili dobijeni rezultati, s obzirom da su bakterije laboratorijski pokazale potencijal za promociju rasta biljaka. Kako je jedan od glavnih izazova u šumarstvu presađivanje sadnica i njihovo uspostavljanje u novim terenskim uslovima, preporuka je da se u budućnosti ispita uticaj bakterija na rast i preživljavanje biljaka nakon presadnje na teren.

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# CONDITION OF NORTHERN RED OAK TREES IN THE URBAN ENVIRONMENT OF BELGRADE (SERBIA)

*Ivana ŽIVANOVIĆ[1], Filip JOVANOVIĆ[1]*, Nenad ŠURJANAC[1], Đorđe FILIPOVIĆ[2], Aleksandar LUČIĆ[1]*

**Abstract:** *Forty-two trees of northern red oak (Quercus rubra L.) were examined in the area of the municipality of Savski Venac, Belgrade, to assess the condition of this allochthonous species in Serbia and its adaptability to urban environments. Physical measurements were taken and ratings of vitality and decorativeness were given. The analyzed trees are in very good condition based on their health status (80.95% of trees without visible indication of disease) and the mean values of ratings for vitality (4.45) and decorativeness (3.88). The obtained values of vitality and some physical measurements were greater than those stated in the literature, suggesting that the species has adapted well to the urban environment of Belgrade and it should be considered a suitable landscape tree species for planting in urban areas of Serbia.*

**Keywords:** *Quercus rubra* L., vitality, decorativeness, physical measurements, adaptability, Belgrade

# STANJE STABALA CRVENOG HRASTA U GRADSKOJ SREDINI BEOGRADA (SRBIJA)

**Sažetak:** *Istraživanje je obuhvatilo 42 stabla crvenog hrasta (Quercus rubra L.) na teritoriji GO Savski venac u Beogradu, radi ispitivanja stanja ove alohtone vrste i njene prilagođenosti urbanoj sredini u Srbiji. Utvrđene su dimenzije stabala i procenjena je njihova vitalnost i dekorativnost. Zabeleženo je da su stabla vrlo dobre kondicije, na osnovu zdravstvenog stanja (80,95% stabala bez vidljivih simptoma oboljenja), kao i srednjih ocena vitalnosti (4,45) i dekorativnosti (3,88). Ustanovljene vrednosti za vitalnost i pojedine dimenzije stabala su bile veće od onih zabeleženih u relevantnoj literaturi, što navodi na zaključak da je ova vrsta drveća dobro prilagođena gradskoj sredini Beograda i da se može preporučiti za sadnju u urbanim područjima Srbije.*

**Ključne reči:** *Quercus rubra* L., vitalnost, dekorativnost, dimenzije, adaptibilnost, Beograd

[1]Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
[2]EC "Foresting", Borska 9c, 11090 Belgrade, Serbia
*Corresponding author. E-mail: filip.jovanovic@forest.org.rs

## 1. INTRODUCTION

One of the links between man and nature is represented by green areas and they play a key role in preserving the natural values of urban areas (Vukadinović et al., 2017). Urban green areas influence the regulation of the microclimate of city districts, reduce air pollution, filter floating particles, mitigate wind blows and soil erosion, influence the reduction of the negative effects of precipitation and reduce the noise level in cities (Prpić, 1992; Vuletić et al., 2010).

The capital of the Republic of Serbia, Belgrade, is located at 116.75 m elevation, at coordinates 44°49'14" north latitude and 20°27'44" east longitude. The urbanized area of the city is 359.92 $km^2$ (Grad Beograd, Sekretarijat za informisanje, 2022). The total area of green spaces in the city of Belgrade is 2,907.37 ha. Parks and squares make up 393.00 ha, greenery of residential areas 1,077.67 ha, green areas of roads 174.89 ha, urban forests 650.88 ha, coasts and shores and Great War Island 225.83 ha, protective areas 35.77 ha, and other categories of greenery 349.24 ha (Milanović, 2006). The significant microclimatic diversity of the city of Belgrade and its surroundings and other ecological factors have led to the formation of numerous plant communities that are typical for the region. The main forest communities in and around Belgrade and the most important dendroflora species were gradually enriched by man. In addition to native species of deciduous trees, there is also a large number of species brought from other climate areas. According to the literature (Maksimović et al., 1979), the most common autochthonous genera are linden, maple, ash, poplar, birch, hornbeam and others, while oaks are less represented. Among the introduced species, the most represented are acacia, honey locust, sophora, horse chestnut, catalpa, sycamore, etc. As for the domestic conifer species, Austrian pine and Norway spruce are the most common. Among the introduced species and varieties of conifers, the most represented are silver fir, cedar, yew, junipers, etc.

Northern red oak (*Quercus rubra* L.) grows naturally in the eastern and central parts of the United States of America (Uzcategui et al., 2020). It was introduced to Europe in 1691 (Gubka & Špišák, 2010). To date, there are only small areas under northern red oak in Serbia (c. 60 ha), but there are significant stands of this species in the vicinity of Belgrade (Lazarević, 2020). Northern red oak has shown exceptional results in the xeromesophilic and xerothermophilic oak habitats. It is a species that tolerates aridity better than sessile oak (*Q. petraea* L.) and has fewer demands on soil fertility. In addition, it easily adapts to different climatic conditions and tolerates low temperatures well (Isajev et al., 2006). It has a large crown and crimson-coloured leaves, almost entirely marcescent on young trees in the winter, with a high decorative value in parks and public gardens and it is a common street tree (Brus, 2011). Northern red oak may be an alternative to native oaks, pedunculate oak (*Q. robur* L.) and sessile oak [*Q. petraea* (Mattushka) Liebl.], on sites that are marginal for the latter, or under expected climate change as a "drought tolerant species" (Ray et al., 2010).

In urban areas, there is an increasing need to assess the health status and mechanical parameters of standing trees, not only for the sanitary and aesthetic function of greenery but also for the safety of people and infrastructure. In this paper, northern red oak trees growing in the area of Belgrade city were examined to assess their condition and adaptability to urban environments.

## 2. MATERIAL AND METHODS

### 2.1. Study area

The examined northern red oak trees are located in the area of the municipality of Savski Venac. The municipality is the traffic, tourist and business center of Belgrade and one of the oldest municipalities of the city. About 40,000 inhabitants live in this municipality, with twice as many people working there (Beogradska opština Savski venac, 2022). Its northernmost point is at 44°48'54", and its southernmost point is at 44°45'15" north latitude. Its westernmost point is at 20°25'29", and its easternmost point is at 20°28'26" eastern longitude. The extension of the municipality in the south-north direction is 6.91 km, and in the west-east direction is 5.20 km (Vojnogeografski institut, 1990). It covers an area of 15.8 km². The highest point of this municipality is located within the Royal Complex (210 m), while the lowest point is the confluence of Topčider river with the Sava river (75 m). The geological substrate consists of sediments of the Holocene age and the alluvial plain of the Sava river. This area is dominated by anthropogenic, modified soils. The climate is temperate and continental, with long hot summers and cold winters. It is characterized by a specific microclimate because residential areas and heavy traffic cause an increase in temperature as compared to the average. However, the municipality also has a high proportion of green areas, which has the opposite effect (Gradski zavod za zaštitu zdravlja Beograd, 2002). The flora of this municipality is quite rich. Among the deciduous trees, oak, birch, maple, cherry plum, apple tree and poplar can be distinguished, along with many conifers, such as pines, spruces, etc. (Wikipedia, 2022).

### 2.2. Data and methodology

Forty-two trees of northern red oak were examined in the study area (Figure 1). The trunk diameter (at breast height), tree height and crown diameter of the analyzed trees were measured, and their vitality and decorativeness were assessed. A diameter tape (Bandmass 10 m, Weiss, Germany) was used to measure the trunk diameter of the trees, and the tree height was measured with a height measuring instrument (Vertex 4, Haglöf, Sweden). The crown diameter was measured by projecting the edges of the crown to the ground and measuring the length along one axis using a measuring tape (Fast Winder Frame 30 m, Weiss, Germany). The vitality and decorativeness of the trees were assessed using the VTA method (Visual Tree Assessment) (Mattheck & Breloer, 1994), according to the rating scales in Table 1.

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

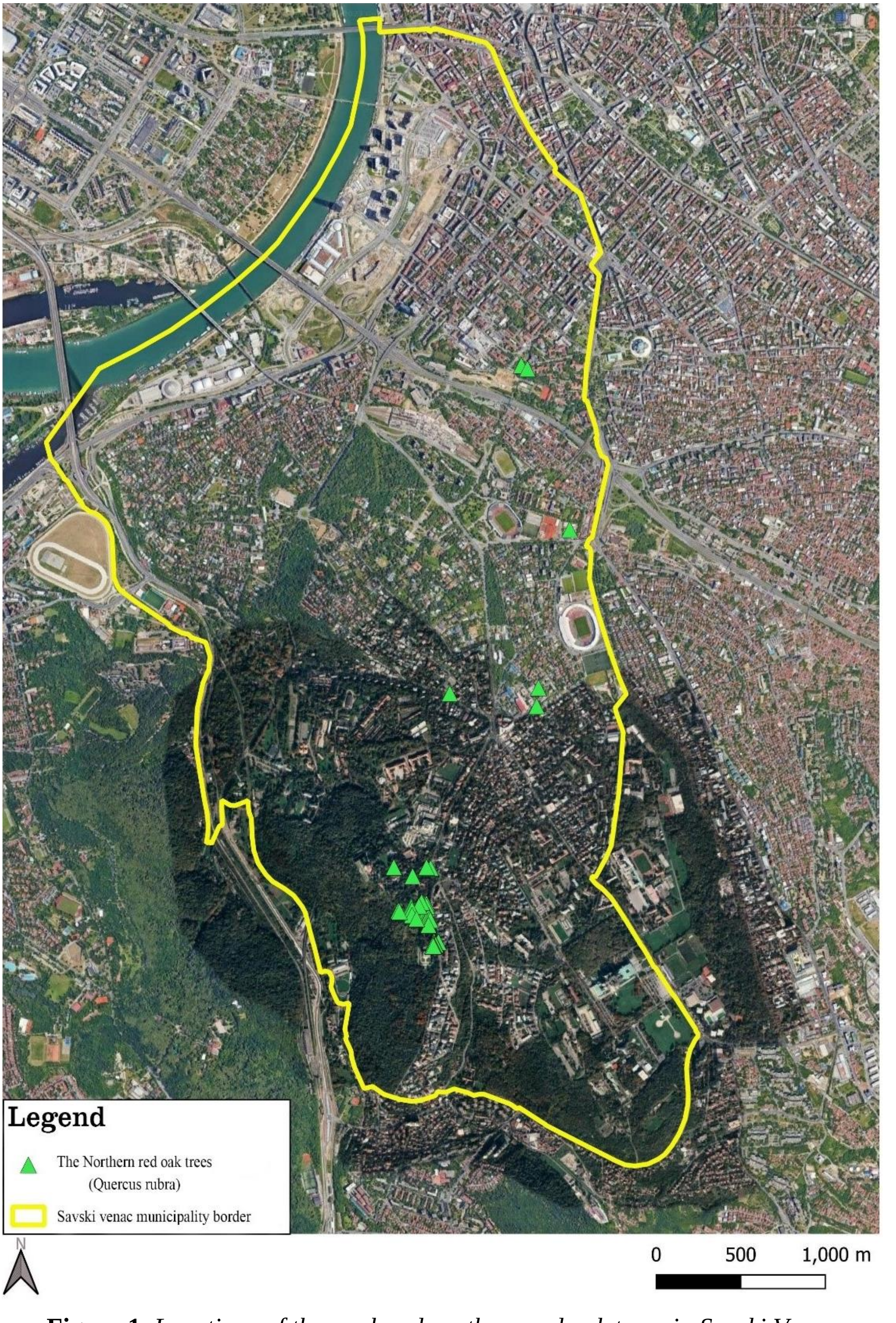


**Figure 1.** *Locations of the analyzed northern red oak trees in Savski Venac municipality, Belgrade, Serbia*

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

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

## 3. RESULTS

The results of descriptive statistics for the vitality, decorativeness and physical measurements of northern red oak trees, growing in the urban area of Belgrade, are shown in Table 2 and Figure 2.

According to the obtained physical measurements, the trunk diameter of the analyzed trees ranged from 7.50 cm to 85.00 cm, with a mean value of 45.00 cm and a coefficient of variation of 34.76%. In addition, the crown diameter ranged from 2.50 m to 17.50 m, with a mean value of 11.73 m and a coefficient of variation of 32.21%. Finally, the height of the analyzed trees ranged from 3.50 m to 22.50 m, with a mean value of 14.28 m and a coefficient of variation of 30.48% (Table 2). These results show that the physical measurements of the analyzed trees are highly variable, indicating that the sample consisted of trees with wide range of age.

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

| Property | Mean value | Standard deviation | Coefficient of variation (%) | Minimum value | Maximum value | Variation range |
|---|---|---|---|---|---|---|
| Trunk diameter (cm) | 45.00 | 15.64 | 34.76 | 7.50 | 85.00 | 77.50 |
| Crown diameter (m) | 11.73 | 3.78 | 32.21 | 2.50 | 17.50 | 15.00 |
| Tree height (m) | 14.28 | 4.35 | 30.48 | 3.50 | 22.50 | 19.00 |
| Vitality (1-5) | 4.45 | 0.67 | 15.05 | 3.00 | 5.00 | 2.00 |
| Decorativeness (1-5) | 3.88 | 0.59 | 15.27 | 3.00 | 5.00 | 2.00 |

On the other hand, the vitality and decorativeness were much less variable features of the analyzed oak trees (coefficients of variation 15.05% and 15.27%, respectively). The vitality ranged from grade 3 to grade 5, with a mean value of 4.45, whereas the grades of decorativeness ranged from 3 to 5, with a mean value of 3.88 (Table 2). It was found that the analyzed trees are in very good condition based on their health status, considering that most of them (80.95%) had no visible indication of disease.

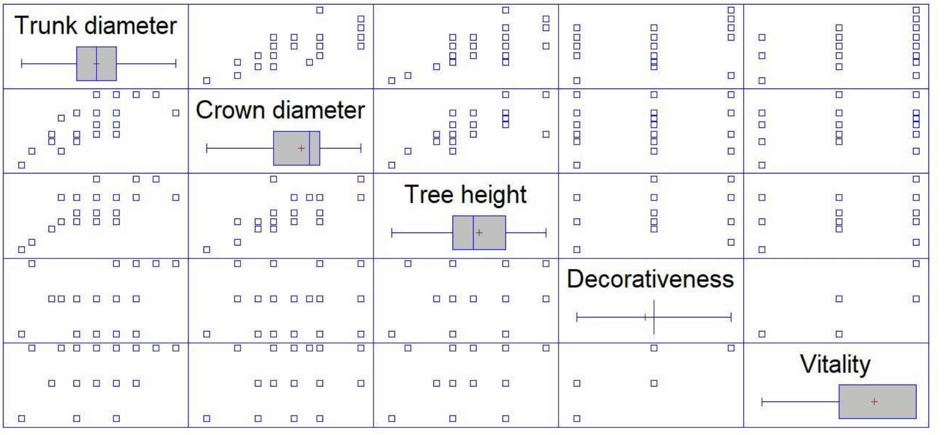


**Figure 2.** *Box-and-Whisker plot of basic parameters of vitality, decorativeness and physical measurements of northern red oak trees in the urban area of Belgrade. Legend: middle sign = mean, middle line = median, box = mean and standard deviation, whisker = variation range.*

In comparison with the literature data, the mean value of trunk diameter of the analyzed northern red oak trees was greater than the mean value reported for pedunculate oak (35.20 cm) (Pretzsch et al., 2015), but less than the mean values recorded for water oak (*Q. nigra* L.) (61.50 cm) (Dahlhausen et al., 2016) and white oak (*Q. alba* L.) (69.90 cm) (Sonti et al., 2019) in similar environments. The mean value of crown diameter of the analyzed trees was greater than that stated by Pretzsch et al. (2015) for pedunculate oak (3.60 m), and by Dahlhausen et al. (2016) for water oak (7.10 m). In contrast, the mean value of tree height obtained in this study was less than that given by Dahlhausen et al. (2016) for water oak (15.90 m).

It is necessary to assess the vitality of park species and determine biotic and abiotic factors that directly or indirectly threaten their condition so that adequate care and protection measures can be applied (Mladenović et al., 2020). The vitality of the sampled trees of northern red oak was greater than the values reported by Bühler et al. (2007) for four oak species (*Q. palustris* Münchh., *Q. petraea*, *Q. robur* and *Q. rubra*) (3.40 on a scale of 0–5, i.e., 2.83 on a scale of 1–5), and by Östberg et al. (2021) for pedunculate oak (66 on a scale of 0–100, i.e., 3.27 on a scale of 1–5). Still, these results were probably influenced by the fact that the majority of the sampled trees are located in the Royal Complex, where the environment conditions are more favorable than those in the city core.

For the establishment of functional green areas in urban environments, healthy planting stock and properly selected plant species are needed, along with appropriate tending and protection measures including substitution of sensitive species with more resistant ones (Mladenović et al., 2018). Based on the obtained results in this study and their comparison with literature data, it can be argued that northern red oak has adapted well to the urban environment of Belgrade, exhibiting very good health condition and adequate physical characteristics. Therefore, this plant species can be recommended for planting in the urban areas of Serbia as a landscape tree.

## 4. CONCLUSION

Based on the obtained data on vitality, decorativeness and physical measurements of northern red oak trees in the urban area of Belgrade, the following conclusions can be drawn:

- physical measurements of northern red oak trees in Belgrade (trunk diameter, tree height and crown diameter) are highly variable, indicating that the sampled trees are of a wide range of age;
- vitality and decorativeness are moderately variable traits of the northern red oak trees in the area;
- the analyzed trees are in very good condition based on their health status (80.95% of trees with no visible indication of disease) and mean values of ratings for vitality (4.45) and decorativeness (3.88);
- the obtained values for the vitality and some physical measurements (crown diameter and, in some cases, trunk diameter) of the sampled trees were greater than those stated in the literature for the same or related species in similar environments.

Finally, it can be concluded that northern red oak has adapted well to the urban environment of Belgrade and it should be considered a suitable landscape tree species for planting in urban areas of Serbia.

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## CONDITION OF NORTHERN RED OAK TREES IN THE URBAN ENVIRONMENT OF BELGRADE (SERBIA)

*Ivana ŽIVANOVIĆ, Filip JOVANOVIĆ, Nenad ŠURJANAC, Đorđe FILIPOVIĆ, Aleksandar LUČIĆ*

### Summary

In urban areas, there is an increasing need to assess the health status and mechanical parameters of standing trees, not only for the sanitary and aesthetic function of greenery but also for the safety of people and infrastructure. In the present paper, northern red oak trees (*Quercus rubra* L.) were examined in the urban area of Belgrade city to assess the condition of this allochthonous species in Serbia and its adaptability to urban environments.

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

The results show that the trunk diameter of the analyzed trees has a range of values 7.50–85.00 cm and a mean value of 45.00 cm; the crown diameter ranged from 2.50 m to 17.50 m, with a mean value of 11.73 m, and the tree height ranged from 3.50 m to 22.50 m, with a mean value of 14.28 m, indicating a wide range of age of the sampled trees. On the other hand, the vitality and decorativeness were much less variable features. The mean value of vitality is 4.45 and the mean value of decorativeness is 3.88 (Table 2). In addition, the analyzed trees are in very good condition based on their health status (80.95% of trees are with no visible indication of disease). In comparison with literature data (Bühler et al., 2007; Dahlhausen et al., 2016; Östberg et al., 2021; Pretzsch et al., 2015), the obtained values for the vitality and physical measurements (crown diameter and, in some cases, trunk diameter) of the sampled trees were greater than those stated for the same species or other oak species [*Q. robur* L., *Q. alba* L., *Q. palustris* Münchh., *Q. petraea* (Mattushka) Liebl.] in similar environments.

Based on the obtained results in this study, it can be concluded that northern red oak has adapted well to the urban environment of Belgrade and it should be considered a suitable landscape tree species for planting in urban areas of Serbia.

# STANJE STABALA CRVENOG HRASTA U GRADSKOJ SREDINI BEOGRADA (SRBIJA)

*Ivana ŽIVANOVIĆ, Filip JOVANOVIĆ, Nenad ŠURJANAC,*
*Đorđe FILIPOVIĆ, Aleksandar LUČIĆ*

## Rezime

U gradskim sredinama je sve izraženija potreba za procenom zdravstvenog stanja i mehaničkih parametara dubećih stabala, ne samo zbog higijensko-sanitarne i estetske funkcije zelenila, već i zbog bezbednosti ljudi i infrastrukture. U radu su ispitana stabla crvenog hrasta (*Quercus rubra* L.) na području grada Beograda, radi procene stanja ove alohtone vrste i njene prilagođenosti urbanoj sredini u Srbiji.

Istraživanje je obuhvatilo 42 stabla koja se nalaze na teritoriji GO Savski venac (slika 1). Prsni prečnik, visina stabala i širina krošnje mereni su odgovarajućim alatima i uređajima (Weiss Bandmass 10 m; Haglöf Vertex 4; Weiss Fast Winder Frame 30 m), dok su vitalnost i dekorativnost stabala procenjeni prema VTA metodi (Mattheck & Breloer, 1994) na petostepenoj skali (tabela 1). Dobijene numeričke vrednosti su obrađene u skladu sa deskriptivnim statističkim metodama.

Rezultati istraživanja pokazuju da prsni prečnik ispitanih stabala ima raspon vrednosti 7,50–85,00 cm i srednju vrednost 45,00 cm; širina krošnje je varirala od 2,50 m do 17,50 m, sa srednjom vrednošću 11,73 m, dok je visina stabala varirala od 3,50 m do 22,50 m, sa srednjom vrednošću 14,28 m, što ukazuje na to da su uzorkovana stabla vrlo različitih starosti. S druge strane, vitalnost i dekorativnost su znatno manje varijabilne odlike ispitanih stabala. Srednja vrednost vitalnosti stabala je 4,45, a dekorativnosti 3,38 (tabela 2). U prilog tvrdnji da su ova stabla veoma dobre kondicije svedoči i njihovo zdravstveno stanje (80,95% stabala je bez vidljivih fitopatoloških promena). U poređenju sa literaturnim podacima (Bühler et al., 2007; Dahlhausen et al., 2016; Östberg et al., 2021; Pretzsch et al., 2015), utvrđene vrednosti za vitalnost stabala i njihove dimenzije (širina krošnje i, u nekim slučajevima, prsni prečnik debla) bile su veće od onih navedenih za ovu vrstu hrasta ili druge hrastove [*Q. robur* L., *Q. alba* L., *Q. palustris* Münchh., *Q. petraea* (Mattushka) Liebl.] u sličnim uslovima.

Na osnovu rezultata ovog rada, moguće je doneti zaključak da je crveni hrast dobro prilagođena vrsta gradskoj sredini Beograda i da se može preporučiti za sadnju u urbanim područjima Srbije.

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# CLIMATE CHARACTERISTICS AND DIAMETER INCREMENT OF EASTERN WHITE PINE: POTENTIAL USE IN AFFORESTATION IN THE BELGRADE AREA (REPUBLIC OF SERBIA)

*Tatjana DIMITRIJEVIC*[1]*, *Mihailo RATKNIC*[2], *Sabahudin HADROVIC*[3]

**Abstract:** *The impact of climate change on forest ecosystems is becoming increasingly apparent. Research indicates that rising air temperatures affect the state of biodiversity, a range of ecological processes, as well as the dynamics of developmental characteristics of individual trees (Ratknić T. et al., 2019a; Dimitrijević T. et al., 2022; Dimitrijević T. et al., 2023). This study investigates how climate affects the size of earlywood, latewood, and the total current increment of Pinus strobus trees in Belgrade. Data related to site changes are compared to site characteristics in its natural sites in North America. The climate model REG_IN indicates that newly emerging site conditions will hinder the establishment of new pine plantations in the urban forests of Belgrade. According to the aridity index (FAI) for the period 2081-2100, the FAI is estimated to reach 7.4, indicating a forest-steppe climate. All the analyses suggest that the emerging conditions will prevent the introduction of Pinus strobus into the urban forests of Belgrade.*

**Keywords:** *Pinus strobus*, climate change, REG_IN model, earlywood, latewood, total increment

# KLIMATSKE KARAKTERISTIKE I DEBLJINSKI PRIRAST BOROVCA: POTENCIJALNA UPOTREBA U POŠUMLJAVANJU NA PODRUČJU BEOGRADA (REPUBLIKA SRBIJA)

**Sažetak:** *Uticaj klimatskih promena na šumske ekosisteme je sve vidljiviji. Istraživanja ukazuju da povećanje temperature vazduha utiče na stanje biodiverziteta, veliki broj ekoloških procesa, kao i dinamiku razvojnih karakteristika pojedinanih stabala (Ratknić T. et al., 2019a; Dimitrijević T. et al., 2022; Dimitrijević T. et al., 2023). U radu je vršeno istraživanje na koji način klima utiče na veličinu ranog, kasnog drveta i ukupnog tekućeg prirasta stabala Pinus strobus na području grada Beograda. Podaci promene staništa poređeni su sa karakteristikama staništa na prirodnim nalazištima na području Severno Američkog kontinenta. Na osnovu klimatskog modela REG_IN ukazuje se da se stvaraju stanišni uslovi koji će onemogućiti uspešno podizanje novih plantaža borovca u urbanim šumama grada Beograda. Na osnovu indeksa aridnosti (FAI) za period 2081-2100., procena*

[1]Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Republic of Serbia
[2]Full member of “Sigma Xi”; Earth Climate Change Team (ECCTeam), New Jersey, USA
[3]Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Republic of Serbia
*Corresponding author. E-mail: tatjanaratknic@yahoo.com

*je da će FAI vrednost iznositi 7,4, odnosno da će klima imati odlike šumsko-stepske klime. Sve ove analize ukazuju da se stvaraju uslovi koji onemogućavaju unošenje Pinus strobus u urbanim šumama Beograda.*

**Ključne reči:** Pinus strobus, klimatske promene, REG_IN model, rano drvo, kasno drvo, ukupni prirast

## 1. INTRODUCTION

Climate change undoubtedly gives rise to the development of new approaches in forestry. These approaches have been triggered by the effects of global and regional climate changes (different climate scenarios, changes in greenhouse gas concentrations, the state of the ozone layer, changes in ultraviolet radiation intensity, etc.).

According to the latest IPCC Report (2023), the mean global air temperature of the planet is estimated to be 1.09 [from 0.95 to 1.20]°C higher in the period 2011–2020 than in 1850–1900, with a greater increase over its land area (1.59 [from 1.34 to 1.83]°C) than over the oceans (0.88 [from 0.68 to 1.01]°C). The mean global air temperature in the first two decades of the 21st century (2001–2020) was 0.99 [from 0.84 to 1.10]°C higher than in 1850–1900. The mean global surface temperature has risen faster since 1970 than in any other 50-year period in at least the last 2000 years (high confidence) (IPCC AR6 SYR, 2023). The concentration of carbon dioxide, the most important greenhouse gas, has increased by 50% compared to the pre-industrial period and is now at 415.7 parts per billion (ppb). The concentration of methane has increased more than 2.5 times (1908 ppb), and the concentration of nitrogen compounds by 25% (334.5 ppb).

Based on the ND-GAIN index of Serbia's vulnerability to climate change and other global challenges, combined with its readiness to improve resilience, Serbia ranks 76th out of 182 ranked countries. The goal of this index is to assist governments, businesses, and communities in better prioritizing investments for a more efficient response to the immediate global challenges ahead (Notre Dame Global Adaptation Initiative, 2023). These changes will have a striking impact on forest ecosystems. Human activities have already led to the destruction of numerous habitats, leaving them mostly fragmented or damaged by long-term pollution from various sources (Ratknić T. et al., 2019b). Existing and future vegetation in the Belgrade area will be developing under conditions of elevated temperatures compared to previous conditions. The isotherms of mean annual air temperatures have shifted by about 160 km to the north, and by the end of the 21st century, the extent of the shift will exceed the ranges of many tree species, leading to their extinction in the areas they are currently present (Barns, B.V., 2009; Iverson et al., 2008; Kirschbaum, M. and Fischlin, A., 1996; Joyce D. and Rehfeldt G., 2012). Climate change will modify forest ecosystems of Belgrade as they will not be able to adapt to the new climatic conditions (Dimitrijević T. and Ratknić M., 2023).

Climate change poses challenges in selecting the most appropriate forest management practices. The rate of climate change hinders the ability of forest ecosystems to adapt to these changes, thereby jeopardizing their sustainable utilisation. One possible solution to address the impact of climate change on forests is through the concept of climate niches (Joyce D. and Rehfeldt G., 2012). The use of climatic conditions to describe a species' niche has become central to much "ecological reasoning and theory" (Pulliam, 2000, based on Joyce D. and Rehfeldt G., 2012). The dependence of growth and increment parameters on climatic factors is one of the elements used in developing species niches and selecting suitable sites with regard to future climate changes (Dimitrijević T. and Ratknić M., 2023). "The central premise of this approach is that the currently realised niche of a species provides the best available metric for projecting the future distribution of suitable habitats" (Pearson, 2007, based on Joyce D. and Rehfeldt G., 2012).

**Figure 1.** *Range of Eastern white pine trees – in the eastern part of North America (in the United States and Canada)*

Based on climate models and changes in forest ecosystems (Ratknić T. at al., 2019b), it is assumed that most native tree species will not be able to adapt to future climatic conditions. This is the reason to introduce non-native species in the urban forests of Belgrade that are more adaptable to future climate conditions than native species, and thus increase the diversity of species in this area. The influence of climatic characteristics has been determined for the Belgrade urban forests of

Douglas fir (Ratknić T. et al., 2019a), larch (Dimitrijević T. et al., 2022), and red oak (Dimitrijević T. et al., 2023). Regarding Eastern white pine cultures in Serbia, two-way volume tables have been constructed (Ratknić M. et al., 1987), and habitat indices have been developed (Ratknić M., 1994).

Eastern white pine (*Pinus strobus*) is distributed across southern Canada, ranging from Newfoundland, Anticosti Island, and the Gaspé Peninsula of Quebec, westward to central and western Ontario, and extreme southeastern Manitoba. Its range extends south to southeastern Minnesota and northeastern Iowa, eastward to northern Illinois, Ohio, Pennsylvania, and New Jersey. In the southern part of its range, it is found mostly in the Appalachian Mountains, reaching down to northern Georgia and northwestern South Carolina. It can also be found in western Kentucky, western Tennessee, and Delaware. A variety of Eastern white pine grows in the mountains of southern Mexico and Guatemala (Wendel G.W. and Smith C., 1990).

This species adapts to a wide range of soils but is most competitive on well-drained sandy soils of low to medium quality sites (Wendel G.W. and Smith C., 1990). It grows in pure stands, although it has also been found in mixed stands with other coniferous and broadleaved species, particularly with *Pinus resinosa* and *Pinus bankiana*, *Abies bansamea*, *Picea rubens*, *Picea glauka*, *Betula papirifera*, as well as in mixed forests with *Tsuga canadensis*, *Acer saccharinum*, and *Betula lutea*. The characteristics of Eastern white pine in its natural sites are presented in Table 1.

**Table 1.** *Characteristics of Eastern white pine in natural sites*

| Regions | Shade Tolerance (ST) | Soil moisture (SM) | Soil reaction (pH) | Rate of growth (RG) | Longevity (L) | Natural Reproduction (NR) |
|---|---|---|---|---|---|---|
| Algonquin Park Region, Ontario | Young – M<br>Old - I | d-w | | s | L | d |
| Southern Ontario | I-M | d-w | | r | L | m-e |
| New York and New England | M | d | N | m | L | e |
| Southeastern United States | M | m | A-N | r | L | m |

Symbols: Shade Tolerance (ST): intolerant (I), medium (M); Soil Moisture (SM): dry (d), medium (m); wet (w); Soil Reaction (pH): (A) acid, neutral (N); Rate of growth (RG): rapid (r), medium (m); average (a); Longevity (L): long (L); Natural Regeneration (NR): difficult (d), easy (e); medium (m);

**Source:** Forbes R., 1955

In Europe, Eastern white pine was first recorded in 1553 in the Royal Garden of Fontainebleau, France, but further mentions regarding its introduction into parks and forests emerged much later, at the beginning of the 18$^{th}$ century. In 1705, it was planted by the Duchess de Bofor at Badminton in Great Britain, and a few years later in Longleat (Kent) on the estate of Lord Weymouth. Successive introductions into other European countries were reported by various authors as follows: in Germany in 1770; in the former Czechoslovakia in 1773; in Switzerland in 1850; in Poland in 1876; in Austria in 1886; and in Bulgaria in 1903. Its rapid growth rate, high-quality wood and good yield, great adaptability to different locations and climatic conditions, and its remarkable ornamental value, were among the main reasons for its introduction (Radu S.. 2008).

It has been frequently used in afforestation in Western Europe but has shown susceptibility to blister rust attacks (*Cronartium ribicola*). In Serbia, it has been used in the reclamation of degraded and deforested areas. Eastern white pine tolerates low winter temperatures and urban conditions well. It grows in moderately moist, acidic soils (calcifuge) but is found to be sensitive to snow breakage.

This study analyses Eastern white pine (*Pinus strobus* L.) as another potential species for planting in the urban forests of Belgrade.

## 2. MATERIAL AND METHODS

The study was conducted in an artificially established stand of Eastern white pine at the locality known as Šuplja Stena. The coordinates of the experimental field are X=7464033; Y=4947582; and Z=283. The study stand is located at an elevation of 283 meters, with a slope of $5^0$ and a westward aspect. The stand is 50 years old, well-preserved, with a complete canopy. Apart from Eastern white pine, individual specimens of spruce (17 trees per hectare) and field maple (8 trees per hectare) were recorded in the stand.

The dependence of the current diameter increments and width of earlywood and latewood on climatic characteristics was examined. The climatic variables included monthly precipitation sums and mean monthly air temperatures during the growing season (from April to September). The independent variables were:

- stand age
- monthly precipitation sums in April (AP_P), May (MA_P), June (JU_P), July (JL_P), August (AU_P), and September (SE_P)
- mean monthly air temperatures in April (AP_T), May (MA_T), June (JU_T), July (JL_T), August (AU_T), and September (SE_T).

## 3. RESULTS

### 3.1. Soil Characteristics

Soil Type: Luvisol (ilimerized soil), profile structure A (0-2 cm) – E (2-40 cm) Bt (40->60 cm).

The surface layer of the soil belongs to the loam textural class. As the soil depth increases, the content of clay increases, and the deeper analysed layers belong to the class of clayey loams. Regarding the reaction of the soil solution in water, the soil is between strongly and very strongly acidic throughout the analysed depth. Regarding the degree of base saturation, the surface layer at 0-20 cm and the layer at 20-40 cm depth are dystrophic, while the deepest analysed layer is eutrophic. This results from base leaching into deeper layers preceding illuviation. The soil is weakly humic throughout the depth of the soil. The availability of total nitrogen in the surface layer is good, while it is moderate in the deeper layers. The availability of plant-accessible forms of phosphorus is poor throughout the depth of the soil, and the quantity of plant-accessible forms of potassium barely exceeds 10 mg/100 g, which is the threshold between poor and moderate availability (Miletić Z. and Eremija S., 2019). The chemical properties of the soil on this experimental field are presented in Table 2, and the physical properties in Table 3.

### 3.2 Phytocenological Characteristics

The site belongs to the forest community of Italian oak and Turkey oak with *butcher's-broom*, a variant of hornbeam (Ass. *Quercetum farnetto-cerris Rud. aculeatetosum* Job.). The following species were recorded in the stand (Stajić S., 2019):

- Tree layer: Canopy (0.8); *Pinus strobus* (4.2); *Quercus cerris* (1.1); *Acer pseudoplatanus* (1.1).
- Shrub layer: Canopy (0.4); mean height 3.0 m; *Acer pseudoplatanus* (3.3); *Acer campestre* (1.1); *Fraxinus ornus* (1.1).
- Grond flora layer: Coverage (0.8); *Rubus hirtus* (5.5); *Hedera helix* (2.3); *Galium aparine* (2.3); *Acer pseudoplatanus* (1.2); *Dryopteris filix-mas* (1.1); *Fraxinus ornus* (1.1).

**Table 2.** *Chemical Properties of the Soil*

| Depth | pH | | Adsorptive complex | | | | | Total | | Accessible | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $H_2O$ | KCl | T | S | T-S | V | Y1 | humus | N | $P_2O_5$ | $K_2O$ |
| cm | | | cmol/kg | | | % | $cm^3$ | % | % | mg/100g | |
| 0-20 | 5.04 | 3.60 | 27.97 | 11.59 | 16.39 | 41.42 | 25.21 | 2.81 | 0.16 | 3.53 | 13.40 |
| 20-40 | 5.02 | 3.66 | 24.97 | 12.35 | 12.62 | 49.45 | 19.42 | 1.88 | 0.11 | 2.26 | 10.70 |
| 40-60 | 5.05 | 3.28 | 23.82 | 14.66 | 9.16 | 61.55 | 14.09 | 1.18 | 0.07 | 2.79 | 11.30 |

**Source:** Miletić Z. and Eremija S., 2019

**Table 3.** *Physical Properties of Soil*

| Depth | Coarse sand | Fine sand | Silt | Clay | Total sand | Total clay | Textural class |
|---|---|---|---|---|---|---|---|
| cm | % | % | % | % | % | % | |
| 0-20 | 0.90 | 32.70 | 38.90 | 27.50 | 33.60 | 66.40 | Loam |
| 20-40 | 0.60 | 32.80 | 36.60 | 30.00 | 33.40 | 66.60 | Clayey loam |
| 40-60 | 0.50 | 29.00 | 38.30 | 32.20 | 29.50 | 70.50 | Clayey loam |

**Source:** Miletić Z. and Eremija S., 2019

### 3.3 Stand Characteristics

General data about the artificially established stand of Eastern white pine are presented in Tables 4 and 5. The total number of trees amounts to 557 per hectare. The maximum number of trees (39%) is in the diameter class of 27.5 cm. The mean stand height is 20.9 m, and the mean diameter is 31.7 cm. The stand has distribution lines of trees and volume by diameter classes typical of even-aged stands. The total basal area is 59.1 $m^2ha^{-1}$, while the total wood volume amounts to 342.6 $m^3ha^{-1}$. The maximum volume is in the diameter class of 32.5 cm.

**Table 4.** *Statistical Indicators of Diameter (D), Height, and Volume Distributions*

| Size | $X_{mean}$ | Min. | Max | Quartile | | σ | V | sd | Coefficient of distribution | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Q1 | Q3 | | % | | $\alpha_3$ | $\alpha_4$ |
| D (cm) | 31.7 | 21.2 | 44.8 | 28.0 | 35.0 | 4.82 | 15.22 | 0.58 | 0.274 | -0.287 |
| H (m) | 20.9 | 16.7 | 27.2 | 19.6 | 21.7 | 3.47 | 1.86 | 0.23 | 0.976 | 2.708 |
| V ($m^3$) | 0.6 | 0.2 | 1.2 | 0.4 | 0.7 | 0.04 | 0.21 | 0.03 | 0.885 | 1.060 |

Source: Original

**Table 5**. *Basic Data on the Eastern White Pine Stand*

| Diameter degree | N | | H | G | V | |
|---|---|---|---|---|---|---|
| (cm) | per ha | % | (m) | $m^2$/ha | $m^{3/}$ha | % |
| 22.5 | 26 | 4.7 | 17.5 | 1.54 | 8.9 | 2.6 |
| 27.5 | 222 | 39.9 | 21.81 | 18.42 | 106.6 | 31.1 |
| 32.5 | 168 | 30.2 | 21.86 | 18.55 | 107.3 | 31.3 |
| 37.5 | 124 | 22.3 | 21.08 | 17.59 | 101.8 | 29.7 |
| 42.5 | 17 | 3.1 | 22.5 | 3.12 | 18.0 | 5.3 |
| Σ | 557 | 100.0 | | 59.1 | 342.6 | 100.0 |

Source: Original

Turkey oak is represented by 17 trees, with a total basal area of 2.41 $m^2$/ha. Its mean diameter is 37.5 cm, while the mean height amounts to 18.1 meters. Field maple is represented by 8 trees, with a total basal area of 1.13 $m^2$/ha. The quadratic mean diameter is 42.5 cm, while the mean height amounts to 22.2 meters. The total volume is 342.6 $m^3$/ha.

