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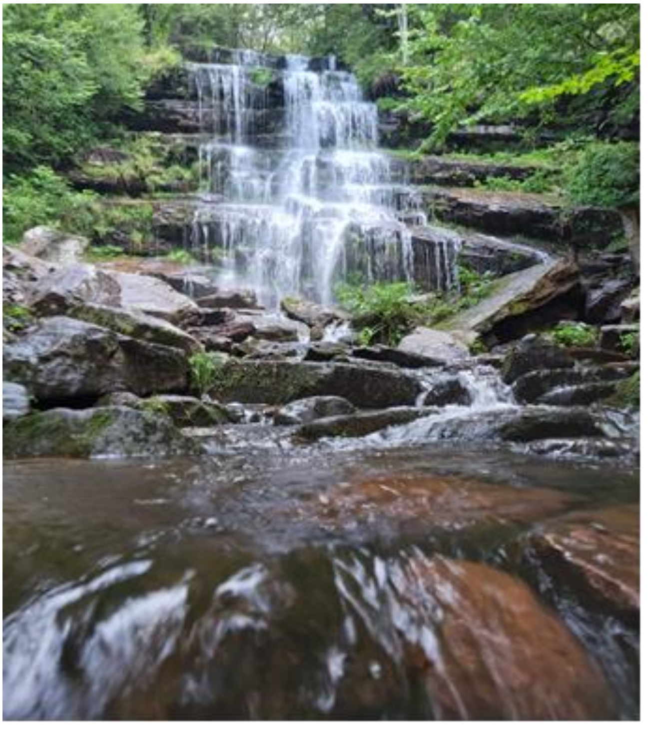

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Review paper

URBAN FORESTS AND CLIMATE CHANGE

Ljiljana BRAŠANAC-BOSANAC[1], *Tatjana ĆIRKOVIĆ-MITROVIĆ*[1], *Nevena ČULE*[1], *Goran ČESLJAR*[1], *Saša EREMIJA*[1], *Ilija ĐORĐEVIĆ*[1]

Abstract: *Spatial and urban plans have recently given an increased focus to the sensitive issue of planning the urban resilience of existing and establishing new urban forests. Urban forests are recognised as an extremely important factor of environmental quality, while scientific studies indicate that the health condition of urban forests is threatened by present-day climate change. There have been relatively few systematic assessments of the causes of tree die-back in urban areas in Serbia. Research, forest establishment planning and tree monitoring to estimate possible consequences to existing trees will enable city authorities and managing bodies to raise the issue of urban forest resilience to climate change to a higher level and incorporate it into urban planning. Future scenarios in which urban forests are resistant to potential adverse climate change will depend on the scope of activities of adaptive planning of urban forest establishment and adaptive management of existing ones. Therefore, it is necessary to conduct long-term studies of monitoring the condition of urban forests in the large cities of Serbia (Belgrade, Novi Sad, Niš, Subotica, etc.) in the coming period in order to identify specific problems and remediate the consequences such as deteriorated tree health condition and die-back.*

Keywords: urban planning, urban green space, adverse effects of climate factors, environmental protection.

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URBANE ŠUME I KLIMATSKE PROMENE

Izvod: *Prilikom izrade prostornih i urbanističkih planova poslednjih godina posebna pažnja poklanja se veoma osetljivoj i važnoj problematici planiranja otpornosti postojećih i podizanja novih urbanih šuma. Urbane šume su prepoznate kao izuzetno važan faktor poboljšanja kvaliteta životne sredine, a naučne studije ukazuju da je zdravstveno stanje urbanih šuma ugroženo novonastalim klimatskim promenama. Sistematske procene uzroka odumiranja stabala u urbanim sredinama u Srbiji su retke. Istraživanje, planiranje podizanja novih, kao i praćenje i sistematsko predviđanje mogućih posledica na postojećim stablima omogućiće upravljačima i gradskim vlastima da problematiku otpornosti urbanih šuma na klimatske promene podignu na viši nivo i inkorporiraju je u urbano planiranje. Budući scenariji u kojima su urbane šume otporne na moguće negativne klimatske promene zavisiće od sprovedenih aktivnosti adaptivnog planiranja podizanja novih urbanih šuma i adaptivnog upravljanja postojećim. Iz tog razloga potrebno je u narednom periodu sprovesti dugoročne studije monitoringa stanja urbanih šuma u većim gradovima Srbije (Beograd, Novi Sad, Niš, Subotica i dr.) kako bi se identifikovali konkretni problemi i sanirale posledice u vidu pogoršanja zdravstvenog stanja i sušenja stabala.*

Ključne reči: urbano planiranje, urbano zelenilo, negativan uticaj klimatskih faktora, zaštita životne sredine.

1. INTRODUCTION

According to data from the World Urbanization Prospects revision, about 50% of the world's population lives in urban areas (UN, 2018). By 2050, this proportion is expected to increase to 68%, and 6.6 billion people are then expected to live in urban areas. Spatial plans define urban forests and forest lands as areas under forest in or around human settlements. Considering the growing trend of urban population, urban forests and urban forestry as a branch of forestry are becoming increasingly important, especially in terms of the quality of life of urban residents.

According to projections of the impact of global climate change (IPCC 2000, 2007, 2009, 2014, 2014a, 2018), the Balkans will be characterised by more frequent temperature extremes, less precipitation in the summer, more river floods in the winter, variability in cereal yields, greater risk of forest fires and threatened stability of forest ecosystems. The Republic of Serbia is one of the countries in the hinterland of the Mediterranean region considered to be particularly affected by global climate change (Đurđević, 2018).

Extreme weather events are becoming increasingly frequent and serious, leaving devastating consequences behind. Numerous research results have revealed a range of potential risks and impacts reflected in urban forests and caused, above all, by climate change (Brune, 2016; Steenberg et al., 2017; Hilbert et al., 2019; Czaja et al., 2020; Esperson-Rodriguez et al., 2021). These consequences put additional pressure on existing social challenges such as poverty, social stratification, and endangered environment (deforestation, air, water and soil pollution etc.).

Remediation and prevention of the climate change effects in urban areas, including floods (due to increased intensity of precipitation), landslides and land subsidence, increased energy consumption for both cooling and heating, damage caused by storms, intense winds, and other weather disasters require effective measures and carefully selected activities at all decision-making levels. The so-called green infrastructure and urban forests within it play a prominent role in reducing and mitigating the adverse effects of climate change within urban areas (Kazmierczak 2010; Hirons 2019).

2. METHODOLOGY

The purpose of the research was to point out the vulnerability of urban forests to climate change, on the one hand, and the importance of healthy, resilient urban forests in the fight against climate change, on the other hand. If we raise the issue this way, it becomes clear that we are facing the effects of climate change that pose new kinds of structural challenges. These challenges cannot be dealt with independently within one area or a sector (e.g., forestry, environmental protection, urbanism, spatial planning, etc.). Therefore, this research applied a problem-based, integral and participative approach.

The problem-based approach to the importance of urban forests for the development and quality of life in large urban centers involved the use of numerous analytical instruments in order to clearly identify (target) existing problems, limitations and possible conflicts within urban areas and define measures to solve them.

The integral approach involved looking at current regulations, guidelines and recommendations regarding the adaptation to climate change in urban areas as defined by various international, EU and national institutions. The application of an integral approach further implied the introduction of new standards, i.e., harmonization with new global and European frameworks, policies and planning practices at all levels of decision-making in Serbia.

Urban environments are characterised by complex conditions and a myriad of conflicting interests and factors present in a given area. Therefore, to get a deeper insight and assess the feasibility of planning solutions, we had to apply a participatory approach. This approach was achieved through an analysis of the legal and planning provisions on different aspects and sectors of spatial planning at the local level.

The conclusions presented in the paper are based on findings from a variety of literature sources and examples of good practice.

3. RESULTS AND DISCUSSION

3.1. Urban forests – concept, significance, functions

Cities share a similar physical structure, consisting of "*grey infrastructure*" (residential and industrial buildings, roads, parking spaces), "*blue infrastructure"* (rivers, lakes, waterways) and "*green infrastructure"* (trees, shrubs, grasses and flowering plants). According to Miller et al. (2015), *green infrastructure* is a strategically planned network of green areas of various categories designed to provide a wide range of ecosystem services and biodiversity protection in urban and peri-urban environments.

Urban forests are critical components of urban environments. They include trees, shrubs with the accompanying soil and green belt vegetation in a variety of settings. They are the "backbone" that supports green infrastructure as they connect rural and urban areas and improve the ecological footprint of cities. They provide ecological diversity and form the main structural and functional elements that make cities and urban regions better places to live (Figure 1).

Figure 1. *Urban forests, 2022 (Orig.)*

3.2. Urban forests and climate change

Urban forest functions are most often classified as environmental, sanitary, hygienic, recreational and decorative-aesthetic (Lješević, 2005).

In recent years, urban forests have been gaining increasing importance and multi-purpose benefits, especially in the context of climate change, because they improve the urban microclimate, make conditions favourable for outdoor recreation and protect soil, buildings and sidewalks from overheating. Besides increasing the total area under vegetation, they improve the quality and quantity of stormwater, regulate the wind rose, reduce the effect of urban heat islands, reduce the total energy used to heat or cool buildings, etc.

Due to the large quantities of concrete, asphalt and metal built in urban structures and the high concentration of transport systems and industrial activities in and around the urban area, the average city temperature values are higher ("heat island effect"), the air is drier and often polluted, precipitation is less efficiently absorbed, and the noise is significantly higher than in rural areas.