### 3.4 Impact of Climate Factors on Current Diameter Increment

By applying the correlation method for weight estimation, a model was constructed to assess the influence of age and analysed climate factors on the total current diameter increment, size of latewood (Ka), and size of earlywood (Ra). The parameters of these models are provided in Table 6. The size of earlywood is negatively influenced by age (AGE), total precipitation in April (AP_P), total precipitation in July (JL_P), total precipitation in August (AU_P), as well as mean air temperatures in April (AP_T), May (MA_T), June (JU_T), July (JL_T), and August (AU_U). Positive influence is observed with total precipitation in May (MA_P), June (JU_P), September (SE_P), and mean air temperature in September (SE_T). The correlation coefficient is 0.615, explaining 37.8% of the earlywood values. The F-test value indicates significance at a 0.01 level.

The size of latewood is negatively influenced by age (AGE), total precipitation in April (AP_P), June (JU_P), July (JL_P), and September (SE_P), as well as the mean monthly air temperature in June (JU_T) and September (SE_T). Positive influence is determined for the total precipitation in May (MA_P) and August (AU_P), and mean air temperature in April (AP_T), May (MA_T), July (JL_T), and August (AU_T). The regression coefficient is 0.803, explaining 64.5% of the latewood values. The F-test value indicates significance at a level of 0.05.

The size of the total current diameter increment is negatively influenced by age (AGE), total precipitation in April (AP_P), July (JL_P), and August (AU_P), as well as the temperature in April (AP_T), May (MA_T), July (JL_T), and August (AU_T). Positive influence is observed with total precipitation in May (MA_P), June

(JU_P), and September (SE_P), as well as mean air temperature in June (JU_T) and September (SE_T). This data are presented in Table 7.

**Table 6.** *The Influence of Age and Analysed Climatic Factors on Current Diameter Increment (Zi), Share of Latewood (Ka) and Share of Earlywood (Ra) (Ra)*

| Independent variable | Dependent variable | | | | | |
|---|---|---|---|---|---|---|
| | Ra | | Ka | | Zi | |
| | Parameters | Error | Parameters | Error | Parameters | Error |
| CONSTANT | 14.876 | 4.960 | 0.453 | 1.661 | 16.652 | 5.490 |
| AGE | -0.068 | 0.254 | -0.865 | 0.222 | -0.322 | 0.234 |
| AP_P | -0.300 | 0.206 | -0.142 | 0.140 | -0.324 | 0.190 |
| MA_P | 0.179 | 0.242 | 0.259 | 0.143 | 0.253 | 0.223 |
| JU_P | 0.076 | 0.201 | -0.102 | 0.139 | 0.180 | 0.185 |
| JL_P | -0.385 | 0.281 | -0.066 | 0.163 | -0.440 | 0.258 |
| AU_P | -0.521 | 0.281 | 0.183 | 0.164 | -0.334 | 0.259 |
| SE_P | 0.040 | 0.211 | -0.010 | 0.150 | 0.740 | 0.195 |
| AP_T | -0.339 | 0.209 | 0.304 | 0.166 | -0.179 | 0.192 |
| MA_T | -0.129 | 0.225 | 0.117 | 0.173 | -0.158 | 0.207 |
| JU_T | -0.065 | 0.264 | -0.181 | 0.191 | 0.100 | 0.243 |
| JL_T | -0.260 | 0.332 | 0.191 | 0.221 | -0.258 | 0.306 |
| AU_T | -0.373 | 0.349 | 0.070 | 0.225 | -0.298 | 0.321 |
| SE_T | 0.045 | 0.235 | -0.230 | 0.163 | 0.240 | 0.217 |
| R | 0.615 | | 0.803 | | 0.688 | |
| $R^2$ | 0.378 | | 0.645 | | 0.473 | |
| Standard error | 24.574 | | 0.329 | | 27.196 | |
| F-test | 1.356 | | 4.056 | | 2.001 | |

**Table 7.** *Type of Effect on the Size of Earlywood (Ra), Latewood (Ka), and Total Current Volume Increment (Zi)*

| Effect | Size | | |
|---|---|---|---|
| | Earlywood | Latewood | Total current diameter increment |
| Positive | • Precipitation sums in June<br>• Precipitation sums in September<br>• Mean air temperature in September | • Precipitation sums in May<br>• Precipitation sums in August<br>• Mean air temperature in April<br>• Mean air temperature in May<br>• Mean air temperature in July<br>• Mean air temperature in August | • Precipitation sums in May<br>• Precipitation sums in June<br>• Precipitation sums in September<br>• Mean air temperature in June<br>• Mean air temperature in September |
| Negative | • AGE<br>• Precipitation sums in April<br>• Precipitation sums in May<br>• Precipitation sums in July<br>• Precipitation sums in<br>• Mean air temperature in April<br>• Mean air temperature in May<br>• Mean air temperature in June<br>• Mean air temperature in July<br>• Mean air temperature in August | • AGE<br>• Precipitation sums in April<br>• Precipitation sums in June<br>• Precipitation sums in July<br>• Precipitation sums in September<br>• Mean air temperature in June<br>• Mean air temperature in September | • AGE<br>• Precipitation sums in April<br>• Precipitation sums in July<br>• Precipitation sums in August<br>• Mean air temperature in April<br>• Mean air temperature in May<br>• Mean air temperature in July<br>• Mean air temperature in August |

Source: Original

The climate prevailing in the natural sites of Eastern white pine in North America is cold and moist. It extends in areas with the mean July temperature ranging between 18° and 23°C. Comparing these data with the July temperature date for the Belgrade area, we can see that it is mostly at the upper limit of the ecological niche or significantly above it (Graph 1). This indicates that, in terms of temperature, the Eastern white pine plantation was established in conditions that corresponded to its natural sites, but due to climate change, the temperature conditions have become unfavorable for its normal growth.

The annual precipitation sums in the natural sites range from about 510 mm in northern Minnesota to about 2030 mm in north-western Georgia. In the Great Lakes region, about two-thirds of the precipitation occurs during the warm season, from April to September. In other locations, half of the precipitation occurs during the warm season. Comparing these data with the precipitation in the Belgrade area, it is evident that it is below the lower limit of the ecological niche (except in a few years) (Graph 2).

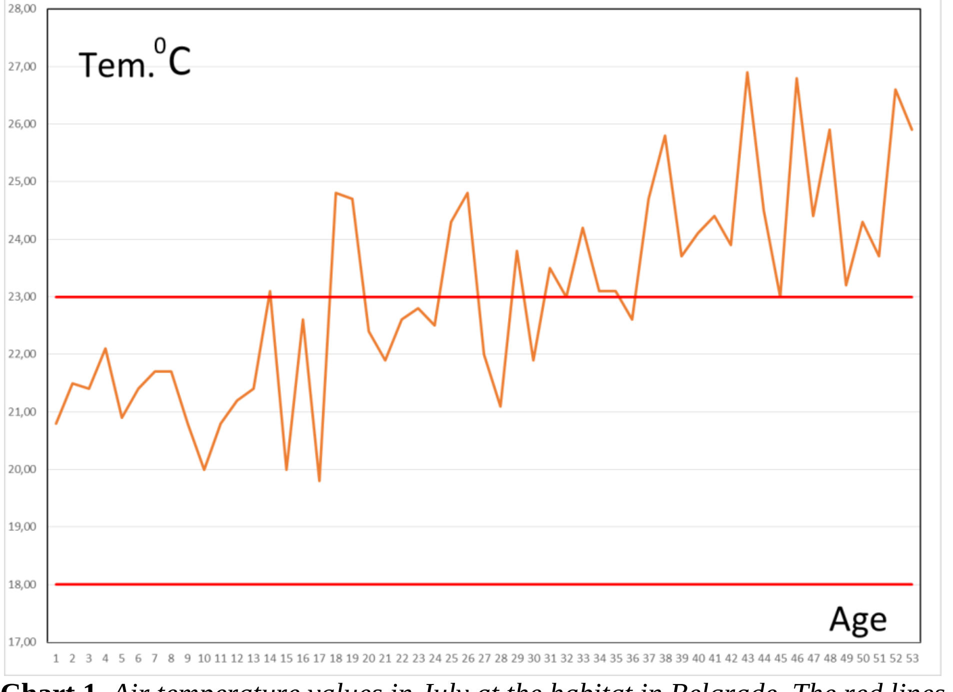


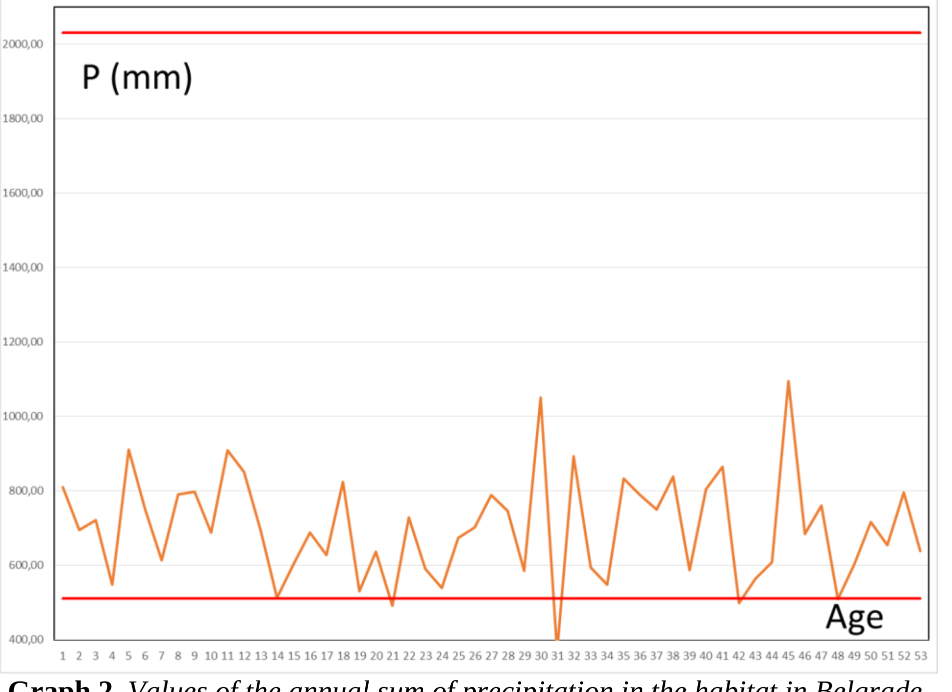

**Chart 1.** *Air temperature values in July at the habitat in Belgrade. The red lines are the ecological temperature niche in July in natural habitats*

Recent climate change projections for Serbia predict a trend of increasing temperatures for the A1B and A2 scenarios for the three observed periods (2011-2040, 2041-2070, and 2071-2100) (Ministry of Agriculture and Environmental Protection, 2015). The expected temperature changes for the observed periods are as follows:

1. 2011-2040 – an increase in temperature of 0.5-0.9°C for A1B, and 0.3-0.7°C for the A2 scenario;

2. 2041-2070 – an increase in temperature of 1.8-2.2°C for A1B, and 1.6-2.0°C for the A2 scenario;
3. 2071-2100 – an increase in temperature of 3.6-4.0°C for A1B, and 3.2-3.6°C for the A2 scenario.

The most pronounced warming, exceeding 4.0°C by the end of the century, is expected for the summer and autumn seasons (MAEP, 2015). The region of Serbia is an area where the air temperature rise will significantly exceed the global average, with an increased incidences of severe droughts and intense precipitation. Summer warming in the Balkans and western Turkey is projected to be 5-6°C for the period 2071-2100 under scenario A2 (Giorgi F. et al., 2009). Applying the ICTP-RegCM3 model for the period 2071-2100, scenario A2 predicts an increase of 7.0°C above the Balkan countries, including Serbia (Önol B. and Semazzi F., 2009). These parameters indicate that site conditions are being created that will hinder the successful establishment of new Eastern white pine plantations in Serbia and the urban forests of Belgrade.




**Graph 2.** *Values of the annual sum of precipitation in the habitat in Belgrade. The red lines are the ecological niche of the annual sum of precipitation in natural habitats*

### 3.3 Forest Aridity Index – FAI

The potential for further introduction of Eastern white pine into urban forests was analysed based on the Forest Aridity Index (FAI). FAI is determined by the ratio of the mean temperatures during critical months (July and August) to the sum of precipitation in the main growing cycle (from May to June) plus the sum of precipitation in the critical growing cycle (from July to August) (Führer E., 2008; 2010). The Forest Aridity Index (FAI) classifies forest regions, allowing for the definition of the distribution areas of certain tree species. Increased values of the Forest Aridity Index (FAI) indicate dry weather conditions during the growing season and critical months, while lower values indicate a cooler and more humid climate (Führer E. et al., 2011). The meteorological characteristics of forest climate categories are: <4.75 (beech climate), 4.75-6.00 (oak-hornbeam climate), 6.00-7.25 (Turkey oak climate), and>7.25 (forest-steppe climate). The values of the Forest Aridity Index (FAI) according to the REG-IN model are shown in Table 8 (Dimitrijević T. et al., 2022). The period 1871-1900 had the lowest FAI value, at 5.4. The values of the index estimated according to the REG-IN model are above 6 and show a rising trend. The FAI value for 2081-2100 is estimated to be 7.4, indicating a climate with forest-steppe characteristics (Table 6). According to this analysis, the ongoing conditions will prevent the introduction of *Pinus strobus* into the urban forests of Belgrade.

**Table 8.** *FAI Values by Analysed Periods and Estimated Values According to the REG-IN Model*

| Periods | Estimated values according to the REG-IN model | | |
|---|---|---|---|
| 1871-1900 | 2021-2050 | 2051-2080 | 2081-2100 |
| 5,4 | 6.4 | 6.9 | 7.4 |

Source: Dimitrijević et al., 2022

### 3.6 Potential Evapotranspiration

Throughout the ecological niche in natural Eastern white pine sites, precipitation is approximately 1 to 1.5 times greater than evaporation from shaded free water surfaces (Wendel G.W. and Smith C.). Annual potential evapotranspiration ranges from 430 to 710 mm, with 56 to 68 per cent occurring in the warm season. There is an excess of moisture in all seasons.

Due to a lack of data on solar radiation, relative air humidity, and wind speed, reference evapotranspiration for the Belgrade City area was calculated using the Hargreaves equation (Hargreaves G.H. and Samani Z.A., 1985). Estimated annual ET values according to the REG-IN model for all three periods are higher compared to the periods from 1871 to 2018, as expected due to the rise in mean annual air temperatures. Annual ET values according to the REG-IN model show a rising trend (Table 9).

**Table 9.** *Reference Evapotranspiration (mm) calculated by the Hargreaves Method*

| Periods | Months | | | | | | | | | | | | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D | |
| 1871-1900 | 17.0 | 26.1 | 55.7 | 89.8 | 127.3 | 145.9 | 161.4 | 142.3 | 96.9 | 58.3 | 27.1 | 15.8 | 963.6 |
| | Estimated values according to the **REG-IN model** | | | | | | | | | | | | |
| 2021-2050 | 21.6 | 32.5 | 53.9 | 90.8 | 132.3 | 152.6 | 164.1 | 150.7 | 100.2 | 63.0 | 34.3 | 19.7 | 1015.7 |
| 2051-2080 | 24.1 | 35.5 | 57.4 | 87.1 | 127.1 | 148.3 | 165.6 | 160.9 | 103.5 | 67.9 | 38.4 | 20.9 | 1036.7 |
| 2081-2100 | 26.9 | 39.8 | 57.4 | 82.4 | 117.3 | 167.8 | 169.8 | 170.2 | 107.4 | 72.9 | 42.3 | 22.5 | 1076.7 |

**Source:** Dimitrijević T. et al., 2022

## 4. CONCLUSION

The size of latewood is negatively influenced by age (AGE), total precipitation in April (AP_P), June (JU_P), July (JL_P), and September (SE_P), as well as the mean monthly air temperature in June (JU_T) and September (SE_T). Positive influence is determined for the total precipitation in May (MA_P) and August (AU_P), and mean air temperature in April (AP_T), May (MA_T), July (JL_T), and August (AU_T). The regression coefficient is 0.803, explaining 64.5% of the latewood values. The F-test value indicates significance at a level of 0.05.

The size of the total current diameter increment is negatively influenced by age (AGE), total precipitation in April (AP_P), July (JL_P), and August (AU_P), as well as the temperature in April (AP_T), May (MA_T), July (JL_T), and August (AU_T). Positive influence is observed with total precipitation in May (MA_P), June (JU_P), and September (SE_P), as well as mean air temperature in June (JU_T) and September (SE_T). This data are presented in Table 7.

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University of Notre Dame, Notre Dame Global Adaptation Initiative, 721 Flanner Hall, Notre Dame, IN 46556 USAPhone 574-631-9103 ndgain@nd.edu, Accessibility Information

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## CLIMATE CHARACTERISTICS AND DIAMETER INCREMENT OF EASTERN WHITE PINE: POTENTIAL USE IN AFFORESTATION IN THE BELGRADE AREA (REPUBLIC OF SERBIA)

*Tatjana DIMITRIJEVIĆ, Mihailo RATKNIĆ, Sabahudin HADROVIĆ*

### Summary

The size of earlywood is negatively influenced by age (AGE), total precipitation in April (AP_P), total precipitation in July (JL_P), total precipitation in August (AU_P), as well as mean air temperatures in April (AP_T), May (MA_T), June (JU_T), July (JL_T), and August (AU_U). Positive influence is observed with total precipitation in May (MA_P), June (JU_P), September (SE_P), and mean air temperature in September (SE_T). The correlation coefficient is 0.615, explaining 37.8% of the earlywood values. The F-test value indicates significance at a 0.01 level. The size of latewood is negatively influenced by age (AGE), total precipitation in April (AP_P), June (JU_P), July (JL_P), and September (SE_P), as well as the mean monthly air temperature in June (JU_T) and September (SE_T). Positive influence is determined for the total precipitation in May (MA_P) and August (AU_P), and mean air temperature in April (AP_T), May (MA_T), July (JL_T), and August (AU_T). The regression coefficient is 0.803, explaining 64.5% of the latewood values. The F-test value indicates significance at a level of 0.05. The size of the total current diameter increment is negatively influenced by age (AGE), total precipitation in April (AP_P), July (JL_P), and August (AU_P), as well as the temperature in April (AP_T), May (MA_T), July (JL_T), and August (AU_T). Positive influence is observed with total precipitation in May (MA_P), June

(JU_P), and September (SE_P), as well as mean air temperature in June (JU_T) and September (SE_T). The climate model REG_IN indicates that newly emerging site conditions will hinder the establishment of new pine plantations in the urban forests of Belgrade. According to the aridity index (FAI) for the period 2081-2100, the FAI is estimated to reach 7.4, indicating a forest-steppe climate. All the analyses suggest that the emerging conditions will prevent the introduction of Pinus strobus into the urban forests of Belgrade.

## KLIMATSKE KARAKTERISTIKE I DEBLJINSKI PRIRAST BOROVCA: POTENCIJALNA UPOTREBA U POŠUMLJAVANJU NA PODRUČJU BEOGRADA (REPUBLIKA SRBIJA)

*Tatjana DIMITRIJEVIĆ, Mihailo RATKNIĆ, Sabahudin HADROVIĆ*

### Rezime

Veličina ranog drveta je pod negativnim uticajem starosti (AGE), sume padavina u aprilu (AP_P), sume padavina u julu (JL_P), sume padavina u avgustu (AV_P), kao i srednje temperature vazduha u aprilu (AP_T), maju (MA_T), junu (JU_T), julu JL_T) i avgustu (AU_U). Pozitivan uticaj je konstatovan sa sumom padavina u maju (MA_P), junu (JU_P), septembru (SE_P) i srednjom temperaturom vazduha u septembru (SE_T). Koeficijent korelacije iznosi 0,615 i objašnjeno je 37,8% vrednosti ranog drveta. Veličina kasnog drveta je pod negativnim uticajem starosti (AGE), sumom padavina u aprilu (AP_P), junu (JU_P), julu (JL_P) i septembru (SE_P), kao i sa srednjom mesečnom temperaturom vazduha u junu (JU_T) i septembrom (SE_T). Pozitivan uticaj utvrđen je sa sumom padavina u maju (MA_P) i avgustu (AV_P), i sa srednjom temperaturom vazduha u aprilu (AP_T), maju (MA_T), julu (JL_T) i avgustu (AV_T). Koeficijent regresije iznosi 0,803 i objašnjeno je 64,5% vrednosti kasnog drveta. Veličina ukupnog tekućeg debljinskog prirasta pod negativnim uticajem je starosti (AGE), sume padavina u aprilu (AP_P), julu (JL_P) i avgustu (AU_P) kao i temperature aprilu (AP_T), maju (MA_T), julu (JL_T) i avgusta (AU_T). Pozitivan uticaj konstatovan je sa sumom padavina u maju (MA_P), junu (JU_P) i septembru (SE_P) i sa srednjom temperaturom vazduha u junu (JU_T) i septembru (SE_T). Na osnovu klimatskog modela REG_IN ukazuje se da se stvaraju stanišni uslovi koji će onemogućiti uspešno podizanje novih plantaža borovca u urbanim šumama grada Beograda. Na osnovu indeksa aridnosti (FAI) za period 2081-2100., procena je da će FAI vrednost iznositi 7,4, odnosno da će klima imati odlike šumsko-stepske klim. Sve ove analize ukazuju da se stvaraju uslovi koji onemogućavaju unošenje Pinus strobus u urbane šume Beograda.

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# INFLUENCE OF THE STRESS FACTOR UNDER THE CONDITIONS OF CLIMATE CHANGES ON WEAKINING OF TREES AND APPERANCE OF PATHOGENIC AND EPYXILOUS FUNGI IN NATURAL BEECH STRANDS

*Miroslava MARKOVIĆ[1]*, Renata GAGIĆ-SERDAR[1], Bojan KONATAR[1], Suzana MITROVIĆ[1]*

**Abstract:** *The paper presents the examination of the health condition of beech stands from the aspect of mechanical and abiotic damage on trees. The research was conducted in Forest Management Office Kucevo, in a hillside beech forest Fagetum moesiacae submontanum of generative origin. The research included 505 trees on 28 sample plots. A strong correlation was found between the appearance of fungi and the presence of injuries – 51.88%, as well as between the presence of fungi and abiotic damage – 47.96%. It was determined that the health condition of high beech forest heavily depended on careful and proper manipulation during logging, while every injury sustained by standing beech trees during felling opened an access point to dangerous microorganisms.*

**Keywords:** mechanical damage, abiotic damage, beech, fungi

# UTICAJ FAKTORA STRESA U USLOVIMA PROMENE KLIME NA SLABLJENJE STABALA I POJAVU PATOGENIH I EPIKSILNIH GLJIVA U PRIRODNIM SASTOJINAMA BUKVE

**Sažetak:** *U radu je prikazano ispitivanje zdravstvenog stanja bukovih sastojina sa aspekta prisustva mehaničkih i abiotičkih ozleda na stablima. Istraživanja su vršena u šumskom gazdinstvu Kučevo, u brdskoj šumi bukve Fagetum moesiacae submontanum, generativnog porekla. Ispitivanjem je obuhvaćeno 505 stabala na 28 oglednih parcela. Konstatovano je da postoji jaka korelaciona veza između pojave gljiva i prisustva ozleda - 51.88%, kao i između prisutnih gljiva i abiotičkih oštećenja - 47.96%. Konstatovano je da za zdravstveno stanje visokih bukovih sastojina izuzetan značaj ima pažljivo i pravilno manipulisanje prilikom seče, a svaka ozleda na bukovim dubećim stablima počinjena pri seči je otvoren put za zarazu opasnim mikroorganizmima.*

**Ključne reči:** mehanička i abiotička oštećenja, bukva, gljive

[1]Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
*Corresponding author. E-mail: mira013@gmail.com

## 1. INTRODUCTION

According to the internationally adopted definition, sustainable management of forest resources means the stewardship and use of forests and forest lands in a way that preserves biodiversity while maintaining their regeneration capacity, vitality and potential to fulfil relevant ecological, economic and social needs, without compromising and causing damage to other ecosystems (Medarevic et al., 2007).

Relative to the global aspect, forest cover in Serbia is close to the worldwide level of 30%, but significantly below the European average of 46%. Out of the total 29.1% of forest area in Serbia, 7.1% is in Vojvodina whereas 37.6% of forests are located in Central Serbia. In the National inventory of forests in Serbia, beech dominates in the total volume and volume increment with the participation of 42.4% and 32.3% respectively (Bankovic et al., 2009).

Due to their abundance in the forest reserves of Serbia, beech forests undoubtedly have the greatest significance, which makes the stewardship of these forests a much more complex and difficult task compared to management of any other tree species. In addition, available references most frequently speak of the quality of tall beech forests in descriptive and general terms – that it is unsatisfactory and in need of improvement (Stojanovic & Krstic, 2003; Koprivica et al., 2009). Natural rejuvenation is the only regeneration method of beech forests, which is the reason why Serbia has no artificially established beech forests or forest cultures (Vučković et al., 2005). All of this makes up the foundation of their biological diversity, stability and sustainability. The biological properties, ecological demands, natural distribution and generally beneficial functions of beech forests make beech the fundamental tree species in Serbian forestry (Karadžić & Milijašević, 2005), although the use of beech lumber on a wider scale is limited by its short lifespan and sensitivity to incidence of diseases and pests.

Beech wood is vulnerable and represents an excellent base for development of numerous parasitic and saprophytic organisms, first and foremost of fungi. In beech coppice forests in Serbia, the total of 147 species of fungi were found on beech trees, out of which 33 species occur on fruits and young crop, 56 species occur on leaves and bark of the branches and the trunk, whereas 58 species cause rot and wood coloration (Karadžić & Milijašević, 2004).

The cause of beech forests dieback is a consequence of simultaneous negative impact of a range of factors. Among these a special place belongs to man, whose irrational exploitation of beech forests almost halved the forest area in Serbia (Markovic et al., 2019; Miletic et al., 2006; Markovic et al., 2011).

Due to increasing sensitivity of forest ecosystems under the conditions of climate changes, and the fact that the vitality of beech trees in forests under stress is directly linked to the interactions in the immediate surroundings, it is necessary to pay more heed to mutual influences of abiotic and biotic factors on withering of tree crowns (Chakraborty et al., 2017; Bayat et al., 2021; Stajić et al., 2022). This paper researched the aspect of incidence of pathogenic microorganisms on beech trees alongside with the presence of injuries on trees, with the aim to contribute to a more rational approach to beech forest protection and maximum preservation of beech stands in Serbia.

## 2. MATERIAL AND METHODS

The beech and stands that it forms are widely present in Serbia and throughout Europe, making the beech the most important species in this area from both economic and environmental standpoints. As such, the beech is central to preservation of stability and biodiversity of forest ecosystems across Europe (Vasić, 2018). For the purposes of preservation and protection of natural beech stands, the site selected for this research was the one on which the observation method revealed a large number of injuries on trees. The paper provides an analysis of the impact of tree injuries on the incidence of pathogenic and epixylic fungi on live beech trees. The research was carried out in the forest holding "Severni Kucaj" (*North Kucaj)* in Kucevo, forest administration Kucevo, in a hillside beech forest *Fagetum moesiacae submontanum* of generative origin. The researched site is located in the forest management unit Crni Vrh, section 42, divisions a and b. The research included the total of 505 beech trees on 28 sample plots.

Circular 500$m^2$ trial experimental plots were placed and marked in the stands at 100 x 100 m distances. Each experimental plot included between 8 and 27 researched trees. Injuries noted on each tree were classified as mechanic (injuries from felling and hauling during harvest) and abiotic (injuries from wind, snow, ice, frost and excessive insulation that caused bark inflammation). In addition, any presence of pathogenic and epyxilic fungi on trees was also noted. On the basis of the obtained data, statistical analysis was conducted in order to determine the correlation link.

## 3. RESULTS

The fungus of high significance which most frequently appears on the researched plots and individual trees is *Apiognomonia errabunda* (Roberge ex Desm.) Höhn. (82.0% of plots and 15.1% of beech trees). In this category, the rarest is the occurence of fungus causing root rot *Armillaria mellea* (Vahl) P.Kumm., which was found on only 7.0% of plots and 0.6% of trees.

In the medium significance category, wood-decaying fungus *Coriolus versicolor* (L.) Quél. was found on all the examined plots (100.00%) but only on 18.3% of trees, while the least frequent was *Dedalea quercina* (L.) Pers., which appeared on 3.6% of plots and 0.2% of trees.

Once of the most significant fungi identified on the tested site was *Neonectria coccinea* (Pers.) Rossman & Samuels, which was present on almost two-thirds of the sample plots (64.3%), and which together with the insect *Cryptococcus fagisuga* Lind. causes the dangerous beech bark disease. As of late, this disease is being regarded as a major factor compromising normal development of beech trees, and merits special attention in view of the fact that it is spreading over ever-larger areas. Measures undertaken against this fungus are classified into several categories: biological preventive measures, which include use of predators and super-parasites against insects (prior to infection with fungus); bio-control of the fungus by means of antagonists (once the infection occurs); silvicultural measures – removal of diseased trees (in advanced stages of the infection), and chemical measures, which are non-economical in forests and thus applied only in parks and tree alleys.

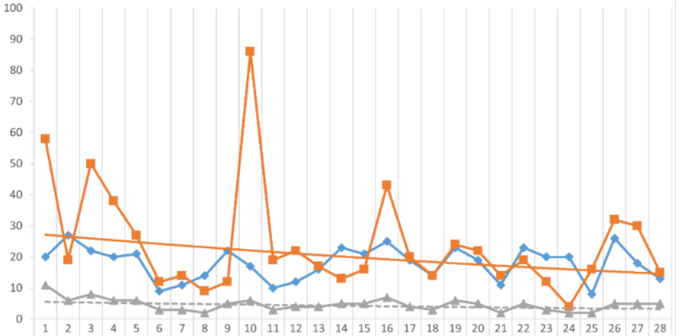
It is important to note that following the infection of beech trees with this fungus, the necrotic bark sections very quickly get infested by wood-decaying fungi and wood-destroying insects, which play a role in rapid tree decay and extinction of beech trees (Karadzic, 2003; Ivković et al., 2007).

Table 1 shows a statistical analysis – simple and multiple linear regression between all pairs of the presented columns and the correlation matrices made between columns $x'$, $y_1$, $y_2$ and $y_3$, as well as columns $x_1$, $x_2$, $x_3$ and $x_3/x'$.

**Table 1.** *Comparative analysis of attacks by fungi and injuries on beech trees in Forest Management Office Kucevo, Managemet Unit Crni Vrh*

| **(x') Number of trees on plot** | **Fungi** | | | **Injuries** | | | **Index ($x_3$/ x')** |
|---|---|---|---|---|---|---|---|
| | ($y_1$) Dangerous fungi | ($y_2$) Other fungi | ($y_3$) Total number of fungi | ($x_1$) Mechanical injuries | ($x_2$) Abiotic injuries | ($x_3$) Mechanical and abiotic injuries | |
| 20 | 5 | 6 | 11 | 16 | 42 | 58 | 2.90 |
| 27 | 3 | 3 | 6 | 12 | 7 | 19 | 0.70 |
| 22 | 5 | 3 | 8 | 16 | 34 | 50 | 2.27 |
| 20 | 4 | 2 | 6 | 4 | 34 | 38 | 1.90 |
| 21 | 3 | 3 | 6 | 10 | 17 | 27 | 1.29 |
| 9 | 1 | 2 | 3 | 4 | 8 | 12 | 1.33 |
| 11 | 0 | 3 | 3 | 7 | 7 | 14 | 1.27 |
| 14 | 0 | 2 | 2 | 2 | 7 | 9 | 0.64 |
| 22 | 3 | 2 | 5 | 5 | 7 | 12 | 0.54 |
| 17 | 4 | 2 | 6 | 8 | 37 | 86 | 5.06 |
| 10 | 1 | 2 | 3 | 2 | 19 | 19 | 1.90 |
| 12 | 2 | 2 | 4 | 8 | 14 | 22 | 1.83 |
| 16 | 2 | 2 | 4 | 10 | 7 | 17 | 1.06 |
| 23 | 3 | 2 | 5 | 10 | 3 | 13 | 0.56 |
| 21 | 3 | 2 | 5 | 14 | 2 | 16 | 0.76 |
| 25 | 2 | 5 | 7 | 16 | 27 | 43 | 1.72 |
| 19 | 1 | 3 | 4 | 11 | 9 | 20 | 1.05 |
| 14 | 1 | 2 | 3 | 3 | 11 | 14 | 1.00 |
| 23 | 4 | 2 | 6 | 14 | 10 | 24 | 1.04 |
| 19 | 3 | 2 | 5 | 5 | 17 | 22 | 1.16 |
| 11 | 0 | 2 | 2 | 6 | 8 | 14 | 1.27 |
| 23 | 3 | 2 | 5 | 1 | 18 | 19 | 0.83 |
| 20 | 1 | 2 | 3 | 3 | 9 | 12 | 0.60 |
| 20 | 0 | 2 | 2 | 1 | 3 | 4 | 0.20 |
| 8 | 0 | 2 | 2 | 1 | 15 | 16 | 2.00 |
| 26 | 3 | 2 | 5 | 12 | 20 | 32 | 1.23 |
| 18 | 3 | 2 | 5 | 15 | 15 | 30 | 1.67 |
| 13 | 3 | 2 | 5 | 7 | 8 | 15 | 1.15 |

Statistical processing of the obtained data on the researched site showed that there is a significant statistical link between all the presented columns, including the number of abiotic injuries and the occurence of fungi. The strongest correlation link, amounting to 51.88%, is the one between the total number of fungi and mechanical injuries (columns $y_3$ and $x_1$). The link between the total number of fungi and abiotic injuries (columns $y_3$ and $x_2$) is only slightly weaker but also strong at 47.96%. Links between the number of dangerous and other fungi ($y_1$, $y_2$) and mechanical and abiotic injuries ($x_1$, $x_2$) are significant and range from 26.70% to 36.47%, where links between the fungi and mechanical injuries are stronger by approximately 2% - 5% than the links between the occurrence of fungi and abiotic injuries. That means that the occurrence of fungi – column $y_3$ (both dangerous and other fungi) is directly linked to the presence with mechanical and abiotic injuries - $x_1$ and $x_2$. In other words, the number of injuries is the determining factor linking the occurrence of fungi and the injuries on trees (figure 1). On sites with a smaller number of injuries the correlation links between the occurrence of fungi and tree injuries are weaker, and vice versa.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (x') Number of trees on plot | 20 | 27 | 22 | 20 | 21 | 9 | 11 | 14 | 22 | 17 | 10 | 12 | 16 | 23 | 21 | 25 | 19 | 14 | 23 | 19 | 11 | 23 | 20 | 20 | 8 | 26 | 18 | 13 |
| (x3) Total number of mechanical and abiotic injuries | 58 | 19 | 50 | 38 | 27 | 12 | 14 | 9 | 12 | 86 | 19 | 22 | 17 | 13 | 16 | 43 | 20 | 14 | 24 | 22 | 14 | 19 | 12 | 4 | 16 | 32 | 30 | 15 |
| (y3) Total number of fungi | 11 | 6 | 8 | 6 | 6 | 3 | 3 | 2 | 5 | 6 | 3 | 4 | 4 | 5 | 5 | 7 | 4 | 3 | 6 | 5 | 2 | 5 | 3 | 2 | 2 | 5 | 5 | 5 |

**Figure 1.** *Ratio of attacks by fungi, injuries and number trees on plot*

It is a well-known fact that health status of the stands is contingent upon a large number of factors, among which year-round climatic conditions must be considered as one of the most critical. Rainy, humid and relatively warm weather favours the activity of the fungi and increases the yield, thus enabling faster colonization by the fungi as well as a more precise identification of the existing microflora. It should also be noted that diagnosis of the disease is greatly impeded by prolonged incubation periods of the fungi colonizing vital trees, while primary symptoms appear on the surface only after several years of attack (reproductive organs – visible carpophores may not appear at all or their appearance might be extended over a number of years).

## 4. DISCUSSION

In addition to an accurate diagnosis, it is essential to make a precise prognosis of the dynamics of development of pathological processes in the plant. However, this prognosis cannot be determined with any reliable level of accuracy for the upcoming calendar years, as climatic conditions are a determining factor for the development of the infection. It is thus possible to make only a rough prognosis, based on mapping the parts of the forest under attack according to the destructor species and attack intensity, and use it as basis for planning the sanitary and silvicultural activities.

Sanitation felling and other phytosanitary measures, which may or may not be carried out in forests, certainly have a great impact on the overall health condition of the stands. Proper stewardship can minimize the existing infections and thus eliminate or greatly mitigate any new infection, which significantly contributes to having the health status of the stands restored and maintained on a satisfactory level.

## 5. CONCLUSION

On the researched site a significant statistical link was found between all columns, including the number of abiotic injuries and the occurence of fungi, which is a consequence of a large number of injuries. The strongest correlation link, amounting to 51.88%, is the one between the total number of fungi and mechanical injuries. The link between the total number of fungi and abiotic injuries is also strong at 47.96%. Links between the number of dangerous and other fungi and mechanical and abiotic injuries are significant and range between 26.70% and 36.47%. This practically means that the incidence of fungi is directly linked to the presence of both mechanical and abiotic injuries.

The number of injuries may be identified as the determining factor linking the occurrence of fungi and the damage on trees. On sites with fewer injuries the correlation links between the occurrence of fungi and the injuries are less strong, and vice versa. Careful and proper handling of trees during felling is critical for the health condition of tall beech stands. Every injury sustained by live beech trees during felling opens the door to infection by pathogenic microorganisms. Proper stewardship may minimize the existing infections and thus eliminate or greatly mitigate any new infection, which significantly contributes to having the health status of the stands restored and maintained on a satisfactory level.

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# INFLUENCE OF THE STRESS FACTOR UNDER THE CONDITIONS OF CLIMATE CHANGES ON WEAKINING OF TREES AND APPERANCE OF PATHOGENIC AND EPYXILOUS FUNGI IN NATURAL BEECH STRANDS

*Miroslava MARKOVIĆ, Renata GAGIĆ-SERDAR, Bojan KONATAR, Suzana MITROVIĆ*

**Summary**

Due to their abundance in the forest reserves of Serbia, beech forests undoubtedly have the greatest significance, which makes the stewardship of these forests a much more complex and difficult task compared to management of any other tree species. Due to increasing sensitivity of forest ecosystems under the conditions of climate changes, and the fact that the vitality of beech trees in forests under stress is directly linked to the interactions in the immediate surroundings, it is necessary to pay more heed to mutual influences of abiotic and biotic factors on withering of tree crowns. Beech wood is vulnerable and represents an excellent base for development of numerous parasitic and saprophytic organisms, first and foremost of fungi. In beech coppice forests in Serbia, the total of 147 species of fungi were found on beech trees, out of which 33 species occur on fruits and young crop, 56 species occur on leaves and bark of the branches and the trunk, whereas 58 species cause rot and wood coloration. It is a well-known fact that health status of the stands is contingent upon a large number of factors, among which year-round climatic conditions must be considered as one of the most critical. Rainy, humid and relatively warm weather favours the activity of the fungi and increases the yield, thus enabling faster colonization by the fungi as well as a more precise identification of the existing microflora. It should also be noted that diagnosis of the disease is greatly impeded by prolonged incubation periods of the fungi colonizing vital trees, while primary symptoms appear on the surface only after several years of attack (reproductive organs – visible carpophores may not appear at all or their appearance might be extended over a number of years). In addition to an accurate diagnosis, it is essential to make a precise prognosis of the dynamics of development of pathological processes in the plant. However, this prognosis cannot be determined with any reliable level of accuracy for the upcoming calendar years, as climatic conditions are a determining factor for the development of the infection. It is thus possible to make only a rough prognosis, based on mapping the parts of the forest under attack according to the destructor species and attack intensity, and use it as basis for planning the sanitary and silvicultural activities. The research was conducted in Forest Management Office Kucevo, in a hillside beech forest Fagetum moesiacae submontanum of generative origin. The research included 505 trees on 28 sample plots. On the researched site a significant statistical link was found between all columns, including the number of abiotic injuries and the occurence of fungi, which is a consequence of a large number of injuries. The strongest correlation link, amounting to 51.88%, is the one between the total number of fungi and mechanical injuries. The link between the total number of fungi and abiotic injuries is also strong at 47.96%. Links between the number of dangerous and other fungi and mechanical and abiotic injuries are significant and range between 26.70% and 36.47%. This practically means that the incidence of fungi is directly linked to the presence of both mechanical and abiotic injuries.

# UTICAJ FAKTORA STRESA U USLOVIMA PROMENE KLIME NA SLABLJENJE STABALA I POJAVU PATOGENIH I EPIKSILNIH GLJIVA U PRIRODNIM SASTOJINAMA BUKVE

*Miroslava MARKOVIĆ, Renata GAGIĆ-SERDAR, Bojan KONATAR, Suzana MITROVIĆ*

## Rezime

Zbog zastupljenosti u šumskom fondu Srbije, bukove šume svakako imaju najveći značaj, zbog čega je gazdovanje bukovim šumama mnogo kompleksniji i teži zadatak u odnosu na sve druge vrste drveća. Zbog sve veće osetljivosti šumskih ekosistema u uslovima promena klime i činjenice da je vitalnost bukovog drveća u šumama pod stresom direktno povezana sa interakcijama u okruženju, neophodno je više pažnje posvetiti međusobnim uticajima abiotičkih i biotičkih činilaca na odumiranje krošnji drveća. Bukovo drvo je neotporno i predstavlja odličnu podlogu za razvoj mnogih parazitnih i saprofitnih organizama, a među njima na prvo mesto dolaze gljive. U izdanačkim šumama bukve u Srbiji, na stablima bukve konstatovano je 147 vrsta gljiva, od kojih se 33 vrste javlja na plodovima i poniku, 56 vrsta na lišću i kori grana i stabla, a 58 vrsta prouzrokuju trulež i obojenost drveta. Poznato je da zdravstveno stanje sastojina zavisi od velikog broja činilaca, pa svakako ne treba zaboraviti da je jedan od presudnih klimatske prilike u toku godine. Kišovito, vlažno i relativno toplo vreme favorizuje aktivnost gljiva i pojačava plodonošenje, što omogućava bržu kolonizaciju gljiva, a i precizniju identifikaciju postojeće mikoflore. Treba napomenuti i da dijagnozu bolesti jako otežava duga inkubacija gljiva koje koloniziraju vitalna stabla, a primarni simptomi se javljaju na površini tek posle višegodišnjeg napada (reproduktivni organi – pojava vidljivih karpofora može da izostane ili da se produži na više godina). Pored tačne dijagnoze, neohodna je i tačna prognoza dinamike razvoja patoloških procesa u biljci, a nju je nemoguće precizno utvrditi za naredne kalendarske godine, jer su opredeljujući faktor za razvoj zaraze vremenske prilike. Zato se prognoza može izvršti samo u grubim crtama, na osnovu kartiranja napadnutih delova šuma po vrsti destruktora i intenzitetu napada i na osnovu toga se moraju planirati sanitarno – uzgojni radovi. Istraživanja su vršena u šumskom gazdinstvu Kučevo, u brdskoj šumi bukve Fagetum moesiacae submontanum, generativnog porekla. Ispitivanjem je obuhvaćeno 505 stabala na 28 oglednih parcela. Na ispitivanom lokalitetu postoji značajna statistička veza između svih kolona, pa i između broja abiotičkih oštećenja i pojave gljiva, što je posledica velikog broja oštećenja. Najjača korelaciona veza postoji između ukupnog broja gljiva i mehaničkih oštećenja i iznosi 51.88%. Veza između ukupnog broja gljiva i abiotičkih oštećenja je takođe jaka i iznosi 47.96%. Veze između broja opasnih i ostalih gljiva i mehaničkih i abiotičkih oštećenja su značajne i iznose 26.70% do 36.47%. To praktično znači da je pojava gljiva u direktnoj vezi sa prisustvom i mehaničkih i abiotičkih oštećenja.

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# ASSESSMENT OF BIOTIC THREATS TO URBAN GREENERY: A CASE STUDY IN STROMOVKA PARK, ČESKÉ BUDEJOVICE

*Marija MILOSAVLJEVIĆ[1]*, Mara TABAKOVIĆ-TOŠIĆ[2], Bojan GAVRILOVIĆ[2], Suzana MITROVIĆ[2], Željko MILOVAC[3], Marko TOMIĆ[4], Saša EREMIJA[2]*

**Abstract:** *Urban greenery, consisting of tree lines, parks and park forests, plays an important role in improving the aesthetics and general well-being of the urban environment. This study focuses on Stromovka Park in České Budejovice and examines the health status of various tree species. The research spans the period from 2021 to 2022 and uses the route method to monitor the occurrence of biotic pests and pathogens, especially mites and insects. Several economically important organisms were identified in the study, including Aceria fraxiniflora (Felt, 1906), Byctiscus betulae (Linnaeus, 1758), Curculio glandium Marsham, 1802, Eriophyes inangulis Nalepa, 1919, Fomes fomentarius (L.) Fr. 1849, Halyomorpha halys (Stål, 1855), Ips typographus (Linnaeus, 1758), Lymantria dispar (Linnaeus, 1758), Loranthus europaeus Jacq., Oxycarenus lavaterae (Fabricius, 1787), Pemphigus spyrothecae Passerini, 1856, Phyllonorycter issikii (Kumata, 1963), Polygraphus poligraphus (Linnaeus, 1758), Prociphilus fraxini (Fabricius, 1777), Rhytisma acerinum Schwein., (1832), Sacchiphantes viridis (Ratzeburg, 1843) and Tetraneura ulmi (Linnaeus, 1758). While most of these organisms showed normal, natural abundance values, increased values were observed in A. fraxiniflora, E. inangulis and O. lavaterae. The application of holistic plant protection principles, from proper cultivation and species selection to monitoring and control measures, remains crucial for maintaining the vitality and longevity of urban green spaces exposed to various biotic and abiotic stress factors.*

**Keywords:** Urban pests, city parks, monitoring, woody plants, pest occurrence, urbanisation

# PROCENA BIOTIČKE UGROŽENOSTI GRADSKOG ZELENILA: STUDIJA SLUČAJA U PARKU STROMOVKA, ČEŠKE BUDEJOVICE

**Sažetak:** *Urbane zelene površine, sastavljene od drvoreda, parkova i park-šuma, igraju važnu ulogu u poboljšanju estetike i opšte dobrobiti urbanih sredina. Ovo istraživanje se fokusira na Stromovka park u Češkim Budejovicama i proučava zdravstveno stanje različitih vrsta drveća. Istraživanje obuhvata period od 2021. do 2022. i koristi maršutnu metodu kako bi se pratila pojava štetočina i patogena, posebno grinja i insekata. U*

[1]Biologické centrum AV ČR, Branišovská 1160/31, 37005 České Budějovice, Czech Republic
[2]Institute of Forestry, Kneza Višeslava 3, 11000 Belgrade, Serbia
[3]Institute of Field and Vegetable Crops, Maksima Gorkog 3, 21101 Novi Sad, Serbia
[4]Faculty of Forestry, Kneza Višeslava 1, 11000 Belgrade, Serbia
*Corresponding author. E-mail: marija.milosavljevic@entu.cas.cz

*istraživanju je identifikovano nekoliko ekonomski važnih organizama, uključujući Aceria fraxiniflora (Felt, 1906), Byctiscus betulae (Linnaeus, 1758), Curculio glandium Marsham, 1802, Eriophyes inangulis Nalepa, 1919, Fomes fomentarius (L.) Fr. 1849, Halyomorpha halys (Stål, 1855), Ips typographus (Linnaeus, 1758), Lymantria dispar (Linnaeus, 1758), Loranthus europaeus Jacq., Oxycarenus lavaterae (Fabricius, 1787), Pemphigus spyrothecae Passerini, 1856, Phyllonorycter issikii (Kumata, 1963), Polygraphus poligraphus (Linnaeus, 1758), Prociphilus fraxini (Fabricius, 1777), Rhytisma acerinum Schwein., (1832), Sacchiphantes viridis (Ratzeburg, 1843) i Tetraneura ulmi (Linnaeus, 1758). Dok su većina ovih organizama pokazivala uobičajeno prisustvo, povećana brojnost primećena je kod A. fraxiniflora, E. inangulis i O. Lavaterae . Primena principa holističke zaštite biljaka, počevši od odgovarajućeg odabira i selekcije biljnih vrsta do praćenja i kontrolnih mera, ostaje ključna za očuvanje vitalnosti i dugovečnosti urbanih zelenih prostora izloženih različitim biotskim i abiotskim stresnim faktorima.*

**Ključne reči:** Urbane štetočine, gradski parkovi, monitoring, drvenaste vrste, pojava štetočina, urbanizacija

## 1. INTRODUCTION

Urban parks and open green spaces play an important role in improving the quality of life in an urbanised society. Empirical studies repeatedly show the impact of urban parks, forests and green spaces, as well as elements such as trees and water, on various aspects of urban life. These natural components not only provide environmental services such as purifying air and water, filtering wind and noise and stabilising the microclimate, but also contribute significantly to social and psychological well-being. The benefits of green spaces are widely recognised and contribute significantly to making modern cities more liveable. Research conducted by Chiesura (2004) suggests that spending time in parks can reduce stress levels, promote contemplation, rejuvenate residents and foster a sense of peace and tranquility. Contemporary understanding emphasises the role that green spaces play in creating well-functioning and liveable cities. These spaces serve, among other things, to support activities and promote everyday health, preserve biodiversity, shape the cultural identity of cities, create opportunities and provide natural solutions to the technical challenges of cities (Kabisch et al., 2016). Given the value of green spaces, it is essential in cities to assess the condition of trees and monitor them continuously. This data is crucial for understanding the condition of forests and their ability to adapt to climate change (Brašanac-Bosanac et al., 2022). However, urban greenery is threatened by both living organisms and environmental factors. The presence of insects, mites and diseases poses a challenge to the health and appearance of plants in green spaces (Ding et al., 2020; Dodds & Orwig, 2011; Dreistadt et al., 1990; Hanousková et al., 2004; Kovač et al., 2021; Moricca et al., 2018).

Due to the importance of urban parks the authors decided to assess the condition of the trees in the largest city park in České Budějovice (South Bohemia), Stromovka Park, which is 68 hectares in size and has the character of a forest park or natural landscape (Milosavljević et al., 2022). It was created in the 1950s and 1960s through voluntary efforts and was originally divided into Stromovka and Dlouhá louka. The park underwent significant changes, including the transformation of the Bagr pond into a swimming pool, reconstruction after a major flood in 2002 and the eradication of the Canadian poplar.

The composition of the trees evolved from fast-growing species to target trees such as oak, beech, maple, lime, pine and spruce (Milosavljević et al., 2022). The meadows have a natural diversity, with various grasses and flowering species. The park has a rich flora and fauna, and over 60 species of birds have been counted during the breeding season. Notable species include the European roller [*Coracias garrulus* Linnaeus, 1758] and the smallest bird in Europe, the goldcrest [*Regulus regulus* (Linnaeus, 1758)] (Macková, 1997). In 1993, a rough botanical survey in Stromovka found a total of 135 species of herbaceous vascular plants (Hanousková, 2006; Hanousková et al., 2004; Werquin & Attwell, 2005). Stromovka serves both ecological and aesthetic purposes and is registered as an important landscape element. Neglected in the past, with improved maintenance, the area has developed into a recreational area with footpaths, inline skating and cycle paths, benches and playgrounds. Addressing these challenges is vital to ensure that urban green spaces remain sustainable and vibrant in the future. Plant diseases and pests can have a significant impact on the health of tree species and it is important to identify them accurately in order to take appropriate action.

The objectives of this study were to: 1) assess the presence of potential pests and diseases, 2) assess the most prevalent species and address their potential impact on the health of tree species in the park.

## 2. MATERIAL AND METHODS

### 2.1. Study area

The study was conducted in Stromovka Park (48° 96' N, 14° 27' E) in 2021 and 2022 (Figure 1). From April to September, observations were made to quantify and evaluate the presence of pests and diseases. These observations provided valuable insight into the current state of pests and their potential impact on the environment.

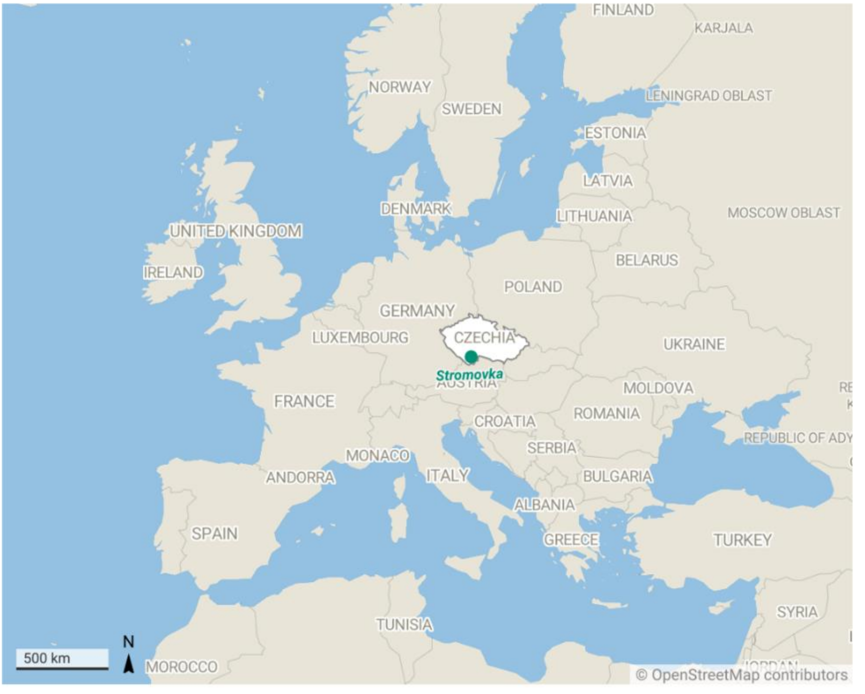


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**Figure 1.** *Study location - Stromovka Park*

## 2.2. Monitoring of the pests

Plant material was collected either randomly or based on symptoms present in the park. The collecting was conducted every two weeks during observed period (April-September). The samples were packed in plastic boxes and stored in a refrigerator at 5°C before being identified in the laboratory using MOTIC optical trinocular, model BA210E, and stereomicroscope, model STM 13 EEB. Taxonomic literature and keys were used for identification, such as those of Agrios, 2005; Amrine et al., 2003; Balachowsky, 1949; Beug et al., 2014; Ciceoi et al., 2017; Crowson, 1956; Hanousková et al., 2004; Hůrka, 2017; Johnson & Lyon, 1991; Mani, 1964; Pirone, 1978; Spadaro et al., 2020; Tomiczek & Jurc, 2007; Tubby & Webber, 2010; Zúbrik et al., 2013.

## 3. RESULTS

Various insects, mites and fungi were collected in Stromovka Park during the study period (Table 1). The organisms are categorised and the following taxonomic orders were identified: Lepidoptera, Coleoptera, Santalales, Hemiptera, Rhytismatales, Trombidiformes and Polyporales. Two species of Trombidiformes, two species of Lepidoptera, four species of Coleoptera, two species of Hemiptera, one species of Rhytismatales and one species of Polyporales were identified (Figure 1 and 2). All species collected in 2021 were also found in the following year, with the same frequency, except for *Oxycarenus lavatere*, where the number of colonies decreased.

**Table 1.** *List of identified species*

| **Species** | **Family** |
|---|---|
| **Fungi** | |
| Polyporales | |
| *Fomes fomentarius* (L.) Fr. | Polyporaceae |
| Rhytismatales | |
| *Rhytisma acerinum* (Pers.) Fr. | Rhytismataceae |
| **Plants** | |
| Santalales | |
| *Loranthus europaeus* Jacq. | Loranthaceae |
| **Mites** | |
| Trombidiformes | |
| *Aceria fraxiniflora* (Felt, 1906) | Eriophyidae |
| *Eriophyes inangulis* Nalepa, 1919 | Eriophyidae |
| **Insects** | |
| Hemiptera | |
| *Halyomorpha halys* (Stål, 1855) | Pentatomidae |
| *Oxycarenus lavaterae* (Fabricius, 1787) | Oxycarenidae |
| *Pemphigus spyrothecae* Passerini, 1856 | Aphididae |
| *Prociphilus fraxini* (Fabricius, 1777) | Aphididae |
| *Sacchiphantes viridis* (Ratzeburg, 1843) | Adelgidae |
| *Tetraneura ulmi* (Linnaeus, 1758) | Aphididae |
| Coleoptera | |
| *Byctiscus betulae* (Linnaeus, 1758) | Attelabidae |
| *Curculio glandium* Marsham, 1802 | Curculionidae |
| *Ips typographus* (Linnaeus, 1758) | Curculionidae |
| *Polygraphus poligraphus* (Linnaeus, 1758) | Curculionidae |
| Lepidoptera | |
| *Lymantria dispar* (Linnaeus, 1758) | Erebidae |
| *Phyllonorycter issikii* (Kumata, 1963) | Gracillariidae |

The percentage of the various taxa is shown in Figure 2. Photos of the frequently encountered pest species are shown in Figure 3.

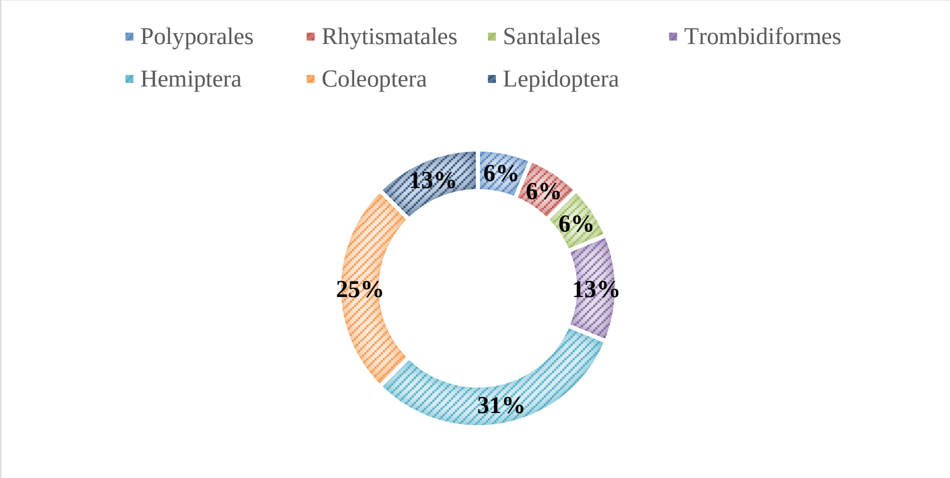


**Figure 2.** *Percentage of the identified species during monitoring*



**(a)** ***Prociphilus fraxini*** **(b)** ***Rhytisma acerinum*** **(c)** ***Byctiscus betulae***



**(d)** ***Eriophyes inangulis*** **(e)** ***Aceria fraxiniflora*** **(f)** ***Oxycarenus lavaterae***

**Figure 3.** *Representatives of the identified pests*

## 4. DISCUSSION

The results of two years monitoring included seventeen pest species that are important for health of park trees. While most of these organisms had normal, natural abundance values, increased values were observed for: *A. fraxiniflora*, *E. inangulis* and *O. lavaterae*. As it has been shown in Table 1, *A. fraxiniflora* and *E. inangulis* belong to family Eriophyidae. Eriophyoid mites have successfully spread across the globe primarily infecting woody species (Jiang et al., 2021; Navajas et al., 2010). The genus Eriophyes is globally recognized for its ability to form gall and erinea. These mites tend to colonize only a limited range of species. The symptoms caused by a mite infection vary depending on both the host tree and the specific mite species involved. The recognizable signs of an infection include the formation of galls or felt like patches known as erinea. Leaves affected by erinea often display, sometimes yellowish spots on their surface while the opposite side carries clusters of mites. *Tilia* spp. (Tiliaceae). *Alnus* spp. (Betulaceae), alongside with *Fraxinus* spp. (Oleaceae) are especially vulnerable to eriophyoid mite infections suggesting that these mites have adapted mechanisms to overcome the chemical defenses of their host trees (Jiang et al., 2021). It is crucial to remain vigilant, about these infections as they can inflict harm upon trees and plants alike. Regular monitoring and early detection can effectively curtail their spread, minimize the resulting damage. *A. fraxiniflora* has been found in Europe (Hungary) for the first time in 2019 (Korda et al., 2019). The presence of this mite led to changes in the growth and appearance of the flowers and fruits, which took on a shape reminiscent of spongy galls (Korda et al., 2019). The flower clusters became distorted (Figure 3e). *E. inangulis* is a mite species that frequently forms galls on the leaves of *Alnus* spp (Jiang et al., 2021). Although these infections occur only sporadically, they can severely impair the function of the leaves. It has been shown that gall-causing parasites cause changes in the structure, physiological processes and biochemical composition of their host plants. Gall formation has been observed to alter gas exchange in leaves, such as photosynthetic rate, stomatal conductance and water utilisation efficiency (Jiang et al., 2021). Therefore, infections by *E. inangulis* have the potential to significantly affect plant health and productivity.

The Lime Seed Bug-*O. lavaterae*, belongs to the family Lygaeidae (Table 1) and the subfamily Oxycareninae. It is a species that occurs in many parts of the world, including Europe, Asia and North America (Arslangündoğdu et al., 2018). In Czech Republic it was first recorded in 2004 (Nedvěd et al., 2023). The adult is about 5-6 mm long and the usually red, white and black in colour. It is commonly found on lime trees (*Tillia* spp.), hence its name, but it can also be found on other trees such as elm, oak and maple (Arslangündoğdu et al., 2018; De Jaegere et al., 2016; Nedvěd et al., 2014; Neimorovets et al., 2020; Velimirović et al., 1992). The most affected is small-leaved lime (*Tilia cordata* Mill.). The laboratory study showed that fecundity in females feeded by *T. cordata* is 230 eggs (Kalushkov & Nedvěd, 2010). The lime seed bug is considered to be a pest because it feeds on the seed of trees, branches and leaves, which can weaken and damage them (Jurc, 2011).

The presence of pests in parks can be a problem for both visitors and the overall well-being of the ecosystem (Parsons & Frank, 2019). To address this issue, it is important to establish pest monitoring programmes. One approach to pest monitoring is to use traps and baits to capture and identify the types of pests that are present in a park. This allows park managers to develop targeted pest control strategies that are effective and also environmentally sound. In addition, inspections of park facilities and vegetation help to identify threaten areas and prevent further spread (Ciceoi et al., 2017; Dodds & Orwig, 2011; Hanousková et al., 2004; Mujezinović et al., 2011). Regular monitoring of parks also serves as a measure against invasive species that can cause serious damage to local ecosystems. By identifying and removing pests, substitution of plants with more resilient ones, park managers can help maintain a thriving and diverse ecosystem for future generations. The data collected during this period can be used to monitor and manage insect populations in the future.

## 5. CONCLUSION

Urbanisation is a growing phenomenon that brings various environmental challenges. One of these challenges is the impact on pests. When natural balance is disturbed, it leads to changes in the distribution and abundance of pests. This can affect the health and functionality of trees, as pests can damage or even kill trees, while their natural enemies play a role in controlling pest populations. During our surveys, we found 17 species that are potentially detrimental for plants in Stromovka Park. Three species: *A. fraxiniflora*, *E. inangulis* and *O. lavaterae* were the most frequent. It was noticed that *Fraxinus* spp. and *Tillia* spp. are more affected by the pest than the other species observed. Also, the proximity of tree species is one of the reasons for the easy spread of pests, which could be improved by planting differently, using more diverse species than the same ones in the tree row. In summary, implementing a pest monitoring programme is part of effective management of any park. Using a combination of traps, baits, visual inspections and other techniques, park managers can efficiently control pests while protecting the health of the ecosystem. Through monitoring and maintenance, urban parks can ensure that they remain a safe and enjoyable environment for their visitors for many years to come.

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## ASSESSMENT OF BIOTIC THREATS TO URBAN GREENERY: A CASE STUDY IN STROMOVKA PARK, ČESKÉ BUDEJOVICE

*Marija MILOSAVLJEVIĆ, Mara TABAKOVIĆ-TOŠIĆ, Bojan GAVRILOVIĆ, Suzana MITROVIĆ, Željko MILOVAC, Marko TOMIĆ, Saša EREMIJA*

### Summary

Urban parks are an important part of every city's infrastructure. They offer people a place to relax and connect with nature. Yet the presence of pests in these parks can be a problem for both visitors and the health of the ecosystem. A two-year study of Stromovka Park, the largest city park in České Budějovice, identified seventeen pest species [*Aceria fraxiniflora* (Felt, 1906), *Byctiscus betulae* (Linnaeus, 1758), *Curculio glandium* Marsham, 1802, *Eriophyes inangulis* Nalepa, 1919, *Fomes fomentarius* (L.) Fr. 1849, *Halyomorpha halys* (Stål, 1855), *Ips typographus* (Linnaeus, 1758), *Lymantria dispar* (Linnaeus, 1758), *Loranthus europaeus* Jacq., *Oxycarenus lavaterae* (Fabricius, 1787), *Pemphigus spyrothecae* Passerini, 1856, *Phyllonorycter issikii* (Kumata, 1963), *Polygraphus poligraphus* (Linnaeus, 1758), *Prociphilus fraxini* (Fabricius, 1777), *Rhytisma acerinum Schwein.*, (1832), *Sacchiphantes viridis* (Ratzeburg, 1843) and *Tetraneura ulmi* (Linnaeus, 1758)] that affect the well-being of park trees. The study found that the tree species *Fraxinus* spp. and *Tillia* spp. were more affected by pests than other species observed. One of the reasons for the easy spread of pests is the proximity of the tree species. This problem could be addressed by planting a greater diversity of species instead of the same species in a tree row. To protect the park's ecosystem and the health of its visitors, it is important to address the problem of pests. Park managers should consider different pest control measures. By taking proactive steps, the park can continue to provide a beautiful and safe environment for its visitors.

**PROCENA BIOTIČKE UGROŽNOSTI GRADSKOG ZELENILA: STUDIJA SLUČAJA U PARKU STROMOVKA, ČEŠKE BUDEJOVICE**

*Marija MILOSAVLJEVIĆ, Mara TABAKOVIĆ-TOŠIĆ, Bojan GAVRILOVIĆ, Suzana MITROVIĆ, Željko MILOVAC, Marko TOMIĆ, Saša EREMIJA*

**Rezime**

Gradski parkovi su važan deo infrastrukture svakog grada. Oni nude ljudima mesto za opuštanje i povezivanje sa prirodom. Ipak, prisustvo štetočina u ovim parkovima može biti problem i za posetioce i za zdravlje ekosistema. Dvogodišnje istraživanje sprovedeno u parku Stromovka, najvećem gradskom parku u Češkim Budejovicama, identifikovalo je sedamnaest vrsta štetočina [*Aceria fraxiniflora* (Felt, 1906), *Byctiscus betulae* (Linnaeus, 1758), *Curculio glandium* Marsham, 1802, *Eriophyes inangulis* Nalepa, 1919, *Fomes fomentarius* (L.) Fr. 1849, *Halyomorpha halys* (Stål, 1855), *Ips typographus* (Linnaeus, 1758), *Lymantria dispar* (Linnaeus, 1758), *Loranthus europaeus* Jacq., *Oxycarenus lavaterae* (Fabricius, 1787), *Pemphigus spyrothecae* Passerini, 1856, *Phyllonorycter issikii* (Kumata, 1963), *Polygraphus poligraphus* (Linnaeus, 1758), *Prociphilus fraxini* (Fabricius, 1777), *Rhytisma acerinum Schwein.*, (1832), *Sacchiphantes viridis* (Ratzeburg, 1843) and *Tetraneura ulmi* (Linnaeus, 1758)], koji utiču na zdravlje parkovskog drveća. Studija je otkrila da su *Fraxinus* spp. i *Tillia* spp. bile više pogođene štetočinama nego druge biljne vrste. Jedan od razloga za lako širenje štetočina je blizina drveća. Ovaj problem bi se mogao rešiti sadnjom većeg broja vrsta umesto iste vrste u drvoredu. Da bismo zaštitili ekosistem parka i zdravlje njegovih posetilaca, važno je pozabaviti se problemom štetočina. Upravnici parkova bi trebali da razmotre različite mere kontrole štetočina. Preduzimajući proaktivne korake, park može da nastavi da pruža prelepo i bezbedno okruženje za svoje posetioce.

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# CHANGES IN THE FOREST GROWING STOCK OF THE TIMOK FOREST AREA FOLLOWING THE ICE STORM IN WINTER 2014/2015

*Branka PAVLOVIĆ[1]*, Vlado ČOKEŠA[1], Ljubinko RAKONJAC[1] ,Violeta BABIĆ[2], Zoran PODUŠKA[1], Nikola MARTAĆ[1], Branko KANJEVAC[2]*

**Abstract:** *In the winter of 2014/2015, extremely cold air masses penetrated from the east and the Carpathians into a large part of eastern Serbia and formed extensive ice layers on infrastructure facilities and forest trees. Forest trees could not withstand large amounts of ice (up to several tons per tree), resulting in widespread ice breaks and ice throws. Extensive damage occurred in the Timok, Morava, Severni Kučaj, Rasina, and Južni Kučaj Forest Areas. In certain parts of the Timok Forest Area, the damage to forest ecosystems was catastrophic and required clear-cutting of large areas. This research focuses on the state-owned forests of the Timok Forest Area (natural forests and artificially established (stands) managed by "Srbijašume" State Enterprise from Belgrade. A comparative analysis of specific indicators of the current state of the forest growing stock in the Timok Forest Area was conducted (forest state by origin, preservation, mixture, tree species, stand classification, and socioecological categorisation). The analysis compared data collected on 31 December 2013 with data collected on 31 December 2021. The research aimed to determine whether there were significant changes in the state of forest growing stock in the Timok Forest Area in the study period.*
**Keywords:** Timok Forest Area, forest growing stock, natural disasters, ice break

# PROMENA STANJA ŠUMSKOG FONDA U TIMOČKOM ŠUMSKOM PODRUČJU KAO POSLEDICA LEDOLOMA U ZIMU 2014/2015. GODINE

**Sažetak:** *Na prostoru većeg dela istočne Srbije u zimu 2014/2015. godine, došlo je do prodiranja izuzetno hladnih vazdušnih masa sa istoka i sa Karpata uslovljavajući pojavu velikih naslaga leda na objektima infrastrukture i stablima šumskog drveća. Velike količine leda (i po nekoliko tona po stablu) šumsko drveće nije moglo da izdrži, što je dovelo do ledoloma i ledoizvala na velikim površinama. Štete većih razmera desile su se na prostoru Timočkog, Moravskog, Severnokučajskog, Rasinskog i Južnokučajskog šumskog područja. U pojedinim delovima Timočkog ŠP došlo je do prave katastrofe po šumske ekosisteme te su morale biti izvršene čiste seče na velikim površinama. Predmet ovog istraživanja su obrasle površine Timočkog šumskog područja (prirodne šume i veštački podignute sastojine) u državnom vlasništvu kojima gazduje JP „Srbijašume"Beograd. Vršena je uporedna analiza*

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

*pojedinih pokazatelja stanja šumskog fonda Timočkog ŠP (stanje šuma po poreklu, očuvanosti, mešovitosti, vrstama drveća, sastojinskoj pripadnosti i cenoekološkoj pripadnosti). Uporedo su analizirani podaci svedeni na dan 31.12.2013. godine i podaci svedeni na dan 31.12.2021. godine. Cilj istraživanja je da se utvrdi da li je došlo do bitnih promena u stanju šumskog fonda na nivou Timočkog šumskog područja.*

**Ključne reči:** Timočko šumsko područje, šumski fond, elementarne vremenske nepogode, ledolomi.

## 1. INTRODUCTION

Forest Area (FA) is an ecological and spatial geographic unit within which forest management is planned and functional sustainability ensured (Jović *et al*., 1991). Forest areas are established by Article 17 of the Law on Forests (*Official Gazette of the Republic of Serbia* No. 30/2010, 93/2012, and 89/2015), which defines that the forest area includes forests of all ownership forms and all purposes, excluding forests in national parks. The Timok Forest Area was formed in line with Article 21 of the Law on Forests (*Official Gazette of the Republic of Serbia* No. 46/91, 83/92, 54/93, 60/93, 67/93, 48/94, 54/96). The areas comprising the Timok Forest Area were defined by the *Forest and Forest Land Inventory,* which is an integral part of the Law.

Research presented in this paper was conducted within the Timok Forest Area, in forests managed by “Srbijašume” State Enterprise from Belgrade, “Timok Forests” Forest Estate from Boljevac. The Timok Forest Area mostly extends to the northeastern part of Serbia, specifically in the Timok Valley (*Ser. Timočka krajina*). This territory represents a geographically integral, closed area separated from adjacent regions by the mountain range extending from Gramada and Svrljig Mountains (*Ser. Svrljiške planine*) to Mt. Midžor in the south towards the Nišava Valley (*Ser. Ponišavlje*). To the north is the Danube River, to the east are the Balkan Mountains (*Ser. Stara planina*), and to the west is a series of high mountains from the eastern branches of Ozren to the Danube. The majority of the FA is covered by tributaries flowing into Svrljiški, Trgoviški, Beli, Crni, and Veliki Timok, which then flow into the Danube. Forests and forest land grow on mountain massifs such as Southern Kučaj, Čestobrodica, Rtanj, Malinik, Crni Vrh, Stara Planina, Tupižnica, Tresibaba, Miroč, Deli Jovan, and Northern Kučaj (Vasić, 2018).

The continental climate in the Timok Valley often gives rise to black ice, a common phenomenon in this region. In the winter of 2014/2015, a large portion of eastern Serbia was hit by extremely cold air masses from the east and the Carpathians, forming extensive ice layers on infrastructure facilities and forest trees (Pavlović *et al*., 2022). An ice catastrophe struck the entire area east of the Morava River, especially east of the Čestobrodica and Crni Vrh mountain passes. Practically, this area was “ice-ridden” for an extended period. Forest trees could not withstand large amounts of ice (up to several tons per tree), resulting in widespread ice breaks and ice throws *(*Marković *et al*., 2018).

In the Timok Forest Area, the “ice front” moved from the Bulgarian border westward and northwestward, affecting mountain masses from the northern branch of the Balkans Mountains (Zaglavak and Suvodol) over Tresibaba, Tupižnica, Slemen, Rtanj, Samanjac to Čestobrodica. Surrounding masses were also affected by the natural disaster, but the damage was less extensive. Significant damage was recorded on the mountain masses of the adjacent (southern) Morava Forest Area. This natural disaster struck natural forests of all structures and compositions in the belt between 600 and 900 meters above sea level.

Due to low temperatures, the rain froze on the ground and formed a thin coating of glaze ice. It also formed a thick sheath of ice on forest trees and shrubs that burdened entire trees, leading to the breakage of branches, tree tops, and lower (thick) portions of trees or causing ice throw of individual and grouped trees (Stojković, 2015).

According to the *"Action Plan for the Restoration of Damaged Forests in State and Private Ownership for 2015-2018"* developed by the "Srbijašume" State Enterprise, significant damage occurred in the Timok (Boljevac Forest Estate), Morava (Niš Forest Estate), Severni Kučaj (Kučevo Forest Estate), Rasina (Kruševac Forest Estate), and Južni Kučaj (Despotovac Forest Estate) Forest Areas (Baković *et al.*, 2015). According to the Action Plan, the damage was recorded on an area of 43,305.78 hectares, with 1,874,046 m$^3$ of dying and damaged trees. Clear-cutting was planned on 1,077.40 hectares, with a significant portion designated for vegetative and artificial regeneration.

**Table 1.** *Overview of Damaged Areas by Forest Areas*

| Forest Area | State forests | | Private forests | | Total for restoration | |
|---|---|---|---|---|---|---|
| | ha | m$^3$ | ha | m$^3$ | ha | m$^3$ |
| Timok | 10,060.72 | 979,682 | 21,588.00 | 219,869 | 31,648.72 | 1,199,551.00 |
| Morava | 6,744.22 | 569,775 | 1,818.00 | 41,946 | 8,562.22 | 611,721.00 |
| Northern Kučaj | 1,612.60 | 7,868 | 460.00 | 3,850 | 2,072.60 | 11,718.00 |
| Rasina | 827.10 | 39,317 | - | - | 827.10 | 39,317.00 |
| Southern Kučaj | 175.14 | 11,339 | 20.00 | 400.00 | 195,14 | 11,739.00 |
| **Total** | **19,419.78** | **1.607,981** | **23,886.00** | **266,065** | **23,886.00** | **1,874,046.00** |

Source: *Action Plan for the Restoration of Damaged Forests in State and Private Ownership for 2015-2018, "Srbijašume" State Enterprise, Belgrade*

In the Timok Forest Area, the following Forest Management Units (FMUs) suffered the greatest damage: FMU Rtanj, FMU Tupižnica, FMU Šaška – Studena – Selačka Reka, FMU Zaglava I, FMU Tresibaba, FMU Vrška Čuka – Babajona – Treći Vrh, FMU Markov Kamen – Mečji Vrh, FMU Čestobrodica, FMU Dubašnica, FMU Zaglavak II, and FMU Stol.

According to Stojković (2015), the apocalyptic scene of ice breaks and ice throws was particularly striking in FMU Vrška Čuka – Babajona – Treći Vrh.

## 2. MATERIAL AND METHODS

According to the Extract from the Forest Growing Stock of the "Srbijašume" State Enterprise, as of 1 January 1 2017, the total area of forests and forest land in the Timok Forest Area was 214,623.42 hectares. A total of 89,190.42 hectares (38%) was in state ownership, while 132,433.00 hectares (62%) were privately-owned. Of the total area in state ownership, forests and forest land covered 79,030.38 hectares (96%), with the remaining cover and uses constituting 3,160.04 hectares (4%). Of the total stocked area in state ownership, 72,694.60 hectares are forests, while forest plantations (artificially established stands up to 20 years old) cover 579.96 hectares.

Of the total non-stocked area in state ownership, 5,755.82 hectares are suitable for afforestation (forest land), 1,713.36 hectares are barren land, 1,273.24 hectares are land for other purposes, and 173.44 hectares are occupied land.

The study examines only the forested areas of the Timok Forest Area, encompassing both natural forests and artificially established stands under state ownership managed by the “Srbijašume” State Enterprise, Belgrade. To achieve this, a comparative analysis of the forest growing stock in the Timok Forest Area considered key indicators such as origin, preservation state, mixture, tree species, stand classification, and socioecological classification.

Natural disasters inflicted substantial damage in some regions of the Timok Forest Area, leading to clear-cutting across more than 1200 hectares of forest stands. This research seeks to assess whether these events resulted in significant alterations to the state of the forest growing stock within the Timok Forest Area.

To analyze specific parameters of the forest growing stock in the Timok Forest Area, data from the database of the “Srbijašume” State Enterprise, Belgrade were employed, covering 11 forest management units (FMUs) under its management. The study aimed to assess the impact of ice storms on the state of the forest growing stock in the Timok Forest Area by comparing data collected on 31 December 2013 with data from 31 December 2021. It's important to note that during this period, the forest area expanded by 3,283.83 hectares, accompanied by a timber stock of 1,024,042.51 m³, posing a challenge for comparative analysis due to these changes. Additionally, alterations in forest stand classifications further complicate the evaluation. For instance, previously designated high forests have been reclassified as coppice forests, and a considerable portion of shrubland is now categorised as coppice forests or thickets. A more accurate depiction is obtained by investigating areas subjected to clear-cutting and examining forest management plans for the most severely affected FMUs.

## 3. RESULTS AND DISCUSSION

### 3.1. Stand State by Origin in the Timok Forest Area

One of the primary alterations in the forest growing stock of the Timok Forest Area relates to its origin. As of 31 December 2013 (Table 2), natural high stands constituted 31.8% of the forest growing stock in the Timok Forest Area, representing 56.5% of its volume and 47.0% of the volume increment. In terms of area, natural coppice stands of hardwoods were prevalent (32.2%), with a volume share of 36.2% and a contribution to volume increment of 38.7%. Artificially established coniferous stands covered 4.9% of the area, 6.8% of the volume, and 14.0% of the volume increment. Shrubland and thickets encompassed 31.1% of the area, while other forms (artificially established broadleaved stands) constituted approximately 0.1% of the forested area.

As of 31 December 2021 (Table 2), natural high stands constituted 30.9% of the forest growing stock in the Timok Forest Area, representing 55.8% of its volume and 46.1% of the volume increment. Natural coppice stands of hardwoods dominated in terms of area, accounting for 34.7%, with a volume share of 37.6% and a contribution to volume increment of 41.3%. Artificially established coniferous stands covered 4.1% of the area, 6.5% of the volume, and 12.3% of the volume increment. Shrubland and thickets encompassed 29.5% of the area, while other forms (artificially established hardwood and softwood stands) constituted approximately 0.7% of the forest stocked area.

The most notable observation is the substantial difference between the total area of the region and the total timber stock. The Timok Forest Area witnessed an expansion of 3,283.83 hectares in the intervening period, resulting in a total timber stock of 1,024,042.51 m³, attributed to the incorporation of areas previously under different ownership. Consequently, providing precise comments on the data derived from the 2013 and 2021 overviews presented in Table 2, concerning changes in the forest growing stock by origin, poses a challenge. A more accurate assessment of changes in the state of the forest growing stock can be derived from the relative share of individual stand forms.