Urban forests contribute to mitigating adverse climate effects in the following ways:

- <u>*Modification and mitigation of temperature extremes*</u>. Urban greenery can lower summer temperatures and heat in cities by 3-4°C (Vogt et al., 2017). Tree canopies create a specific forest microclimate that moderates weather extremes, which is important for the daily temperature variation, especially in summer and winter (Aram et al., 2019). Trees reduce the heating and radiation of buildings, sidewalks and roadways and help regulate the temperature in the urban environment by modifying solar radiation. According to Dawson (2007), a shade made by a large tree can reduce the temperature in buildings by as many degrees as 15 air conditioners (about 4220 kJ) would do in a similar but unshaded building.
- <u>*Increase in relative air humidity in the urban environment*</u>. Maintaining the humidity regime is one of the important ecological roles of green areas. In summer, plants exude a greater amount of moisture through the process of evapotranspiration. According to Lješević (2005), wide-crown trees and shrubs planted along sidewalks improve the street microclimate since 200 gr of water evaporates from 1 m^2 of a lawn, which significantly increases air humidity.
- <u>*The wind protection role.*</u> Greenery is more elastic than buildings, and thus withstands wind blows more easily than buildings. Within the greenery, the wind speed is reduced by 40-50%, and in a wide green zone with dense planting, the wind can be completely calmed. The best protection against the wind is provided by mixed stands of trees, shrubs, bushes and lawns, of different widths, but not less than 50 m (Lješević, 2005).
- <u>*Better quality and cleaner air.*</u> Trees improve air quality by releasing oxygen and removing air pollutants. Keller's (1979) research and measurements show that lead is reduced by about 85% behind shelterbelts. Trees absorb gaseous pollutants (such as carbon monoxide, nitrogen oxides, ozone and sulfur oxides) and filter fine particles, such as dust, dirt or smoke, from the air by trapping them on their leaves and bark. The same author states that one mature tree can absorb 48 lbs of CO_2 a year and release an amount of oxygen into the atmosphere enough for the life of two people.
- <u>*Energy saving*</u>. Proper design of tree planting around buildings can reduce the need for air conditioning by 30% and reduce winter heating bills by 20-50% The energy saved by planting trees around buildings is 10-50% for cooling and 4-22% for heating (Dawson, 2007).

Table 1. *The role of urban forests in climate change mitigation*

Issue	Benefits of urban forests
Emission of greenhouse gases	They sequester carbon and mitigate climate change.
Extreme weather events	They mitigate extreme events and have positive effects on the microclimate.
The "heat island" effect	They make shade and lower the temperature.
Floods	They mitigate torrential waters and reduce flooding.
Exposure to harmful sun rays	They provide shade.
Lack of energy	Energy saving through shading/cooling, firewood production.

3.3. The impact of climate change on urban forests and possible adaptation

The occurrence and survival of vegetation in an area, its distribution and altitude differentiation depend on a range of environmental conditions, including the climate characteristics of the area, primarily the air temperature and amount of precipitation. Climate change, caused by natural variations or human activity, increases the frequency and consequences of extreme weather events such as heat waves, droughts, floods, strong winds, etc., and negatively affects both individual trees and larger areas of urban forests (Brandt et al., 2016, Hilbert et al., 2019, Esperon-Rodriguez et al., 2021).

Tree decline in urban areas often results from the long-term, continuous accumulation of effects of various stress factors (Czaja et al, 2020) and interactions between them (extreme weather, pests and diseases, herbivores, unplanned construction and usurpation of green areas). Tree decline can also be caused by improper forest management, selection of inappropriate plant species, poor quality planting stock, inappropriate place or planting technique, poor site preparation, lack of maintenance, etc. Due to some forest disturbance, caused either by human activity (forest cutting, etc.), or a natural cycle (environmental disruption, death of old trees, pest attacks and diseases, etc.), forest ecosystems can start releasing stored CO_2 back into the atmosphere (Brašanac-Bosanac, 2013) and instead of purifying the air, they emit harmful substances.

Drought has a particularly harmful effect on forest ecosystems, as it can cause damage, diseases and dieback of both individual trees and larger areas. The changes and consequences observed through the analysis of numerous indicators of the state and changes in the urban greenery can give us a long-term perspective and guidelines for managers of resources on how to achieve adaptation and preventive protection (Figure 2).

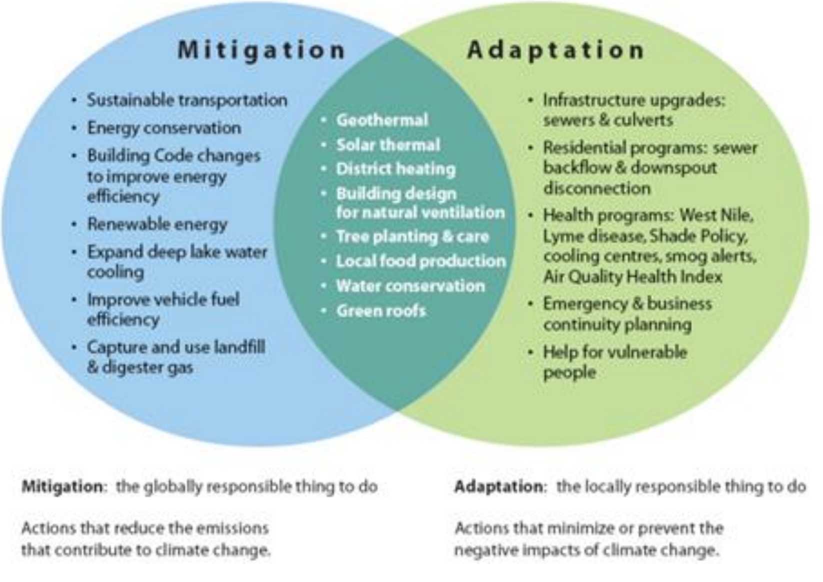

Figure 2. *Green spaces as means to both mitigate and adapt to climate change (Source: Kazmierczak, A., Carter, J., 2010)*

3.4. Legislation regulating the issue of urban forests

The issues of green infrastructure, environmental protection of urban areas and the impact of climate change on life in them are analysed have been defined by numerous strategic documents and regulations of the European Union. Particularly significant documents and regulations are *Paris Agreement 2015* (UNFCCC, 2015), *European Green Deal 2019-2024* (EU Commission, 2019), *Forging a climate-resilient Europe – the new EU Strategy on Adaptation to Climate Change 2021* (EUR-Lex, 2021), *Cooling buildings sustainably in Europe: exploring the links between climate change mitigation and adaptation, and their social impacts* and others ((EEA 2022). Serbia has legislation related to climate change and adaptation to it (Brašanac-Bosanac, 2014). However, there are no regulations and strategies directly relating to the importance and condition of urban forests and green infrastructure in terms of adaptation to climate change (Marić et al., 2015).

4. CONCLUSIONS

Urbanization has occurred relatively rapidly around the world. Cities cover only 2% of the world's land area, but their inhabitants consume over 75% of natural resources, causing numerous and diverse problems. As of 2008, more than 50% of the world's population lives in cities, and this is expected to rise to 70% by 2050. In most cases, the rapid expansion of cities takes place without any land use planning strategy, and the pressure caused by migration leaves harmful effects on the entire environment, climate, forests and green spaces in and around cities. The effectiveness of the urban green space system depends on the mutual relationship with its environment, especially with the suburban forest areas and the greenery in them. That is why it is necessary to consider the city and its suburban zone as a unique spatial planning and regional unit.

The results of numerous research studies indicate that unfavorable climatic conditions caused by rising temperatures, decreasing precipitation and other extreme weather events may have long-term consequences on the distribution, function and production of urban forests.

The mere existence of regulations, both international and national, is not enough to use green infrastructure to combat climate change and implement adaptation measures. It is necessary to manage forests and other categories of greenery in urban and peri-urban areas in a planned and sustainable manner (respecting the principles of sustainable development and adopting a stricter approach to prevention). Such an approach would improve the quality of life of city residents, enable the adaptation of urban forests and greenery to the existing climate change and prevent future adverse effects.

Implementing sustainable management of urban greenery will:

- ***reduce detrimental effects of climate change*** (by mitigating weather extremes, reducing torrential rainfall, lowering the impact of wind and sandstorms, lessening the “heat island” effect);
- ***create a healthier living environment*** (by filtering air and improving air quality);

- ***create a more diverse and attractive environment*** (by providing a natural experience for residents of urban and peri-urban environments);
- ***provide a more pleasant living environment*** (space for recreation and various social events);
- ***increase biodiversity*** (by creating different landscapes and maintaining cultural traditions).

Based on the obtained research results, it is recommended to have trees in all urban street rows (especially in large cities burdened with air pollution from various sources, such as Belgrade, Novi Sad, Niš, Subotica, etc.) inspected once or twice a year to record problems and propose remedial measures. The application of bio-climatic principles in urban areas is limited, but by promoting the establishment of urban forests and other forms of green infrastructure in the coming period, we can achieve the results we have hoped to achieve. Monitoring, protection, restoration of existing and establishment of new urban forests are only some of the measures to reduce the negative effects of climate change in cities. These measures require certain financial investments to be provided by the local community. They can be partly obtained from different programs and actions that stimulate or subsidize investors (expedited building permitting, discounts on utility services or a financial bonus when building a certain type of green infrastructure, horizontal or vertical greens, etc.).

With the aim of providing conditions for the promotion of larger urban forests in the Republic of Serbia, our recommendations are as follows:

- innovating the proposal of the Draft Law on the Protection and Improvement of Green Areas in accordance with new trends while respecting climate change and the role of green infrastructure;
- establishing legal and planning frameworks in spatial and urban planning in terms of recognising the role of urban forests in achieving energy efficiency;
- drafting the Rulebook for the establishment of monitoring, criteria, assessment of the condition of urban forests in Serbia and recommendations for their improvement, as well as other necessary accompanying regulations;
- promoting research on the health status of trees in urban areas, as well as research that quantifies the positive impacts achieved by urban forests: reducing air temperature, mitigating the impact of “heat islands”, stormwater runoff, air purification, etc.;
- due to the high costs of financing and implementing projects for monitoring and protecting the existing green infrastructure and projects for afforestation of newly-established plantations, it is necessary to achieve mutual cooperation of all stakeholders in the area, while respecting the autonomy of local authorities.

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URBAN FORESTS AND CLIMATE CHANGES

Ljiljana BRAŠANAC-BOSANAC, Tatjana ĆIRKOVIĆ-MITROVIĆ, Nevena ČULE, Goran ČESLJAR, Saša EREMIJA, Ilija ĐORĐEVIĆ

Summary

The impacts of climate change on urban forests are still poorly understood and quantified. Complex interactions within multifunctional urban systems, such as infrastructural corridors, roads and park areas force us to view space as an integrated whole and adjust the interest of individual sectors to the general interest of environmental protection. Due to the increasingly dynamic urban development trends and their impact on the environment, the modern approach to planning urban areas is increasingly turning to strategic planning of urban forest and green infrastructure establishment as a way of combating climate change effectively. An inventory of the condition of urban trees and continuous monitoring are necessary to provide essential information about urban forests and their ability to adapt to future climate changes.

URBANE ŠUME I KLIMATSKE PROMENE

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Rezime

Efekti klimatskih promena na urbane šume još uvek su nedovoljno shvaćeni i kvantifikovani. Složene interakcije unutar višenamenskih urbanih sistema, poput infrastrukturnih koridora, saobraćajnica i parkovskih površina nameće potrebu za integrativnim sagledavanjem prostora, u kojem se sektorski interesi prilagođavaju potrebama opšteg interesa zaštite životne sredine. Kao posledica sve dinamičnijih razvojnih trendova gradova i njihovog uticaja na životnu sredinu, savremeni pristup planiranja urbanih celina sve se više okreće strateškom planiranju podizanja urbanih šuma i zelene infrastrukture kao načinu efikasne borbe protiv klimatskih promena. Da bi se dobile potrebne informacije o urbanim šumama i njihovoj sposobnosti da se prilagode budućim klimatskim promenama neophodno je izvršti popis stanja gradskog drveća i kontinuirano pratiti sve promene.

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ACTIVITY OF ENZYME CATALASE IN PLANTS FROM METAL TAILINGS OF LEAD-ZINC MINE "TREPČA"

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Abstract *The environment of Northern Kosovo and Metohija has been remarkably influenced for a long time by the huge metallurgical complex "Trepča". The technological process of ore exploitation and processing in the Mining and Metallurgical Chemical Company "Trepča" has resulted in a large amount of discharged material, deposited on metal tailings that are mostly located in inappropriate areas, partially covered with vegetation, mostly consisted of several invasive plants. The activity of the enzyme catalase was investigated in plant species collected from abandoned metal tailings "Žitkovac" and compared with the same plant species from the environment from the vicinity of Niš city. Measurements of enzyme activity were carried out in the underground and above-ground parts of plant species Artemisia vulgaris, Cichorium intybus, Erigeron canadensis, Robinia pseudacacia, Medicago sativa, Teucrium chamaedrys, Plantago lanceolata, Rumex acetosella, Tanacetum vulgare and Euphorbia cyparissias using gasometric method. The results have indicated that an increase of catalase activity in tested plants from the metal tailings is possibly a consequence of stress caused by specific environmental conditions.*

Key words: catalase, metal tailings, plants, mine, Trepča.

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AKTIVNOST ENZIMA KATALAZE U BILJKAMA SA METALNOG JALOVIŠTA RUDNIKA OLOVA I CINKA "TREPČA"

Izvod: *Životna sredina Severnog Kosova i Metohije je dugo bila pod jakim uticajem ogromnog metalurškog kompleksa „Trepča“. Tehnološki proces eksploatacije i prerade rude u Rudarsko-Metalurško Hemijskom Kombinatu „Trepča“, rezultirao je velikim količinama ispuštenog materijala, koji se taložio na metalnim jalovištima, koje se uglavnom nalaze na neprikladnim površinama, delimično su obrasle vegetacijom, i uglavnom su sastavljene od po nekoliko invazivnih biljaka. Ispitivana je aktivnost enzima katalaze kod biljnih vrsta sakupljenih sa napuštenog metalnog jalovišta „Žitkovac” i upoređena sa istim biljnim vrstama iz okoline grada Niša. Merenja enzimske aktivnosti vršena su u podzemnim i nadzemnim delovima biljnih vrsta Artemisia vulgaris, Cichorium intybus, Erigeron canadensis, Robinia pseudacacia, Medicago sativa, Teucrium chamaedrys, Plantago lanceolata, Rumex acetosella, Tanacetum vulgare and Euphorbia cyparissias gasometrijskom metodom. Rezultati su pokazali da je izvesno povećanje aktivnosti katalaze u ispitivanim biljkama sa metalnog jalovišta verovatno posledica stresa izazvanog specifičnim uslovima sredine.*

Ključne reči: katalaza, metalno jalovište, biljke, rudnik, Trepča.

1. INTRODUCTION

The territory of Kosovo and Metohija was an object of numerous studies as a region with extremely disturbed ecological conditions caused mainly by the work of the Mining and Metallurgical Chemical Company (MMCC) “Trepča” (Elezović and Elezović, 2010; Jablanović et al., 1985; Milentijević, 2005; Milentijević et al., 2016; Nedeljković and Milentijević, 2006; UNDP in Kosovo, 2011; Trajković, 1995; Trajković et al., 1998). In the period 1965-1985, the MMCC “Trepča” was one of the biggest producers of lead, zinc, silver and gold in Europe. With the mining capacity of up to 10.000 t of metal ores daily, this giant had produced around 120.000 t of raw lead, 100.000 t refined lead, 100 t of silver, 80.000 t electrolyte zinc, 140.000 t mineral fertilizers, 50.000 t super phosphate.

Althought the Metalurgical complex stoped operating at full capacity in 1999, it has been having strong influence on air pollution and registred strong impact on living world (Jablanović et al.,1985; Trajković, 1995; Trajković et al., 1998). The dire legacy of flotation landfills has remained a serious source of pollutants after cessation of mining activities (Milentijević, 2005; Nedeljković and Milentijević, 2006; Elezović and Elezović, 2010; UNDP in Kosovo, 2011; Milentijević et al., 2016).

The technological process of ore exploitation and processing in “Trepča” have resulted in a large amount of discharged material and industrial wastes that remained after the process of extraction of mineral resources. This material was dumped in spoil heaps, mostly located in inappropriate areas (Figure 1). These facilities were without proper construction and monitoring system to keep track on the impacts on the surrounding ecosystems. They have caused an enormous pollution of the local area, including watercourses, rivers, air, and agricultural land contamination. Flotation tailings “Žitkovac” that was our study area is one of these sites.

The environmental impact of mining waste deposits in the Northern Kosovo and Metohija was studied (Milentijević et al., 2016) and according to these results the tailings “Žitkovac” is the most problematic, covering 26 ha and containing about 3-8.5 million tonnes waste (Elezović and Elezović, 2010). The chemical composition of the tailings “Žitkovac” was investigated showing dominant presence of pyrite (FeS_2, 31.4%), iron (Fe, 22.15%), sulfur (S, 8.2%), arsenic (As, 8.2%), zinc (Zn, 1.62%), manganese (Mn, 7%), lead (Pb, 0.48%) (Milentijević et al., 2010).

Plants that grow at contaminated areas have capacity to adapt to the extreme environmental conditions through changes in morphology and/or physiology. According to Nešić et al. (2005) enzyme catalase takes part in defence mechanism to protect plant from free radicals which are increasingly formed in stressfull conditions, such as exposure to pollution (Radotić and Dugić, 1999). Having in mind harmful effects of contaminated soils on human health, growing interest of scientists but also of the society is development of economically acceptable remediation technologies, including phytoremediation (Stojanović et al., 2010).

Biochemical and physiological changes appear before the morphological and are the first indicators of presence of pollutants in the environment. They are reflected in the higher concentration of certain biochemical parameters, i.e. enzymes, some amino-acids, organic acids, etc. By increasing or decreasing synthesis of certain physiologically active compounds, plans are trying to protect themselves and to survive under adverse conditions.

Biochemical and physiological changes in plants caused by the presence of pollutants are reflected in defense mechanisms that include increased antoxidant activity (Haraguchi et al., 1997) with participaton of enzymes catalase and peroxidase. The substrate of both enzymes is hydrogen-peroxide, produced in different metabolic processes, as reduced form of oxygen, and it can cause several metabolic changes in the plant tissues (Markovic et al., 2015). Because of the high toxicity to living cells, its degradation to nontoxic forms is necessary (Nešić et al., 2005). Catalase breaks down toxic H_2O_2 into H_2O and molecular O_2. This reaction is essentials for plant life. The catalase further oxidizes toxic molecules which include phenol, formic acid, formaldehyde, and alcohol (Markovic et al., 2015). Catalase has an important role in plants defending processes from pollution through elimination of free radicals, which concentration has increased as a response to the presence of heavy metals as pollutants.

Contamination of soil with copper, nickel and other heavy metals had negative influence on the soil enzymes and on the test plants (Wyszkowska et al., 2005a, 2005b, 2008, 2009). The soil enzyme activity use as an indicator of changes in soil properties caused by environmental stress such as heavy metal pollution (Ciarkowska, 2015). Lin et al. (2015) discusse the effect of heavy metal stress on the antioxidant enzymes activities.

While effects of heavy metals on soil enzyme activity in numerous recent studies were observed (Chen et al., 2005; Wyszkowska et al., 2005a, 2008, 2009, 2015; Yang et al., 2006; Khan et al., 2007; Güsler and Erdoĝan, 2007; Karaca et al., 2010; Angelovičovà et al., 2014), lesser investigations were conducted on enzyme activity in plants that grow on heavy metal contaminated soils (Assche and Clijsters, 1990; Clijsters et al., 1999).

The investigations of physiological changes (reflected in the activity of enzyme catalase (CAT; EC 1.11.1.6) in plants that grow in polluted environmental conditions on tailings and comparison to ones from unpolluted area were in the focus of the present study.

2. MATERIAL AND METHODS

2.1. Study area

The study area of the mining waste deposits "Žitkovac" is situated to the north of Kosovo and Metohija on the left bank of river Ibar, in the vicinity of village Žitkovac. Administratively it belongs to the municipality of Zvečan and Kosovska Mitrovica. The landfill was active in period from 1963 to 1974. Flotation tailings are transported from Zvečan, where processed lead and zinc ore from Stari Trg mine (Milentijević et al., 2016).

It has the typical continental climate with long and hot summers and cold winters. According to the meteorological station Kosovska Mitrovica, the average precipitation from 1991-2013 was 637 mm, and average annual temperature 10.3 °C. Mean wind velocity for Kosovska Mitrovica is 1.9 m/s, and the most frequent blowing direction is north with an average velocity of 2.3 m/s and northwesterly wind with an average velocity of 2.1 m/s (Radovanović et al., 2012).

The Ibar River's alluvial plain is the landscape where the metal tailings is situated (Nikić, 2003). Tailing material of the study area shows permanent toxic pollution of water and agricultural land (Nedeljković and Milentijević, 2006).