**Table 2.** *State of Forests by Origin in the Timok Forest Area on 31 December 2013 and 31 December 2021*

| **Stand origin** | **Area** | | **Volume** | | **Volume increment** | |
|---|---|---|---|---|---|---|
| | **ha** | **%** | **m³** | **%** | **m³** | **%** |
| Natural hardwood high stands 2013 | 22704.39 | 31.59 | 4499767.3 | 56.4 | 93374.4 | 46.9 |
| Natural hardwood high stands 2021 | 22917.32 | 30.49 | 4973646.78 | 55.28 | 106127.70 | 45.59 |
| Difference | 212.93 | -1.10 | 473879.50 | -1.16 | 12753.29 | -1.35 |
| Natural softwood high stands 2013 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Natural softwood high stands 2021 | 6.23 | 0.01 | 445.6 | 0.0 | 11.6 | 0.0 |
| Difference | 6.23 | 0.01 | 445.61 | 0.00 | 11.64 | 0.01 |
| Natural hardwood coppice stands 2013 | 23120.57 | 32.17 | 2884329.5 | 36.2 | 77005.3 | 38.7 |
| Natural hardwood coppice stands 2021 | 25953.25 | 34.53 | 3371537.1 | 37.5 | 95840.7 | 41.2 |
| Difference | 2832.68 | 2.36 | 487207.59 | 1.30 | 18835.44 | 2.46 |
| Natural softwood coppice stands 2013 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Natural softwood coppice stands 2021 | 175.90 | 0.23 | 4531.3 | 0.1 | 156.3 | 0.1 |
| Difference | 175.90 | 0.23 | 4531.31 | 0.05 | 156.27 | 0.07 |
| Natural coniferous high stands 2013 | 95.42 | 0.13 | 7122.6 | 0.1 | 271.4 | 0.1 |
| Natural coniferous high stands 2021 | 103.48 | 0.14 | 7122.6 | 0.1 | 271.4 | 0.1 |
| Difference | 8.06 | 0.00 | 0.00 | -0.01 | 0.00 | -0.02 |
| Natural high stands of conifers and broadleaves 2013 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Natural high stands of conifers and broadleaves 2021 | 187.66 | 0.25 | 34529.3 | 0.4 | 993.8 | 0.4 |
| Difference | 187.66 | 0.25 | 34529.31 | 0.38 | 993.81 | 0.43 |
| Artificially established hardwood stands 2013 | 1.71 | 0.00 | 106.1 | 0.0 | 5.6 | 0.0 |
| Artificially established hardwood stands 2021 | 527.44 | 0.70 | 19807.9 | 0.2 | 801.0 | 0.3 |
| Difference | 525.73 | 0.70 | 19701.78 | 0.22 | 795.36 | 0.34 |
| Artificially established softwood stands 2013 | 33.73 | 0.05 | 543.5 | 0.0 | 22.6 | 0.0 |
| Artificially established softwood stands 2021 | 7.29 | 0.01 | 319.6 | 0.0 | 8.3 | 0.0 |
| Difference | -26.44 | -0.04 | -223.85 | 0.00 | -14.30 | -0.01 |
| Artificially established coniferous stands 2013 | 3533.88 | 4.92 | 539370.9 | 6.8 | 27801.0 | 14.0 |
| Artificially established coniferous stands 2021 | 3072.25 | 4.09 | 585190.0 | 6.5 | 28568.0 | 12.3 |
| Difference | -461.63 | -0.83 | 45819.06 | -0.26 | 767.04 | -1.70 |
| Shrublands 2013 | 14096.72 | 19.61 | 41847.8 | 0.5 | 425.7 | 0.2 |
| Shrublands 2021 | 10700.69 | 14.24 | 0.0 | 0.0 | 0.0 | 0.0 |
| Difference | -3396.03 | -5.38 | -41847.80 | -0.52 | -425.71 | -0.21 |
| Thickets 2013 | 8292.37 | 11.54 | 0.0 | | 0.0 | |
| Thickets 2021 | 11511.11 | 15.31 | 0.0 | 0.0 | 0.0 | 0.0 |
| Difference | 3218.74 | 3.78 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Total 2013** | **71878.79** | | **7973087.73** | | **198905.96** | |
| **Total 2021** | **75162.62** | | **8997130.23** | | **232778.81** | |
| Difference | **3283.83** | | **1024042.51** | | **33872.85** | |

Source: *Database of SE "Srbijašume" on 31 December 2013 and 31 December* 2021 *and authors' calculations.*

For a more comprehensive understanding of changes in the forest growing stock, the paper presents a summary of clear-cut stand areas by origin (Table 3). It's important to note that the extent of the area affected by the ice storm exceeds what is shown in this table. However, clear-cutting wasn't implemented on a significant portion of that area and, therefore, is not the focus of this study. Natural high stands of hardwoods saw an increase in area of approximately 200 hectares. Between 2015. and 2020., around 160 hectares of these stands underwent clear-cutting. However, nearly all clear-cut natural stands were left for vegetative regeneration, leading to a reduction in the initial forest growing stock of natural high stands of hardwoods. The expansion of the forested area contributed to the increase in the area of natural high stands of hardwoods in Table 2.

Following the ice storm, slightly over 800 hectares of natural coppice stands of hardwoods underwent clear-cutting. Their rise in the forest growing stock by a little over 2,800 hectares is, in part, the outcome of converting natural high stands of hardwoods affected by the natural disaster (approximately 160 hectares) into lower silvicultural forms through vegetative regeneration. The increase is also associated with the transformation of substantial areas covered by thickets into coppice forests and, undoubtedly, the expansion of the forested area.

The natural disaster had a profound impact on artificially established coniferous stands, leading to a reduction of approximately 460 hectares in their stock. Nearly half of this decrease (about 250 hectares) was a direct result of the ice storm and associated ice throws. Through biological reforestation efforts, some of these areas were replanted with hardwoods, contributing to the overall increase in the share of artificially established stands of hardwoods in the forest stock, while simultaneously decreasing the proportion of artificially established coniferous stands.

The substantial decrease in thickets (by 3,396.03 hectares) and the corresponding rise in shrubland (by 3,283.83 hectares) were not a direct result of the natural disaster. Instead, these changes were primarily due to the conversion of extensive areas covered by thickets into higher silvicultural forms, such as coppice stands, and permanent stages, namely shrubland.

Other alterations in the forest growing stock cannot be directly linked to the natural disaster but rather stem from the conversion of one stand type into another during the new forest inventory and the expansion of the forested area.

**Table 3.** *Structure by Origin of Ice-damaged Areas Subjected to Clear-Cutting in the Timok Forest Area from 2015 to 2020*

| **Origin** | **Area(ha)** |
|---|---|
| High | 161.31 |
| Coppice | 810.98 |
| AES | 248.74 |
| **Total** | **1221.03** |

## 3.1. Stand State by Origin in the Timok Forest Area

As of 31 December 2013, the preservation state of the forest stock in the Timok Forest Area was unsatisfactory. Well-preserved stands were the most dominant, constituting 42.5% of the area, 71.3% of the volume, and 75.4% of the volume increment. Thinned stands covered 19.5% of the area, accounting for 24.2% of the volume and 23.2% of the volume increment. In contrast, devastated stands, thickets, and shrublands collectively comprised 38.0% of the area, representing 4.6% of the total standing timber volume and 1.5% of the volume increment. The notable presence of devastated stands, thickets, and shrublands (38.0%) pointed to areas requiring extensive intervention and posing challenges. It's crucial to highlight that this area encompassed a significant proportion of shrubland, representing a permanent stage of vegetation, as opposed to thickets, which signify a degradation phase (Pavlović *et al*., 2022).

In the forest stock of the Timok Forest Estate, as of 31 December 2021, well-preserved stands accounted for 31.0% of the area, 52.6% of the volume, and 56.7% of the volumetric increment. There was a significant increase in the share of thinned stands, contributing to 32.5% of the area, 44.0% of the volume, and 40.7% of the volume increment. Devastated stands, thickets, and shrublands collectivelly made up 37% of the area, accounting for 3.5% of the total standing timber volume.

**Table 4.** *Forest Preservation State in the Timok Forest Area on 31 December 2013 and 31 December 2021*

| Stand State | Area | | Volume | | Volume increment | |
|---|---|---|---|---|---|---|
| | ha | % | m³ | % | m³ | % |
| Well-preserved stands 2013 | 30563.72 | 42.5 | 5684412.8 | 71.3 | 150015.0 | 75.4 |
| Well-preserved stands 2021 | 23263.93 | 31.0 | 4727991.7 | 52.5 | 131953.0 | 56.7 |
| Difference | -7299.79 | -11.5 | -956421.1 | -18.8 | -18062.0 | -18.7 |
| Thinned stands 2013 | 14027.53 | 19.5 | 1925477.8 | 24.2 | 46008.6 | 23.2 |
| Thinned stands 2021 | 24442.54 | 32.5 | 3959163.4 | 44.0 | 94819.0 | 40.7 |
| Difference | 10415.01 | 13.0 | 2033685.6 | 19.8 | 48810.4 | 17.5 |
| Devastated stands 2013 | 4898.45 | 6.8 | 321349.4 | 4.1 | 2456.6 | 1.3 |
| Devastated stands 2021 | 5244.35 | 7.0 | 309975.1 | 3.4 | 6006.8 | 2.6 |
| Difference | 345.9 | 0.2 | -11374.3 | -0.7 | 3550.2 | 1.3 |
| Shrublands and thickets 2013 | 22389.09 | 31.2 | | | | |
| Shrublands and thickets 2021 | 22211.8 | 29.6 | | | | |
| Difference | -177.29 | -1.6 | | | | |
| **Total 2013** | **71878.79** | | **7931240.0** | | **198480.2** | |
| **Total 2021** | **75162.62** | | **8997130.2** | | **232778.8** | |
| **Difference** | **3283.83** | | **1065890.2** | | **34298.6** | |

Source: *Database of the "Srbijašume" State Enterprise as of 31 December 2013 and 31 December 2021 and authors' calculations*

The data in Table 4 indicates a significant decrease in the share of well-preserved stands by nearly 7,300 hectares (11.5%), while the share of thinned stands increased significantly by approximately 10,400 hectares (13%). Clear-cutting, resulting from the natural disaster, was conducted on an area of about 1,200 hectares (Table 3). These stands were reclassified as thinned in the new inventory. They should have been categorised as devastated stands because the damage from the natural disaster was total. However, they underwent artificial or natural regeneration, leading the planner to define them as thinned. It is important to note that a substantial part of the stands damaged by ice storm was not clear-cut, and some of these stands were classified as thinned stands. The increase in the area of thinned stands in the new inventory also resulted from converting shrublands into this silvicultural form, and to a lesser extent, from the expansion of the forested area by nearly 3,300 hectares. The increase in devastated stands in the forest growing stock was significantly smaller but still noteworthy (around 350 hectares).

The reduction in the share of shrublands during the study period by nearly 180 hectares resulted from converting certain areas covered by shrublands into higher silvicultural forms, specifically thinned stands.

The presence of thinned (insufficiently stocked) and devastated stand categories, shrublands, and thickets, on almost half of the total forested area, with all the associated negative effects (reduced ecological stability, underutilised site potential, diminished productivity compared to well-preserved stands, etc.), represents one of the fundamental, long-term challenges in managing our forests (Banković *et al*., 2009).

### 3.3. Stand State by Mixture in the Timok Forest Area

According to the state summary as of 31 December 2013, pure stands covered 36,630.30 hectares, which was 51% of the area. They accounted for 6,470,495.7 $m^3$ or 81.2% of volume and 157,431.1 $m^3$ or 79.2% of volume increment. Mixed stands covered 12,859.40 hectares (17.9%), accounting for 1,460,744.3 $m^3$ (18.3%) of volume and 41,049.1 $m^3$ (20.6%) of volume increment. The remaining area of 22,389.09 hectares (31.2%) comprised shrublands and thickets (Table 5).

According to the state summary as of 31 December 2021, pure stands covered 36,330.37 hectares, which was 48.3% of the area. They accounted for 6,944,750.1 $m^3$ or 77.2% of volume, and 173,597.9 $m^3$ or 74.6% of volume increment. Mixed stands covered 16,620.45 hectares (22.1%), with a volume of 2,052,380.2 $m^3$ (22.8%) and a volume increment of 59,181.2 $m^3$ (25.4%). The remaining area of 22,211.80 hectares (29.6%) comprised shrublands and thickets where the mixture, volume, and volume increment were not determined (Table 5).

**Table 5.** *Forest State by Mixture in the Timok Forest Area on 31 December 2013 and 31 December 2021*

| Mixture | Area | | Volume | | Volume increment | |
|---|---|---|---|---|---|---|
| | ha | % | $m^3$ | % | $m^3$ | % |
| Pure stands 2013 | 36630.30 | 51.0 | 6470495.6 | 81.2 | 157431.1 | 79.1 |
| Pure stands 2021 | 36330.37 | 48.3 | 6944750.1 | 77.2 | 173597.9 | 74.6 |
| Difference | -299.93 | -2.6 | 474254.4 | -4.0 | 16166.8 | -4.6 |
| Mixed stands 2013 | 12859.40 | 17.9 | 1460744.3 | 18.3 | 41049.0 | 20.6 |
| Mixed stands 2021 | 16620.45 | 22.1 | 2052380.2 | 22.8 | 59181.2 | 25.4 |
| Difference | 3761.05 | 4.2 | 591635.9 | 4.5 | 18132.2 | 4.8 |
| Shrublands and thickets 2013 | 22389.09 | 31.1 | 41847.8 | 0.5 | 425.7 | 0.2 |
| Shrublands and thickets 2021 | 22211.80 | 29.6 | | | | |
| Difference | -177.29 | -1.6 | | | | |
| **Total 2013.** | **71878.79** | | **7973087.7** | | **198905.9** | |
| **Total 2021.** | **75162.62** | | **8997130.2** | | **232779.1** | |
| **Difference** | **3283.83** | | **1024042.5** | | **33873.3** | |

Source: *Database of the "Srbijašume" State Enterprise as of 31 December 2013 and 31 December 2021 and authors' calculations*

The data presented in Table 5 indicates a decrease in the share of pure stands, accompanied by a notable increase in mixed stands. Besides the reasons mentioned earlier, such as the expansion of the forested area, this trend can be attributed to the greater vulnerability of pure stands, being a less stable stand type, which led to their replacement by artificially established coniferous stands in the form of monocultures. A significant portion of the areas that underwent clear-cutting were reforested with multiple tree species, resulting in the classification of these areas as artificially established mixed stands in the new forest inventory.

The areas covered by thickets and shrublands decreased due to the partial conversion of thickets into, most likely, mixed coppice stands.

The prevalence of pure stands, which are regarded as ecologically, functionally, and even productively inferior stand forms, poses a significant strategic challenge for the forests of Serbia (Banković *et al*., 2009). In contrast, mixed stands represent more stable forest ecosystems and demonstrate greater resilience to adverse abiotic and biotic influences, stressing the necessity to reduce the expansion of monocultures (Pavlović *et al*., 2022).

## 3.4. Stand State by Tree Species in the Timok Forest Area

The inventory of forests managed by the "Srbijašume" State Enterprise records a total of 75 tree species, comprising 59 broadleaved and 16 coniferous species. The number of tree species is of great importance from a biodiversity conservation perspective (Banković *et al*., 2009).

As indicated in Table 6, both before and after the natural disaster in the Timok Forest Area, broadleaved species maintained their dominance. They represented 93.4% of the volume and 86.2% of the increment. Among broadleaved species, beech was the most prominent, contributing to 72.3% of the total standing timber volume and 64.2% of the current volume increment. Other significant contributors to the standing timber volume among broadleaved species included sessile oak (9.0%), hornbeam (3.7%), Turkey oak (3.2%), Hungarian oak (2.6%), locust (0.5%), manna ash (0.4%), and sycamore (0.3%). Other hardwood species had minimal representation.

Coniferous stands accounted for only 6.6% in terms of volume and 13.8% in terms of increment. These were artificially established stands formed through afforestation of barren land and reclamation of devastated hardwood forests using spruce, pine, Douglas fir, and larch seedlings. The most significant coniferous species included Austrian pine with 4.6% volume and 10.2% volume increment, spruce with 1.3% volume and 2.1% volume increment, and Scots pine with 0.3% volume and 0.6% volume increment. Other coniferous species with notable contributions to volume included fir (0.3% volume, 0.5% volume increment), Douglas fir (0.1% volume, 0.2% volume increment), and Eastern white pine (0.1% volume, 0.3% volume increment).

The large number of tree species represents significant biodiversity and species richness, contributing to multiple environmental benefits (Pavlović *et al*., 2022). Particular attention should be devoted to species with the status of relict, endemic, rare, and endangered, according to the IUCN category – TBFRA 2000 (International Union for Conservation of Nature – Temperate and Boreal Forest Resource Assessment), as well as protected and strictly protected species, according to the Regulation on the Proclamation and Protection of Strictly Protected and Protected Wild Species of Plants, Animals, and Fungi ("Official Gazette of RS" no.

5/10, 47/2011, 32/2016, and 98/2016). Therefore, special consideration should be given to species such as Turkish hazel, Balkan maple, various forest fruit trees such as walnut, service tree, wild service tree, etc., and shrub species such as those from the *Daphne* genus, as well as numerous herbaceous species such as *Ramond*a, etc. (Pavlović *et al*., 2022).

**Table 6.** *Forest State by Tree Species in the Timok Forest Estate as of 31 December 2013*

| Tree species | Volume | | Volume increment | |
|---|---|---|---|---|
| | m³ | % | m³ | % |
| Beech | 5761269.0 | 72.3 | 127661.8 | 64.2 |
| Sessile oak | 721555.8 | 9.0 | 16243.9 | 8.2 |
| Hornbeam | 292060.7 | 3.7 | 7608.6 | 3.8 |
| Turkey oak | 257581.8 | 3.2 | 6852.0 | 3.4 |
| Hungarian oak | 205728.0 | 2.6 | 6693.8 | 3.4 |
| Locust | 37517.2 | 0.5 | 1768.8 | 0.9 |
| Flowering ash | 28750.3 | 0.4 | 891.5 | 0.4 |
| Sycamore | 25551.4 | 0.3 | 690.1 | 0.3 |
| Field maple | 20796.4 | 0.3 | 633.1 | 0.3 |
| Turkish hazel | 20215.6 | 0.3 | 490.8 | 0.2 |
| OHS | 17511.3 | 0.2 | 469.1 | 0.2 |
| Oriental hornbeam | 11859.0 | 0.1 | 297.6 | 0.1 |
| Norway maple | 9767.9 | 0.1 | 259.1 | 0.1 |
| Common ash | 9619.1 | 0.1 | 235.8 | 0.1 |
| Large-leaved lime | 7144.7 | 0.1 | 246.4 | 0.1 |
| European aspen | 4371.9 | 0.1 | 164.0 | 0.1 |
| Cherry | 3684.0 | 0.0 | 11.6 | 0.0 |
| Silver lime | 3580.5 | 0.0 | 102.6 | 0.1 |
| OSS | 1659.5 | 0.0 | 31.9 | 0.0 |
| Wych elm | 1537.1 | 0.0 | 43.8 | 0.0 |
| Wild service tree | 1023.8 | 0.0 | 0.0 | 0.0 |
| Downy oak | 950.2 | 0.0 | 0.7 | 0.0 |
| **Broadleaves** | **7443735.1** | **93.4** | **171397.2** | **86.2** |
| Austrian pine | 363435.0 | 4.6 | 20371.9 | 10.2 |
| Norway spruce | 105127.3 | 1.3 | 4140.0 | 2.1 |
| Scots pine | 24424.1 | 0.3 | 1286.2 | 0.6 |
| Fir | 22579.3 | 0.3 | 916.4 | 0.5 |
| Douglas fir | 6865.5 | 0.1 | 290.0 | 0.2 |
| Eastern white pine | 6585.8 | 0.1 | 502.7 | 0.3 |
| Larch | 325.0 | 0.0 | 0.0 | 0.0 |
| Yew | 6.7 | 0.0 | 0.0 | 1.0 |
| **Conifers** | **529348.7** | **6.6** | **27507.2** | **13.8** |
| **Total** | **7973083.8** | **100.0** | **198904.4** | **100.0** |

Source: *Database of the "Srbijašume" State Enterprise as of 31 December 2013 and authors' calculations*

The state of the forest growing stock by tree species in the Timok Forest Area after the natural disaster was almost unchanged. Namely, the most significant broadleaved and coniferous species, as well as their share in terms of volume and volume increment, did not undergo significant alterations.

### 3.5. Stand State by Stand Classification in the Timok Forest Area

According to the state assessment from 2013, beech forests dominated the forest growing stock of the Timok Forest Estate, covering 44.2% of the total forested area. Beech was followed by thickets and shrublands, occupying an area of 22,132.74 hectares, or 30.8% of the forested area (Table 7). The next in rank were sessile oak forests with 8.7%, hornbeam forests with 3.7%, Hungarian oak forests with 3.3%, Turkey oak forests with 3.0%, pine forests with 2.7%, forests of locust, aspen, and birch with 1.4%, spruce forests with 1.3%, followed by maple and ash forests, lime forests, and poplar forests with a minimal share in the total forested area. The prevalence of beech forests was even more evident when considering their contribution to the total volume (73.6%) and volume increment (65.6%). They were followed by sessile oak forests with a share in volume of 9.5% and in volume increment of 8.8%, pine forests with 5.0% in volume and 11.0% in increment, hornbeam forests with a volume share of 3.1% and an increment share of 3.5%, Hungarian oak forests with a volume share of 2.9% and an increment share of 3.7%, Turkey oak forests with a volume share of 2.8% and an increment share of 3.1%, spruce forests with 1.3% in volume and 2.1% in increment. Forests of other broadleaves and conifers had a negligible share in volume and volume increment (Table 7).

According to the state summary from 2021, beech forests continued to prevail, covering 43.2% of the forested area. Thickets and shrublands followed, occupying an area of 22,211.80 hectares, or 29.6% of the forested area. Significant contributions were also made by sessile oak forests with 8.5%, hornbeam forests with 4.2%, Turkey oak forests with 4.1%, Hungarian oak forests with 3.4%, pine forests with 2.5%, forests of locust, aspen, and birch with 1.6%, spruce forests with 1.1%, forests of other conifers with 0.7%, and ash and maple forests with 0.6%. Other categories had a negligible share in the total forested area. When considering the share in the total volume and volume increment, beech forests were also prevalent (contributing 71.9% in volume and 64.0% in volume increment). Sessile oak forests followed with a volume share of 9.5% and an increment share of 9.3%, pine forests with 4.6% in volume and 9.4% in increment, hornbeam forests with a volume share of 4.1% and an increment share of 4.3%, Turkey oak forests with 3.6% share in volume and 4.3% share in increment, Hungarian oak forests with a volume share of 3.0% and an increment share of 3.8%, spruce forests with 1.5% share in volume and 2.2% share in increment, and forests of other conifers with 0.5% in volume and 0.8% in increment. Forests of other broadleaves and conifers had a negligible share in volume and volume increment (Table 7).

By expanding the forested area by 3,283.83 hectares, the timber stock in high, coppice and artificially established stands without thickets and shrublands increased by 1,060,058 $m^3$. Even in stands where the area decreased, the timber stock increased. The area covered by shrublands and thickets slightly increased, not so much due to the addition of a small area, but primarily because a large part of them were converted into coppice stands, as mentioned earlier. The expansion of the area had the most significant impact on the increase in Turkey oak forests, followed by beech and hornbeam forests. Ice breaks and ice throws caused the most significant damage in artificially established stands of spruce, Austrian pine, and Scots pine. This led to the reduction of the area covered by these species. These areas were often artificially regenerated using broadleaved species, and these biological activities contributed to the expansion of their stands, primarily beech and sessile oak, and the reduction of areas covered by stands of the mentioned coniferous species.

**Table 7**. *Forest State by Stand Type in Timok Forest Area as of 31 December 2013*

| Stand unit | Area | | Volume | | Volume increment | |
|---|---|---|---|---|---|---|
| | ha | % | m³ | % | m³ | % |
| Beech forests 2013 | 31747.20 | 44.2 | 5869464.2 | 73.6 | 130390.4 | 65.6 |
| Beech forests 2021 | 32491.25 | 43.2 | 6464732.7 | 71.9 | 148914.3 | 64.0 |
| Difference | 744.05 | -1.0 | 595268.5 | -1.7 | 18523.9 | -1.6 |
| Sessile oak forests 2013 | 6238.53 | 8.7 | 759462.6 | 9.5 | 17527.1 | 8.8 |
| Sessile oak forests 2021 | 6356.14 | 8.5 | 850859.5 | 9.5 | 21721.5 | 9.3 |
| Difference | 117.61 | -0.2 | 91396.9 | 0.0 | 4194.4 | 0.5 |
| Hornbeam forests 2013 | 2651.26 | 3.7 | 250190.6 | 3.1 | 7019.9 | 3.5 |
| Hornbeam forests 2021 | 3151.68 | 4.2 | 364265.0 | 4.1 | 9958.5 | 4.3 |
| Difference | 500.42 | 0.5 | 114074.4 | 1.0 | 2938.6 | 0.8 |
| Hungarian oak forests 2013 | 2345.79 | 3.3 | 230211.4 | 2.9 | 7396.3 | 3.7 |
| Hungarian oak forests 2021 | 2516.29 | 3.4 | 269063.5 | 3.0 | 8823.1 | 3.8 |
| Difference | 170.50 | 0.1 | 38852.1 | 0.1 | 1426.8 | 0.1 |
| Turkey oak forests 2013 | 2155.05 | 3.0 | 223612.4 | 2.8 | 6160.7 | 3.1 |
| Turkey oak forests 2021 | 3044.90 | 4.1 | 320578.2 | 3.6 | 9928.9 | 4.3 |
| Difference | 889.85 | 1.1 | 96965.8 | 0.8 | 3768.2 | 1.2 |
| Pine forests 2013 | 1918.81 | 2.7 | 396889.4 | 5.0 | 21923.1 | 11.0 |
| Pine forests 2021 | 1868.82 | 2.5 | 408958.8 | 4.6 | 21848.1 | 9.4 |
| Difference | -49.99 | -0.2 | 12069.4 | -0.4 | -75.0 | -1.6 |
| Locust, aspen and birch forests 2013 | 1024.27 | 1.4 | 37090.8 | 0.5 | 1748.0 | 0.9 |
| Locust, aspen and birch forests 2021 | 1209.01 | 1.6 | 38451.3 | 0.4 | 1894.6 | 0.8 |
| Difference | 184.74 | 0.2 | 1360.5 | -0.1 | 146.6 | -0.1 |
| Spruce forests 2013 | 945.50 | 1.3 | 105181.8 | 1.3 | 4073.6 | 2.1 |
| Spruce forests 2021 | 797.41 | 1.1 | 138045.7 | 1.5 | 5044.8 | 2.2 |
| Difference | -148.09 | -0.2 | 32863.9 | 0.2 | 971.2 | 0.1 |
| Ash and maple forests 2013 | 203.82 | 0.3 | 9959.5 | 0.1 | 321.1 | 0.2 |
| Ash and maple forests 2021 | 479.82 | 0.6 | 37337.3 | 0.4 | 1094.3 | 0.5 |
| Difference | 276.00 | 0.3 | 27377.8 | 0.3 | 773.2 | 0.3 |
| Forest of other broadleaves 2013 | 196.95 | 0.3 | 2523.3 | 0.1 | 38.6 | 0.0 |
| Forest of other broadleaves 2021 | 244.52 | 0.3 | 16359.3 | 0.2 | 353.1 | 0.2 |
| Difference | 47.57 | 0.0 | 13836.0 | 0.1 | 314.5 | 0.2 |
| Forests of other conifers 2013 | 165.60 | 0.2 | 15642.3 | 0.2 | 774.4 | 0.4 |
| Forests of other conifers 2021 | 517.66 | 0.7 | 44777.9 | 0.5 | 1931.7 | 0.8 |
| Difference | 352.06 | 0.5 | 29135.6 | 0.3 | 1157.3 | 0.4 |
| Fir forests 2013 | 99.39 | 0.1 | 33238.7 | 0.4 | 1109.7 | 0.6 |
| Fir forests 2021 | 183.82 | 0.2 | 33453.8 | 0.4 | 969.7 | 0.4 |
| Difference | 84.43 | 0.1 | 215.1 | 0.0 | -140.0 | -0.2 |
| Lime forests 2013 | 32.53 | 0.1 | 2906.1 | 0.1 | 94.7 | 0.1 |
| Lime forests 2021 | 38.17 | 0.1 | 6670.4 | 0.1 | 181.2 | 0.1 |
| Difference | 5.64 | 0.0 | 3764.3 | 0.0 | 86.5 | 0.0 |
| Poplar forests 2013 | 20.42 | 0.1 | 569.7 | 0.0 | 15.1 | 0.0 |
| Poplar forests 2021 | 27.48 | 0.0 | 2391.5 | 0.0 | 83.2 | 0.1 |
| Difference | 7.06 | -0.1 | 1821.8 | 0.0 | 68.1 | 0.1 |
| Willow forests 2013 | 0.93 | 0.0 | 129.5 | 0.0 | 1.4 | 0.0 |
| Willow forests 2021 | 23.85 | 0.0 | 1185.6 | 0.0 | 31.8 | 0.0 |
| Difference | 22.92 | 0.0 | 1056.1 | 0.0 | 30.4 | 0.0 |
| **Total (excluding thickets and shrublands) 2013** | **49746.05** | **69.2** | **7937072.2** | **100.0** | **198594.0** | **100.0** |
| **Total (excluding thickets and shrublands) 2021** | **52950.82** | **70.5** | **8997130.2** | **100.0** | **232778.8** | **100.0** |
| **Difference** | **3204,77** | **1,3** | **1060058,0** | **0,0** | **34184,8** | **0,0** |
| **Total (thickets and shrublands) 2013** | **22132,74** | **30,8** | | | | |
| **Total (thickets and shrublands) 2021** | **22211,80** | **29,6** | | | | |
| **Difference** | **79,06** | **-1,2** | | | | |

Source: *Database of the "Srbijašume" State Enterprise as of 31 December 2013 and 31 December 2021 and authors' calculations.*

### 3.6. Forest State by Socioecological Classification in the Timok Forest Area

Socioecological classification is defined by site and phytosociological classification, serving as an ecological characteristic of forests that does not significantly change between two management periods. However, it is not a fixed category; rather, such changes, require a much longer time period. Changes in socioecological units can result from long-term and gradual climate changes. In this context, we are addressing weather extremes occurring in specific years, which, as such, cannot individually have a significant impact on the site and potential vegetation. They can only temporarily "disturb" the ecosystem balance. If the site is not significantly altered, the ecosystem returns to balance through vegetation succession. As this process is not short, the task of forest managers is to accelerate it through artificial regeneration, bypassing some stages in succession and quickly creating the climax stages and oroclimax-conditioned forest communities (Pavlović *et al*., 2022). Artificial regeneration of clearcut areas was carried out several times, both with species compatible with the site and with species that were not suitable for the potential vegetation. On the other hand, pioneer tree species and vegetative regeneration from stumps and shoots more commonly occurred. This spontaneous vegetation represented different stages in the succession of vegetation on clearcut surfaces.

As presented in Table 8, the most prevalent forest type in the forest growing stock was the mountain beech forest (*Fagetum moesiacae montanum*) on various brown soils (33.89%). It was followed by the submontane beech forest (*Fagetum moesiacae submontanum*) on acidic brown and other soils (17.27%), the Oriental hornbeam forest (*Carpionion orientalis moesiacum*) on rendzinas and various eroded soils (11.96%), the sessile oak and hornbeam forest (*Querco-carpinetum moesiacum*) on brown and leached brown soils (11.47%), and the sessile oak forest (*Quercetum montnaum*) on brown soils (10.96%). Other socioecological units covered less than 10% of the area.

**Table 8.** *Forest State by Socioecological Classification in the Timok Forest Area as of 31 December 2021*

| **Socioecological unit** | **Površina** | |
|---|---|---|
| | **ha** | **%** |
| Mountain beech forest (*Fagetum moesiacae montanum*) on various brown soils | 24357.37 | 33.89 |
| Submontane beech forest (*Fagetum moesiacae submontanum*) on acidic brown and other soils | 12412.45 | 17.27 |
| Oriental hornbeam forest (*Carpionion orientalis moesiacum*) on black soil and various eroded soils | 8594.22 | 11.96 |
| Sessile oak and hornbeam forest (*Querco - carpinetum moesiacum*) on brown and brown leached soils | 8245.77 | 11.47 |
| Sessile oak forest (*Quercetum montnaum*) on brown soils | 7876.97 | 10.96 |
| Typical forest of Hungarian oak and Turkey oak (*Quercetum frainetto-cerris typicum*) on brown leached soils | 4356.91 | 6.06 |
| Forest of Oriental hornbeam with oaks (*Carpino orientalis-Polyquercetum*) on pararendzinas and shallow eutric cambisol over loess | 2966.22 | 4.13 |
| Sessile oak and Turkey oak forest (*Quercetum petraeae-cerris*) on soils over loess. silicate rocks and limestone | 875.25 | 1.22 |
| Turkey oak forest (*Quercetum cerris*) on A-C to A1-A3-B1-C soil series | 544.55 | 0.76 |
| Forest of Hungarian oak and Turkey oak with Oriental hornbeam (*Quercetum frainetto-cerris carpinetosum orientalis*) on dystric brown and eutric brown soils | 391.29 | 0.54 |
| Forest of Hungarian oak and Turkey oak with hornbeam (*Quercetum frainetto-cerris carpinetosum betuli*) on brown and leached soils and diluvium | 345.47 | 0.48 |
| Forest of beech. hornbeam. and noble broadleaves (*Aceri - Carpini - Fagetum moesiace montanum*) on humus-silicate and more or less skeletal brown soils | 317.26 | 0.44 |
| Spruce forest (*Piceion excelsae serbicum*) on distric humus-silicate brown soils and black soils over limestone | 248.40 | 0.35 |
| Forest of Hungarian oak and Turkey oak with sessile oak (*Quercetum frainetto-cerris petraetosum*) on various brown and humus-silicate soils | 69.13 | 0.10 |
| Forest of different oaks with manna ash (*Orno-Polyquercetum*) on various shallow soils | 58.71 | 0.08 |
| Forest of beech and fir (*Abieti-Fagetum serpentinicum*) on peridotites. serpentinised peridotites. and serpentinites | 49.09 | 0.07 |
| Forest of Hungarian oak and Turkey oak with pedunculate oak (*Quercetum frainetto-cerris quercetosum roboris*) on eutric cambisol and leached to pseudogley soils | 40.24 | 0.06 |
| Forest of sessile oak. hornbeam and Turkey oak (*Carpino - Quercetum petraeae - cerris*) on soils over loess and acidic silicate rocks | 35.15 | 0.05 |
| Forest of beech and sessile oak (*Querco-Fagetum*) on various brown and leached brown soils | 32.86 | 0.05 |
| Forest of white and black poplar Šuma bele i crne topole (*Populetum albo-nigrae*) on a mosaic of different alluvial soils | 29.73 | 0.04 |
| Forest of Turkey oak and large-leaved downy oak (*Quercetum cerris-virgilianae*) on poorly developed soils over loess. marl. and limestones | 11.55 | 0.02 |
| Forest of different oaks and hornbeam (*Carpino- Polyquecetum*) on soils formed over loess | 8.40 | 0.01 |
| Hungarian oak forest (*Quercetum frainetto*) on leached and leached acidic brown soils | 6.46 | 0.01 |
| Forest of white poplar (*Populetum albae*) on dry recent alluvial deposits. initial phases. and other dry variants of alluvial pararendzinas (semigley soils) | 3.82 | 0.01 |
| Forest of white willow (*Salicion albae*) on moist recent alluvial deposits and gleysols | 0.93 | 0.00 |
| Black alder swamp forest (*Alnetum glutinosae*) on alpha/beta to beta-gleysol and humogley | 0.59 | 0.00 |
| **Total** | **71878.79** | **100.00** |

Source: *Database of the "Srbijašume" State Enterprise as of 31 December 2021 and authors' calculations*

## 5. CONCLUSION

The natural disaster manifested as ice breaks, snow breaks, ice throws, and snow throws during the winter of 2014/2015, had adverse effects on the forest growing stock and the state of forests in some parts of the Timok Forest Area.

The damage varied in intensity, with approximately 1200 hectares experiencing such extensive damage that clear-cutting became necessary. Artificially established stands were nearly completely destroyed, while natural stands struck by this icy catastrophe suffered significant harm.

Accurately assessing changes in the forest estate after the natural disaster proves challenging when relying solely on a comparison of conditions before and after the event. This difficulty arises from the expansion of the Timok Forest Area by 3283.83 hectares, encompassing a total growing stock of 1.024.042.51 m³, through the incorporation of areas previously managed by other owners. Additionally, certain stands underwent alterations in their stand structure during new forest inventories. To comprehend changes in the forest growing stock, an examination of areas requiring clear-cutting as a necessary measure, alongside biological and silvicultural operations within management units, was employed. It should be noted that clear-cutting was not performed over a large area within less damaged stands. Some of these stands changed the category they belonged to from preserved to thinned and devastated stands in the new forest inventory.

The most significant changes in the forest growing stock were related to the origin and preservation state of stands. Besides the increase in the forest area by over 3200 ha, a large part of high forests were converted to coppice forests, a lower silvicultural form, as they were left to regenerate vegetatively. Consequently, the area under coppice forests, mainly of hardwoods, increased. Conversely, artificially established conifer stands suffered extensively, with some areas being afforested with hardwoods. This led to the increase in the share of artificially established stands of hardwoods in the forest growing stock, but not enough compared to the increase in hardwood coppice forests. The reduction in the share of artificially established conifer stands was beneficial in terms of forest stability against potential future weather disasters. All stands that were clear-cut and artificially or naturally (vegetatively) regenerated were defined as thinned in the new inventory, even though they were essentially devastated. The limited success of artificial regeneration makes these areas (former artificially established conifer stands) prone to natural regeneration through vegetation succession. Pure stands, particularly conifer monocultures, displayed increased vulnerability to the natural disaster, contributing to changes in the forest growing stock concerning stand mixture.

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# CHANGES IN THE FOREST GROWING STOCK OF THE TIMOK FOREST AREA FOLLOWING THE ICE STORM IN WINTER 2014/2015

*Branka PAVLOVIĆ, Vlado ČOKEŠA, Ljubinko RAKONJAC ,Violeta BABIĆ, Zoran PODUŠKA, Nikola MARTAĆ, Branko KANJEVAC*

## Summary

During the winter of 2014/2015, ice rain inflicted substantial damage to forest trees in eastern Serbia. This study focuses on the state-owned forest areas within the Timok Forest Area, encompassing both natural forests and artificially established stands under the management of the "Srbijašume" State Enterprise. The natural disaster, characterised by icebreaks and ice throws, caused severe devastation in some parts of the Timok Forest Area, prompting extensive clear-cutting measures on approximately 1200 hectares of forest stands. The primary objective of this research was to determine whether notable changes occurred in the state of the forest growing stock at the area level. The artificially established stands affected by the natural disaster faced near-total destruction. Concerning natural forests, all stand types and structures situated between 600 and 900 meters above sea level were affected by this ice calamity. It moved from the northern part of the Balkan Mountains along the border with Bulgaria, in a west-northwest direction until reaching Čestobrodica. Every natural stand in its way incurred damage. Over the study period, there was a significant decrease in the share of high stands of hardwoods, while the proportion of coppice stands of hardwoods experienced an increase. Concurrently the share of artificially established conifer stands, particularly monocultures, decreased, leading to a rise in artificially established mixed stands of hardwoods. Additionally, the proportion of preserved stands decreased, whereas thinned and devastated stands witnessed an increase. In some areas, artificial regeneration was not entirely successful. Natural regeneration initiated in these regions, marked by the colonisation of pioneer species at various stages of vegetation succession.