2.2. Plant material

Enzyme activity assessment was carried out on the woody branches and leaves of invasive plant species *Robinia pseudoacacia* and on the underground and above-ground parts of other plants (*Artemisia vulgaris, Cichorium intybus, Erigeron canadensis, Medicago sativa, Teucrium chamaedrys, Plantago lanceolata, Rumex acetosella, Tanacetum vulgare* and *Euphorbia cyparissias*). The plant material was identified using the key for the regional flora (Josifović, 1970-1986; Velchev, 1982-1989) and the voucher specimens was deposited in the Herbarium Moesiacum Niš (HMN), Department of Biology and Ecology, Faculty of Science and Mathematics, University of Niš (*Table 1*).

Table 1. *Repository data of herbarium specimens of plants used in this study*

Inventory number	Plant species	Location	Habitat	Date
12495	*Artemisia vulgaris* L.	Žitkovac	metal tailings	27.9.2016.
12496	*Cichorium intybus* L.	Žitkovac	metal tailings	27.9.2016.
12500	*Erigeron canadensis* L.	Žitkovac	metal tailings	27.9.2016.
12509	*Robinia pseudacacia* L.	Žitkovac	metal tailings	27.9.2016.
12510	*Medicago sativa* L.	Žitkovac	metal tailings	27.9.2016.
12514	*Teucrium chamaedrys* L.	Žitkovac	metal tailings	27.9.2016.
12516	*Plantago lanceolata* L.	Žitkovac	metal tailings	27.9.2016.
12517	*Rumex acetosella* L.	Žitkovac	metal tailings	27.9.2016.
13114	*Tanacetum vulgare* L.	Niš	ruderal places	29.9.2016.
13115	*Euphorbia cyparissias* L.	Niš	ruderal places	29.9.2016.
16428	*Artemisia vulgaris* L.	Niš	ruderal places	29.9.2016.
16429	*Cichorium intybus* L.	Niš	ruderal places	29.9.2016.
16430	*Erigeron canadensis* L.	Niš	ruderal places	29.9.2016.
16431	*Robinia pseudacacia* L.	Niš	ruderal places	29.9.2016.
16432	*Medicago sativa* L.	Niš	ruderal places	29.9.2016.
16433	*Teucrium chamaedrys* L.	Niš	ruderal places	29.9.2016.
16434	*Plantago lanceolata* L.	Niš	ruderal places	29.9.2016.
16435	*Rumex acetosella* L.	Niš	ruderal places	29.9.2016.
16436	*Tanacetum vulgare* L.	Žitkovac	metal tailings	27.9.2016.
16437	*Euphorbia cyparissias* L.	Žitkovac	metal tailings	27.9.2016.

2.3. Methodology

The plant material was collected in the autumn from the metal tailings "Žitkovac". The same plant species were collected from the uncontaminated area near city of Niš (eastern Serbia). They have served as the control plant group. Plant samples were put into liquid nitrogen in which they transported and then put into a freezer kept at -20ºC where they were stored until the analysis. The underground and above-ground plant parts were separated before the analysis and cut into little pieces.

Catalase activity was measured using the gasometric method (Mosheva, 1982) and expressed as ml of O_2. Detailed description of the method is given in Markovic et al. (2015).

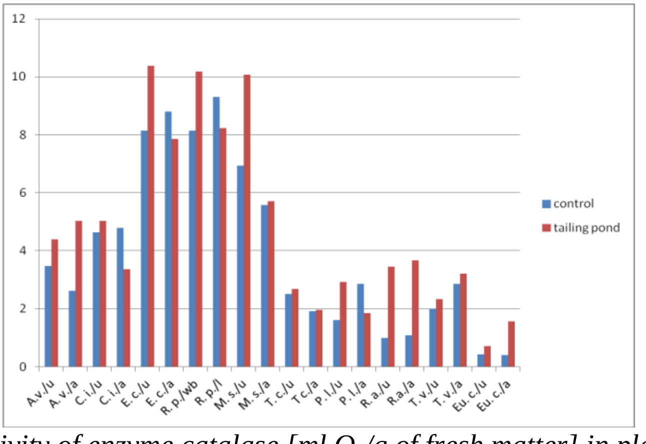
3. RESULTS AND DISCUSSION

Activity of enzyme catalase was measured in underground and above-ground plant parts from the spoil heaps and from the uncontaminated area which represent a control group. The results, given in *Figure 1*, show that catalase activity is mostly increased in the underground parts of the experimental samples from the tailings, compared to the control samples from the uncontaminated habitats. In above-ground plant parts the activity of catalase is different in the experimental samples in comparison the control samples. These differences may be related to morphological, anatomical, and chemical structure of investigated plants which are probably genetically conditioned which had been confirmed in previous investigations (Nešić et al., 2005).

In the roots of *Erigeron canadensis* and *Medicago sativa*, and in woody branches of *Robinia pseudoacacia* from the metal tailings the activity of catalase is highest (> 10 O_2/g of fresh matter). In all other samples the catalase activity is lower (< 10 O_2/g of fresh matter).

It was noticed that the activity of catalase in the invasive species *Erigeron canadensis* is increased in the root of the experimental samples, compared to the control samples from the uncontaminated habitat, while the catalase activity in the above ground parts is decreased in experimental samples. The activity of catalase in the woody branches of the invasive species *Robinia pseudoacacia* is increased in the experimental samples in comparison the control samples, while the catalase activity in the leaves is decreased of the experimental samples. The results show a significant increase in catalase activity in the roots of invasive species *Erigeron canadensis* and woody branches of invasive species *Robinia pseudoacacia*. Increased catalase activity in underground parts of invasive plants is probably a consequence of stress caused by chemical changes in soil on the tailings (Jakšić et al., 2017).

Negruckaja and Ermukova (1990) found that the catalase activity in experimantal intoxication increases only in young plants and does not change in plants which are premanently exposed to pollution. In contrast, studies of Trajković (1995) and Trajković et al. (1998) suggest an increase in catalase activity in some plants that are permanently exposed to pollution.



Graph 1. *Activity of enzyme catalase [ml O_2/g of fresh matter] in plants on metal tailings and the uncontaminated area (control).*

Legend: Tested plants: Artemisia vulgaris – A.v., Cichorium intybus – C.i., Erigeron canadensis – E.c., Robinia pseudoacacia – R.p., Medicago sativa – M.c., Teucrium chamaedrys – T.c., Plantago lanceolata – P.l., Rumex acetosella – R.a., Tanacetum vulgare – T.v., Euphorbia cyparissias – Eu.c. Plant parts: u – underground plant parts; a – above-ground plant parts; wb – woody branches; l – leaves

4. CONCLUSIONS

Plants growing at contaminated areas have capacity for adaptation to the environmental conditions through changes in physiology. In present study was noticed that the activity of catalase in underground parts is higher in all samples from the metal tailings, while in above-ground parts is different in comparison to the control samples. An increased catalase activity is a result of stress that is caused by chemical changes in the soil on tailings representing good metabolic way of detoxification, which belongs to the mechanisms of defence and acquiring resistance. The future investigations of biochemical and physiological changes in plants on metal tailings are necessary to better understand impact of soil contamination on machanisms of acquiring resistance on polluted areas. Additional studies are also needed to determine the fate of various compounds in the plant metabolic cycle to ensure that plant droppings and products do not contribute toxic or harmful chemicals into the food chain.

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ACTIVITY OF ENZYME CATALASE IN PLANTS FROM METAL TAILINGS OF LEAD-ZINC MINE "TREPČA"

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Summary

The territory of Kosovo and Metohija has been the subject of numerous studies as a region of extremely disturbed ecological conditions, mainly caused by the work of the Mining and Metallurgical Chemical Combine (RMHK) “Trepča”. The technological process of ore exploitation and processing at RMHK "Trepča" has resulted in a great deal of industrial waste that remains after the extraction of mineral raw materials. This material is disposed of in waste dumps, mostly located in unsuitable areas. The facilities are without appropriate systems for monitoring the surrounding ecosystems. They have caused massive pollution of local areas, including waterways, rivers, air and agricultural land. One of these sites is the flotation tailings pond “Žitkovac”, which is the area of our research.

Catalase activity was determined in the woody branches and leaves of the invasive plant species *Robinia pseudoacacia* and in the underground and aerial parts of other plants (*Artemisia vulgaris, Cichorium intybus, Erigeron canadensis, Medicago sativa, Teucrium chamaedrys*, *Plantago lanceolata, Rumex acetosella, Tanacetum vulgare* and *Euphorbia cyparissias*). The plant material was identified using keys in the Flora of Serbia, and specimens were deposited in the herbarium of the Department of Biology and Ecology of the Faculty of Science and Mathematics in Niš – Herbarium Moesiacum Niš (HMN).

Catalase activity was measured in the underground and aboveground parts of plants from the “Žitkovac” metal tailings pond and from an uncontaminated area in the vicinity of Niš, representing the control group of samples. The results showed that the activity of catalase was slightly increased in the underground parts of samples from the tailings pond compared to the control samples from unpolluted habitats. In the aerial parts of plants, catalase activity in the experimental samples differed from that in the control

samples. These differences may be related to the morphological, anatomical and chemical structure of the examined plants, which are probably genetically determined.

Plants growing in contaminated areas have the ability to adapt to environmental conditions through changes in their physiology. In this research, it was observed that catalase activity in the underground parts was higher in all samples from the metal tailings pond, while in the aboveground parts it was different compared to the control samples. The increased catalase activity is the result of stress caused by chemical changes in the soil at the tailings dump and is a metabolic pathway of detoxification, which is part of the defense mechanisms and acquisition of resistance. Future studies of biochemical and physiological changes in plants at metal tailings dumps are necessary to better understand the impact of soil contamination on resistance acquisition mechanisms in polluted areas.

AKTIVNOST ENZIMA KATALAZE U BILJKAMA SA METALNOG JALOVIŠTA RUDNIKA OLOVA I CINKA "TREPČA"

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Rezime

Teritorija Kosova i Metohije bila je predmet brojnih proučavanja kao region sa izuzetno poremećenim ekološkim uslovima, uzrokovanim uglavnom radom Rudarsko-Metalurško Hemijskog Kombinata (RMHK) „Trepča”. Tehnološki proces eksploatacije i prerade rude u RMHK „Trepča“ rezultirao je velikom količinom industrijskog otpada, koji je zaostao nakon procesa vađenja mineralnih sirovina. Ovaj materijal je odložen na gomile otpada, uglavnom locirane na neprikladnim područjima. Ovi objekti su bili bez odgovarajućih sistema za praćenje na okolne ekosisteme. Oni su izazvali ogromno zagađenje lokalnoih područja, uključujući vodotoke, reke, vazduh i zagađenje poljoprivrednog zemljišta. Jedno od ovih nalazišta je flotaciono jalovište „Žitkovac”, koja predstavlja naše područje istraživanja.

Aktivnost enzima katalaze određena je u drvenastim granama i listovima invazivne biljne vrste *Robinia pseudoacacia* i u podzemnim i nadzemnim delovima drugih biljaka (*Artemisia vulgaris, Cichorium intybus, Erigeron canadensis, Medicago sativa, Teucrium chamaedrys, Plantago lanceolata, Rumex acetosella, Tanacetum vulgare* и *Euphorbia cyparissias*). Biljni materijal je identifikovan pomoću ključeva u Flori Srbije, a herbarijumkski primerci deponovani su u Herbariumu Departmana za biologiju i ekologiju Prirodno-matematičkog fakulteta u Nišu- *Herbarium Moesiacum Niš* (HMN).

Merena je aktivnost enzima katalaze u podzemnim i nadzemnim delovima biljaka sa metalnog jalovišta „Žitkovac“ i sa nekontaminiranog područja u okolini Niša, koji predstavlja kontrolnu grupu uzoraka. Rezultati su pokazali da je aktivnost katalaze neznatno povećana u podzemnim delovima oglednih uzoraka iz jalovišta, u poređenju sa kontrolnim uzorcima sa nezagađenih staništa. U nadzemnim delovima biljaka aktivnost katalaze je drugačija u oglednim uzorcima u poređenju sa kontrolnim uzorcima. Ove razlike mogu biti povezane sa morfološkom, anatomskom i hemijskom strukturom ispitivanih biljaka, koje su verovatno genetski uslovljene.

Biljke koje rastu na kontaminiranim područjima imaju sposobnost prilagođavanja na uslove sredine kroz promene u fiziologiji. U ovom istraživanju uočeno je da je aktivnost katalaze u podzemnim delovima veća u svim uzorcima sa metalnog jalovišta, dok je u nadzemnim delovima različita u odnosu na kontrolne uzorke. Povećana aktivnost katalaze je rezultat stresa koji je uzrokovan hemijskim promenama u zemljištu na jalovištu, što

predstavlja metabolički način detoksikacije, koji spada u mehanizme odbrane i sticanja otpornosti. Buduća istraživanja biohemijskih i fizioloških promena u biljkama na metalnom jalovištu su neophodna da bi se bolje razumeo uticaj kontaminacije zemljišta na mehanizme sticanja otpornosti u zagađenim područjima.

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USE OF THE SPAD METER TO ESTIMATE CHLOROPHYLL CONTENT IN DIFFERENT SESSILE OAK (*Quercus petraea* (Matt.) Liebl.) PROVENANCES IN SERBIA

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Abstract: *Chlorophyll is the main participant in the process of photosynthesis, which content can tell about plant physiological health condition. In this research, the SPAD values of the one-year-old Sessile oak seedlings of 5 Serbian provenances were measured during June, August, and October of 2021. The measuring was performed by the SPAD device, and the data were presented through the SPAD index values. The research results confirmed that the environmental conditions where the plants grow have a dominant effect on the chlorophyll content, concerning the origin of the individuals. In further research, it is necessary to accurately determine on a greater plant sample the relationship between chlorophyll content and SPAD index values.*

Key words: sessile oak, provenances, SPAD, chlorophyll.

PRIMENA SPAD U PROCENI SADRŽAJA HLOROFILA RAZLIČITIH SRPSKIH PROVENIJENCIJA HRASTA KITNJAKA

Izvod: *Hlorofil je glavni učesnik procesa fotosinteze, čiji sadržaj govori o fiziološkom stanju biljke. U ovom radu merene su SPAD vrednosti jednogodišnjih sadnica hrasta kitnjaka 5 srpskih provenijencija tokom juna, avgusta i oktobra 2021. godine. Merenje je obavljeno pomoću SPAD uređaja, a podaci predstavljeni kroz vrednosti SPAD indeksa. U ovom radu potvrđeno je da dominatan efekat na sadržaj hlorofila imaju uslovi*

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sredine u kojoj se biljke nalaze, u odnosu na poreklo jedinki. U daljem istraživanju neophodno je precizno utvrditi odnos koncentracije hlorofila i SPAD jedinica, na većem uzorku.

Ključne reči: hrast kitnjak, provenijencije, SPAD, hlorofil.

1. INTRODUCTION

Photosynthesis is a fundamental phytochemical process on Earth that enables the development of complex organisms. The central participant in the process is chlorophyll, the *green pigment* existing in all organisms capable of absorbing light photons and converting this energy into the chemical form of carbohydrates that make it available to all other heterotrophs. Higher plants have chlorophyll a and b, essential for primary photosynthetic reaction. Therefore, the chlorophyll content in plant organs especially leaves as primary photosynthetic organs, is of major importance for their metabolism. However, the variability of chlorophyll content among plant species, functional plant groups, and natural forest communities particularly on high scales, is not been completely clarified until today (Li et al., 2018). Chlorophyll synthesis is a complex, multi-stage process, which is largely affected by temperature, water, and nutrient availability, i.e. soil characteristics, etc. Considering the involvement of numerous enzymes, the whole process is polygenically determined.

The quality and intensity of sun irradiation can vary significantly during a certain time in a location. Plants inhabited the land about half a billion years ago and being the sessile organisms, they have developed sophisticated adaptation mechanisms on the environment, through communication with other organisms (microorganisms primarily), but also by controlling their own processes. Hence, plants are capable to adapt to different light intensities and qualities, and depending on available wavelengths at the time, can properly adjust the chlorophyll's relation to provide the existence.

In spite of multiple factors affecting chlorophyll content, its investigation is an important parameter in overall plant health state perception. The collected data can indicate the stressor influence which is very important in plant production, or the individual or group differences and similarities in terms of the photosynthesis process, its efficacy, and sunlight energy processing in general. Ling et al. (2011) report that chlorophyll leaf concentration is an indicator of chloroplast development, photosynthetic capacity, nitrogen leaf content, and plant health in general.

As one of the modes of fast, efficient, and completely safe chlorophyll content measurement in a plant leaf, the SPAD-502 Plus (Soil Plant Analysis Development; Konica-Minolta, Inc. Japan) device is being used. It measures the difference between red (650 nm) and infrared (940 nm) emitted light transmission, with the help of two diodes, presenting the final SPAD value, or index. The red light of 650 nm wavelength presents the value of chlorophyll absorption, while the 940 nm wavelength presents the factor of correction for leaf thickness of different plant species. The idea in SPAD device appliance is that increased leaf chlorophyll concentration increases also absorption of red light, and since all leaves transmit a high fraction of close infrared light, the relationship between SPAD and chlorophyll can be seen theoretically as cause and effect (Wang, Li, 2018).

The chlorophyll content dynamics in leaves of Sessile oak (*Quercus petraea* (Matt.) Liebl) in Serbia have not been investigated so far using the SPAD device, according to the knowledge of the authors. After the Common oak, the Sessile oak is the most common oak species in the growing stock of the Republic of Serbia. It is an autochthonous species, inhabiting elevations between 300 and 1300 m a.s.l. The Sessile oak forms more than 20 forest types, and it is one of the most valuable forest species in terms of the area of occurrence, volume, application in the economy, and wood quality. The Sessile oak is also one of the most common oak species cultivated in seedling nurseries in Serbia (Popović et al., 2019). Concerning the wide tolerance range and related to climate change, it is assumed that Sessile oak will expand its area in the future. The Sessile oak individual trees of different provenances are locally adapted to present environmental conditions. Physical modifications lead to different physiological patterns for the adaptation purpose, which all impact final plant fitness.

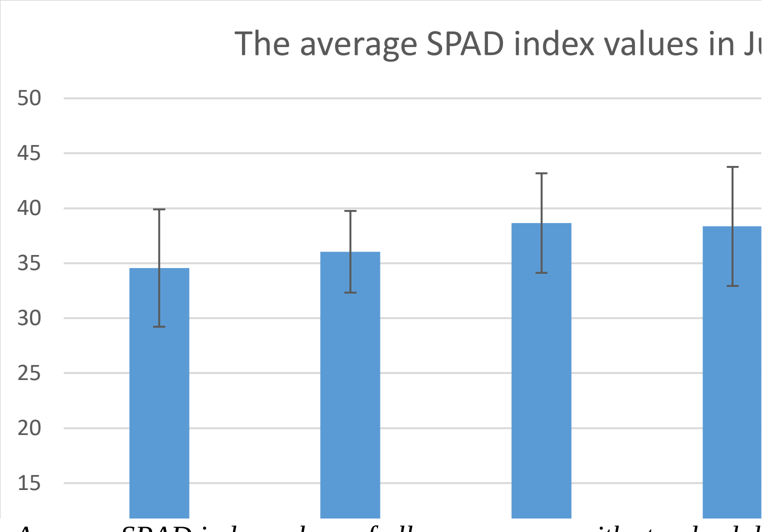
This research aimed to investigate chlorophyll content variability by measuring the leaf SPAD index of containerized one-year-old Sessile oak seedlings of 5 populations, originating from Serbia, during one growing season.