# PROMENA STANJA ŠUMSKOG FONDA U TIMOČKOM ŠUMSKOM PODRUČJU KAO POSLEDICA LEDOLOMA U ZIMU 2014/2015. GODINE

*Branka PAVLOVIĆ, Vlado ČOKEŠA, Ljubinko RAKONJAC ,Violeta BABIĆ, Zoran PODUŠKA, Nikola MARTAĆ, Branko KANJEVAC*

## Rezime

Na području istočne Srbije u zimu 2014/2015. godine, ledena kiša je pričinila velike štete na šumskom drveću. Predmet ovog istraživanja su obrasle površine Timočkog ŠP (prirodne šume i veštački podignute sastojine) u državnom vlasništvu kojima gazduje JP „Srbijašume“ Beograd. Elementarna vremenska nepogoda je u pojedinim delovima Timočkog ŠP pričinila ogromne štete u vidu ledoloma i ledoizvala, te su morale biti izvršene čiste seče na velikim površinama (oko 1200 ha šumskih sastojina). Cilj istraživanja je da se utvrdi da li je došlo do bitnih promena u stanju šumskog fonda na nivou područja. Veštački podignute sastojine, zahvaćene vremenskom nepogodom stradale su gotovo u celosti, a od prirodnih šuma zahvaćeni su svi sastojinski i strukturni oblici u pojasu između 600 i 900 m nadmorske visine. Ledena stihija se kretala pravcem od severnog dela Stare planine od granice sa Bugarskom u smeru zapad-severozapad, do Čestobrodice. Stradale se sve prirodne sastojine koje su se našle na udaru. U analiziranom periodu, naročito se smanjilo učešće visokih šuma tvrdih lišćara, a povećalo ućešće izdanačkih sastojina tvrdih lišćara. Takođe se smanjilo učešće veštački podignutih sastojina četinara (monokultura), na račun povećanja

veštački podignutih mešovitih sastojina tvrdih lišćara. Takođe se realno smanjilo učešće očuvanih, a povećalo učešće razređenih i devastiranih sastojina. Na pojedinim mestima, veštačko obnavljanje nije u potpunosti uspelo. Na ovim površinama je takođe započelo prirodno obnavljanje, naseljavanjem pionirskih vrsta u različitim fazama sukcesija vegetacije.

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# ASSESSMENT OF THE CONDITION OF NATURAL VALUES OF THE FOREST MANAGEMENT UNIT "JASENOVO-BOŽETIĆI" IN THE AREA OF SOUTHWEST SERBIA

*Miloš RAČIĆ[1]*, Branko KANJEVAC[2], Nikola MARTAĆ[1], Dejan MILETIĆ[3], Nenad PETROVIĆ[2]*

**Abstract:** *This paper presents the assessment of the condition of natural values of forest stands in relation to the origin, structural form, mixedness as well as in relation to affiliation of the forest stand to forest management type. The object of the research is the Forest management unit "Jasenovo-Božetići" which belongs to the Western forest region in Serbia. Assessment of the condition has been performed in accordance with the method developed on the project entitled Contribution of Sustainable Forest Management to Low Emission and Resilient Development (GCP/SRB/002/GEF). The total area on which the assessment of natural values was carried out amounts to 1684.7 ha. Based on the final assessment of biodiversity, the stands of low natural value cover the area of 1205.6 ha (71.5%), the stands of lower medium natural value cover 300.9 ha (17.9%), the stands of higher medium natural value 178.2 ha (10.9%), while stands of high natural value are not registered.*

**Keywords:** natural values, forest stand, forest management type, Southwest Serbia.

# OCENA STANJA PRIRODNIH VREDNOSTI GAZDINSKE JEDINICE „JASENOVO-BOŽETIĆI" NA PODRUČJU JUGOZAPADNE SRBIJE

**Sažetak:** *U ovom radu prikazana je ocena stanja prirodnih vrednosti sastojina u odnosu na poreklo, strukturni oblik, mešovitost kao i u odnosu na pripadnost sastojine gazdinskom tipu. Objekat istraživanja je gazdinska jedinica „Jasenovo-Božetići" koja pripada Zapadnoj šumskoj oblasti u Srbiji. Ocena stanja je vršena u skladu sa metodom koji je razvijen na projektu pod nazivom Doprinos održivog gazdovanja šumama niskim emisijama i prilagodljivom razvoju (GCP/SRB/002/GEF). Ukupna površina na kojoj je vršena ocena prirodnih vrednosti iznosi 1684,7 ha. Na osnovu konačne ocene biodiverziteta, sastojine niske prirodne vrednosti pokrivaju površinu od 1205,6 ha (71,5%), sastojine srednje niže prirodne vrednosti 300,9 ha (17,9%), sastojine srednje više prirodne vrednosti 178,2 ha (10,9%), dok sastojine visoke prirodne vrednosti nisu registrovane.*

**Ključne reči:** prirodne vrednosti, sastojina, gazdinski tip, jugozapadna Srbija

[1]Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
[2]The Faculty of Forestry, Kneza Višeslava 1, 11030 Belgrade, Serbia
[3]PE Srbijašume, Bulevar Mihajla Pupina 113, 11070 Belgrade, Serbia
*Corresponding author. E-mail: milosracic96@yahoo.com

## 1. INTRODUCTION

In many countries, safeguarding biodiversity has been set as one of the leading principles and goals in forest policy (Kuuluvainen, 2009). Managed forests are a key component of strategies aimed at tackling the climate and biodiversity crises (Asbeck *et al.* 2021).

Forest ecosystems are a critical component of the world’s biodiversity as many forests are more biodiverse than other ecosystems. Forest loss is primarily caused by agricultural expansion, while an increase in forest area may occur through natural expansion of forests, e.g. on abandoned agricultural land, or through reforestation (including through assisted natural regeneration) or afforestation. These natural and human-induced changes have different impacts on forest biodiversity (FAO and UNEP, 2020). Under the European Green Deal, the EU’s Biodiversity Strategy for 2030 tackles the protection and restoration of nature by making a number of specific commitments and setting several targets. Biodiversity-friendly practices for enhancing the quantity and quality of EU forests are also being promoted. The Biodiversity Strategy announced, among other objectives, guidelines on biodiversity-friendly afforestation, reforestation and tree planting (European commission, 2023).

This paper presents the assessment of the condition of natural values of forest stands in relation to the origin, structural form, mixedness as well as in relation to affiliation of the forest stand to forest management type in the area of the Forest management unit (FMU) “Jasenovo-Božetići” in accordance with the method developed on the project entitled Contribution of Sustainable Forest Management to Low Emission and Resilient Development (GCP/SRB/002/GEF). The assessment of the natural values of forest stands has not been an integral part of forest management planning in Serbia until present. Considering the actual importance of the biodiversity topic, the development of this method and its implementation into a modern forest management planning system contributes not only to the assessment of the current condition, but also the possibility of further monitoring of the changes of condition of natural values.

## 2. MATERIAL AND METHODS

The object of the research is the Forest management unit (FMU) “Jasenovo-Božetići“, which belongs to Western forest region. Forest Enterprise „Prijepolje“, i.e. Forestry Administation „Nova Varoš“ manages the above FMU. Total stocking area of the FMU is 2077.84 ha, which is 55.1% of the total area. High forests occupy 28.6%, coppice forest 13.1%, cultivated forest stands 3.0%, and brushwood 10.4% of the total area of the forest management unit. Unstocked land occupies 1689.88 ha, which equals to 44.9% of the total area of the forest management unit.[4]

The method of assessment of natural values was developed on the project entitled Contribution of Sustainable Forest Management to Low Emission and Resilient Development (GCP/SRB/002/GEF). It should be noted that the mentioned methodology can potentially be upgraded depending on the outputs that will arise as

[4] https://upravazasume.gov.rs/ogs-za-gj-jasenovo-bozetici/

a result of its application. According to the method itself, forest stands are classified into four categories based on the final assessment of natural values, namely:

- Forest stands of high natural value (≥7);
- Forest stands of higher medium natural value (3-6);
- Forest stands of lower medium natural value (1-2);
- Forest stands of low natural value (≤0)

The final marks are obtained by adding up positive and negative marks of attributes (ANNEX 1) which are grouped into five categories, namely:

1) Structure and composition,
2) Valuable biodiversity trees/ Habitat trees,
3) Key and valuable biotopes,
4) Key species,
5) Impacts and threats.

Data processing was carried out using program *OsnovaIN* within software package *Osnova2020* in order to obtain a representation of the assessment of natural values of forest stands in relation to the origin, structural form, mixedness, and affiliation of the stand to management type.

## 3. RESULTS AND DISCUSSION

The assessment of the natural values of FMU “Jasenovo-Božetići“ was carried out in 197 sections on the total area of 1684.7 *ha*. Areas registered as brushwood on the total of 393.1 *ha* are excluded from the procedure of assessment of natural values.

**Table 1.** *Assessment of natural values at the level of section*

| Final biodiversity assessment | P (ha) | P (%) |
|---|---|---|
| Low natural value | 1205.6 | 71.5 |
| Lower medium natural value | 300.9 | 17.9 |
| Higher medium natural value | 178.2 | 10.6 |
| High natural value | 0.0 | 0.0 |
| Total | 1684.7 | 100.0 |

From the presented Table 1 it can be seen that in the area of the FMU in question stands with low natural value are the most represented, on the area of 1205.6 *ha* which is 71.5% of the analysed sections. Forest stands assessed as stands with lower medium natural value cover an area of 300.9 *ha* i.e. 17.9%, while stands assessed as stands with higher medium natural value cover 178.2 *ha*, i.e. 10.6 %. Forest stands of high natural value are not registered in the territory of this FMU.

**Table 2.** *Assessment of natural values in relation to the origin of forest stands*

| Origin of the forest stand | Final biodiversity assessment | P (ha) | P (%) |
|---|---|---|---|
| High natural forest stands | Low natural value | 602.7 | 56.0 |
| | Lower medium natural value | 295.4 | 27.4 |
| | Higher medium natural value | 178.2 | 16.6 |
| Total high natural forest stands | | 1076.3 | 100.0 |

| Origin of the forest stand | Final biodiversity assessment | P (ha) | P (%) |
|---|---|---|---|
| Coppice forest stands | Low natural value | 492.7 | 100.0 |
| Total coppice forest stands | | 492.7 | 100.0 |
| Cultivated forest stands | Low natural value | 110.2 | 95.2 |
| | Lower medium natural value | 5.5 | 4.8 |
| Total cultivated forest stands | | 115.7 | 100.0 |
| Total | | 1684.7 | 100.0 |

Table 2 shows the assessment of the natural value of stands based on origin. High natural stands cover an area of 1076.3 ha, of which stands with a low natural value are represented on 56%, i.e. 602.7 ha, stands of lower medium natural value on 27.4%, i.e. 295.4 ha, while stands of higher medium natural value are represented on 16.6%, i.e. 178.2 ha. Coppice forest stands are present on 492.7 ha, where all stands are assessed as low natural value. Cultivated forest stands are represented on 115.7 ha, of which 95.2%, i.e. 110.2 ha, fall into the category of stands of low natural value, while 4.8%, i.e. 5.5 ha, fall into the category of lower medium natural value. The establishment of artificial spruce stands in this area affected the floristic composition of the forest, as the number of vascular flora species decreased compared to natural beech forests (Stajić, S. et al., 2022).

**Table 3.** *Assessment of natural values in relation to the structural form of forest stands*

| Structural form | Final biodiversity assessment | P (ha) | P (%) |
|---|---|---|---|
| Even-aged | Low natural value | 1091.5 | 92.1 |
| | Lower medium natural value | 93.4 | 7.9 |
| Total even-aged forest stands | | 1184.9 | 100.0 |
| Uneven-aged | Low natural value | 114.1 | 22.8 |
| | Lower medium natural value | 207.5 | 41.5 |
| | Higher medium natural value | 178.2 | 35.7 |
| Total uneven-aged forest stands | | 499.8 | 100.0 |
| Total | | 1684.7 | 100.0 |

Table 3 shows the assessment of natural values based on the structural form of the forest stand. Even-aged stands are represented on the area of 1184. 9 ha, 92.1% of which, i.e. 1091.4 was assessed as low natural value, while forest stands of lower medium natural value cover the area of 93.4 ha i.e. 7.9 %. Uneven-aged forest stands are present on 499.8 ha, 22.8%, i.e. 114.1 ha of which are stands of low natural value, stands of lower medium natural value are present on 207.5 ha, i.e. 41.5%, while stands assessed as higher medium natural value are represented on 178.2 ha i.e. 35.7%.

In the boreal forests of Europe, in order to preserve biodiversity, as an alternative, continuous-cover forestry practices have been suggested, which are often based on selective cutting and can create mixed-aged and mixed-species stands. The additional challenges for forestry arising from climate change produce not only trade-offs (e.g., between natural wildfire disturbances and timber production), but also opportunities (e.g., a shift from rotation forestry to continuous-cover forestry supports carbon storage, sequestration, and biodiversity conservation). The management of trees, deadwood, and soil will be critical to biodiversity in forest ecosystems (Hylander *et al.* 2022). The highest species richness was found in old forest stands with a species-rich regeneration layer and downed deadwood (positive correlations with quadratic mean diameter at breast height, species richness within the regeneration layer and downed deadwood in most of the analysed strata) (Storch *et al*. 2021).

**Table 4.** *Assessment of natural values in relation to mixedness of forest stands*

| Mixedness | Final biodiversity assessment | P (ha) | P (%) |
|---|---|---|---|
| Pure | Low natural value | 1108.5 | 79.9 |
| | Lower medium natural value | 181.8 | 13.1 |
| | Higher medium natural value | 97.1 | 7.0 |
| Total pure forest stands | | 1387.4 | 100.0 |
| Mixed-species | Low natural value | 97.2 | 32.7 |
| | Lower medium natural value | 119.1 | 40.1 |
| | Higher medium natural value | 81.1 | 27.3 |
| Total mixed-species forest stands | | 297.4 | 100.0 |
| Total | | 1684.7 | 100.0 |

Table 4 shows an overview of the assessment of natural values of stands in relation to mixedness. The area of pure forest stands amounts to 1387.4 ha, out of which the area of 1108.5 ha or 79.9% is covered by forest stands of low natural value, stands of lower medium natural value cover 181.8 ha or 13.1%, while stands of higher medium natural value cover 97.1 ha i.e. 7.0 %. Mixed-species forest stands cover 297.4 ha, out of which stands of low natural value cover 32.7% or 97.2 ha, forest stands of lower medium natural value cover 40.1% i.e. 119.1 ha, and stands of higher medium natural value cover 27.3 % or 81.1 ha.

The biodiversity of Europe's forests over large areas critically depends on the species composition of stands aged below 100 years. Increasing the shares of oak trees, in habitats suitable for them, would significantly increase the biodiversity of managed forests in Central Europe. This could be achieved primarily by increasing the share of oak at the expense of Scots pine, the species that least promotes the formation of microhabitats and bird richness in mature stands below 100 years old. An alternative strategy might be to allow pines to achieve greater ages. Our findings also suggest that increasing the shares of hornbeam and birch may benefit forest biodiversity. In managed forest, trees of lower commercial value, such as hornbeam and birch, should be promoted in management plans, in addition to other measures such as setting aside of old growth stands and retention of dead wood and living trees (Piechnik *et al* 2022).

Table 5 represents the assessment of natural values based on the management type. The highest average score 3 was given to management type High mixed-species forests of beech, fir and common spruce, as well as management type High mixed-species forests of common spruce – High forests of coniferous and deciduous trees, while management type Coppice mixed-species forests of beech obtained the lowest grade -1.9.

By studying the connection between forest management and biodiversity indicators, 14 measures for preservation of biodiversity has been defined (Oettel and Lapin, 2021):

- Provide horizontal and vertical structural heterogeneity;
- Adapt tree species composition;
- Promote deadwood quantity and quality;
- Provide habitat structures;
- Increase tree species diversity;
- Conserve habitat trees and veteran trees;
- Provide spatial heterogeneity at landscape level;
- Reduce understory density;
- Provide unmanaged forest patches;
- Increase rotation period;
- Provide uneven-aged forests under continuous forest cover;
- Avoid forest fragmentation and habitat isolation;
- Adapt habitat management for indicator species;
- Perform active monitoring.

**Table 5.** *Assessment of natural values in relation to the management type of forest*

| Management type of forest | Final biodiversity assessment | Average score | P (ha) | P (%) |
|---|---|---|---|---|
| Mixed-species coppice forest of beech | LNV | -1.9 | 399.5 | 100.0 |
| | Total | | 399.5 | 100.0 |
| Mixed-species coppice forest of beech - High forests of beech and other deciduous and coniferous trees | LNV | -1.7 | 69.2 | 100.0 |
| Mixed-species coppice forests of oaks | LNV | -1.7 | 24.0 | 100.0 |
| Brushwood and bushy vegetation | / | / | 393.1 | 100.0 |
| High mixed-species forests of pines | LNV | -1.8 | 53 | 90.6 |
| | LMNV | 1 | 5.5 | 9.4 |
| | Total | -1.6 | 58.5 | 100.0 |
| High mixed species forests of pines – High forests of deciduous and coniferous trees | LNV | -1.5 | 47.4 | 100.0 |
| High mixed-species forests of beech | LNV | -0.9 | 100.5 | 48.0 |
| | LMNV | 1.3 | 65.7 | 31.4 |
| | LMNV | 4 | 42.9 | 20.5 |
| | Total | 0.2 | 209.1 | 100.0 |
| High mixed-species forests of other soft deciduous trees | LNV | 0 | 13.6 | 100.0 |
| High mixed forests of other conifers | LMNV | 1 | 29.5 | 100.0 |
| High mixed forests of common spruce | LNV | -0.4 | 487 | 61.6 |
| | LMNV | 1.1 | 200.2 | 25.3 |
| | HMNV | 3 | 103.4 | 13.1 |
| | Total | 0.3 | 790.6 | 100.0 |
| | LNV | 0 | 11.5 | 40.2 |
| | HMNV | 3 | 17.1 | 59.8 |

| Management type of forest | Final biodiversity assessment | Average score | P (ha) | P (%) |
|---|---|---|---|---|
| High mixed forests of common spruce – High forests of deciduous and coniferous trees | Total | 1 | 28.6 | 100.0 |
| High forests of beech, fir and common spruce | HMNV | 3 | 14.7 | 100.0 |
| | | | 2077.8 | 100.0 |

*LNV-Low natural value; LMNV-Lower medium natural value; HMNV-Higher medium natural value

## 4. CONCLUSION

Based on the presented results, it is concluded that stands of high natural value are not registered, the largest percentage of the area (71.5%) is occupied by stands of low natural value, then stands of lower medium natural value (17.9%), while the smallest percentage of the area (10, 6%) cover stands of higher medium natural value.

By analysing the obtained results of the assessment of natural values of stands by origin, structural form, mixedness and management type, the following can be concluded:

- Stands of high origin proved to be stands of greater importance for the preservation of natural values compared to stands originating from coppice forest and cultivated stands,
- By comparing uneven-aged and even-aged stands it can be concluded that uneven-aged stands are better from the aspect of preservation of natural values,
- The composition of the stands indicates the presence of three categories of stands (low, lower medium and higher medium natural value) in both pure and mixed-species stands. However, observing the percentage ratio of these categories, it can be clearly seen that the share of stands with a mark of lower medium and higher medium natural value is higher in mixed-species stands compared to stands that are pure in composition. Therefore, it is concluded that mixed-species stands have a more beneficial effect on biodiversity preservation.
- On the basis of the marks given to the stands in relation to affiliation to management type, the statement that the mixed-species stands of uneven-aged structural form and high origin have a favourable effect on the preservation of natural values is confirmed.

Taking in consideration the obtained results, it is recommended to investigate the assessment of natural values at the silvicultural group level in the future.

**Acknowledgement:** *For the preparation of this paper the data was used from the research performed within the project entitled: Contribution of Sustainable Forest Management to Low Emission and Resilient Development (GCP/SRB/002/GEF)*

**ANNEX 1.** *Presentation of attributes and manner of scoring of natural values*

| Biodiversity indicators | | Structural and other attributes | Score | |
|---|---|---|---|---|
| **Structure and composition** | Structural form of forest stand | Uneven-aged stand | +1 | |
| | | Selection stand | +1 | |
| | | Virgin forest | +3 | |
| | Stand layers | Multi-layered forest stands (≥2 layers) | +1 | |
| | Young crop | Patches of natural regeneration (young plants H >3 m with d.b.h. ≤5 cm) | +1 | |
| | Dead wood | Standing dead wood (d.b.h. > 30 cm) | +1 | |
| | | Laying dead wood (diameter >30 cm) | +1 | |
| | | Part of laying dead wood (diameter > 50cm, length > 2 m) | +1 | |
| | | Breakage (diameter >30 cm, height > 1m) | +1 | |
| | | Absence of any dead wood | | -1 |
| | Naturalness | First regime of protection | +3 | |
| | | High natural forest | +1 | |
| | | Number of tree species (<2, monocultures) | | -1 |
| | | Artificial stands (non-natural) | | -1 |
| **Valuable biodiversity trees /Habitat trees** | Living special trees | Trees of exceptional dimensions | +1 | |
| | | Large solitary sun-exposed trees with wide crown | +1 | |
| | Tree microhabitats | Standing dying back old trees | +1 | |
| | | Old trees with damaged/broken top | +1 | |
| | | Old trees with damaged or coarse bark | +1 | |
| | | Nesting trees | +1 | |
| | | Hollow trees, trees with cracks or cavities (cavity D>30 cm) | +1 | |
| | Trees with fungi, mosses, lichen, lianas and parasites/semi parasites on the trunk | Significant moss cover on tree stem (>40%) | +1 | |
| | | Significant lichen cover on tree stem (>30%) | +1 | |
| | | Presence of fungi species on tree stem | +1 | |
| **Key and valuable biotopes** | Valuable biotopes within forest stand | Areas with high concentration of old growth and dead wood (>0.2 ha) | +1 | |
| | | Wetlands - marsh, fen; small pools, ponds, wet zones (>0.2 ha) | +1 | |
| | | Natural springs | +1 | |
| | | Seasonal or permanent streams | +1 | |
| | | Steep slopes (inclination >30 degrees) | +1 | |
| | | Cliffs or ravines (>0.2ha) | +1 | |
| | | Caves | +1 | |
| | | Large rocks with significant mosses/lichens coverage (>2m3) | +1 | |
| **Key species** | Protected wild species | Strictly protected and protected wild species | +1 | |
| **Impacts and threats** | Invasive species | Presence of any invasive species | | -1 |
| | Non-native tree species | Presence of any non-native or introduced tree species | | -1 |
| | Threats from negative impacts | Significant presence of anthropogenic negative impacts | | -1 |
| | SCORE OF NATURAL VALUES ASSESSMENT (SUM OF POSITIVE AND NEGATIVE POINTS) | | | |

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COMMISSION STAFF WORKING DOCUMENT GUIDELINES ON BIODIVERSITY-FRIENDLY AFFORESTATION, REFORESTATION AND TREE PLANTINGhttps://ec.europa.eu/transparency/documentsregister/detail?ref=SWD(2023)61&lang=en

Forest Management Plan for FMU "Jasenovo-Božetići" https://upravazasume.gov.rs/ogs-za-gj-jasenovo-bozetici/

# ASSESSMENT OF THE CONDITION OF NATURAL VALUES OF THE FOREST MANAGEMENT UNIT “JASENOVO-BOŽETIĆI” IN THE AREA OF SOUTHWEST SERBIA

*Miloš RAČIĆ, Branko KANJEVAC, Nikola MARTAĆ, Dejan MILETIĆ, Nenad PETROVIĆ*

**Summary**

This paper presents the assessment of the condition of natural values of forest stands as indicators for biodiversity assessment in relation to the origin, structural form, mixedness as well as in relation to affiliation of the forest stand to forest management type. The object of the research is the Forest management unit “Jasenovo-Božetići” which belongs to the Western forest region in Serbia. The main goal of this work is to show how the strcuctural characteristics of the stands affect the preservation of natural values.

Assessment of the condition has been performed in accordance with the method developed on the project entitled Contribution of Sustainable Forest Management to Low Emission and Resilient Development (GCP/SRB/002/GEF). The total area on which the assessment of natural values was carried out amounts to 1684.7 ha. Based on the final assessment of biodiversity, the stands of low natural value cover the area of 1205.6 ha (71.5%), the stands of lower medium natural value cover 300.9 ha (17.9%), the stands of higher medium natural value 178.2 ha (10.9%), while stands of high natural value are not registered. Areas registered as brushwood on the total of 393.1 *ha* are excluded from the procedure of assessment of natural values. On the basis of the marks given to the stands in relation to affiliation to management type, the statement that the mixed-species stands of uneven-aged structural form and high origin have a favourable effect on the preservation of natural values is confirmed.

# OCENA STANJA PRIRODNIH VREDNOSTI GAZDINSKE JEDINICE „JASENOVO-BOŽETIĆI“ NA PODRUČJU JUGOZAPADNE SRBIJE

*Miloš RAČIĆ, Branko KANJEVAC, Nikola MARTAĆ, Dejan MILETIĆ, Nenad PETROVIĆ*

**Rezime**

U ovom radu prikazana je ocena stanja prirodnih vrednosti sastojina kao indikatora za ocenu biodiverziteta u odnosu na poreklo, strukturni oblik, mešovitost kao i u odnosu na pripadnost sastojine gazdinskom tipu. Objekat istraživanja je gazdinska jedinica „Jasenovo-Božetići“ koja pripada Zapadnoj šumskoj oblasti u Srbiji. Glavni cilj ovog rada je prikaz kako utiču navedene strukturne karakteristike sastojina na očuvanje prirodnih vrednosti. Ocena stanja je vršena u skladu sa metodom koji je razvijen na projektu pod nazivom Doprinos održivog gazdovanja šumama niskim emisijama i prilagodljivom razvoju (GCP/SRB/002/GEF). Ukupna površina na kojoj je vršena ocena prirodnih vrednosti iznosi 1684,7 ha. Na osnovu konačne ocene biodiverziteta, sastojine niske prirodne vrednosti pokrivaju površinu od 1205,6 ha (71,5%), sastojine srednje niže prirodne vrednosti 300,9 ha (17,9%), sastojine srednje više prirodne vrednosti 178,2 ha (10,9%), dok sastojine visoke prirodne vrednosti nisu registrovane. Površine koje su registrovane kao šikare i šibljaci na ukupno 393,1 ha izuzete su iz postupka ocene prirodnih vrednosti. Na osnovu ocena koje su ponele sastojine u odnosu na pripadnost gazdinskom tipu, potvrđuju se navodi da sastojine visokog porekla, mešovitog sastava i raznodbnog strukturnog oblika povoljno utiču na očuvanje prirodnih vrednosti.

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# FOREST FIRE RISK MAPPING IN THE MUNICIPALITY OF BOLJEVAC

*Tatjana DIMITRIJEVIĆ[1]*, Mihailo RATKNIĆ[2], Goran ĐORĐEVIĆ[3], Sabahudin HADROVIĆ[1]*

**Abstract:** *The research was conducted in the Municipality of Boljevac, which geographically belongs to Eastern Serbia – Timočka Krajina, and administratively to the Zaječar District. Forest protection from fires in this area is of great importance as it can pose a threat. Spatial data within the Geodatabase are organised into the following thematic units: orographic characteristics (altitude, aspect, slope, soil erosion index, heat degrees by altitude, and thermal coordinates of aspect and slope), climate data (mean annual air temperatures, mean annual precipitation), geological and soil characteristics, vegetation (forest types, forest stands by degree of degradation, forest stands by age), fuel material (dead wood and stumps, forest edge on the boundary of forests/non-forests), isokeraunic map, human impact (human factor – human risk, history of fires and its impact on forest fire vulnerability, accessibility of the forest complex and hydrographic data, degree of organisation of areas designated for tourist and recreational activities, other biotechnical measures of protection). Based on 973,152 Geodatabase records grouped into 30,411 homogeneous units, zones were identified based on the degree of vulnerability to forest fires. An analysis of all parameters that affect the degree of vulnerability to varying extents revealed that 33.01% of the total forest area belongs to the first degree of vulnerability - very high vulnerability, 37.10% to the second degree - high vulnerability, while the third degree - moderate vulnerability is represented on 22.02% of the area, and the fourth degree - low vulnerability on 7.87% of the area. The fifth degree - no vulnerability to forest fires was not observed in the Municipality of Boljevac.*

**Keywords:** risk map, forest fire, geodatabase, Municipality of Boljevac

# IZRADA KARTE RIZIKA OD ŠUMSKIH POŽARA NA PODRUČJU OPŠTINE BOLJEVAC

**Sažetak:** *Istraživanje je obavljeno na području Opštine Boljevac koje geografski pripada Istočnoj Srbiji – Timočkoj krajini, a administrativno Zaječarskom okrugu. Zaštita šuma od požara na ovom području ima veliki značaj. Prostorni podaci unutar Geodatabaze su organizovani po sledećim tematskim celinama: orografske karakteristike (nadmorske visine, ekspozicije, nagib, indeks spiranja zemljišta, stepeni toplote prema nadmorskoj visini*

[1]Institute of Forestry, Kneza Viseslava 3, 11030 Belgrade, Serbia
[2]Full member of “Sigma Xi”; Earth Climate Change Team (ECCTeam), New Jersey, USA
[3]Academy of Vocational Technical Studies, Belgrade, Serbia
*Corresponding author. E-mail: tatjanaratknic@yahoo.com

*i toplotne koordinate ekspozicije i nagiba), klimatski podaci (srednja godišnja temperature vazduha, srednja godišnja količina padavina), geološke i pedološke karakteristike, vegetacija (tipovi šuma, sastojine po stepenu degradiranosti, sastojina po starosti), gorivi materijal (mrtvo drvo i panjevi, ivica šume na granici šuma/ne šuma), isokeraunička karta, antropogeni uticaji (antropogeni factor-rizik od čoveka, istorija požara i njen uticaj na ugroženost šuma od požara, otvorenost šumskog kompleksa i hidrografski podaci, stepen uređenosti prostora za turističe i izletničke aktivnosti, ostale biotehničke mere zaštite). Na osnovu 973.152 podatka Geodatabaze grupisanih u 30.411 homogenih celina izdvojene su zone po stepenu ugroženosti od šumskog požara. Analizom svih parametara koji u razuličitom stepenu utiču na stepen ugroženosti konstatovano je da 33.01% ukupne površine pod šumom pripada prvom stepenu ugoženosti – veoma velika ugroženost, 37.10% drugom spenu – velika ugroženost, trećem stepnu – srednja ugroženost zastupljena je na 22.02% površine i četvrtom stepenu – mala ugroženost na 7.87%. Peti stepen – nema ugroženosti šuma od požara nije konstatovana na području Opštine Boljevac.*

**Ključne reči:** karta rizika, šumski požar, geodatabaza, opština Boljevac

## 1. INTRODUCTION

Global warming is accompanied by increasingly intense and prolonged forest fires in the northern parts of the world, resulting in additional carbon dioxide ($CO_2$) emissions and accelerating climate change. A decade-long monitoring revealed that much more carbon dioxide was emitted into the atmosphere during forest fires than forests could absorb during the process of photosynthesis in the Northern Hemisphere. This trend is expected to worsen in the coming years. Climate change alters the fire regime and leads to various environmental effects (Bowman et al., 2009). Forest fires cause significant economic losses (Lohman et al., 2007). At the Conference on Climate Change and Security (IES, 2012), Serbia was marked as an area with potentially dramatic changes in ecosystems, an increase in forest fires, and negative impacts on agriculture.

Forests, besides their ecological significance in preserving vital life cycles, have various other functions related to trade, tourism, economy, health and recreation, etc. Once, forests covered a much larger area of the planet than they do today. Forest fires are a crucial element in the Earth's system, linking climatic characteristics, human activity, and vegetation type (Ichoku et al., 2003). With 200 – 500 million hectares of burned areas per year, fires cause damage over larger areas and destroy biomass worldwide more than any other factors negatively affecting natural ecosystems (Lavorel et al., 2007; Ichoku et al., 2008).

Forest fire danger prediction is one of the fundamental tasks in forest fire prevention. It can minimise fire damage, while a well-developed system of detection, preparation for the fire season, good mobility and readiness can prevent the occurrence of forest fires. Assessments of the forest fire danger are based on scenarios of when and where a fire occurs and how it develops. Elements for determining the time of fire occurrence are defined by the fire season, i.e., the dynamics of forest fire occurrence defined by long-term monitoring. Risk mapping is of utmost importance for forest fire risk management (Ratknić, 2021).

## 2. MATERIAL AND METHODS

The research was conducted in the Municipality of Boljevac, located in eastern Serbia in the valley of the Black Timok River. The municipality covers an area of 827 $km^2$. Its territory geographically belongs to Eastern Serbia – Timočka Krajina, and administratively to the Zaječar District. The diverse composition of the soil has contributed to the richness of plant and animal species. Agricultural land accounts for 46%, while forests cover 51% of the total area. Broadleaved forests dominate in the forest complex. The most significant natural resources include an extensive forest area, water potential, climatic and soil conditions suitable for agricultural production (livestock farming, medicinal herbs, fruit growing, and vegetable cultivation), mineral resources (dolomite, clay – Bentonite, decorative stone), and conditions for the development of tourism and eco-tourism. For this reason, protecting forests from fires in this area is of utmost importance, as it can endanger the advancement of the municipality's tourism and other potentials.

The methodology presented in the dissertation entitled "Integrated Model for Protection and Management of Forest Fires in the Republic of Serbia (Ratknić T., 2018)" was utilised to create a forest fire risk map for the Municipality of Boljevac. Topographic maps at a scale of 1:25000 were used as a data source for the elevation representation of the terrain. To create the digital terrain model (DTM), contour lines were vectorised using a semi-automatic vectorisation method, and elevation points and structural lines were vectorised manually on the screen. The digital model was created in TIN format and then converted to GRID format, i.e., into a pixel matrix where each grid cell attributes the elevation in the state elevation system. The grid resolution was 15 m. A personal spatial database in mdb format was created for the Boljevac area. Spatial data within the Geodatabase are organised by thematic units and represented in cartographic form.

## 3. RESULTS

In the Boljevac area, 30,411 homogeneous units were identified using the method of visual interpretation of aerial images (and some high-resolution satellite images) (Map 1).

### 3.1. Orografic Characteristics

Orografic characteristics are decisive factors and modifiers of environmental conditions significant in the prevention and extinguishing of fires, cultivation of burned vegetation, and burned area rehabilitation. The minimum elevation in the Digital Terrain Model (DTM) is 185 m, and the maximum is 1550 m. It covers an area of 828 $km^2$ (Map 2). Orographic characteristics with the predominant influence are elevation, slope, and aspect. Sites with different elevations, aspects and slopes vary in the duration and intensity of sunlight, and consequently in the conditions for fuel material drying.

Elevation in lowland areas does not modify environmental conditions to a great extent, but in medium high and high areas, it is a decisive factor determining changes in macro and microclimates, soil composition, and vegetation composition.

For example, with a 100-meter elevation increase, air temperature decreases by 0.55°C (0.60°C in summer, 0.40°C in winter), and the growing season shortens by 11.5 days.

The difference in exposure to solar heat can be 1.5-2.5 times greater on southern than northern slopes. Fire incidences are more common on sun-exposed slopes, where they spread faster and with greater destructive power. Sun exposure is higher on slopes (mountains) compared to flat areas, as well as on steep sides than on levelled ones. Surface areas of homogeneous units based on elevation classes, exposure, slope, and points are presented in Table 1, as well as Maps 3, 4, and 5.

The slope of the terrain affects the soil moisture, the speed of water runoff, and the depth and duration of the snow cover. The degree of slope affects stability, erosion, deposition of weathering products, mineral formation, the thickness of the dead organic cover, as well as the depth and type of soil. Certain slopes are crucial for assessing hazards and contribute to significant variations in vulnerability, the rate of spread, intensity, and speed of forest fire movement.

**Table 1**. *Surface Areas of Homogeneous Units Based on Elevation Classes, Aspect, Slope, and Points*

| Elevation | | | | Aspect | | | | Slope | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Elevation class (m a.s.l.) | Points | Area (ha) | % | Aspect class | Points | Area (ha) | (%) | Slope (%) | Points | Area (ha) | (%) |
| <500 | 15 | 41511 | 50.2 | southern and plain | 20 | 26768 | 32.3 | ≤15 | 5 | 59439 | 71.8 |
| 500-800 | 10 | 29794 | 36.0 | eastern and western | 10 | 27029 | 32.7 | 15-30 | 10 | 22705 | 27.4 |
| >800 | 5 | 11454 | 13.8 | northern | 5 | 28962 | 35.0 | 31-45 | 15 | 615 | 0.7 |

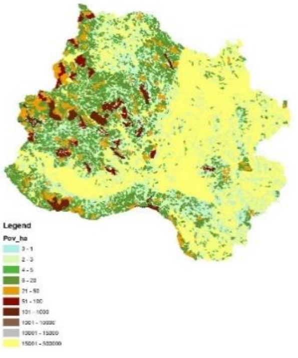
The slope of the terrain affects soil erosion. If soil erosion on a slope of 10% is designated with an index of 100, the erosion on other slopes is provided in Table 2 (Đorđević, G., 2012). Terrain erosion affects the type and quantity of combustible material on a specific surface area, as well as the potential for movement and communication in areas at risk or affected by fire (Map 6).

**Table 2**. *Soil Erosion Index Relative to Slope*

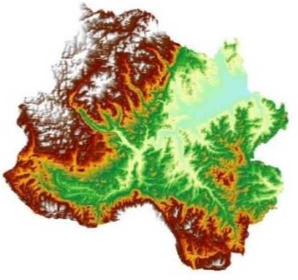
| Slope % | 1 | 2 | 5 | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|---|
| Erosion index | 10 | 12 | 33 | 100 | 186 | 256 | 312 | 354 |
| Area | 1448 | 1468 | 5257 | 12378 | 13674 | 12178 | 10023 | 26332 |
| % | 1.8 | 1.8 | 6.4 | 15.0 | 16.5 | 14.7 | 12.1 | 31.8 |

**Heat degrees relative to elevation (Coordinate V).** Coordinate V is dependent on the terrain's elevation. The highest value (18) is assigned to the heat coordinates of terrain with elevations up to 99 meters, while terrains exceeding 1800 meters in elevation have a value of 0 (Map 7).

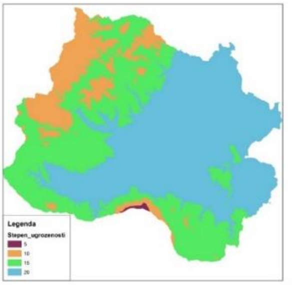
**Heat coordinates of aspect and slope (Coordinate E).** Coordinate E is derived from combinations of aspect and slope, grouped into nine heat degrees. The first group comprises combinations with the lowest annual solar radiation sum and is labelled 1. Groups with the highest annual solar radiation sum have heat coordinate value 9 (Lujić R., 1960) (Map 8). Together with the map of heat degrees (Coordinate E), they provide thermal conditions for each isolated homogeneous unit (Map 9).



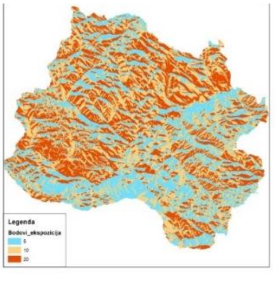

**Map** 1. *Homogeneous Units Grouped by Area*



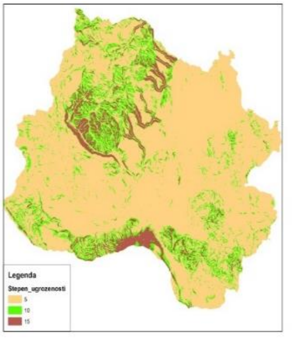
**Map 2**. *Digital Terrain Model*



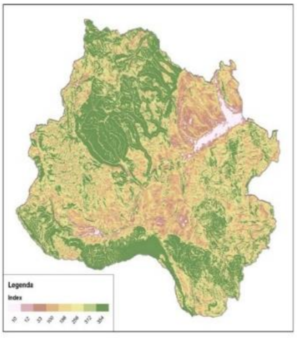

**Map 3.** *Elevation Classes by Points*




**Map 4.** *Aspect Classes by Points*




**Map 5.** *Slope Classes with Points*



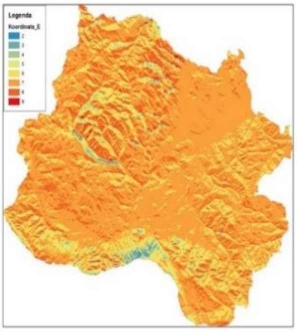

**Map 6**. *Erosion Index*

### 3.2 Climate Characteristics

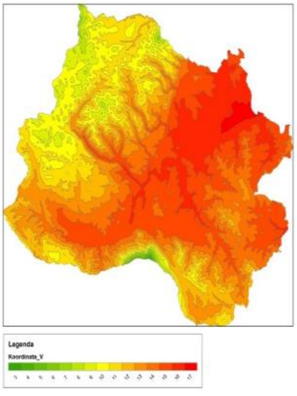
The climate interacts with all factors influencing forest fire vulnerability. Besides various climate parameters affecting the drying of combustible materials (air temperature, relative humidity, precipitation, wind, cloud cover, drought periods, etc.), three key parameters are used in assessing forest fire vulnerability: mean annual air temperature, mean annual precipitation, and mean annual relative humidity. When utilising these parameters, it is essential to incorporate the duration of drought periods and their distribution throughout the year in the assessment of the climate's impact on forest fire vulnerability (Table 3.).