2. MATERIAL AND METHODS

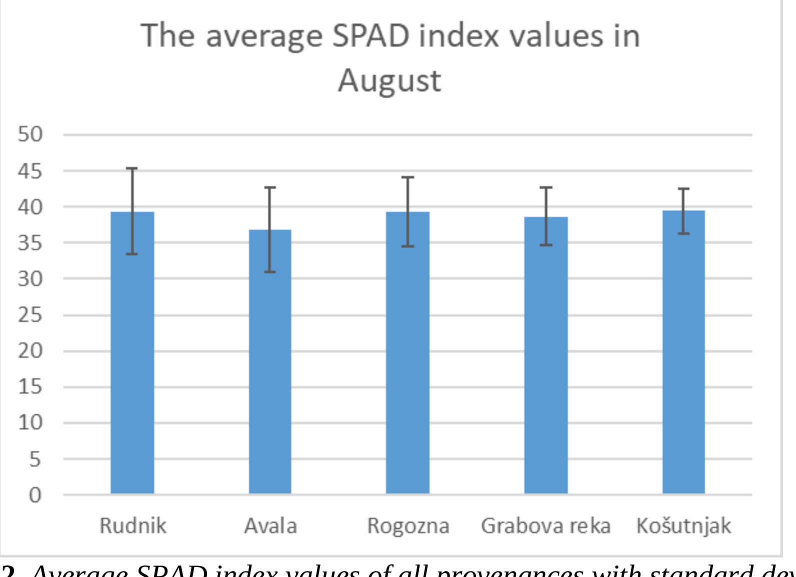
During the autumn of 2020, the Sessile oak seeds were collected in 5 natural stands of different provenances, as follows: Rudnik, Avala, Rogozna, Grabova reka, and Košutnjak. The acorns were stratified in the sand and left to overwinter on 4 °C. In spring 2021, the containerized seedlings were produced from seeds (container type HIKO-V-350), and peat was used as a substrate (Freepeat). Plants were nurtured in semi-controlled conditions in the seedling nursery of the Institute of Forestry in Belgrade (44°46’55”N 20°25’21”E), in half-shadow. They were watered regularly, without any fertilization treatment. The SPAD leaf measurements were taken by the SPAD chlorophyll meter (SPAD-502 Plus, Minolta, Inc.) on a sample of 10 plants per provenance, during one growing period. The dates were chosen to follow vegetation’s crucial phases and seasonal dynamics, but also 3 phases of leaf age. The measurements were performed on the following dates: on June 23 – at the beginning of the season when the young developed leaves were measured; on August 3, – in the middle of the season, when large, fully developed leaves were measured; and on October 21, at the end-season when the leaves had occasional signs of chlorophyll degradation. The SPAD sensor was placed randomly on leaf mesophyll, avoiding leaf nerves. The measured area was 2 mm x 3 mm, and the measurement of small leaves was also enabled.

3. RESULTS AND DISCUSSION

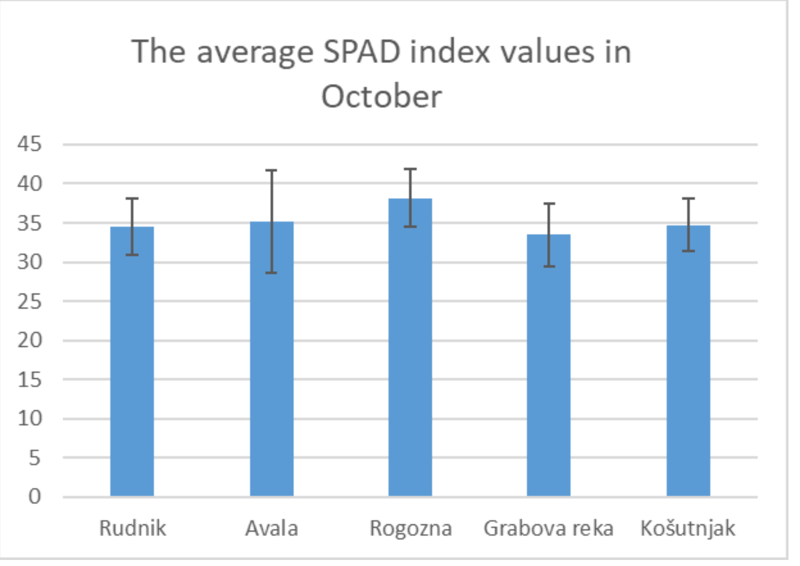
Average SPAD index values of one-year-old Sessile oak seedlings different in origin, measured over the months are presented on graphs 1, 2, and 3.



Graph 1. *Average SPAD index values of all provenances with standard deviation in June*



Graph 2. *Average SPAD index values of all provenances with standard deviation in August*



Graph 3. *Average SPAD index values of all provenances with standard deviation in October*

The average values of meteorological data for June, August, and October on the territory of Belgrade are presented in Table 1.

Table 1. *Average values of some meteorological parameters for June, August, and October on the territory of Belgrade*

Month	June	August	October
Average value of maximal monthly temperatures	29.6°C	29.7°C	16.9°C
Precipitation (mm)	34.2	38.2	73.4

In a habitat, plants are affected by numerous factors, and the light is spatially and temporarily the most variable (Pearcy, 1999). Therefore, plants have evolved mechanisms of adaptation. Plants tested in this experiment, although different in their origin, demonstrated a relatively uniform response to sun irradiation exposition during all investigated months of one growing season. The highest average values of the SPAD index are reported for August in the "Košutnjak" provenance. The highest individual value was also noted in August, in the population of "Rogozna", numbering 49.4.

The lowest average SPAD index values are detected in October, in the "Grabova reka" provenance, valuing 33.48. When analyzing individually, the lowest value was reported in the "Grabova reka" population in June, numbering 24.9 SPAD units. Interestingly, the highest average SPAD unit value in June, at the beginning of the season, had seedlings of "Rogozna" population, as well as in October, at the season's end. The lowest average values in June had seedlings of the "Rudnik" provenance, while in October the lowest average values had the "Grabova reka" provenance seedlings.

Atar et al., (2020) investigated in their research the SPAD values of *Quercus hartwissiana* Steven species, in May and October, and obtained the average maximal SPAD value of 32.7 for May, and 28.8 for October. Jagiełło-Leńczuk et al. (2015) reported maximal values for Common oak in mid-July, numbering 49.9 SPAD units, while the average value of measurements taken in the period from May to November was 31.8.

When analyzing the SPAD unit values per provenance over the year, the highest average values had the "Rogozna" population and the lowest the "Avala" population.

The highest standard deviation of SPAD values was detected in June, in the "Košutnjak" provenance.

During the season, plant dieback was also detected. The provenance "Košutnjak" lost the highest number of individuals, two, while one individual lost "Avala" and "Grabova reka" provenances. The causes of plant dieback are high temperatures, the occurrence of oak powdery mildew, and attacks of insects from the genus *Corythucha*.

The total average SPAD values of all provenances during the vegetation season showed a small variation range. The highest values were in August when meteorological conditions were optimal and also the leaf was in a stage of full development and capacity. On the other hand, the total leaf chlorophyll amount and specific leaf area increased with increasing shadow (Niinemets, 2010) to compensate for photosynthetic losses (Popović et al., 2016). Bearing in mind the fact that containerized seedlings were grown in the half-shadow conditions, and their canopies overlapped, these conditions were one of the influence factors which was also reported in the research of Bielinis et al. (2015).

The lowest average values were in October when plants were slowly entering the phase of leaf rejection.

Similar results were obtained by Bielinis et al. (2015) who investigated chlorophyll content in Sessile oak: the total amount of chlorophyll increased from May to July, with a peak in July to August, and during September the concentration values decreased. Louise et al. (2009) in their research of two-year-old Sessile oak seedlings reported an increase in chlorophyll content, which achieved the plateau phase at the end of May when leaves were wholly formed. Afterward, the chlorophyll concentration gradually decreased from July to September, with the leaf aging.

Chlorophyll is very important for plants. Hence, the general opinion is that leaf chlorophyll content is mainly influenced by environmental factors, concerning phylogenetic ones, and that plant adapts to them to optimize the photosynthetic process (Li et al., 2018). This was also confirmed by Arab et al. (2020) who investigated the effect of the Sessile oak seedling origin on a foliar response to arid conditions, where great phenotypic plasticity has been detected, and only a small number of leaf characteristics were genetically fixed.

Also, the leaf structure parameters change with aging, undoubtedly leading to a change in leaf optical properties (Silla et al., 2010). In this research there can be seen a regular pattern in all provenances, where the SPAD unit values have been increasing from the beginning of the season towards its middle, correlating with the leaf development and chlorophyll content, and the SPAD index values decrease at the end of the growing season, in parallel with leaf drying processes. The results also correlate with the dynamics of changing average temperature values. The measured values of SPAD units can also be influenced by changes in growth conditions, which could lead to the redistribution of chloroplasts in leaf mesophyll cells (Naus et al., 2010). The negative impact could be caused by a common oak pathogen – fungi *Erysiphe alphitoides* (Griffon et Maubl.), that provokes oak powdery mildew disease. Ashy scrum on the adaxial side of the leaf is the fungus mycelium which changes the leaf transmission, consequently affecting the measured SPAD values. In the presented research, during the growing season, there have been detected 2 strong attacks of this pathogen – at the beginning of June and during September.

4. CONCLUSIONS

The SPAD chlorophyll meter is a practical technical device that enables fast and simple measurement of a great number of plant samples in a short time interval, without making any kind of damage to a plant organism. In this research, the SPAD values of the one-year-old Sessile oak seedlings of 5 different Serbian provenances were measured. Similar average values were noted among all individuals with minor differences. It has been confirmed that environmental conditions have a dominant impact on the chlorophyll content, in relation to the origin of plants. In further research, it is necessary to accurately determine the relationship between chlorophyll content and SPAD index values in a greater plant sample.

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Sanja JOVANOVIĆ, Ljubinko RAKONJAC, Aleksandar LUČIĆ, Vladan POPOVIĆ

Summary

Chlorophyll is the main participant in the photosynthetic process, which content indicates plant physiological condition. In this research, the SPAD values of the one-year-old Sessile oak seedlings of 5 Serbian provenances were measured during June, August, and October of 2021. The measures were taken by the SPAD device and the data were presented in the SPAD index values.

The greatest average values were recorded during August in the "Košutnjak" provenance. The lowest average SPAD index values have been detected in October, in the "Grabova reka" provenance. When analysing the values of the SPAD units during the year, the population of "Rogozna" had the highest mean values, and the "Avala" population had the lowest. Total average SPAD values of all provenances during the growing season manifested a small variation range.

In this research, it has been confirmed that chlorophyll content is mainly affected by environmental conditions where plants are nurtured, in relation to their origin. In spite of their different „genetic content'', the plants showed a small variation range in chlorophyll quantity and adapted to the environs, where they were living. In further research, it is necessary to accurately determine the relationship between chlorophyll content and SPAD units, in a greater plant sample.