**Table 3.** *Parameters of the Impact of Climate Elements on Forest Fires*

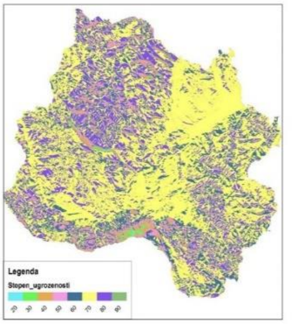
| Mean Annual Air Temperature | | | | Mean Annual Precipitation | | | |
|---|---|---|---|---|---|---|---|
| Category | Points | A(ha) | % | Category | Points | A(ha) | % |
| Over 12ºC | 30 | | | Up to 800 mm | 30 | 81958 | 99.0 |
| 9.1-12.0 ºC | 20 | 28720 | 34.7 | 801-1200 mm | 20 | 800 | 1.0 |
| Up to 9.0 ºC | 10 | 54038 | 65.3 | Over 1200 mm | 10 | | |



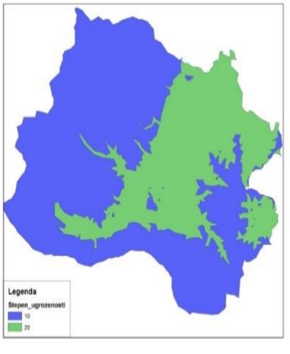
**Map 7**. *Coordinate V*



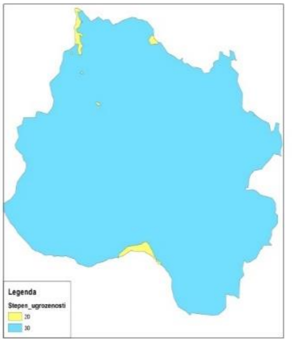
**Map 8.** *Coordinate E*



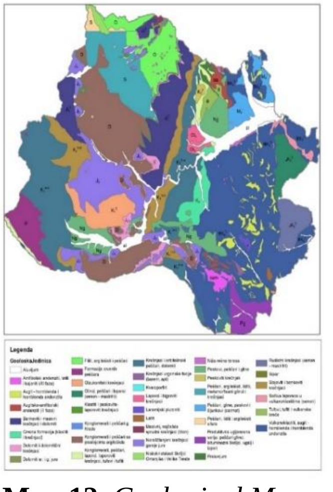
**Map 9.** *Corordinate E vulnerability*



**Map 10**. *Mean Annual Temperatures by Points*



**Map 11.** *Annual Precipitation by Points*



**Map 12**. *Geological Map*

### 3.3 Geological and Pedological Characteristics

Soil geological composition has a significant impact on both the occurrence of forest fires and firefighting conditions. Soils are formed from rocks that can be igneous, metamorphic or sedimentary. Depending on the region, tectonic damage to rocks and their mineral composition creates over time a pedosphere with surface soils of different compositions and thicknesses. The vegetation cover, i.e., plant communities that form on the surface, is developed depending on the type and characteristics of the soil, climate conditions, etc. Geological soil composition, alongside other elements, indirectly influences the formation of various types of vegetation, their characteristics, and their susceptibility to ignition and burning.

The flammability of vegetation on the soil surface depends on the dryness and aridity of the terrain, which is particularly high in the hottest months. Rainwater quickly filters into the underground layers when it encounters permeable rocks, leaving the surface dry and devoid of water. This increases the flammability of combustible materials and greatly favours the occurrence of fires. In such areas, firefighting is challenging because there are usually no water sources available for extinguishing. A better situation is observed in semi-permeable and impermeable petrographic areas, where the environments are moister, with surface waters and lush vegetation, reducing the risk of fire occurrence. However, even these areas are at risk of fire, especially in the summer months. These terrains hinder and slow the movement of vehicles, which can further complicate firefighting actions (Table 4.).

**Table 4**. *Soil Types and Their Impact on the Degree of Forest Fire Vulnerability*

<table>
<tr><th>Soil Type</th><th>Subtype</th><th>Points</th><th>Area (ha)</th><th>%</th></tr>
<tr><td>Leptosol</td><td>All Subtypes</td><td>80</td><td>3286</td><td>4.0</td></tr>
<tr><td>Colluvial Soils (Colluvium)</td><td>All Subtypes</td><td>80</td><td>1548</td><td>1.9</td></tr>
<tr><td>Limestone – Dolomite Black Soil (Kalkomelanosol)</td><td>All Subtypes</td><td>60</td><td>37465</td><td>45.3</td></tr>
<tr><td>Rendzina</td><td></td><td>80</td><td>886</td><td>1.1</td></tr>
<tr><td rowspan="2">Humus Silicate (Ranker)</td><td>Eutric</td><td>80</td><td rowspan="2">472</td><td rowspan="2">0.6</td></tr>
<tr><td>Distric</td><td>60</td></tr>
<tr><td>Vertisol (Smonica)</td><td>All Subtypes</td><td>60</td><td>14127</td><td>17.1</td></tr>
<tr><td>Brown Eutric Soil (Eutric Cambisol)</td><td>All Subtypes</td><td>40</td><td>968</td><td>1.2</td></tr>
<tr><td rowspan="2">Distric Brown or Acid Brown (Distric Cambisol)</td><td>Deep</td><td>40</td><td rowspan="2">18470</td><td rowspan="2">22.3</td></tr>
<tr><td>Very Deep</td><td>20</td></tr>
<tr><td rowspan="2">Brown Soil on Limestone and Dolomite (Kalkokambisol)</td><td>Shallow & Medium Deep</td><td>60</td><td rowspan="2">1498</td><td rowspan="2">1.8</td></tr>
<tr><td>Deep</td><td>40</td></tr>
<tr><td>Ilimerized or leached (Fluvisol</td><td>All Subtypes</td><td>40</td><td>3233</td><td>3.9</td></tr>
<tr><td>Pseudogley</td><td></td><td>40</td><td>419</td><td>0.5</td></tr>
<tr><td>Semigley</td><td></td><td>20</td><td>386</td><td>0.5</td></tr>
</table>

## 3.4 Vegetation

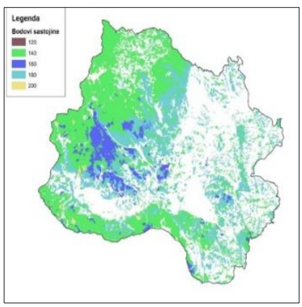
### 3.4.1 Vegetation by Forest Types

The vegetation, represented by the dominant tree species and the combustible material in the forest that gives rise to various types of combustible materials, forms the basis affected directly or indirectly by all other factors and resulting in varying degrees of susceptibility to fire. The main vegetation parameters determining the degree of forest fire vulnerability are presented in Table 5.

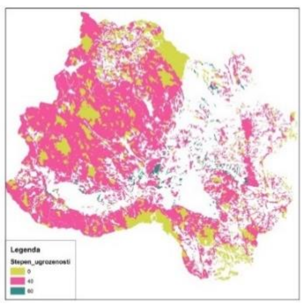
**Table 5.** *Vegetation Parameters Determining the Degree of Forest Fire Vulnerability*

| FOREST TYPE | Points | Area (ha) | % |
|---|---|---|---|
| **Category I** – Xerothermic and Mesothermic Coniferous forests (natural and artificial) with higher resin content: natural and artificially-established Austrian pine forests; natural and artificially-established Scots pine forests | 200 | 262 | 0.6 |
| **Category II** - IIa - Xerothermic Broadleaved Forests: Downy oak forests, Manna ash forests, Oriental hornbeam forests, Turkey oak forests | 180 | 16337 | 35.3 |
| **Category III** – Mesophilic and Frigoriphilic Forests (natural and artificial) with lower resin content: Silver fir forests, Norway spruce forests, Serbian spruce forests, Macedonian pine forests, Artificially established larch stands, Artificially established Douglas fir stands, Artificially established Scots pine stands, Artificially established Abies grandis stands, Artificially established stands of other species with similar characteristics | 160 | 122 | 0.3 |
| **Category IV** | | | |
| IVa - Broadleaved and Coniferous Mesophilic and Frigoriphilic Mixed Forests (natural and artificial): Fir forests, Norway spruce forests, Beech forests | 140 | 26346 | 57.0 |
| IVb - Mixed Forests of Mesophilic and Mesothermic Broadleaved Species: Common hornbeam and sessile oak forests | | | |
| **Category V** – Forests Dominated by Mesophilic Deciduous Tree Species: Beech forests, Common hornbeam forests, Birch forests, Willow forests | 120 | 3188 | 6.9 |


**Map 13.** *Soil Map by Points*




**Map 14.** Vegetation Units by Points




**Map 15.** *Map of Human Impact*

Forests can be classified in various ways (based on tree species, cultivation methods, age, purpose, etc.), but they are most commonly divided into coniferous forests, broadleaved forests, and mixed forests. Additionally, special forms such as scrubwood, thickets, maquis, garigue, and degraded forests are considered due to their specific susceptibility to fire. Artificially established stands (cultures) are categorised separately within the further classification of vegetation, irrespective of age, as age affects the vulnerability of forests to fire (increased age decreases the susceptibility to fire in natural forests). However, in cultures, this difference is negligible. Further classification of natural coniferous, mixed, and broadleaved forests is done based on light requirements and age, although there are other properties of specific forest types that contribute to their susceptibility to fire, such as resin, tannin, essential oil contents, forest density, and ground vegetation.

### 3.4.2 Stand Condition by Degree of Degradation

Degraded stands include forests with pronounced degradation of stands and habitats. This forest fire risk group includes scrubwooda and thickets, and partially xerothermic and mesothermic broadleaved forests on warmer slopes.

**Table 6**. *Stand Condition by Degree of Degradation*

| Stand Condition by Degree of Degradation | Points | Area (ha) | % |
|---|---|---|---|
| Degraded stands | 100 | 30625.58 | 66.2 |
| Scrubwood and thickets | 160 | 4042.07 | 8.7 |

### 3.4.3 Stand age

Regarding stand age, the age (in years) of the species identified in the homogeneous unit is entered. The age of trees is closely related to the fundamental parameters of stand structure, cultivation needs, and forest production characteristics. The age refers to the entire homogeneous unit, representing the average age for the entire set of trees of the homogeneous unit (Table 7).

**Table 7.** *Stand Age, Points, and Surface Area Representation*

| Stand Age | Points | Area (ha) | % |
|---|---|---|---|
| Up to 30 years | 80 | 1315 | 2.8 |
| 31 to 60 years | 60 | 5859 | 12.7 |
| Over 60 years | 40 | 35039 | 75.8 |
| Uncategorized | | 4042 | 8.7 |

## 3.5 Fuel Material

### 3.5.1 Dead Wood and Stumps

The quantity, condition, and structure of dead wood and stumps remaining in the forest are important ecological information indicating the degree of stand naturalness. It is also an essential basis for calculating carbon stocks in the forest ecosystem. The term "dead wood" includes physiologically dead trees or tree parts. Three categories of dead wood are distinguished: "lying" wood, dry branches and stumps, and thicker and thinner pieces of wood for which specific measurement procedures are defined. There are four degrees of decomposition of trees, stumps, and branches (wood is solid and hard; wood shows signs of decay; wood is in an advanced stage of decay, and wood is decomposed). Assessment is carried out for all categories of dead wood. The presence of dead wood (regardless of the stage of decomposition), with the points defining the risk of fire occurrence and spread, is divided into four groups (Table 8).

**Table 8**. *Presence of Dead Wood and Points*

| Dead Wood Presence | Represented in m³/ha | Points | Area (ha) | % |
|---|---|---|---|---|
| Significant Presence | >10.0 | 20 | 2637 | 5.6 |
| Present | 7.22 | 10 | 31130 | 67.3 |
| Minor Presence | <3.0 | 5 | 7956 | 17.2 |
| Not Present | 0 | 0 | 4532 | 9.8 |

### 3.5.2 Forest Edges at the Forest/Non-forest Boundary

The forest located on the border between the forest and non-forest land categories generally has a different internal structure. On the other hand, it represents a factor that contributes to the spread of fires to forest areas and the transition from surface to crown fires. The layered edge of the forest with a developed canopy cover (heterogeneous, sufficiently dense and irregular) is considered ecologically favourable. The presence of shrubs, along with the length, type, form, density, and composition of the forest edge, is determined for each homogeneous unit.

The presence of shrubs on the forest edge and their width are evaluated (the occasional presence of shrubs with coverage below 5% is not taken into account) (Table 9).

**Table 9.** *Presence Of Shrubs on the Forest Edge*

| Presence of shrubs on the forest edge | Points | Area (ha) | % |
|---|---|---|---|
| No shrub belt | 0 | 485 | 0,2 |
| Shrub belt under 10 m | 5 | 1178 | 0,5 |
| Shrub belt over 10 m | 10 | 647 | 0,3 |

Based on the way the "forest" category changes into the "non-forest" category, the forest edge can be classified into five types (Table 10).

**Table 10**. *Type of Forest Edge*

| Forest edge type | Area (ha) | % |
|---|---|---|
| open area, plantation, young growth, or dwarf conifers at the upper forest boundary, etc.; | | |
| trees with normally developed crowns (unbranched trees) without a shrub layer or only sporadically with shrubs; | 134 | 5.8 |
| forest edge composed of branched trees without a shrub layer or with sporadically present shrubs (partial canopy of tree crowns); | 97 | 4.2 |
| forest edge consisting of trees and shrubs (steep stand canopy) | 608 | 26.3 |
| layered forest edge, with a belt of lower trees and shrubs in front of taller trees (layered stand canopy) | 1471 | 36.3 |

**Shape of the forest edge**. The forest edge can have different shapes (straight, irregular, and highly irregular) (Table 11).

**Table 11.** *Shape of the Forest Edge*

| Forest Edge Shape | Area (ha) | % |
|---|---|---|
| Straight forest edge | | |
| Irregular-shaped forest edge (undulating, rounded) | 1529 | 66.2 |
| Highly irregular-shaped forest edge | 781 | 33.8 |

The density of the forest edge is determined to a depth of 10 m from the forest edge, viewed from the non-forest land into the interior of the stand. The percentage of the forest covered with shrubs and lower branches of trees up to a height of 2 m was assessed (Table 12).

**Forest Edge Depth**. The total depth of the forest edge, indicating a different structure from the interior of the stand, is assessed. If the estimated average depth of the forest edge is wider than 10 m, it is assigned 10 points (Ratknić, T., 2018). The presence of shrubs on the forest edge is also assessed (occasional presence of shrubs with coverage below 5% is not included), and a belt of 10 m in width is assigned 10 points (Ratknić, T., 2018).

**Table 12.** *Forest Edge Density*

| Forest edge density | Points | Area (ha) | % |
|---|---|---|---|
| Open forest edge, 0-25% coverage | 10 | 120 | 5,2 |
| Sparse forest edge, 26-50% coverage | 20 | 363 | 15,7 |
| Moderately dense forest edge, 51-75% coverage | 30 | 973 | 42,1 |
| Dense forest edge, 76-100% coverage | 40 | 855 | 37.0 |

**Table 13.** *Forest Edge Depth*

| Forest Edge Depth | Points | Area (ha) | % |
|---|---|---|---|
| Forest edge is narrower than 10 m | 10 | 784 | 34 |
| Forest edge is wider than 10 m | 20 | 1526 | 66 |

**Effect of the Forest Edge and Adjacent Land on the Stand.** Any potential impact on the forest land, along with activities carried out on it is assessed, including the impact of the forest edge itself, which can have a positive or negative influence on the condition, stability, and production of the stand. Positive effects include, for instance, wind protection, wildlife shelter, prevention of domestic animal entry into the forest, biodiversity protection, and similar benefits. The impact is considered negative when there are no such positive characteristics and when activities on the nearest non-forest environment cause damage to the forest land and stands (such as root damage from plowing, car or agricultural machinery parking, mushroom picking, waste dumping, livestock grazing, etc.). The assessment is complex, and the impact is classified into three categories (Table 14).

**Table 14.** *Effect of Forest Edge and Adjacent Land on Stand*

| Effect of forest edge and adjacent land on stand | Area (ha) | % |
|---|---|---|
| Positive effect | | |
| Negative effect | 2310 | 100% |
| Very strong negative effect | | |

### 3.6 Isokeraunic Map

Although natural phenomena contributing to forest fires account for approximately 1% of all forest fire causes, this phenomenon should not be overlooked. There are areas that are affected by certain natural phenomena, and during specific periods, they can frequently be agents of forest fires. The most common natural phenomenon causing forest fires is atmospheric discharge or lightning strikes, as well as the effect of solar heat that can encounter a specific focus and lead to the ignition, usually of dry grass as fuel. Increasing attention is also given to the theory that many forest fires are caused by 'solar winds,' but this theory has not been scientifically proven and will not be considered in this methodology. Atmospheric discharge is a a natural phenomenon that causes forest fires. Table 15 presents the number of lightning strikes and the degree of danger expressed in points."

**Table 15.** *Number of Lightning Strikes and Degree of Danger Expressed in Points*

| Number of Lightning Strikes | Danger Level | Points | Area (ha) | % |
|---|---|---|---|---|
| Up to 32 | Low | 0 | | |
| 33 to 36 | Moderate | 10 | 46255 | 100 |
| Above 36 | Significant | 20 | | |

### 3.7 Anthropogenic Influences

### 3.7.1 Anthropogenic Factor – Human-Related Fire Risk

Nearly 98% of forest fires are directly or indirectly related to human activities. The presence of humans in the forest, including shepherds, tourists, fruit gatherers, and hunters, increases the risk of forest fires. The vulnerability increases if their activities involve the use of fire, such as burning stubble, plant residues, and using fire for any purpose in the forest. Therefore, the risk posed by humans is a significant indicator of forest fire vulnerability. Table 16 provides some indicators of the impact of human activities on the vulnerability of forests.

If reagarding the human-related forest fire risk, a forest can be classified into multiple risk categories, the impact of these factors on the vulnerability of forests to fires is expressed as the total number of points.

**Table 16.** *Parameters of Human Impact on Forest Fire Incidence*

| Category | Points | Area (ha) | % |
|---|---|---|---|
| Category 1: Tourist and recreational forests, forests adjacent to agricultural land and waste disposal sites | 60 | 7916 | 17.11% |
| Category 2: Forests traversed by public roads, power lines, or used for grazing | 40 | 5272 | 11.40% |
| Category 3: Forests used for forest product gathering, hunting, fishing, and silviculture | 20 | | |
| Uncategorized | 0 | 33068 | 71.49% |

### 3.7.2 Fire History and its Impact on Forest Fire Vulnerability

The history of fires, specifically the number of fires within a certain time interval in a particular area, affects the the degree of forest vulnerability to fires. The number of fires in the observed area indicates which part of the area is more susceptible to fire and the overall vulnerability of the forest to fires. Additionally, the combustible material is not the same in areas with frequent fire occurrences, as the weather conditions that affect the combustible material are prone to change in these locations. Table 17 presents some characteristics determining the degree of forest fire vulnerability related to the frequency of fires in the study area over a 10-year period.

**Table 17.** *Parameters of Fire History Influencing the Degree of Forest Fire Vulnerability*

| Number of Fires in the Area in a 10-Year Period | Points |
|---|---|
| 5 or more | 40 |
| 2 to 4 | 20 |
| Up to 2 | 10 |

### 3.7.3 Forest Complex Accessibility and Hydrographic Data

The accessibility of the forest complex through pathways is fundamental for the successful prevention of forest fires. This includes the maintenance of firebreaks by cleaning and pruning, thinning, and reduction of combustible material. The accessibility of the forest complex is depicted in Table 18.

**Table 18**. *Accessibility of the Forest Complex*

| Accessibility of the Forest Complex | Points | Area (ha) | % |
|---|---|---|---|
| Forest complex is accessible (most areas are accessible via a developed road network; firebreaks are regularly maintained) | 5 | | |
| Forest complex is partially accessible (large parts are poorly accessible, or accessible through forest roads unsuitable for firefighting vehicles; firebreaks are poorly maintained) | 20 | | |
| Forest complex is not accessible, no firebreaks | 40 | 46255.64 | 100 |

Map 16 shows the geodatabase of the road network of the Boljevac Municipality. Map 17 depicts the geodatabase for the hydrographic network and water sources.

### 3.7.4 Organisation of the Areas Designed for Tourist and Recreational Activities

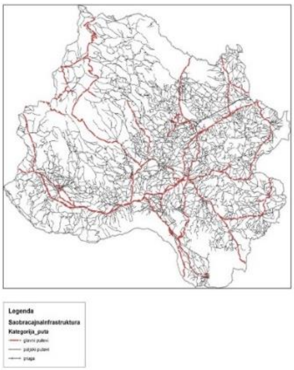
Due to the high number of people, campfires, and the use of various means of ignition, recreation areas pose a special danger and risk of fire occurrence. There are relatively few organised recreation areas that can meet all safety measures and reduce the risk of fire. An area is considered a designed recreational area if it is equipped with well-designed and designated places for casmpfire, firefighting equipment, and organised guard services to oversee and guide activities, as well as alert to activities that may cause a fire (Table 19). Map 18 displays geodatabases for natural and cultural values expressed through the locations of tourist facilities and protected natural assets.

### 3.7.5 Other Biotechnical Protection Measures

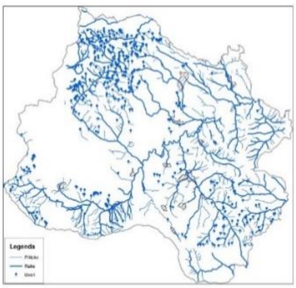
Other biotechnical measures for forest fire protection include planting mixed forests with less fire-prone fuel material, constructing and regularly maintaining firebreaks, building and maintaining water supply points, constructing observation points, establishing a forest surveillance system and developing and implementing a system of forest fire risk assessment (Table 20).

**Table 19.** *Degree of spatial organisation and number of points*

| Degree of organisation | Points | Area (ha) | % |
|---|---|---|---|
| Forest complex is organised for tourist and picnicking activities (designated and secured fireplaces, sand bucket extinguishers in case of small fires in their initial stages, forest fire warning signs) | 5 | 4626 | 10,0 |
| Forest complex is partially organised for tourist and picnicking activities (forest fire warning signs) | 20 | 10824 | 23.4 |
| Forest complex is completely unsuitable for tourist and picnicking activities (no designated fireplaces or forest fire warning signs) | 40 | 30806 | 66.6 |



**Map 16.** *Road Network*



**Map 17.** *Hydrological Network and Water Sources*

**Map 18.** *Tourist Facilities and Protected Natural Assets*

**Table 20.** *Biotechnical protection measures and points*

| Degree of Organisation | Points | Area (ha) | % |
|---|---|---|---|
| Forest complex with biotechnical protection measures (mixed forests with less fire-prone fuel material, regularly maintained firebreaks, built and maintained water supply points, observation points, established forest surveillance system and implemented system of forest fire risk assessment) | 5 | 2590 | 5,6 |
| Forest complex without biotechnical protection measures | 40 | 43665 | 94,4 |

### 3.8 Forests fire vulnerability risk: location of cameras and visibility zones

Based on the parameters for assessing the vulnerability of forests to fire, we calculated the sum of points for all represented parameters in the observed area. The degree of forest vulnerability to fire was determined based on the total number of points. Table 21 provides the categorisation of forest vulnerability to fire based on the number of points.

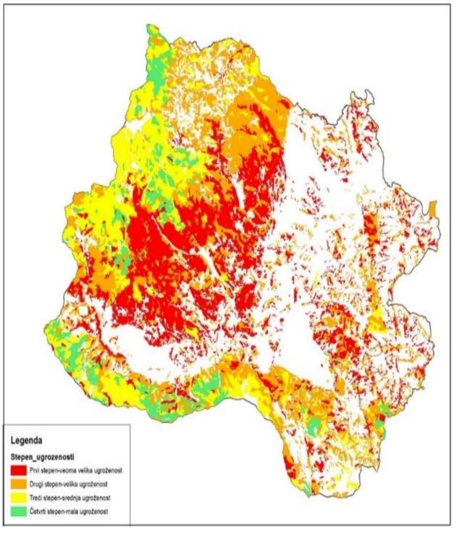
**Table 21.** *Categorisation of Forest Fire Vulnerability*

| Degree of Forest Fire Vulnerability | Total Points | Colour | Area (ha) | % |
|---|---|---|---|---|
| First degree - very high vulnerability | > 681 | red | 15270 | 33.01% |
| Second degree - high vulnerability | 601-681 | orange | 17160 | 37.10% |
| Third degree - moderate vulnerability | 531-600 | yellow | 10186 | 22.02% |
| Fourth degree - low vulnerability | <531 | green | 3640 | 7.87% |
| Fifth degree - no vulnerability | | blue | | |

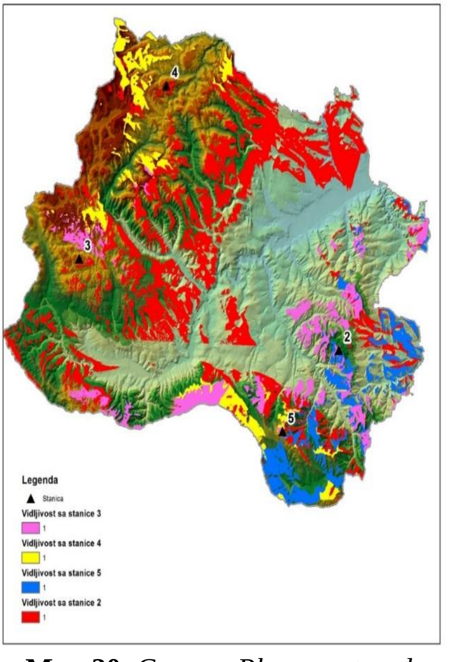
### 3.8.1 Camera Placement and Visibility Zones

Reducing damage caused by outdoor fires involves three prerequisites through the implementation of automatic observation and data collection systems, namely:

1. early detection of fires at their ignition;
2. timely and rapid implementation of necessary firefighting activities, requiring objective and relevant information;
3. detection and penalisation of deliberately set fires;




**Map 19**. *Categorization of Forest Fire Vulnerability*




**Map 20**. *Camera Placement and Visibility Zones*

A more technologically advanced method of monitoring open spaces is video surveillance, where an observer sits in a control center and simultaneously monitors multiple cameras. The automatic observation system aims at both preventive firefighting activities and activities related to fire extinguishment, encompassing two segments:

- preventive firefighting activities, which involve 24-hour observation in the visible and near-infrared spectrum, linked with an alarm expert system for early detection of outdoor fires based on recognising smoke and fire occurrences. This includes the capability of quickly transmitting and storing footage on a central device.
- activities related to firefighting involving remote video presence with camera control tailored to users, supporting fire monitoring and firefighting action management.

Map 20 displays the layout of locations for camera placement and visibility zones at different distance levels.

## 5. CONCLUSION

Based on 973,152 data points from the Geodatabase grouped into 30,411 homogeneous units, we identified zones by degrees of forest fire vulnerability. Through an analysis of all parameters that influence the degree of vulnerability to varying extents, it was observed that 33.01% of the total forest area falls into the first degree of vulnerability – very high vulnerability, 37.10% into the second degree – high vulnerability, the third degree – moderate vulnerability accounts for 22.02% of the area, and the fourth degree – low vulnerability for 7.87%. The fifth degree – no vulnerability to forest fires was not observed in the Boljevac Municipality area.

The installation of four cameras is planned to provide surveillance over all areas threatened by the occurrence of a forest fire. Such detection systems, enabling quick response and timely reporting of forest fires, are more acceptable from the financial aspects as as they incur lower costs, provide faster fire detection and notification regardless of the time of day and weather conditions. They allow for faster organisation and deployment of firefighting units, thus increasing the efficiency of firefighting. This method of fire monitoring allows for quicker response in the initial stages of a fire, requiring fewer personnel and less firefighting equipment. Connecting such integrated systems for forest fire detection with the forest fire hazard index and geographic information systems supporting the forest fire area opens up significant possibilities in both preventive and organisational forest fire protection.

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## FOREST FIRE RISK MAPPING IN THE MUNICIPALITY OF BOLJEVAC

*Tatjana DIMITRIJEVIĆ, Mihailo RATKNIĆ, Goran ĐORĐEVIĆ,*
*Sabahudin HADROVIĆ*

Based on 973,152 data points from the Geodatabase grouped into 30,411 homogeneous units, we identified zones by degrees of forest fire vulnerability. Through an analysis of all parameters that influence the degree of vulnerability to varying extents, it was observed that 33.01% of the total forest area falls into the first degree of vulnerability – very high vulnerability, 37.10% into the second degree – high vulnerability, the third degree – moderate vulnerability accounts for 22.02% of the area, and the fourth degree – low vulnerability for 7.87%. The fifth degree – no vulnerability to forest fires was not observed in the Boljevac Municipality area. The installation of four cameras is planned to provide surveillance over all areas threatened by the occurrence of a forest fire. Such detection systems, enabling quick response and timely reporting of forest fires, are more acceptable from the financial aspects as as they incur lower costs, provide faster fire detection and notification regardless of the time of day and weather conditions. They allow for faster organisation and deployment of firefighting units, thus increasing the efficiency of firefighting. This method of fire monitoring allows for quicker response in the initial stages

of a fire, requiring fewer personnel and less firefighting equipment. Connecting such integrated systems for forest fire detection with the forest fire hazard index and geographic information systems supporting the forest fire area opens up significant possibilities in both preventive and organisational forest fire protection.

## IZRADA KARTE RIZIKA OD ŠUMSKIH POŽARA NA PODRUČJU OPŠTINE BOLJEVAC

*Tatjana DIMITRIJEVIĆ, Mihailo RATKNIĆ, Goran ĐORĐEVIĆ, Sabahudin HADROVIĆ*

Na osnovu 973.152 podataka Geodatabaze grupisanih u 30.411 homogenih celina izdvojene su zone po stepenu ugroženosti od šumskog požara. Analizom svih parametara koji u razuličitom stepenu utiču na stepen ugroženosti konstatovano je da 33.01% ukupne površine pod šumom pripada prvom stepenu ugoženosti – veoma velika ugroženost, 37.10% drugom stepenu – velika ugroženost, trećem stepenu – srednja ugroženost zastupljena je na 22.02% površine I četvrtom stepenu – mala ugroženost na 7.87%. Peti stepen – nema ugroženosti šuma od požara nije konstatovan na području Opštine Boljevac. Predviđeno je postavljanje četiri kamere koje zonama vidljivosti obezbeđuju nadzor na svim površinama koje su ugrožene od nastanka šumskog požara. Ovakvi sistemi detekcije koji omogućuju brzo reagovanje i pravovremeno vršenje dojave šumskih požara su pre svega finansijski bolji, jer su troškovi manji, daju bržu detekciju požara i brzu dojavu, bez obzira na doba dana i vremenske uslove, što omogućuje bržu organizaciju, brži izlazak jedinica na gašenje požara što povećava efikasnost gašenja. Ovaj način nadgledanja požara omogućava brže reagovanje u početnoj fazi požara, potrebu za manjim brojem ljudi i potrebu za manjom količinom opreme za gašenje. Povezivanjem ovakvih integralnih sistema za detekciju šumskih požara sa indeksom opasnosti od nastanka šumskih požara i geografskim informacionim sistemima koji podržavaju oblast šumskih požara, otvaraju se velike mogućnosti i u preventivnoj i organizacionoj zaštiti šuma od požara

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Review paper

# POSSIBILITIES FOR THE USE OF BIOMASS FROM FORESTRY WITH THE AIM OF ESTABLISHING A CIRCULAR BIOECONOMY IN SERBIA

*Ljiljana BRAŠANAC-BOSANAC[1]*, Nevena ČULE[1], Ilija ĐORĐEVIĆ[1], Goran ČEŠLJAR[1], Tatjana ĆIRKOVIĆ-MITROVIĆ[1]*

**Abstract:** *In the last ten years significance of biomass is growing, due to exhaustion of fossil fuel reserves and their negative impact on climate and environment. In the region of Southeastern Europe, biomass is the most significant renewable energy source, due to abundance of forests and agricultural areas. Serbia is one of the countries of Southeastern Europe with significant potentials for using biomass from forests and wood processing industry in the form of wood residues. Despite its potential, the use of wood biomass in Serbia is not efficient. Significant amounts of wood residue produced in the course of tree felling and timber assortment production are left unused in forests. It is necessary to improve the national legislative and regulatory frameworks and support mechanisms for the rational use of biomass, make a precise assessment of its potential and promote the importance of the circular bioeconomy in Serbia in the coming period. The paper presents the results of a complex analysis of the current state of the circular bioeconomy in Europe Union countries, comparing with state in Serbia, the goals and initial results of the CEE2ACT project, and highlights the importance of the formation and long-term functioning of the National Bioeconomy Hub.*

**Keywords:** forestry, biomass, circular bioeconomy, CEE2ACT, HUB, sustainable development

# MOGUĆNOSTI KORIŠĆENJA BIOMASE IZ ŠUMARSTVA U CILJU USPOSTAVLJANJA CIRKULARNE BIOEKONOMIJE U SRBIJI

**Sažetak:** *Usled iscrpljivanja rezervi fosilnih goriva i njihovog negativnog uticaja na klimu i životnu sredinu, korišćenje biomase poslednjih deset godina dobija sve veći značaj. U zemljama Jugoistočne Evrope, biomasa je najznačajniji obnovljivi izvori energije, zbog obilja šuma i poljoprivrednih površina. Srbija predstavlja jednu od zemalja u regionu Jugoistočne Evrope koja ima značajne potencijale za korišćenje biomase iz šumarstva i drvno-prerađivačke industrije u obliku drvnog ostatka. Uprkos potencijalu, upotreba drvne biomase u Srbiji nije efikasna. Značajne količine drvnog ostatka nastalog pri seči drveta i proizvodnji drvnih sortimenata ostaju neiskorišćene u šumama. U predstojećem periodu neohodno je da se unaprede nacionalni zakonodavni i regulatorni okviri, kao i mehanizmi*

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

*podrške racionalnoj upotrebi biomase, izvrši precizna procena njenih potencijala i mogućeg korišćenja i promoviše značaj cirkularne bioekomije u Srbiji. U radu su prikazani rezultati kompleksne analize aktuelnog stanja cirkularne bioekonomije u zemljama Evropske Unije, upoređujući ga sa stanjem u Srbiji, ciljevi i početni rezultati CEE2ACT projekta i istaknut je značaj formiranja i dugotrajnog funkcionisanja Nacionalnog Centra za Bioekonomiju (NCB).*

**Ključne reči:** šumarstvo, biomasa, cirkularna bioekonomija, CEE2ACT, NCB, održivi razvoj

## 1. INTRODUCTION

The Republic of Serbia is one of the countries with significant biomass potential, both in terms of biodiversity and distribution. Numerous studies and analyzes show that biomass is the most significant potential renewable energy source in Serbia. It is estimated at 3,448 Mtoe annually, of which 48% is agricultural and 44% wood biomass (table 1). But, despite its great potential, the use of biomass in Serbia has not been efficient. Wood biomass is most abundant in the mountainous regions of central Serbia and its current utilization rate is very high (over 70%).

The Central and Eastern European countries wanted to devote more attention to developing national strategies or action plans aimed at promoting the transition to the bioeconomy in Europe with a bottom-up approach. For this reason, the Horizon project CEE2ACT was launched in September 2022. The Institute of Forestry from Belgrade has been involved in the implementation of the CEE2ACT project. The main objective of this project is to enable countries in Central Eastern Europe and beyond (Bulgaria, Croatia, Czech Republic, Greece, Hungary, Poland, Romania, Serbia, Slovakia and Slovenia) to develop strategies and action plans for a circular bioeconomy, using innovative governance models and examples of good practices from developed countries.

The realization of circular bioeconomy in Serbia can be called a pioneering undertaking, because this term is not recognized in strategic, legal and institutional frameworks in Serbia. Adoption and implementation of the National Bioeconomy Strategy and Action plans, the National Bioeconomy Hub (NHB) establishment, support and financial incentives for entrepreneurs who apply the principles of the bioeconomy and sustainability are some of the measures that need to be implemented to realize a circular bioeconomy in Serbia.

With the aim of improving the use of biomass from forestry paper studies resources and gives recommendations for increasing the utilization of forest-based biomass for energy purposes and establishing circular bioeconomy in Serbia.

## 2. MATERIAL AND METHODS

In order to determine the potential and real state of biomass from forestry and to observe effective solutions and proposals for measures that would increase the use of wood biomass for energy purposes in Serbia, the methods of analysis, synthesis and generalization are used.

Data on potential and actual biomass related to the topic of biomass and circular economy were obtained from the Institute for Statistics of the Republic of

Serbia, SE "Srbijašume", SE "Vojvodinašume", existing laws, strategies and action plans, scientific works, studies and projects.

Bioeconomy Strategy does not exist in Serbia, but there is the concept of circular economy. The concepts of both the bioeconomy and the circular economy have been introduced in the European Union (EU) in response to concerns about long-term sustainability and the prevailing resource-intensive economic model. Although different in origin - the first mostly driven by an innovation agenda and the second by environmental concerns and resource scarcity - both aim to contribute to strategic and operational EU policy objectives.

Concept of existing circular economy in Serbia is analyzed and elaborated through 3 national strategies - Strategy of Agriculture and rural development in the Republic of Serbia for the period 2014-2024, Strategy of Industrial policy of the Republic of Serbia from 2021-2030, Strategy of Sustainable urban development of the Republic of Serbia until 2030 and 2 national programs - Waste Management Program in the Republic of Serbia for the period 2022-2031 and Public Procurement Program 2019-2023.

## 3. RESULTS

### 3.1. EU rules on sustainable biomass

Biomass is derived from organic material such as trees, plants, and agricultural and urban waste. It can be used for heating, electricity generation, and transport fuels. Increasing the use of biomass in the EU can help diversify Europe's energy supply, create growth and jobs, and lower greenhouse gas emissions. It is also needed in the electricity production to balance variable renewables.

For biomass to be effective at reducing greenhouse gas emissions, it must be produced in a sustainable way. Biomass production involves a chain of activities ranging from the growing of feedstock to final energy conversion. Each step along the way can pose different sustainability challenges that need to be managed.

The European Union does not prescribe how a state should organize its own agriculture, forestry, waste management whether there will be one or more enterprises, but it requires the legislation to be in accordance with the principles respected by European countries (the principle of sustainable development, ecological principles, Pan-European Criteria and Indicators, etc.). In accordance with the Kyoto Protocol, the Paris Agreement and the EU Directives, and based on the obligation to increase the share of renewable energy sources in the total energy consumption, a lot of EU countries are encouraging the use of biomass as fuel. Increasing the use of biomass in the EU can help diversify Europe's energy supply, create growth and jobs, and lower greenhouse gas emissions. It is also needed in the electricity production to balance variable renewables.

In the Figure 1, overview of EU strategies, policies and legislative documents relevant to the biomass, circular economy and bioeconomy is shown.

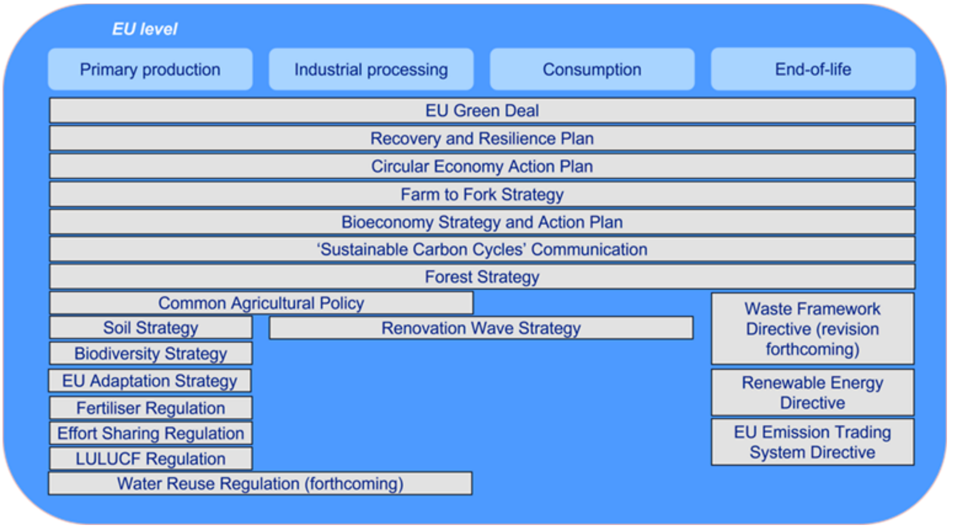


**Figure 1.** *Overview of EU strategies, policies and legislative documents relevant to the biomass, circular economy and bioeconomy*
*Source: European Commission (2021), OECD (2022) (Adapted by authors)*

### 3.2. Current status of the use of biomass from forestry in Serbia

Of the registered 3448 Mtoe biomass potential in Serbia, about 1.67 Mtoe is derived from agriculture and food processing industry, while biomass from forestry accounts about 1.53 Mtoe (table 1).

**Table 1**. *Technical potential of BIOMASS in the Republic of Serbia*

| Types of BIOMASS | Available realized technical potential (Mtoe) | Unrealized available technical potential (Mtoe) | Total available tehnical potential (Mtoe) |
|---|---|---|---|
| **Agricultural biomass** | | | |
| Agricultural crop residue | 0.033 | 0.99 | 1.023 |
| Residue from fruit growing, viticultureand fruit processing | - | 0.605 | 0.605 |
| Liquid manure | - | 0.042 | 0.042 |
| **Total AB** | **0.033** | **1.637** | **1.67** |
| **Biomass from forestry** | | | |
| Wood (forest-bassed) biomass | 1.021 | 0.509 | **1.53** |
| Energy plantation | - | - | not available |
| **Biodegradable waste** | | | |
| Biodegradable municipal waste | 0 | 0.205 | 0.205 |
| Biodegradable waste (excluding minicipal) | 0 | 0.043 | 0.043 |
| Total BW | 0 | 0.248 | 0.248 |
| **BIOMASS IN RS (Mtoe)** | **1.054** | **2.394** | **3.448** |

*Source: Energy Sector Development Strategy of the Republic of Serbia for the period by 2025 with projections by 2030 (2016) (Adapted by authors)*

Biomass from forestry belongs to solid biomass which includes firewood, plant mass of fast-growing plants, branches and wood waste from forests, sawdust, bark and wood residue from the wood-processing industry. Despite the great potential of wood mass, biomass from forestry in Serbia has not been used sufficiently. There are several reasons:

- ✓ Significant amounts of wood residue produced in the course of tree felling and timber assortment production are left unused in forests.
- ✓ Poorly developed forest road infrastructure (insufficiently opened);
- ✓ difficult accessibility (terrain with extremely unfavorable orographic characteristics and poor access to forest stands);
- ✓ In the areas with extremely unfavorable orographic characteristics and poor access to forest stands, the profitability of the collected products is disputable;
- ✓ Inappropriate mechanization for the collection and transportation of wood biomass, i.e., high costs of biomass collection making the collection of forest residue unprofitable;
- ✓ Unsolved logistics problems in the collection and distribution;
- ✓ The absence of a regulated biomass market and appropriate technologies for its use as fuel;
- ✓ The poor financial power of potential buyers and expensive commercial loans;
- ✓ The lack of state subsidies for the construction of biomass plants;
- ✓ Demographic emptying of villages and border settlements, together with the economic underdevelopment of local communities and extreme poverty of the population, especially in the Southern and Eastern Serbia limits the possibilities of collecting and using this biomass.

Intensive use of forest biomass requires the establishment of system measures for control and supervision in the chain of use as well as the adaptation of the planning and forest management pattern (Brašanac-Bosanac, Lj. et al. 2018). It is necessary that wood and wood biomass be given the right importance in Serbia, not only in energy balances and official consumption analyses but also in the application of methods for estimating its consumption. Sustainable use of biomass brings an opportunity for Serbia by providing additional natural resources for the economy and products, and closing the biological cycle of biodegradable materials.

### 3.3. Relations and overlaps between the deferent concepts of economy

Green, Circular and Bio - economy are mainstreamed as global sustainability concepts.

Despite their evidently different assumptions and operationalization strategies, the concepts of green economy, bioeconomy, bio-based economy, circular economy and circular bioeconomy joined by the common ideal to reconcile economic, environmental and social goals. In the past decade, they have all gained political interest, coming to exercise great influence on several societal actors and their activities, including for instance industries, academia, NGO's and policy makers (D'Amato, D. et al. 2017).

Us result of this research, comparative analysis of the relationships and overlaps between these five concepts is showen in Figure 2.

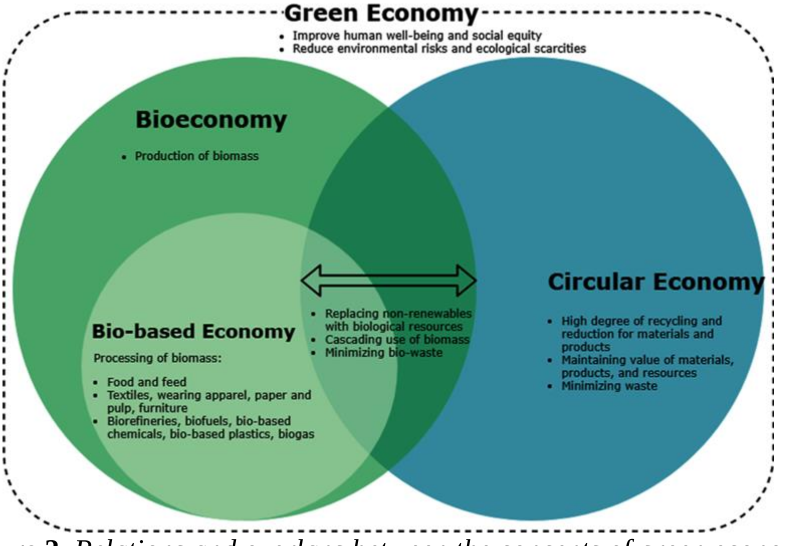


**Figure 2.** *Relations and overlaps between the concepts of green economy, bioeconomy, bio-based economy and circular economy*
*Source: Kardung et al. (2021) and Philp and Winickoff (2018) (Adapted by authors)*

**Green economy**
The green economy is a concept that emphasizes the lowering of environmental risks and ecological scarcities. The concept applies to low carbon, resource-efficient and socially inclusive economies.

**Bioeconomy**
The bioeconomy is part of the green economy. Relates to promoting global economic growth and technological development for primary production and industry, especially where advanced life sciences are applied to the conversion of biomass into materials.

**Bio-based economy**
The bio-based economy is part of the bioeconomy and relates to converting biological resources into products and materials. Food and feed production usually involves processing agricultural goods, which enters into the bio-based economy.

**Circular economy**
The circular economy relates to the use of products and materials that show the highest degree of recycling and lowest waste. That is, the linear production model “take, make and dispose” is replaced by a circular model in which waste products (disposed of in a linear model) are kept within the system. In this way, waste materials are drastically reduced, recycled and remanufactured.
**Circular bioeconomy**

The circular bioeconomy is a complex and dynamic system and thus decision-makers need new strategies and tools to steer and govern this complex system towards the desired outcomes. The circular bioeconomy is seeking new ways of producing and consuming resources while respecting our planetary boundaries and moving away from a linear economy, based on extensive use of fossil and mineral resources. The importance of a CE in the priority area of biomass lies in its potential to contribute to climate change mitigation, socio-economic development and environmental protection over time by maintaining the value of bio-based products, materials and resources in the economy for as long as possible (Figure 3).

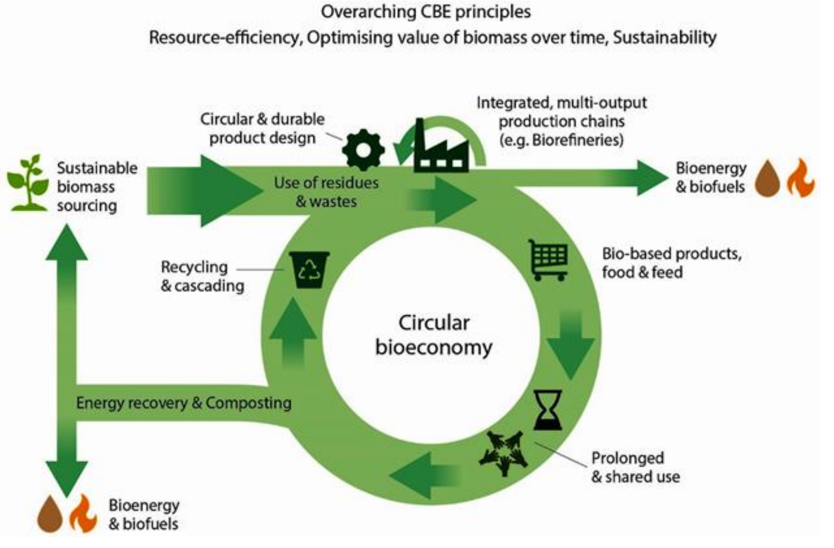


**Figure 3.** *Overarching Circular Bioeconomy principles*
*Source: Stegmann, P., Londo, M., Junginger, M. (2020)*

## 3.4. The importance of a Circular Bioeconomy in EU

In the Updated Bioeconomy Strategy 2018, the European Commission states that "*the European Bioeconomy needs to have sustainability and circularity at its heart*" to manage concerns around increasing demands for biomass for short-lived and linear use. In contrast, a comprehensive circular economy needs to include the bioeconomy, which consists of organic material from agriculture, forestry, fisheries, the food and feed industry and organic processes of waste, as well as knowledge-based processes and applications (Carus, M., Dammer, L., 2018).

Developed countries of the European Union understands the circular bioeconomy as the economy that uses renewable biological resources to sustainably produce food, bio-based materials, feed, products, fuels and bioenergy, and in which waste products are kept within the system. Their policies of development and Strategies of Bioeconomy are focused on the sustainable conversion of biomass and bio-based resources into marketable products, and places biomass production and processing in a single system, while underscoring the role of technology in biological resources to create added value and encourage new business models.

Despite many efforts and activities, there has been a poor approach to the bioeconomy in Serbia for several decades.

EU countries understands the circular bioeconomy as a new techno-socio-economic paradigm of production and consumption. This requires: 1) rethinking its development orientations and principles; 2) taking advantage of its technological solutions; 3) setting economic thinking on a new pathway; 4) strengthening political and institutional support; 5) ensuring policy coherence across objectives, instruments and practices; and 6) involving relevant stakeholders in policy design processes to a greater extent.

Biomass also helps diversify Europe's energy supply, create growth and jobs, and lower GHG emissions.

According to the and latest available data from European Commission (Joint Research Centre, Biomass flows) the total biomass supply in the EU27 added up to 1 billion tons of dry matter. The agriculture sector is the biggest producer of biomass (69%), followed by forestry (31%) and fisheries (<1%). Around 60% of the biomass in the European Union is used for food and feed, with 24% of identified biomass used for energy and 16% for biomaterials3 (Gurria Albusac, P. et al., 2022).

### 3.5. Circular Bioeconomy and establishment of the National Bioeconomy HUB in Serbia

Concept of bioeconomy is not recognized in strategic, legal and institutional frameworks in Serbia. Most of the representatives of the target groups have heard of the concept of circular economy, which is defined in different frameworks, but they are not familiar with the details.

Since September 2022, the Institute of Forestry from Belgrade with its team of experts has been involved in the implementation of the HORIZON EUROPE CEE2ACT project "Empowering the Central and Eastern European Countries to Develop Bioeconomy Strategies and Action Plans", in which 17 European countries participate. The objective of CEE2ACT is to empower more than 10 beneficiary countries in Central Eastern Europe and beyond to develop bioeconomy strategies and action plans, through knowledge transfer and innovative governance models enabling sustainability and resilience, to achieve better informed decision-making processes, societal engagement and innovation.

The realization of CEE2ACT project is very important for Serbia. Based on the obtained results and guidelines, it can enable the implementation of circular bioeconomy concept, as one of the seven key ways to achieve climate neutrality, identified in the European Clean Planet Strategy. Also, the Project can help Serbia join Europe on its way to become the first climate-neutral continent by 2050 within the framework of the European Green Deal.

The series of workshops and the bottom-up participatory approach of the CEE2ACT project are designed to empower 10 countries of Central and Eastern Europe and beyond: Bulgaria, Croatia, Czech Republic, Greece, Hungary, Poland, Romania, **Serbia**, Slovakia, and Slovenia to develop Circular Bioeconomy Roadmaps, Strategies and Action Plans through knowledge transfer and adoption of innovative management models of developed bioeconomy countries, taking into account the relevant economic, social and environmental aspects of each country individually. The 10 National Bioeconomy Hubs are built on existing networks and clusters, and they will be supported by e-solutions such as inventories of best practices, e-learning modules, self-assessment tool, B2B matchmaking tool, and methodology for developing bioeconomy strategies and action plans.

The establishment of the National Bioeconomy Hub and the first CEE2ACT workshop "Building trust and understanding between stakeholders for the development of bioeconomy strategies" was held in Belgrade on October 6, 2023. The workshop aimed to foster collaboration, trust, and understanding among stakeholders, the driving forces behind shaping Serbia's bioeconomy future. The objectives were twofold: to establish a shared vision for the national bioeconomy, uniting different players in relevant sectors, and to create broad support for bioeconomy goals and activities, with a shared commitment to local engagement and idea exchange. The workshop brought together a diverse group of 29 participants. Twenty-one stakeholders from 20 different institutions were present, including decision-makers in the creation and implementation of policies, public administrators, actors in the primary sector of the economy, the waste sector and the bio-based industry, small and medium-sized enterprises, public enterprises, suppliers of raw materials, scientific research and educational institutions and organizations for environmental protection. It should be noted that there were no representatives of non-governmental organizations and civil society organizations.

## 4. DISCUSSION

Application of circular business models play an essential role in the transition to a circular bioeconomy. Innovation and examples of good practices helps companies bring bio-based products and services with a higher value added onto the market and helps them compete in global value chains. Circular business models help the economy to reduce the use of natural resources and the generation of industrial and household wastes (OECD, 2019). Despite existing of Road map of circular economy, the knowledge capacities about circular bioeconomy in Serbia has not established yet. Serbian companies are characterised by a lack of forward planning and a general concern and feare for innovation. They are mostly engaged in low value-adding activities in global value chains, therefore, the share of domestic value added is low in Serbia, especially in manufacturing. The purpose of establishing and existing the NBH in Serbia is to improve the legislative and regulatory framework and support mechanisms for the rational use of biomass in the coming period.

## 5. CONCLUSION

Despite all potential, advantages and the existence of potential investors, we cannot be satisfied with the level and modes of utilization of biomass in Serbia. In order to improving the use of forest-based biomass for energy purposes in Serbia it is necessary to adopt relevant measures existing in other European countries and the regulations harmonized among decision makers in the fields of agriculture, forestry, energy and environmental protection. It must not be allowed for the increase of woody biomass demand to lead to the increased pressure on forests and exceeding of allowed cuts. In that case, positive effects of biomass use on one side could lead to the degradation of forests on the other. Because of that it is very important that Serbia get Bioeconomy Strategy.

The analysis of the circularity potential in the Serbian biomass production sector and the stakeholder consultation process identified the need to promote the use of natural bio-based solutions in agriculture and forestry, such as compost or bio-based products. It also identified the need to support new initiatives for alternative source of energy production. The national circular economy strategy should focus efforts on these two key areas of primary production. According to the consulted stakeholders, agriculture and forestry have most potentials in the circular bioeconomy of Serbia.

In the next few years Serbia will need to step up its innovation efforts in the use of biomass from forestry, including the use of circular business models, by increasing the effectiveness of its existing technical and financial support for innovation in this area. The technical support may consist of better communication of information to companies about financing opportunities beyond conventional grants, and helping them develop business plans of a higher quality that would help them secure external funding. According to some of the consulted stakeholders, access to finance and to business support is the key challenge that Serbian forestry companies face in the country.

The key solution is in knowledge transfer. It is necessary to define which sectors are the carriers of innovative ideas and which institutions are involved in the implementation of these ideas, what capacities exist for the short-term support of start-ups, etc. Active participation of all HUB stakeholders (20 so far) in the CEE2ACT project, conducting and participating in workshops, better cooperation with scientific research institutions, formation of clusters, networking, knowledge transfer and conducting workshops with cluster participants could best promote the concept of bioeconomy in Serbia in the near future.

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***CEE2ACT project (2022-2024), that has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement, No. 101060280.*

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## POSSIBILITIES FOR THE USE OF BIOMASS FROM FORESTRY WITH THE AIM OF ESTABLISHING A CIRCULAR BIOECONOMY IN SERBIA

*Ljiljana BRAŠANAC-BOSANAC, Nevena ČULE, Ilija ĐORĐEVIĆ, Goran ČEŠLJAR, Tatjana ĆIRKOVIĆ-MITROVIĆ*

### Summary

The bioeconomy includes and interlinks all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture), and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services). It is very important to promote a circular and low-carbon economy, create new local value chains and provide solutions for the current food security and energy independence crisis, while protecting biodiversity and the environment. The circular bioeconomy uses renewable biological resources to sustainably produce food, bio-based materials, feed, products, fuels and bioenergy, and in which waste products are kept within the system by transforming them into value-added products. The CEE2ACT project is empowering Central and Eastern European countries to develop circular bioeconomy strategies. To date, there are 17 Member States of EU including many countries from Central and Eastern Europe (CEE) that do not have a national bioeconomy strategy and

action plan despite their high biomass resource base and new bioeconomy potential. Serbia is one of them. However, there are relevant regional initiatives supporting bioeconomy in Central and Eastern European countries. National Bioeconomy Hub with Serbian Chamber of commerce, clusters and other organizations, institutes, faculties and other research institutions and organizations in it, can play an important role in the dissemination and knowledge transfer of financing instruments. Dissemination of examples of good practice from EU countries, profitable business successes and innovative business models can be a useful tool for attracting the attention of small and medium-sized enterprises and entrepreneurs in Serbia to the circular bioeconomy, especially in the forestry sector.

## MOGUĆNOSTI KORIŠĆENJA BIOMASE IZ ŠUMARSTVA U CILJU USPOSTAVLJANJA CIRKULARNE BIOEKONOMIJE U SRBIJI

*Ljiljana BRAŠANAC-BOSANAC, Nevena ČULE, Ilija ĐORĐEVIĆ, Goran ČEŠLJAR, Tatjana ĆIRKOVIĆ-MITROVIĆ*

### Rezime

Bioekonomija obuhvata i povezuje sve sektore primarne proizvodnje koji koriste i proizvode biološke resurse (poljoprivreda, šumarstvo, ribarstvo i akvakultura), kao i sve privredne i industrijske sektore koji koriste biološke resurse i procese za proizvodnju hrane, bio-proizvodi, energija i usluge). Veoma je važno promovisati cirkularnu i niskougljeničnu ekonomiju, kreirati nove lokalne lance vrednosti i obezbediti rešenja za trenutnu krizu bezbednosti hrane i energetske nezavisnosti, istovremeno štiteći biodiverzitet i životnu sredinu. Kružna bioekonomija koristi obnovljive biološke resurse za održivu proizvodnju hrane, biomaterijala, stočne hrane, proizvoda, goriva i bioenergije, pri čemu se otpadni proizvodi zadržavaju unutar sistema i pretvaraju u proizvode s dodatom vrednošću. Projekat CEE2ACT osnažuje zemlje Centralne i Istočne Evrope da razviju strategije cirkularne (kružne) bioekonomije. Do danas, postoji 17 država članica Evropske Unije, uključujući mnoge druge zemlje iz Centralne i Istočne Evrope (CEE) koje nemaju nacionalnu bioekonomsku strategiju i akcioni plan uprkos njihovoj visokoj bazi resursa biomase i novom bioekonomskom potencijalu. Srbija je jedna od njih. Međutim, postoje relevantne regionalne inicijative koje podržavaju bioekonomiju u zemljama Centralne i Istočne Evrope. Nacionalni Centar za bioekonomiju sa Privrednom komorom Srbije, klasterima i drugim organizacijama, institutima, fakultetima i drugim istraživačkim institucijama i organizacijama u njemu, može imati važnu ulogu u širenju i transferu znanja o instrumentima finansiranja. Upoznavanje sa primerima dobre prakse iz zemalja EU, profitabilnim poslovnim uspesima i inovativnim poslovnim modelima može biti korisno sredstvo za privlačenje pažnje malih i srednjih preduzeća i preduzetnika u Srbiji na cirkularnu bioekonomiju, posebno u sektoru šumarstva.

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Original scientific paper

# ANTIVIRAL PROPERTIES OF LIGNICOLOUS FUNGI OF SERBIA

*Zlatan RADULOVIĆ[1]*, Dragan KARADŽIĆ[2], Ivan MILENKOVIĆ[2], Katarina MLADENOVIĆ[1], Jelena BOŽOVIĆ[1]*

**Abstract:** *Fungi have multiple roles in nature. However, from his point of view, man most often views them as useful or harmful (depending on his primary activity). Thus, wood decaying fungi are most often seen as parasitic and saprophytic organisms, economically harmful, overlooking their useful functions. One of their useful functions is a possibility of their use in the treatment of various diseases. The results of the research of antiviral properties of lignicolous fungi are presented in this paper. Samples for isolation and identification of fungi are collected on several sites in Serbia. It has been determined that the fungi that cause wood decay have various antiviral properties, most often against viruses such as influenza, hepatitis, herpes, SARS-CoV-2 and HIV.*
**Keywords:** viruses, fungi, polysaccharides, fruiting bodies.

# ANTIVIRUSNA SVOJSTVA LIGNIKOLNIH GLJIVA SRBIJE

**Sažetak:** *Gljive imaju višestruku ulogu u prirodi. Međutim, čovek ih sa svog stanovišta najčešće posmatra kao korisne ili štetne (zavisno od svoje primarne aktivnosti). Tako i gljive truležnice drveta najčešće posmatra kao parazitske i saprofitske organizme, ekonomski štetne, previđajući njihove korisne funkcije. Jedna od korisnih funkcija je njihova mogućnost korišćenja u lečenju različitih bolesti. U radu su prikazani rezultati proučavanja antivirusnih svojstava lignikolnih gljiva. Uzorci za izolaciju i identifikaciju gljiva prikupljani su na više lokaliteta u Srbiji. Konstatovano je da gljive izazivači truleži drveta imaju različita antivirusna svojstva i to najčešće protiv virusa gripa, hepatitisa,* herpesa, SARS-CoV-2 i HIV-a.
**Ključne reči:** virusi, gljive, polisaharidi, plodonosna tela.

## 1. INTRODUCTION

The majority of lignicolous fungi cause wood decay and in this way they cause relatively large damages to the forest economy (due to the loss of wood mass). These fungi cause white or brown rot of the wood depending on whether they break down lignin (causing the white rot) or cellulose and hemicellulose (causing the

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

brown rot). Although some fungi sometimes cause large damages, causing die-back of the trees, still the importance of fungi in the process of organic matter circulation is immeasurable.

In addition to causing the wood rot and reducing the value of wood mass, large number of lignicolous fungi have medicinal properties. Thanks to the content of immunomodulatory polysaccharides, proteins, polysaccharide-protein complexes, polyphenols, steroids, triterpenoids, fatty acids, nucleotides, pigments, and polyacetylene components, fungi started to be used for obtaining antibiotics and other medicines (Karadžić, D., *et. al.* 2022).

Nowadays, according to Lindequist, U. *et al.*, (2005) between 80 and 85% of medicinal preparations obtained on the basis of fungi are extracted from fruiting bodies, collected in nature or artificially cultivated. Only 15% of preparations are obtained from the extract of mycelia (PSK and PSP from *T. versicolor*), and very small percent is obtained by filtering a pure fungi culture (schizophyllan from *S. commune*).

Viruses cause great epidemics on all continents, which leads to severe symptoms and mortality in humans and huge treatment costs. In addition, the constant emergence of new strains represents the additional challenge in the fight against the viruses. The antiviral properties of fungi and the possibility of their application in the treatment of various human diseases caused by viruses have been discovered lately.

## 2. MATERIAL AND METHODS

Global research of lignicolous fungi has been carried out on the territory of the whole Serbia (except Kosovo), while somewhat more detailed researches have been carried out in the territories of Goč, National Park Tara, National Park Fruška Gora, National Park Đerdap, Natural Park Stara Planina, Majdanpečka Domena and Srem.

The determining of the species has been carried out based on the appearance of the fruiting bodies (carpophores), type of the rot, and the appearance of the obtained pure culture. From the rotten parts of the trunks the isolation of the fungi was carried out on appropriate nutrient substrates (PDA- Potato Dextrose Agar; MEA- Malt Extract Agar). Nutrient substrates have been prepared according to the recipe of Bootha, C. (1971). The objective of these isolations was to isolate pure cultures of fungi from a rot-affected wood and to carry out identification based on their appearance. For determination of the fungi publications of the following authors were used: Bondarcev, A.S. (1953), Breitenbach, J. et Kränzlin, F. (1986), Hagara, L. (2014), Karadžić, D. and Anđelić, M. (2002) and others.

Antiviral properties of fungi have been researched by searching the references in PubMed search engine, by combining the terms “mushroom” and “antiviral”. Some properties are listed from the available literature in the Russian language. Only antiviral properties of fungi recorded in Serbia were taken into account.

## 3. RESULTS

The obtained results are presented in Table 1.

**Table 1.** *Antiviral properties of lignicolous fungi*

| Fungus | Biological activity | Bioactive component or the part of a fungus with medicinal properties | References |
|---|---|---|---|
| *Daedaleopsis confragosa* (Bolt.: Fr.) J. Schröt. | Antiviral effect | Aqueous extracts of mycelia | Teplyakov a, P. T., *et. al.* (2012) |
| *Fomes fomentarius* (L.) Fr. | Antiviral effect (virus of influenza H1N1 and herpes simplex virus type HSV-2, strain BH). | Mycelia of fungi | Krupodorova, T., *et. al.,* (2014) |
| *Ganoderma lucidum* (Fr.) Karst. | Antiviral effect (herpes, herpes zoster, viral hepatitis A, B and C and HIV) | Triterpenes (ganoderic acid beta, lucidumol B, ganodermanondiol, ganodermanontriol, and ganolucidic acid A) | Min, B.S., et. *al.* (1998). |
| *Grifola frondosa* (Dicks.) Gray | Hepatitis B | D – fraction of polysaccharides | Gu, C.Q., *et al.* (2006) |
| | HIV | β-glucans | Halpern, G. M. (2007) |
| *Inonotus obliquus* (Fr.) Pilát | Antiviral effect | Fruiting body | Мелькумов, Г. М., Золототрубов а, А. С. (2017) |
| *Laetiporus sulphureus* (Bull.) Murrill. | Antiviral effect against HSV-1 | Extracts of mycelia | (Квачева, З.Б., *et. al.* 2005). |
| *Lentinus edodes* (Berk.) Singer | COVID 19 | Lentinan | Murphy, E., *et. al.,* (2020) |
| | Hepatitis B, AIDS, | Polysaccharides (LEP-1 and LEP-2), lentinan, eritadenine | Zhaoa, Y.M., *et. al.,* (2018,); Bisen, P.S., *et. al.,* (2010) |
| *Lentinus tigrinus* (Bull.) Fr. | Antiviral effect (HIV-1) | Laccase from fungal mycelia | Xu, L., *et al.* (2012) |
| *Lenzites betulina* (L.) Fr | Antiviral effect on viruses H5N1 and H3N2 | Aqueous extracts of mycelia | Teplyakova, T. V. et. al., (2012) |
| *Phellinus igniarius* (L. ex Fr.) Quél | Antiviral effect (Influenza viruses A and B, H9N2, human H3N2, bird H9N2 and viruses H1N1 resistant to oseltamivir (Tamiflu). | Aqueous extract | Lee, S., et al. (2013); Власенко, В. А., et *al.* (2012) |
| *Phellinus pini* (Thore. Ex Fr.) Pilát. | Antiviral (SARS-CoV-2) | Aromatic sesquiterpenoides of fruiting body | Li, X., et *al.,* (2021) |
| | Antiviral effect against herpes simplex virus 1 (HSV-1). | Polysacccharides of aqueous extract of hot water (variants of β-1,3-glucan) | Lee, S.M., et *al.,* (2010) |
| *Schizophyllum commune* Fr. | Hepatitis B | Polysaccharide sizophyran (SPG) | Kakumu, S., *et al.* (1991) |
| *Sparassis crispa* (Wulfen) Fr. | Inhibits the synthesis of the HIV virus | Fungal extract | Wang, J. et al. (2007) |

## 4. DISCUSSION

Antiviral properties of basidiomycetes from the territory of the Altai Mountains have been researched by Teplyakova, P. T., *et. al.* (2012). Properties of several fungi were examined and among them also *Daedaleopsis confragose,* to viruses H5N1 (subtype of the virus influenza A, causative agent of bird flu) H3N2 (subtype of the virus influenza A). Aqueous extracts of mycelia of these fungi contain proteins, polysaccharides and terpenoids which prevent replication of viruses in cells.

In their research, Krupodorova, T., *et. al.,* (2014) have examined *in vitro* antiviral activity of mycelia of 10 fungi against the type A influenza virus. (serotype H1N1) and the herpes simplex virus type 2 (HSV-2), strain BH. All the examined species of fungi have inhibited reproduction of the influenza virus H1N1. Four species, *Pleurotus ostreatus, Fomes fomentarius, Auriporia aurea* and *Trametes versicolor* have shown efficiency against virus HSV-2, strain BH, with levels of inhibition similar as for influenza virus type A.

*G. lucidum* is efficient against viral diseases by strengthening immunity of an organism and preventing reproduction of viruses. Therefore, it is very effective in viral diseases, such as herpes, herpes zoster (viral diseases caused by chickenpox in childhood, that affect skin and nerve endings), viral hepatitis A, B and C and HIV. In case of HIV, it was shown that triterpenes isolated from fruiting bodies and spores (ganoderic acid beta, lucidumol B, ganodermanondiol, ganodermanontriol, and ganolucidic acid A) inhibit HIV-1 protease (M i n, B.S., *et. al.* 1998).

The results of the research of Gu, C.Q., Li, J., Chao, F.H. (2006), indicate that D-fraction of polysaccharides extracted from *G. frondosa,* in combination with human interferon alpha-2b (IFN), increases nine times the antiviral activity of interferon, so they can be used for efficient therapy against chronical infections of the hepatitis B virus.

According to Halpern, G. M. (2007) active ingredients of *G. frondosa* are β-glucans fractions D and MD and grifon-D. *G. frondosa* helps in control of diabetes, weight loss, control of high blood pressure, it is efficient against HIV virus, as well as in treatment of prostate and bladder cancer.

*I. obliquus* (chaga) has anti-inflammatory, anti-tumour, antiviral and immunomodulatory effects. On the basis of this fungus for anti-tumour and immunomodulatory effect commercial preparations have been produced (Melkumov, G. M., Zolotorubova, A. S. 2017).

Extracts of mycelia of the fungus *L. sulphureus* are efficient against variants of herpes simplex virus type 1 (HSV-1) which showed resistance to inhibitors acyclovir and phosphonoacetic acid (Kvacheva, Z.B., *et al.* 2005).

Murphy, E., *et. al.,* (2020), have researched immunomodulatory and cytoprotective properties of lentinan from the fruiting body of the fungus *L. edodes* and lentinan from commercial preparation (Carbosynth-Lentinan). The commercial preparation has contained larger quantities of α-glucan and smaller quantities of β-glucan. Both extracts have decreased the activation of NF-κB transcription factor caused by cytokine in alveolar epithelium of cell line of human lung adenocarcinoma A549. The extract from the fruiting body showed greater efficiency in smaller doses.

In contrast, in macrophages activated by THP-1 cells (cells of acute monocytic leukaemia), the extract of commercial preparation decreased more efficiently the production of proinflammatory cytokines (tumour necrosis factor alpha (TNF-α), interleukin-8, interleukin-2, interleukin-6, interleukin-22) as well as transforming growth factor beta (TGF-β) and interleukin-10.

The commercial extract has weakened early apoptosis (death) of cells caused by oxidative stress, while the “natural” extract weakened late apoptosis.

The obtained results show significant physical-chemical differences between these two lentinan extracts, which cause different *in vitro* immunomodulatory and lung cytoprotective effects which can have positive effect for COVID-19 patients with cytokine storm. COVID-19 causes inflammatory or cytokine storm in lungs with excessive and uncontrolled release of proinflammatory cytokines. Therefore, to reduce the mortality rate of the patients, it is very important to block the cytokine storm and start anti-inflammatory therapy quickly.

By studying optimal conditions for ultrasound-assisted extraction of polysaccharides of *L. edodes*, Zhaoa, Y.M., *et. al.*, (2018) have determined that the amount of extracted polysaccharides is the largest when the temperature of extraction is 45°C, the time of extraction 21 minute and ultrasound power is 290 W. Under these optimal conditions the experimental yield of polysaccharides of *L. edodes* has been 9.75%, which represents the increase of 1.62 times compared to the conventional method in the hot water. In the further procedure, crude polysaccharides have been purified to obtain two polysaccharide fractions (LEP-1 and LEP-2). The chemical analysis showed that these two fractions are rich in glucose, arabinose and mannose. The continuation of the research showed that both polysaccharide fractions *in vitro* have strong antiviral activity against the hepatitis B virus. LEP-2 showed a stronger inhibitory activity than LEP-1. The results suggested that the polysaccharides with relatively high molecular mass have stronger inhibitory activity than the ones with lower molecular mass.

According to Bisen, P.S., *et. al.*, (2010) *L. edodes is* used in medicine for treatment of diseases which include weakened immunological function (including AIDS), cancer, fungal infections, bronchitis, heart diseases, hyperlipidaemia (including high blood cholesterol), hypertension, infectious diseases, diabetes, hepatitis and the regulation of urinary incontinence (involuntary flow of urine). The most significant substances that have pharmacological properties are lentinan, eritadenine, mycelium of shiitake and extracts from fungi culture.

Reverse transcriptase is DNA polymerase enzyme which transcribes single-stranded RNA into single-stranded DNA. Transcription is the conversion of genetic information from DNA form into RNA. In their research, Xu, L., *et al.* (2012) from mycelium of culture of the fungus *L. tigrinus* have isolated the enzyme laccase which in concentration $IC_{50}$ = 2.4 μM has an inhibitory effect on the reverse transcriptase of the virus HIV-1 (human immunodeficiency virus), preventing the normal replication of this virus. Laccase has inhibited reverse transcriptase of the virus HIV-1 in the range from 27.7% to 86.3%, depending on the concentrations of laccase (1.5 μM to 15 μM). The maximum laccase activity has been observed at a pH of 4, at a temperature of 60°C. The mechanism of the inhibitory reaction is most probably the protein-protein interaction.

In their research, Teplyakova, T. V. et. al., (2012) state that aqueous solution of mycelia of 11 species of fungi shows antiviral activity on influenza viruses (bird flu H5N1) and H3N2. Against the H5N1 virus, *Datronia mollis, Laricifomes officinalis, Trametes gibbosa* and *L. betulina* have shown the greatest effect. Against the H3N2 virus all the researched species have shown antiviral activity and *Daedaleopsis confragosa* and *Ischnoderma benzoinum* have had the greatest effect.

Lee, S., et al. (2013) researched the effect of aqueous extract of *P. igniarius* on viruses. They have determined that the aqueous extract is efficient against influenza viruses A and B, including the pandemic virus H9N2 from 2009, human virus H3N2, bird virus H9N2 and viruses H1N1 resistant to oseltamivir (Tamiflu). Virologic tests have discovered that the extract can interfere with one or more stages in the influenza virus replication cycle, including binding of the virus to the target cell.

In their research, Vlasenko, V. A., et *al*. (2012) have determined antiviral properties of aqueous extract of the fungi *Phellinus igniarius* and *Phellinus conchatus*. *P. igniarius* can be used for treatment of humans infected by viruses H5N1 and H3N2. These authors state also *P. hartigii*, *P. laevigatus*, *P. laricis*, *P. lundellii*, *P. punctatus* and *P. tremulae* as the species that have various biological activities.

The COVID-19 epidemic caused by the SARS-CoV-2 virus has led to a large amount of research to develop effective inhibitors to block the interaction of SARS-CoV-2 virus spikes and angiotensin-converting enzyme (ACE2) on the human cell membrane. In this way, the entry of the virus into a cell is obstructed or blocked. Five aromatic cadinane sesquiterpenoids have been isolated by chemical analysis of fruiting bodies of *P. pini*, four of which are new, named piniterpenoids (A, B, C and D), as well as three known lignans. All the aromatic cadinane sesquiterpenoids inhibited the interaction of SARS-CoV-2 spikes and ACE2, with the values of $IC_{50}$ in the range from 64.5 to 99.1 μM. These results have shown that aromatic sesquiterpenoids of *P. pini* can be useful in the development of agents for supressing the virus SARS-CoV-2 (L i, X., et *al*., 2021).

Out of the aqueous extract (hot water) of *P. pini* Lee, S.M., et *al*. (2010) have isolated the compounds EP-AV1 and EP-AV2. They have determined that those are polysaccharides which consist of glucose as the main sugar residue, as well as other secondary sugars such as galactose, xylose, and mannose. They represent the variants of β-1,3-glucan, with high molecular masses. In addition, these polymers contain up to 10% of phenolic compounds. In further research, these polysaccharides have shown antiviral activity against herpes simplex virus 1 (HSV-1).

According to Kakumu *et al*. (1991), patients suffering from hepatitis B virus can use polysaccharide sizophyran (SPG), since it enhances immune response of the organism to the virus, increasing especially the production of interferon gamma (IFN-γ).

Reverse transcriptase is one of the main enzymes in replication of human immunodeficiency virus (HIV virus). The compound obtained by extraction of fruiting bodies of 16 species of fungi in hot water inhibits reverse transcriptases and in this way stops replication of the HIV virus. Extracts of *Lactarius camphoratus*, *Trametes suaveolens*, *Sparassis crispa*, *Pleurotus sajor-caju*, *Pleurotus pulmonarius* and *Russula paludosa* show inhibition over 50% in the concentration of 1mg/mL.

The greatest inhibitory activity (97.6%) has been shown by extract of *R. paludosa*. Extract of *S. crispa* has shown inhibition of 70.3% in the concentration of 1 mg/mL, but it has not been determined which component of the extract causes it. (Wang, J., *et al.*, 2007).

## 5. CONCLUSION

Based on the obtained results we concluded the following:

- Numerous lignicolous fungi have some antiviral properties;
- Compounds with antiviral properties are most frequently isolated from aqueous extract of mycelia or fruiting body;
- Polysaccharides of fungi (D-fraction of polysaccharides, lentinan, eritadenine, various variants of β-1,3-glucan and sizophyran), aromatic sesquiterpenoides (piniterpenoides A, B, C and D) and triterpenes (ganoderic acid beta, lucidumol B, ganodermanondiol, ganodermanontriol, and ganolucidic acid A) have antiviral properties;
- The researched fungi have shown effect against the following viruses: influenza virus A, (subtypes H5N1, H3N2, H9N2 and H1N1), influenza virus B, herpes simplex virus (HSV-1 and HSV-2), herpes zoster virus, virus causing hepatitis A, B and C and HIV virus;
- Fungi *L. edodes* and *P. pini* can be used in fight against the epidemic of COVID-19 acting in different ways. Lentinan blocks cytokine storm in patients, while aromatic sesquiterpenoids *P. pini* obstruct or block entry of virus into a cell;
- For a more significant application of fungi in treatment of viral diseases a better knowledge of the mechanism of action of antiviral compounds as well as significantly larger number of laboratory and clinical tests are necessary. For now, fungi can be used as auxiliary remedy for treatment of viral diseases.

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# ANTIVIRAL PROPERTIES OF LIGNICOLOUS FUNGI OF SERBIA

*Zlatan RADULOVIĆ, Dragan KARADŽIĆ, Ivan MILENKOVIĆ,*
*Katarina MLADENOVIĆ, Jelena BOŽOVIĆ*

## Summary

Viruses cause great epidemics on all continents, which leads to severe symptoms and mortality in humans and enormous treatment costs. In addition, the constant emergence of new strains represents an additional challenge in the fight against viruses. Thanks to the content of immunomodulatory polysaccharides, proteins, polysaccharide-protein complexes, polyphenols, steroids, triterpenoids, fatty acids, nucleotides, pigments, and polyacetylene components, fungi started to be used for obtaining antibiotics and other medicines. The antiviral properties of fungi and the possibility of their application in the treatment of various human diseases caused by viruses have been discovered lately. The studies showed that polysaccharides of fungi (D-fraction of polysaccharides lentinan, eritadenine, various variants of β-1,3-glucan and sizophyran), aromatic sesquiterpenoides (piniterpenoides A, B, C and D) and triterpenes (ganoderic acid beta, lucidumol B, ganodermanondiol, ganodermanontriol, and ganolucidic acid A) have antiviral properties. The researched fungi showed effect against the following viruses: influenza virus A (subtypes H5N1, H3N2, H9N2 and H1N1), influenza virus B, herpes simplex virus (HSV-1 and HSV-2 ), herpes zoster virus, virus causing hepatitis A, B and C and HIV virus. Fungi *L. edodes* and *P. pini* can be used in the fight against COVID-19 epidemic having effect in different ways. Lentinan blocks cytokine storm in patients while aromatic sesquiterpenoids of *P. pini* obstruct or block entry of viruses into a cell. For more significant application of fungi in treatment of viral diseases better knowledge of the mechanism of action of antiviral compounds is necessary as well as significantly larger number of laboratory and clinical tests. For now, fungi can be used as auxiliary remedy for treatment of viral diseases.