PRIMENA SPAD U PROCENI SADRŽAJA HLOROFILA RAZLIČITIH SRPSKIH PROVENIJENCIJA HRASTA KITNJAKA

Sanja JOVANOVIĆ, Ljubinko RAKONJAC, Aleksandar LUČIĆ, Vladan POPOVIĆ

Rezime

Hlorofil je glavni učesnik procesa fotosinteze, čiji sadržaj govori o fiziološkom stanju biljke. U ovom radu merene su SPAD vrednosti jednogodišnjih sadnica hrasta kitnjaka 5 srpskih provenijencija tokom juna, avgusta i oktobra 2021. godine. Merenje je obavljeno pomoću SPAD uređaja, a podaci predstavljeni kroz vrednosti SPAD indeksa.

Najveće prosečne vrednosti zabeležene su tokom avgusta meseca, u provenijenciji Košutnjak. Najmanje prosečne vrednosti SPAD indeksa ustanovljene su u oktobru, u provenijenciji Grabova reka. Kada posmatramo vrednosti SPAD jedinica provenijencija tokom godine, najveće prosečne vrednosti imala je populacija Rogozna, a najmanje Avala. Prosečne ukupne SPAD vrednosti svih provenijencija tokom vegetacione sezone ispoljile su mali opseg varijacija.

U ovom radu potvrđeno je da dominatan efekat na sadržaj hlorofila imaju uslovi sredine u kojoj se biljke nalaze, a ne poreklo jedinki. Biljke, uprkos svom različitom „genetskom sadržaju", ispoljile su mali opseg varijacija količine hlorofila i prilagodile okolini u kojoj su sve obitavale. U daljem istraživanju neophodno je precizno utvrditi odnos koncentracije hlorofila i SPAD jedinica, na većem uzorku.

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MORPHOMETRIC CHARACTERISTICS OF *PAULOWNIA ELONGATA* S. Y. HU. AND *PAULOWNIA FORTUNEI* SEEM. HEMSL. LEAVES AND FERTILISATION IN DIFFERENT SITES

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Abstract: *The paper presents the results of the analysis dealing with the impact of plant fertilisation in the first year after planting on the leaf morphological characteristics. The analysis was conducted within the research into the potential introduction and adaptation of paulownia to different sites in Serbia. The results related to the effects of fertilisation on the quality of plant leaves are useful for the cultivation of certain types of soil where the morphometric analysis of leaves reveals structure-function relationships, i.e., more detailed indicators of the species' adaptability. The research was conducted in two localities. Sample plots with Paulownia elongata S. Y. Hu. and Paulownia fortunei Seem. Hemsl. were established in Obrenovac and Pambukovica, where leaf material was collected for laboratory analysis. The following morphometric leaf characteristics were measured: leaf area, leaf perimeter, leaf lamina length, central nerve length, maximum leaf width, leaf width at 1 cm from the base of the leaf, petiole length, distance between the 3rd and 4th nerve, the number of nerves to the left side of the midrib, and the number of veins to the right side of the midrib. The obtained results of leaf morphometric measurements were statistically processed in the Statgraphics software. Based on the results of measuring the leaf morphometric characteristics, fertilisation has a positive effect on the size of the leaves of the studied paulownia species.*

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Key words: fast-growing species, leaf morphology, phenotypic stability, introduction, adaptation.

MORFOMETRIJSKE KARAKTERISTIKI LISTOVA VRSTA *PAULOWNIA ELONGATA* S. Y. HU. I *PAULOWNIA FORTUNEI* SEEM. HEMSL. U ODNOSU NA PRIHRANJIVANJE NA RAZLIČITIM STANIŠTIMA

Izvod: *U radu su prikazani rezultati analize uticaja prihranjivanja biljaka u prvoj godini nakon sadnje, na morfološke karakteristike listova u okviru istraživanje mogućnosti introdukcije i adaptacije paulovnija na različita staništa u Srbiji. Dobijanje rezultata o uticaju prihranjivanja na kvalitet listova biljaka je značajno za gajenje na određenim tipovima zemljišta gde morfometrijska analiza listova pokazuje strukturno-funkcionalne veze, odnosno detaljnije pokazatelje adaptibilnost vrste. Istraživanja su sprovedena na dva lokaliteta. Ogledna polja na lokalitetima u Obrenovcu i Pambukovici su osnovana sa vrstama Paulownia elongata S. Y. Hu. i Paulownia fortunei Seem. Hemsl.. U okviru oglednih polja vršeno je prikupljanje lisnog materijala za analizu u laboratorijskim uslovima. Izvršena su merenja morfometrijskih karakteristika listova: površina lista, obim lista, dužina lisne ploče, dužina centralnog nerva, širina lista na najširem delu lisne ploče, širina lista na 1 cm od osnove lista, dužina peteljke, razmak između 3. i 4. nerva, broj nerava na levoj strani od centralnog nerva, i broj nerava na desnoj strani od centralnog nerva. Dobijeni rezultati morfometrijskih merenja listova statistički su obrađeni u programu Statgraphics. Na osnovu rezultata merenja morfometrijskih karakteristika listova utvrđeno je da prihranjivanja ima pozitivan uticaj na veličinu listova analiziranih vrsta paulovnije.*

Ključne reči: brzorastuće vrste, morfologija lista, fenotipska stabilnost, introdukcija, adaptacija.

1. INTRODUCTION

Besides efforts to preserve and protect native species, modern society is faced with the need to introduce new species that are resilient to changing environmental conditions and human impact. Preserving and increasing areas under forests is a high priority while selecting adequate species poses serious challenges (Ivetić and Vilotić, 2014). Numerous research studies deal with the introduction of new species and their adaptation to ongoing climatic and environmental changes. These studies are of great importance in finding the most effective solutions to reduce the adverse effects of climate change (Betts et al., 2008; Innes et al., 2009). The limited supply and increasing demand for wood have made the use of fast-growing species for wood and biomass production a pressing need (Swamy et al., 2006; Mishra et al., 2010).

In the struggle to enhance plantation forestry in Serbia, the potential use of new tree species has to be given greater focus (Ivetić and Vilotić, 2014). Due to its rapid growth and coppice vigour, Paulownia Sieb. & Zucc. species have high biomass and biofuel production potential (Lucas-Borja et al., 2011; Yadav et al., 2013).

Thanks to the large leaf mass rich in nitrites, Paulownia litterfall has a crucial ameliorative role in improving the soil quality around trees. Because of this property, in some areas in China, green manure is made with Paulownia leaves and used to improve the ecological properties of the soil (Zhu et al., 1986). When mixing it with other tree species, it is necessary to follow the growth trends because, as a light-loving species, Paulownia is unsuitable for mixing with other similar species (Zhu et al., 1986; Williams, 1993).

Afforestation is usually carried out in soils poor in nutrients that have to be improved by adding different types of fertilisers (Stilinović, 1991). The decision on when what and how much fertiliser to use depends primarily on the soil conditions. It is also affected by biological characteristics and the stage in the development of plants (Tucović and Simić, 2002; Hawkins et al., 2005). Providing plants with a proper nutrition system or necessary plant assimilates should ensure the formation of biologically healthy material resistant to adverse environmental conditions. This way, plants can develop and grow well in plantations and cultures (Jacobs et al., 2005, Mitrović et al., 2012). Research by García-Morote et al. (2014) show that fast-growing species can be grown even in semi-arid regions, provided they obtain minimum irrigation.

In young Paulownia trees (in the juvenile development phase), the leaves have a wavy rim with pronounced lobes. They are extremely large and can be as long as 90 cm (Graves, 1989). On the other hand, the leaves of mature trees are smaller, 15-30 cm in length and 10-20 cm in width, full perimeter (Innes, 2009). The leaves are covered with thick hairs on both sides (Kays et al., 1998).

The large and hairy Paulownia leaves have a very useful role in removing sulfur and carbon dioxide from the air and retaining solid pollutants, smoke and dust in the canopy (Zhu et al., 1986; Šijačić-Nikolić et al., 2008). Zhang et al. (2007) investigated contaminated soil near a lead and zinc smelter. The obtained results suggest that seedlings of Paulownia fortunei Seem. Hemsl. growing on soil highly contaminated with heavy metals can significantly improve the structure and function of the communities of soil microorganisms. Paulownia is considered a pioneer species (Zhu et al., 1986). It can accumulate large amounts of heavy metals and thus perform soil phytoremediation (Stanković et al., 2009; Bahri et al., 2015). The content of heavy metals in the leaves of Paulownia growing in urban conditions shows that this genus has a high urban pollution tolerance.

All these facts indicate that Paulownia trees can be used in the restoration of degraded land and wastewater, and grown in tree rows, windbreaks, urban environments and roadsides (Doumett et al., 2011, Mitrović et al., 2011).

The size of the leaf is vital for the process of photosynthesis and the production of nutrients that are directly correlated with the production of the entire plant biomass and the role of leaves in air purification. Therefore we have conducted a comparative analysis of ten main leaf properties (Morphological leaf analysis was done according to the modified protocol "Assessments of oak leaf morphology") and plant fertilisation in the first year after planting.

2. MATERIAL AND METHODS

Sample plots were established in localities with different orographic features, climatic conditions and physical and chemical properties of the soil:

1. The sample plot in Veliko Polje near Obrenovac – Site 1;
2. The sample plot in the village of Pambukovica near Ub – Site 2;

The sample plots at the sites in Obrenovac (Site 1) and Pambukovica (Site 2) were established by planting Paulownia trees of generative origin. The seeds were collected from well-adapted genotypes of two Paulownia species from a sample area in Bela Crkva. Container seedlings produced by generative reproduction were used as starting material to establish experimental plantations.

Seedlings were planted in rows at a 4x4 m spacing. Each row had 25 plants. There were 12 rows of *Paulownia elongata* seedlings and 12 seedlings of *Paulownia fortunei* species. The seedlings were planted by hand in holes with a diameter of 30x30 cm.