# ANTIVIRUSNA SVOJSTVA LIGNIKOLNIH GLJIVA

*Zlatan RADULOVIĆ, Dragan KARADŽIĆ, Ivan MILENKOVIĆ,*
*Katarina MLADENOVIĆ, Jelena BOŽOVIĆ*

## Rezime

Virusi izazivaju velike epidemije na svim kontinentima, što dovodi do teških simptoma i smrtnosti kod ljudi, i ogromnih troškova lečenja. Pored toga, stalna pojava novih sojeva predstavlja dodatni izazov u borbi protiv virusa. Zahvaljujući sadržaju imunomodulirajućih polisaharida, proteina, polisaharidno-proteinskih kompleksa, polifenola, steroida, triterpenoida, masnih kiselina, nukleotida, pigmenta i poliacetilenskih komponenti, gljive su počele da se koriste za dobijanje antibiotika i drugih lekova. U poslednje vreme su otkrivena antivirusna svojstva gljiva i mogućnost njihove primene u lečenju raznih bolesti čoveka izazvanih virusima. Istraživanja su pokazala da antivirusna svojstva imaju polisaharidi gljiva (D -frakcija polisaharida, lentinan, eritadenin, različite varijante β-1,3-glukana i sizofiran), aromatični seskviterpenoidi (piniterpenoidi A, B, C i D), i triterpeni (beta ganoderinska kiselina, lucidumol B, ganodermanondiol, ganodermanontriol i ganolucidna kiselina A). Proučavane gljive su pokazale dejstvo protiv sledećih virusa: virus gripa A (podtipovi H5N1, H3N2, H9N2 i H1N1), virus gripa B, herpes simpleks virusa (HSV-1 i HSV-2), herpes zoster virusa, virusa izazivača hepatitisa A, B i C i HIV virusa. Gljive *L. edodes* i *P. pini* mogu se koristiti u borbi protiv epidemije COVID-19 delujući na

različite načine. Lentinan kod pacijenata blokira citokinsku oliju dok aromatični seskviterpenoidi *P. pini* ometaju ili blokiraju ulazak virusa u ćeliju. Za značajniju primenu gljiva u lečenju virusnih bolesti neophodno je bolje poznavanje mehanizma delovanja antivirusnih jedinjenja kao i znatno veći broj laboratorijskih i kliničkih testiranja. Za sada se gljive mogu koristiti kao pomoćno sredstvo za lečenje virusnih bolesti.

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# TRADITIONAL MEDICINAL USE OF SILVER BIRCH IN THE PIROT DISTRICT (SERBIA)

*Marija S. MARKOVIĆ[1]*, Biljana M. NIKOLIĆ[1], Dejan S. PLJEVLJAKUŠIĆ[2], Ljubinko B. RAKONJAC[1], Sonja Z. BRAUNOVIĆ[1], Filip A. JOVANOVIĆ[1], Vesna P. STANKOV JOVANOVIĆ[3]*

**Abstract:** *A total of 631 informants were surveyed on the knowledge and use of medicinal plants, in the four municipalities of the Pirot District. Betula pendula (silver birch) was mentioned by 11 respondents for the following applications: against urinary tract inflammation, kidney and bladder diseases, gastric bacteria, kidney and bile sand, kidney and urinary tract diseases, prostate disease, proteins in the urine, and for kidney and urinary tract regeneration. The medicinal uses of silver birch leaves against gastric bacteria, as well as the use of the juice from birch tree for kidney and urinary tract regeneration can be considered novelties in our research because they were not mentioned in previously published ethnobotanical papers on the Balkans.*
**Keywords:** *Betula pendula*, silver birch, medicinal use, Pirot District

# TRADICIONALNA LEKOVITA UPOTREBA BREZE U PIROTSKOM OKRUGU (SRBIJA)

**Sažetak:** *Anketiran je 631 ispitanik o poznavanju i korišćenju lekovitih biljaka u četiri opštine Pirotskog okruga.. Betula pendula (breza) je pomenuta od strane 11 ispitanika za sledeće primene: protiv urinarnih infekcija, lečenje bešike i bubrega. protiv bakterija u želudcu, bubrežnog i žučnog kamenca, bolesti bešike i bubrega, bolesti prostate, i proteina u mokraći i za regeneraciju bubrega i mokraćnih kanala. Lekovita upotreba listova breze protiv bakterija u želudcu, kao i uopotreba soka iz drveta breze za regeneraciju bubrega i mokraćnih kanala mogu se smatrati novinama našeg istraživanja, jer nisu pomenute u prethodno publikovanim etnobotaničkim radovima na Balkanu.*
**Ključne reči:** *Betula pendula*, breza, lekovita upotreba, Pirotski okrug

[1] Institute of Forestry, Kneza Višeslava 3, 11000 Belgrade, Serbia
[2] Institute for Medicinal Plant Research Dr Josif Pančić, Tadeuša Košćuška 1, 11000 Belgrade, Serbia
[3] Faculty of Sciences and Mathematics, University of Niš, Višegradska 33, 18000 Niš, Serbia
*Corresponding author. E-mail: markovicsmarija9@gmail.com

## 1. INTRODUCTION

*Betula pendula* Roth, commonly known as silver birch, is a species of tree in the family Betulaceae, native to Europe and parts of Asia, though in Southern Europe. Silver birch grows in rare light forests, especially after wildfire in the belt of oak forests (Marković, 2013). It is present in the Pirot District at Stara planina Mt and Ruj Mt.

The silver birch contains significant amounts of flavonoid heterosides, and also tannins, resins, saponins, and essential oil (Marković et al., 2020; Pelagić, 2009; Sarić, 1989).

Sarić (1989) and Tucakov (1990) mentioned the use of silver birch buds and leaves for urinary tract treatment because they help the excretion of salt and water. The buds are also used in cosmetics to make shampoo. Tasić et al. (2001) mentioned the use of silver birch leaves against rheumatic pain, arthritis, and gout. The leaves and bark are used against skin diseases (Sarić, 1989). According to Pelagić (2009), silver birch buds and leaves are used for the secretion of urine and bile. It is a mild disinfectant for the urinary tract, and it is good for sweating in case of colds and elevated body temperature. The same authors state that the juice that leaks in the form of syrup, when a young birch tree is cut in early spring, contains mineral substances and organic acids, and can be drunk against inflammation of the kidneys and bladder, as well as against gout and rheumatism.

Silver birch can only be harvested with appropriate permits, as it is a protected plant species in Serbia under national legislation (Službeni glasnik Republike Srbije, 2010).

This study aimed to collect and research traditional knowledge about the use of silver birch in the Pirot District for medicinal purposes. The aim of the research was also to find traditional forms of medicinal use of silver birch, which have not been recorded in previous ethnobotanical research on the Balkan Peninsula.

## 2. MATERIAL AND METHODS

Studies on the knowledge and use of medicinal plants were conducted in the form of a population survey. The questionnaires on the knowledge and use of medicinal plants included residents of 144 villages in four municipalities of the Pirot District: Pirot, Babušnica, Bela Palanka, and Dimitrovgrad. A total of 631 respondents were surveyed with the questionnaire on knowledge and use of medicinal plants, of which 337 were men and 294 were women. The results of a study on the traditional medicinal use of silver birch were compared with previous ethnobotanical research on the use of this species on the Balkan Peninsula.

## 3. RESULTS

According to the results of the questionnaire on the knowledge and use of medicinal plants, siver birch was mentioned by 11 respondents (6 men, 5 women), i.e. 1.9% of the total number of respondents. Out of a total of 4817 reports collected in the Pirot District, only 12 reports reported the medicinal use of birch (0.25%). In terms of national structure, 10 respondents were of Serbian nationality, and one respondent was of Bulgarian nationality. In the municipality of Pirot, 9 reports on the medicinal use of silver birch were given, in the municipality of Babušnica 1 report, in the municipality Bela Palanka 1 report, and in the municipality of Dimitrovgrad 1 report. The age of the respondents who mentioned the medicinal use of siver birch was 44 to 79 years.

**Table 1.** *Overview of the survey results on the use of Betula pendula in the population of the Pirot District.*

| Municipality | Village | Nationality | Gender | Age | Plant part | Form | Medicinal use | Group |
|---|---|---|---|---|---|---|---|---|
| Pirot | Velika Lukanja | Srb. | M | 62 | folium | Infusion | Kidney and urinary tract diseases | Ur |
| Pirot | Visočka Ržana | Srb. | M | 64 | cortex | Decoction | Urinary tract inflammation | Ur |
| Pirot | Visočka Ržana | Srb. | Ž | 79 | folium | Infusion | Against gastric bacteria | Dg |
| Pirot | Vranište | Srb. | Ž | 46 | succus | Syrup | Kidney and utinary tract regeneration | Ur |
| Pirot | Gnjilan | Srb. | Ž | 78 | folium | Infusion | Urinary tract inflammation | Ur |
| Pirot | Mali Jovanovac | Srb. | M | 55 | folium | Infusion | Proteins in the urine | Ur |
| Pirot | Mali Jovanovac | Srb. | M | 55 | folium | Infusion | Prostate disease | Rp |
| Pirot | Ponor | Srb. | M | 77 | folium | Infusion | Kidney and bile sand | Ur |
| Pirot | Rsovci | Srb. | M | 60 | folium | Infusion | Urinary tract inflammation | Ur |
| Babušnica | Zavidince | Srb. | Ž | 44 | folium | Infusion | Kidney and bladder diseases | Ur |
| Bela Palanka | Klisura | Srb. | M | 56 | folium | Infusion | Kidney and bladder diseases | Ur |
| Dimitrovgrad | Boljev Dol | Bug. | Ž | 57 | folium | Infusion | Urinary tract inflammation | Ur |

**Note:** Group of diseases: Dg – digestive, Ur – urinary, Rp – reproductive.

Leaves of silver birch were most often used in the form of an infusion (10 reports), and less often bark in the form of decoction (1 report), or juice from the three in the form of syrup (1 report) (Table 1, 2).

**Table 2.** *Medicinal uses of silver birch mentioned by respondents with parts of plant and forms used.*

| Medicinal use | Number of respondents | Part/parts of the plant | Form |
|---|---|---|---|
| Urinary tract inflammation | 3 | leaf (*folium*) | infusion |
| Urinary tract inflammation | 1 | bark (*cortex*) | decoction |
| Kidney and bladder diseases | 2 | leaf (*folium*) | infusion |
| Kidney and bile sand | 1 | leaf (*folium*) | infusion |
| Kidney and urinary tract diseases | 1 | leaf (*folium*) | infusion |
| Kidney and urinary tract regeneration | 1 | juice from three | succus |
| Prostate disease | 1 | leaf (*folium*) | infusion |
| Proteins in the urine | 1 | leaf (*folium*) | infusion |

The greatest number of respondents mentioned internal use against urinary tract inflammation of the birch leaves (3 reports) in the form of an infusion, and birch bark (1 report) in the form of decoction (Table 1, 2). The twice-mentioned medicinal use of silver birch leaves in the form of infusion was against kidney and bladder diseases. One respondent each mentioned the use of leaves in the form of infusion against gastric bacteria, kidney and bile sand, kidney and urinary tract diseases, prostate disease, and proteins in the urine. One respondent mentioned the use of juice from the three in the form of syrup for the treatment of kidney and urinary tract regeneration (Table 1 and 2).

## 4. DISCUSSION

The results of our study are compared with previous ethnobotanical research on the traditional medicinal use of plant species in the Balkans.

Šarić Kundalić et al. (2010) mentioned the use of silver birch in Bosnia against renal gravel in the form of juice, and against renal ailments in the form of tea, which were similar medicinal uses, compared to our study.

Pieroni et al. (2011) recorded the use of silver birch against bruises externally during ethnobotanical research in Pešter in Southwestern Serbia, which had different medicinal uses compared to our research.

Popović et al. (2012) found that the population from Deliblato Sands used „sister" species *Betula verrucosa* internally as an anti-anemic, antiscorbutic, antihelmintic, antipyretic, diuretic, and antiseptic agent, which are different medicinal uses compared to our research.

Šavikin et al. (2013) mentioned the use of silver birch against hyperglycemia in the Zlatibor District, which was different compared to our study.

Mustafa et al. (2015) mentioned the use of the „sister" species *Betula alba* as a diuretic, and against urinary disorders, in Kosovo and Metohija, which were similar medicinal uses, compared to our study. The same authors mentioned the medicinal use against edema and alopecia, which are different medicinal uses compared to our research.

In the ethnobotanical research on Suva Planina Mt in Southeastern Serbia, Jarić et al. (2015) noted that silver birch was used for kidney problems, which are similar medicinal uses compared to our research.

Pieroni et al. (2015) reported the use of silver birch as a diuretic, which was similar applications compared to our research.

Saric Kundalic et al. (2016) noted the use of *B. pendula* against urogenital system disorders, which was similar medicinal uses, compared to our study. The same authors mentioned the uses against gall and liver ailments, malaria, irregular heartbeat, common cold, blood purification, skin ailments, and gout, which were different in comparison with our research.

Janaćković et al. (2019), noted for the Negotin Krajina the use of silver birch for immune system strengthening, which was different as in our research.

Matejić et al. (2020) mentioned for the Svrljig regions the use of silver birch against skin diseases, and productive cough, which were different in comparison with our research. The same authors mentioned for the Timok region the use of silver birch for the treatment of kidney colic, which was a different medicinal application compared to our research.

Mustafa et al. (2020) mentioned the use of silver birch for the treatment of the urinary system, and for the bladder, in Štrpce in the southern part of Kosovo and Metohija, which the respondents in our research also mentioned.

Mullalia et al (2021) in the Anadrini region of Kosovo and Metohija recorded the use of silver birch against prostate diseases, which was the same use as in our research. The same authors mentioned the medicinal use of silver birch against alopecia, which was a different use compared to our research.

The medicinal uses of silver birch leaves against gastric bacteria, and the use of the juice from the birch tree for kidney and urinary tract regeneration were not mentioned in previous ethnobotanical research on the Balkan Peninsula, so the mentioned uses can be considered the novelties of our research.

The protection of the populations of *B. pendula* in the Pirot District should be taken into consideration because it is on the list of protected species in Serbia (Službeni glasnik Republike Srbije, 2010).

## 5. CONCLUSION

Based on the presented data, which were obtained by surveying the rural population in four municipalities of the Pirot District, it can be concluded that the silver birch (*Betula pendula*) was usually used for a urinary group of diseases: kidney and urinary tract diseases in general, urinary tract inflammation, kidney and bladder diseases, kidney and bile sand, prostate disease, and proteins in the urine. Silver birch was used in the Pirot District less often for the group of digestive diseases (against gastric bacteria), and group of reproductive diseases (prostate disease).

Different and new uses, which were mentioned by respondents in the Pirot District in comparison with previous research on the Balkan Peninsula, were the use of birch leaves in the form of infusion against gastric bacteria, and the use of juice from trees for kidney and urinary tract regeneration.

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## TRADITIONAL MEDICINAL USE OF SILVER BIRCH IN THE PIROT DISTRICT (SERBIA)

*Marija S. MARKOVIĆ, Biljana M. NIKOLIĆ, Dejan S. PLJEVLJAKUŠIĆ, Ljubinko B. RAKONJAC, Sonja Z. BRAUNOVIĆ, Filip A. JOVANOVIĆ, Vesna P. STANKOV JOVANOVIĆ*

**Summary**

The subject of this paper was the investigation of the ethnopharmacological application of silver birch in the Pirot District. The study was conducted in the form of surveys among the rural population (631 informats) in four municipalities Pirot, Babušnica, Bela Palanka, and Dimitrovgrad. The results were compared with previous ethnobotanical research on the medicinal use of this plant species on the Balkan Peninsula.

Silver birch (*Betula pendula*) was mentioned by 11 respondents. Four respondents reported the internal use of birch against urinary tract inflammation, of which three respondents reported the use of leaves in the form of infusion, and one respondent reported the use of bark in the form of decoction. Two respondents reported the use of birch leaves in the treatment of kidney and bladder diseases. One respondent each reported the use of leaves in the form of infusion against gastric bacteria, kidney and bile sand, kidney and urinary tract diseases, prostate disease, and proteins in the urine. One respondent mentioned the use of juice from the three in the form of syrup for kidney and urinary tract regeneration.

The medicinal uses of silver birch leaves against gastric bacteria, as well as the use of the juice from birch tree for kidney and urinary tract regeneration were not mentioned in previously published ethnobotanical papers on the Balkan Peninsula, so the mentioned applications can be considered the novelties of this research.

# TRADICIONALNA LEKOVITA UPOTREBA BREZE U PIROTSKOM OKRUGU (SRBIJA)

*Marija S. MARKOVIĆ, Biljana M. NIKOLIĆ, Dejan S. PLJEVLJAKUŠIĆ, Ljubinko B. RAKONJAC, Sonja Z. BRAUNOVIĆ, Filip A. JOVANOVIĆ, Vesna P. STANKOV JOVANOVIĆ*

## Rezime

Predmet ovog rada bilo je proučavanje etnofarmakološke upotrebe breze u Pirotskom okrugu (Jugoistočna Srbija). Istraživanje je sprovedeno u vidu ankete među ruralnim stanovništvom (631 ispitanik) u četiri opštine: Pirot, Babušnica, Bela Palanka i Dimitrovgrad. Rezultati su upoređeni sa prethodnim etnobotaničkim istraživanjima o lekovitoj upotrebi ove biljne vrste na Balkanskom poluostrvu.

Breza (*Betula pendula*) je pomenuta od strane 11 ispitanika. Četiri ispitanika su pomenula unutrašnju upotrebu breze protiv urinarnih infekcija, od kojih su tri ispitanika pomenula upotrebu listova u vidu infuzuma, a jedan ispitanik je pomenuo upotrebu kore u vidu dekokta. Dva ispitanika su pomenula upotrebu listova breze za lečenje bešike i bubrega. Po jedan ispitanik je pomenuo upotrebu listova breze u vidu infuzuma protiv bakterija u želudcu, bubrežnog i žučnog kamenca, bolesti bešike i bubrega, bolesti prostate, i proteina u mokraći. Jedan ispitanik je pomenuo upotrebu soka iz drveta u vidu sirupa za regeneraciju bubrega i mokraćnih kanala.

Lekovita upotreba listova breze protiv bakterija u želudcu, kao i upotreba soka iz drveta breze za regeneraciju bubrega i mokraćnih kanala nisu pomenute u prethodno publikovanim etnobotaničkim radovima na Balkanskom Poluostrvu, pa se pomenute upotrebe mogu smatrati novinama ovog istraživanja.

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# HEADQUARTERS FOR EMERGENCY SITUATION AS ELEMENTS OF THE RISK MANAGEMENT SYSTEM FOR LARGE FOREST FIRES

*Goran ĐORĐEVIĆ[1], Tatjana DIMITRIJEVIĆ[2], Marko TOMIĆ[3], Vanja STOJANOVIĆ[2], Tatjana ĆIRKOVIĆ-MITROVIĆ[2], Ljiljana BRAŠANAC-BOSANAC[2]*

**Abstract:** *In recent years, forest fires are becoming more frequent, which is partly a consequence of global warming and the appearance of extremely hot summers, more frequent occurrences of drought, as well as increased wind intensity, but primarily as a consequence of great human carelessness and sometimes evil intentions. Large forest fires are a serious danger and their occurrence and spread directly endangers people, buildings, material goods and the environment. Emergency situation during this type of fires can be declared when a large area of quality forest is affected, when there is an immediate danger to people, material goods or the environment. When declaring an emergency situation, emergency headquarters and expert operational teams are activated whose task is to manage the risk in forest fire protection and to take measures to reduce the risk and protect people and material goods. The functioning of the operations centers and the effective implementation of measures have a direct impact on the efficiency of extinguishing large forest fires and the degree of efficiency in protecting people, buildings and property. The main goal of this paper was the analysis of the work and significance of the headquarters for emergency situation as a risk management factor in forest fire protection.*
**Keywords:** emergency headquarters, forest fire, GIS, risk, legal regulations

# ŠTABOVI ZA VANREDNE SITUACIJE KAO ELEMENTI SISTEMA UPRAVLJANJA RIZIKOM KOD VELIKIH ŠUMSKIH POŽARA

**Sažetak:** *Šumski požari sve su češći, kao posledica globalnog zatopljenja i pojave ekstremno toplih leta i češćih pojava suše, narušene stabilnosti kišne sezone i pojačanog intenziteta vetrova, ali prvenstveno kao posledica velike ljudske nepažnje, a ponekad i zle namere. Veliki šumski požari predstavljaju ozbiljnu opasnost i njihovo pojavljivanje i širenje direktno ugrožavaju ljude, materijalna dobra i životnu sredinu. Vanredna situacija prilikom nastanka ove vrste požara može biti proglašena kada je zahvaćena velika površina kvalitetne šume, kada preti neposredna opasnost za ljude, objekte i materijalna dobra, ili je u većoj meri ugrožena životna sredina. Prilikom proglašenja vanredne situacije aktiviraju se štabovi za vanredne situacije i stručno operativni timovi čiji je zadatak da upravljaju rizikom u zaštiti šuma od požara i preduzimaju mere kako bi se umanjio rizik i zaštitili ljudi i materijalna*

[1]Academy of Vocational Technical Studies, Serbia
[2]Institute of Forestry, Kneza Višeslava 3, Belgrade, Serbia
[3]PE NP "Tara" Bajina Bašta
*Corresponding author. E-mail: tatjana.cirkovic@forest.org.rs

*dobra. Način rada štaba za vanredne situacije i efikasno preduzimanje mera direktno utiče na efikasnost u gašenju velikih šumskih požara i stepen efikasnost zaštite ljudi, objekata i materijalnih dobara. Osnovni cilj ovog rada bila je analiza funkcionisanja i značaja štabova za vanredne situacije kao faktora upravljanja rizikom u zaštiti od požara u šumama.*

**Ključne reči:** štab za vanredne situacije, šumski požar, GIS, rizik, zakonski propisi

## 1. INTRODUCTION

Wildfires are the most extreme form of devastation or complete destruction of forests. The damage they inflict and the consequences they cause, as well as the forest area they destroy every year, make wildfires a worldwide problem that requires the involvement of all social institutions and entities in their prevention and suppression. More than 50,000 forest fires occur worldwide every year, destroying approximately 400,000 hectares of forests. The increasing number of forest fires is in correlation with a number of factors, the most common of which are: the frequency and duration of drought periods, the increasing presence of people in forests, non-compliance with legislation, etc. The occurrence of forest fires depends on climate conditions, humidity, the amount of flammable plant material and human activity (Ratknić, T. et al. 2018, Ratknić, T. et al. 2021).

Large forest fires are a danger and their occurrence and spread pose a danger to people, buildings, material goods and the environment. When large forest fires occur, a large organization is needed to remedy them, and under certain conditions, an emergency situation can be declared, in order to establish an organization that will more easily confront the raging fire. In such cases, emergency headquarters are activated and all structures are involved in order to reduce the risk and effectively fight the fire. The success of extinguishing operations depends on the way of organization and the use of all resources in preventing the spread of fire and protecting people and material goods. The risk management system in all its phases can use emergency headquarters as an element of forest fire protection.

## 2. METHODOLOGY

In this research, the method of analysis, generalization us well us integral approach have been applied.

To study the set of measures and procedures for prevention, preparedness and response to emergency situation caused by forest fires, method of analysis was applied. Law on Emergency Situations (Official Gazette of the RS, no. 111/2009, 92/2011, 93/2012), Law on Reducing the Risk of Emergency Management (Official Gazette of the RS, no. 87/2018) and Regulation on the composition, method and organization of the work of emergency headquarters (Official Gazette of the RS, no. 27/2020), was analyzed.

Method of generalization was used for the recommendations and proposals of measures in emergency situation as elements of the risk management system for large forest fires in Serbia. The integral approach involved looking at current regulations, guidelines and recommendations for the role of emergency headquarters as a risk management factor in forest fire protection. Suggestions were made for improving legal solutions in the area of their better functioning.

# 3. RESULTS

## 3.1 Risk management system in forest fire protection

Risk management involves a set of measures and procedures for prevention, preparedness, response to an unwanted event (accident) as well as remediation of the consequences of an unwanted event in order to reduce the risk and create conditions under which the risk can be more acceptable.

The consequences of forest fires (Đorđević, G., 2012) can be:

- Very severe - Large area affected by fire (several hundred hectares), with human casualties and major material damage to buildings;
- Severe - Large area affected by fire, without human casualties and major material damage to buildings;
- Medium-severe - Medium area affected by fire (several tens of hectares) and damage to buildings with certain material damage;
- Minimal - Smaller area affected by the fire (less than ten tens of hectares);
- Insignificant - Small area affected by fire (of several $m^2$).

Efficient risk management in forest fire protection consists of four operating modes that complement each other and influence each other. Figure 1 shows a general scheme of elements of risk management in forest fire protection.

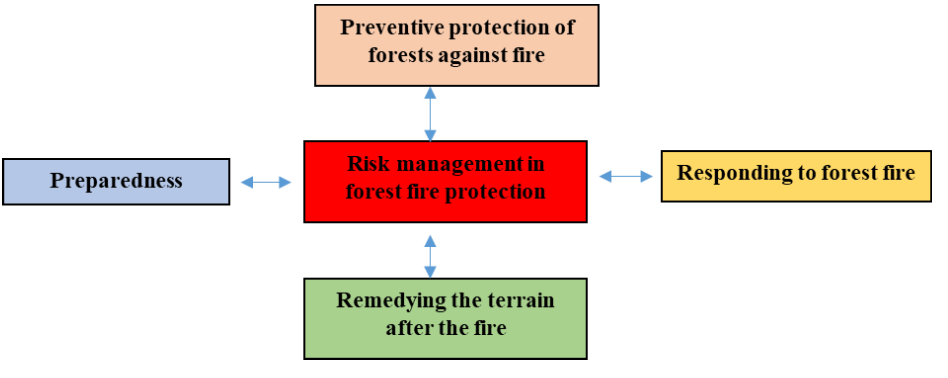


**Figure 1.** *General scheme of risk management elements in forest fire protection*

## 3.2 Emergency situation and responsibility of emergency headquarters

### 3.2.1 The concept of an emergency situation and the method of declaration

According to the "Law on Emergency Situations" (*Official Gazette of the RS", no. 111/2009, 92/2011, 93/2012*), a state of emergency is declared when the risks and threats or the resulting consequences of a catastrophe for the population, material and cultural goods or the environment are of such a scale and intensity that their occurrence or consequences cannot be prevented or eliminated by the regular action of the competent authorities and offices, which is why their mitigation and elimination require the necessary use of special measures, additional forces and resources and enhanced work regime.

When it comes to forest fires, an emergency situation is most often declared when the event also occurs when it takes on a large scale and threatens the population, buildings and material goods. It is necessary to declare an emergency situation when there are extreme conditions for the occurrence of forest fires in order to take measures that will prevent the occurrence of forest fires.

In *Law on Emergency Situations* (*Official Gazette of the RS", no. 111/2009, 92/2011, 93/2012)* an emergency situation is declared by:

- For the territory of the Republic of Serbia – the Government at the proposal of the state headquarters for emergency situations.
- For the territory of the autonomous province – the Executive body of the autonomous province at the proposal of the provincial headquarters for emergency situations.
- For the territory of the city or part of the city – the mayor at the proposal of the city headquarters for emergency situations.
- For the territory of the city municipality – the president of the municipality at the proposal of the headquarters for emergency situations of the city municipality.
- For the territory of the municipality – the president of the municipality at the proposal of the municipal headquarters for emergency situations.

#### 3.2.1.1 Work of emergency headquarters during large forest fires

a) In order to prevent forest fires, the duties and tasks of the headquarters for emergency situations are:
   - Holding meetings in times of immediate danger of forest fires and discussing the risks for their occurrence and the possibility of preventive measures.
   - Contacting and exchanging information with meteorological services about weather conditions and monitoring weather alarms and analyzing the possibility of fire.
   - Contacting and consulting with institutions and experts dealing with forest protection and preparing measures to be taken to prevent fire (for example, the interactive map in GIS is the basis of the forest fire risk management system - Figure 2).
   - Giving recommendations, conclusions and orders regarding the danger and taking measures to reduce the risk (for example, place the cameras and visibility zones of area for the purpose of timely forest fire registration - Figure 3).
   - Putting on standby all entities that deal with protection and have means, equipment, technique and expert staff for forest fire protection.
   - Reviewing and analyzing forest fire protection plans and making sure that measures from the plans are followed.
   - Forming a professional operational team for fire protection and experts who deal with forest fire protection and including them in the work of the headquarters.

- Activating the monitoring system of areas under the forest in the area where danger threatens and analyzing the ways of quick fire alarm if a fire occurs.
- Examining the condition of fire-fighting equipment as well as the water intakes of water supply for fire-fighting and issuing orders in case of deficiencies.
- Taking care of informing the public about dangers and providing notifications and warnings through public information media.
- Maintaining constant contact with professional services and is consulting on measures to be taken to reduce risk.

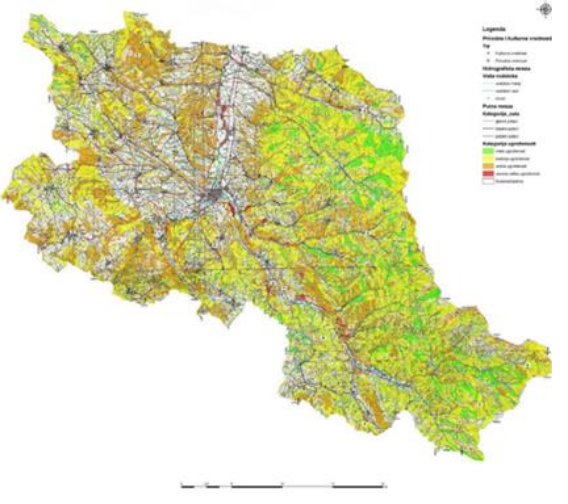

**Figure 2.** *The interactive map in GIS is the basis of the forest fire risk management system (Municipality of Knjaževac)*
(Source: Ratknić T. et al., 2021)

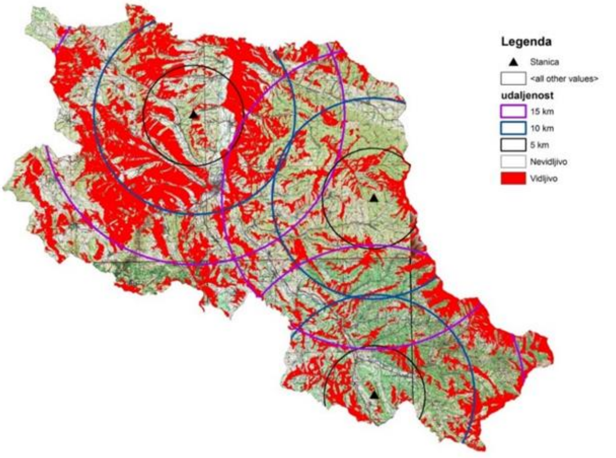


**Figure 3.** *Map of located cameras and visibility zones for the area of the Municipality of Knjaževac*
*(Source: Ratknić T. et al., 2021)*

b) When a forest fire occurs, the duties of the headquarters for emergency situations are observing, and analyzing the situation and evaluating further events. It is necessary to get involved in the work of all structures at the local level that participate in the remediation of the consequences. The headquarters coordinate the work all public services that participate in the remediation of the consequences trough the:
   - Holding regular meetings and making recommendations and conclusions.
   - Coordinating providing and procuring equipment for remediating the consequences and means for extinguishing fires.
   - Monitoring the development of events, the spread of fires and coordinating the work of all entities.
   - Communicating and coordinating work with other headquarters for emergency situations if the fire has affected the area of several municipalities.
   - Seeking help from other authorities and offices if the situation requires it (use of the army, etc.).
   - Organizing the evacuation and medical assistance of the population according to elaborate plans.
   - Providing necessary provisions and food for people who are threatened by the fire.
   - Coordinating and ensuring that all infrastructure facilities and water supply for the population are in order.
   - Reporting and providing information through the means of public information.
   - Forming and coordinating volunteer teams and involving them in the work.

c) The work of the headquarters for emergency situations after the event are:
   - Forming the commission and assessing the damage.
   - In cooperation with expert services, consulting and providing assistance in terrain remediation.
   - Hiring machinery and other equipment for remediation.
   - Helping people whose buildings and property have been damaged by fire.
   - Making recommendations, conclusions and orders regarding the current situation.
   - If is necessary, ordering permanent on-duty staff and assistance in the area after the forest fire.

### 3.2.1.2 Organization of municipal headquarters for emergency situations

According to the Official Gazette of the RS, no. 27/2020, Headquarters for emergency situations are organized at several levels, namely: Republic Headquarters, Provincial Headquarters, District Headquarters, City Headquarters, and Headquarters for Emergency Situations of the City Municipality and Municipal Headquarters for Emergency Situations. Municipal Headquarters for emergency situations as the most frequent participants in risk mitigation and risk management in forest fire protection.

The municipal headquarters for emergency situations consists of the Commander, Deputy Commander, Chief and members of the headquarters (representatives of municipal authorities, managers of public enterprises and companies, representatives of the Ministry of Internal Affairs, representatives of the Serbian Army, the Serbian Red Cross, citizens' associations, other legal entities and institutions and others in accordance with the proposal of the municipal administration and the organizational unit of the competent office for the territory of the municipality).

### 3.3 Phases in the work of emergency headquarters

The headquarters for emergency situations implements its activities through three phases: preventive phase, operational phase and recovery phase.

Activities in the preventive phase include the organization and implementation of tasks and measures implemented by the headquarters in the period before an emergency situation. The headquarters for emergency situations conducts activities to review the state of readiness for an organized response to risks and threats and familiarizes itself with the achieved level of development and building of the risk reduction and emergency management system.

The activities of the headquarters for emergency situations that are carried out in the operational phase are the direct management and coordination of subjects and forces of the risk mitigation system and the management of emergency situations in the affected territory in order to protect and save the lives and health of people, animals, material and cultural assets, the environment, infrastructure and other protected values.

After the end of the emergency situation, the analysis of the situation in the affected territory, in terms of the number and condition of the endangered and injured population, households, infrastructure, the analysis of the work of the participants and other necessary data as assessed by the emergency headquarters, are carried out.

The headquarters for emergency situations actively participates in the recognition of the need to undertake recovery measures, the organization and implementation of measures and tasks of restoration, reconstruction and remediation, taking into account the mitigation of the risk of future disasters.

### 3.4 Work of the headquarters during the risk of occurrence or occurrence of large forest fires

According to the Đorđević, G. (2012), in the case of extremely large fires, in addition to the head of the firefighting activity, there are:

- The Plan Manager, whose task is to provide maps and data after the reconnaissance, to monitor the meteorological situation and the development of fires, accept the replacement of personnel, provide supplies of water and food, inform the public.
- The Communication Manager ensures constant radio communication between the leaders of the firefighting activity, the municipal

headquarters and the head of the firefighting sector and the people participating in the firefighting on the extinguishing line.

- The Equipment Manager takes care of the reception and arrangement of firefighting equipment, the supply and provision of firefighting equipment, the supply of fuel, etc.
- Sector Managers manage the firefighting activity in their sector and coordinate the work of commanders in each sector.

Duties and tasks in the organization of extinguishing large fires are divided into four basic groups:

1. Planning activities (collection and analysis of information and creation of an action plan);
2. Activities on the fire line (safe, simultaneous execution of attacks and final extinguishing based on the extinguishing plan);
3. Insurance and support operations (insurance and deployment of personnel and equipment based on the established action plan);
4. Operations management tasks (coordination of all groups during firefighting, and implementation of all measures and tasks that ensure timely suppression of fire) (Đorđević, G. 2012).

In order to successfully extinguish all fires, regardless of their size, special attention is paid to firefighting plan, which is created on the basis of operational firefighting plans for specific areas, to which information is added about the specific fire that occurred. The preparation of the firefighting plan include fire reconnaissance, making a forecast of fire development and operational-tactical plan.

Depending on the size of the fire, the reconnaissance is carried out by the head of the extinguishing operation himself or by sector managers. The most complete information about large fires is often obtained from aerial reconnaissance.

Very important element in risk management in forest fire protection is the remediation of the terrain, that is, the actions and measures taken after extinguishing the forest fire. This element corresponds to the post-risk regime when the damaged system must be restored to its normal function. The duration of these activities depends on the degree of damage to the system and the possibility of remediation. In the forest after a fire, two comparative negative processes most often develop: the washing of the nutrient substrate from the soil surface and the appearance of harmful insects and diseases. One of the ways to prevent these negative processes is the removal of burned trees from the area where the fire occurred and reforestation (Đorđević, G. 2012; Ratknić, T. et al. 2017, 2018; Ratknić, T, et al., 2021).

The tasks of expert-operational teams during large fires are:

- Analyzing the situation in extreme conditions for the occurrence of forest fires and giving recommendations and proposals to the headquarters for emergency situations.
- In extreme conditions of forest fires, suggesting preventive and organizational measures to prevent fires from occurring.
- Establishing contact with other services and carrying out coordination and exchange of information essential for mitigating the situation.

- Suggesting a way to mitigate risk based on the situation in the field and providing guidelines for action on fire and how to protect endangered buildings and infrastructure.
- Exchanging information with the meteorological service on data relevant to the speed and direction of fire spread.
- Proposing the type of equipment for effective firefighting and cooperating with the office in charge of firefighting.
- Considering forest fire protection plans and proposing measures for remediation after the fire (Đorđević, G., 2022).

## 4. CONCLUSION

The role of the headquarters for emergency situations during large forest fires and the declaration of emergency situations is very important, and success in risk management in forest fire protection depends on the organization and manner of operation of the headquarters. In areas where forest fires are frequent, organization in all segments of risk management is of crucial importance. That's why the headquarters for emergency situations should be trained and equipped for situations when there is a danger of forest fires. This implies in the organizational part that the headquarters are staffed with people who are experts or are involved in forest fire protection, representatives of authorities and organizations that can help in the event of forest fires, as well as the procurement of adequate firefighting equipment. Headquarters should be used in all segments of risk management in forest fire protection, especially when there are extremely dangerous periods from the occurrence of forest fires.

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Regulation on the composition, method and organization of the work of the headquarters for emergency situations *Official Gazette of the RS*, No.27/2020)

## HEADQUARTERS FOR EMERGENCY SITUATION AS ELEMENTS OF THE RISK MANAGEMENT SYSTEM FOR LARGE FOREST FIRES

*Goran ĐORĐEVIĆ, Tatjana DIMITRIJEVIĆ, Marko TOMIĆ, Vanja STOJANOVIĆ, Tatjana ĆIRKOVIĆ-MITROVIĆ, Ljiljana BRAŠANAC-BOSANAC*

The role of the headquarters for emergency situations during large forest fires and the declaration of emergency situations is very important, and success in risk management in forest fire protection depends on the organization and manner of operation of the headquarters. In areas where forest fires are frequent, organization in all segments of risk management is of crucial importance. That's why the headquarters for emergency situations should be trained and equipped for situations when there is a danger of forest fires. This implies in the organizational part that the headquarters are staffed with people who are experts or are involved in forest fire protection, representatives of authorities and organizations that can help in the event of forest fires, as well as the procurement of adequate firefighting equipment. Headquarters should be used in all segments of risk management in forest fire protection, especially when there are extremely dangerous periods from the occurrence of forest fires.

## ŠTABOVI ZA VANREDNE SITUACIJE KAO ELEMENTI SISTEMA UPRAVLJANJA RIZIKOM KOD VELIKIH ŠUMSKIH POŽARA

*Goran ĐORĐEVIĆ, Tatjana DIMITRIJEVIĆ, Marko TOMIĆ, Vanja STOJANOVIĆ, Tatjana ĆIRKOVIĆ-MITROVIĆ, Ljiljana BRAŠANAC-BOSANAC*

Uloga štabova za vanredne situacije prilikom velikih šumskih požara i proglašenja vanrednih situacija je vrlo važna, i od organizaciji i načina delovanja štabova zavisi i uspešnost u upravljanju rizikom u zaštiti šuma od požara. U područjima gde su šumski požari česti organizacija u svim segmentima upravljanja rizikom je od presudnog značaja. Zato štabove za vanredne situacije treba obučavati i opremati i za situacije kada preti opasnost od šumskih požara. To podrazumeva u organizacionom delu da u štabovima budu ljudi koji su stručnjaci ili se bave zaštitnom šuma od požara, predstavnici organa i organizacija koje mogu pomoći prilikom šumskih požara kao i nabavku adekvatne opreme za gašenje požara. Štabove treba koristiti u svim segmentima upravljanja rizikom u zaštiti šuma od požara, a naročito kada postoje ekstremno opasni periodi od nastanka šumskih požara.

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

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