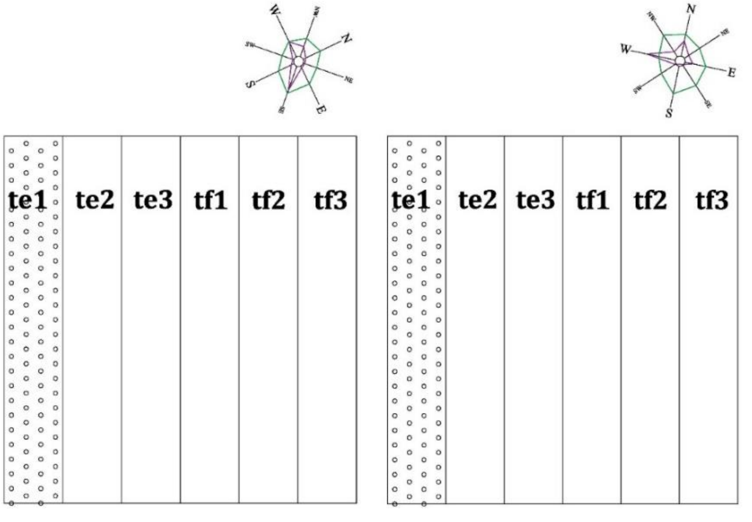

Figure 1. *Schema of sample plots with a wind rose (velocity and frequency) in Obrenovac (left) and Pambukovica (right)*

(te1 – seedlings of P. elongata from treatment group 1 (with a large amount of fertiliser added); te2 – seedlings of P. elongata from treatment group 2 (with a small amount of fertiliser added); te3 – seedlings of P. elongata not fertilised (control group); tf1 – seedlings of P fortunei from treatment group 1 (with a large amount of fertiliser added); tf2 – P. fortunei seedlings from treatment group 2 (with a small amount of fertiliser added); tf3 - P. fortunei seedlings not fertilised (control group)

Each sample plot was divided into six treatment groups (each treatment group had four rows of 25 plants), which differed in the amount of fertiliser (fertor) added and the control group of plants that were not fertilised.

The type of fertiliser to be used to supply plants with nutrients was selected based on soil analysis. Due to the heavy mechanical composition and the acidic pH, chicken manure – fertor (http://www.mrf-garden.com) was used in both localities. Fertor is an organic fertiliser (in the form of pellets) produced from 100% chicken manure, with other organic substances of plant origin added to increase its nutritional value. A high share of total organic matter maintains and improves the physical properties of the soil. Some macro- and micro-elements are easily accessible and available to plants, while some are released gradually. The fertiliser was added to the plants in the amount of 240 g per plant (t1) and 120 g per plant (t2). Control areas (t3) did not receive any fertiliser.

Leaves were sampled in the field at the end of the first and second growing seasons. They were collected from the same portion of the canopy, i.e., the same nodes.

The collected leaves were herbilised and scanned. Using the AutoCAD software, the scanned leaves were measured with a precision of 1 mm. The sample included 150 plants per site. Five leaves were taken from each plant whose morphometric characteristics were to be measured. It added up to 750 leaves per site or 1500 for both.

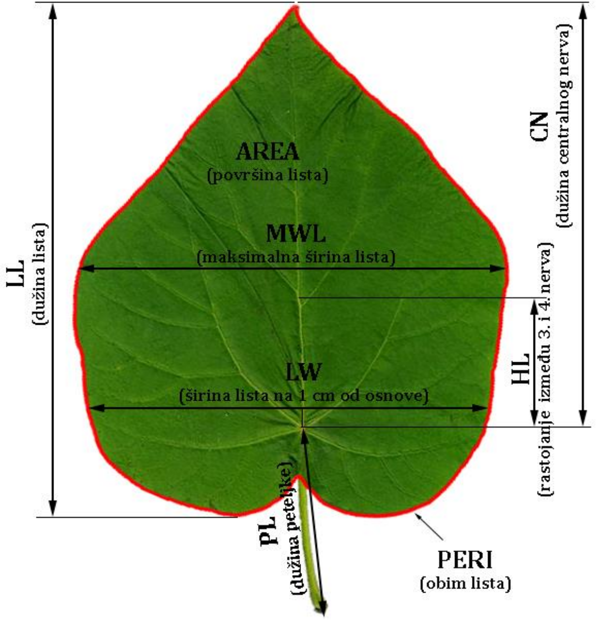

Figure 2. *Schematic representation of analysed measurement parameters of Paulownia leaves*

Source:http://www.european-trees.com/requete-leaf-simple-lisse--1a4.html (modified)

Ten following ten leaf properties were measured (the morphological leaf assessment was done according to the modified protocol of "Assessments of oak leaf morphology": http:/www.pierroton.inra.fr/Fairoak/Protocoles/OAKMORPH.html):

1. total leaf area without petiole, in cm^2 (AREA);
2. total leaf perimeter, without petiole, in cm (PERI);

3. length of the leaf lamina, from the leaf base to the top of the leaf, in cm (LL);
4. length of the central nerve (CN);
5. maximum leaf width, in cm (MWL);
6. leaf width at 1 cm from the leaf base, in cm (LW);
7. leaf petiole length, from the base of the leaf to the top of the petiole, in cm (PL);
8. distance between the 3rd and 4th nerve, in cm (HL);
9. number of nerves on the left side of the leaf (NLL); and
10. number of nerves on the right side of the leaf (NLR).

Special data entry forms were created for leaf morphometric measurements. They were statistically processed in the STATGRAPHICS software (Statistical Graphics Corporation, USA). The experimental design corresponds to a three-way and two-way analysis of variance: ANOVA III.

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

ANOVA III assesses the effect of each factor separately and their interactions. The size of the aggregate sample (number of aggregate sample elements) for ANOVA III is n=1500 (2x2x3x125=1500) within which the following ten properties were measured: leaf area, leaf perimeter, leaf lamina length, central nerve length, maximum leaf width, leaf width at 1 cm from the leaf base, leaf petiole length, distance between the 3rd and 4th nerve, the number of nerves to the left of the leaf nerve, and the number of nerves to the right of the central leaf nerve.

4. RESULTS AND DISCUSSION

Site 1 is located in Veliko Polje, Obrenovac municipality. The sample plot is located on the left bank of the Kolubara River at 74 m a.s.l. The terrain of the plot is flat without a slope, and the plant rows are northwest-southeast oriented.

Table 1. *Physical properties of the soil at the site in Obrenovac (Site 1)*

Profile depth (cm)	Coarse sand	Fine sand	Silt	Clay	Total sand	Total clay	Texture class
	%						
0-20	4.50	48.62	20.58	26.30	53.12	46.88	Sandy loam
20-40	4.20	46.60	22.30	26.90	50.80	49.20	Loam

The soil at Site 1 has good water and air permeability and a sufficiently high retention capacity of available water. Regarding its texture, it belongs to the class of sandy loam. The surface soil layer belongs to the class of sandy loam, and the deeper layer to loam. Although the analysed layers belong to different textural classes, they are similar, i.e., there is no strong differentiation of profiles by textural composition. The content of individual textural fractions in both layers is close to the limit values between sandy loam and loam. This soil is well-permeable to water and well-aerated throughout the depth of the solum (Table 1).

Table 2. *Chemical properties of the soil at the site in Obrenovac (Site 1)*

Profile depth (cm)	pH		Adsorptive complex					Total		C/N	Available	
	H2O	KCl	T	S	T-S	V	Y1	humus	N		P2O5	K2O
			equ.m.mol/100g			%	cm^3	%	%		mg/100g	
0-20	5.91	4.74	32.50	24.94	7.56	76.74	11.63	2.55	0.19	7.59	23.55	19.39
20-40	5.87	4.77	32.90	25.27	7.63	76.80	11.74	2.03	0.12	10.13	21.63	17.45

Site 1 has medium soil pH. The total adsorption capacity is high due to the high proportion of clay in the texture. According to the content of total humus, both analysed layers are low in humus. A narrow C/N ratio is favourable for the mineralisation of organic matter. The availability of easily accessible forms of phosphorus is good throughout the solum depth, and the availability of accessible potassium is medium (Table 2).

Site 2 is located in Pambukovica near Ub. It belongs to the Kolubara District in the Tamnava microregion. The sample plot is located on Jastrebovac Hill, municipality of Ub. The plot has undulating terrain with the lowest point at 162.60 m and the highest at 176.11 m above sea level. The relief of this area is flat to hilly, with slight height differences. The plot mostly has a southeastern aspect. It is northwestern in a small part. The plot is surrounded by beech-oak forests. The average altitude is 174.69 m. The planted rows run north to south.

Table 3. *Physical properties of the soil at the site in Pambukovica (Site 2)*

Profile depth (cm)	Coarse sand	Fine sand	Silt	Clay	Total		Texture class
					sand	clay	
	%						
0-20	0.60	44.50	29.00	25.90	45.10	54.90	Loam
20-40	0.40	42.20	25.70	31.70	42.60	57.40	Sandy clay loam

The surface layer of the soil at Site 2 belongs to the loam class and has good water and air permeability. With the depth of the soil solum, the share of clay and fine sand increases, and the textural class changes to sandy clay loam, which is slightly less permeable to water and air (Table 3).

Table 4. *Chemical properties of the soil at the site in Pambukovica (Site 2)*

Profile depth (cm)	pH		Adsorptive complex					Total		C/N	Available	
	H2O	KCl	T	S	T-S	V	Y1	humus	N		P2O5	K2O
			equ.m.mol/100g			%	cm^3	%	%		mg/100g	
0-20	5.35	3.84	32.13	19.56	12.57	60.87	19.34	1.47	0.15	5.87	<LD	8.76
20-40	5.41	3.94	32.66	21.51	11.15	65.86	17.15	0.98	0.13	4.41	<LD	7.94

The soil pH range is very acidic throughout the whole solum. The total adsorption capacity is high. The surface layer has a low level of total humus content, while the deeper layer has a low to very low level. The content of total nitrogen is low, and the ratio of carbon to nitrogen is narrow. In both layers we studied, the amount of plant-available phosphorus is below the detection limit of the Al-method, which means that this soil is very poor in plant-available forms of phosphorus. The amounts of plant-available forms of potassium are within the limits of poor availability throughout the entire depth of the profile (Table 4).

Table 5 and Table 6 present the mean values of the analysed leaf parameters of seedlings at both sites, obtained by descriptive statistics.

Regarding the property **leaf area** (Table 5), there are differences in the mean values of the groups (measurements) depending on site, species and treatment factors. Seedlings at Site 1 have significantly higher mean values of leaf area than seedlings at Site 2. The difference between species is statistically significant, i.e., *Paulownia elongata* seedlings have higher mean values of leaf area compared to *Paulownia fortunei* seedlings. The difference between all three treatments is statistically significant. The seedlings from the group fed with a large amount of fertiliser have higher mean values of the leaf area, and the seedlings from the control group have the lowest mean values.

Regarding the property **leaf perimeter** (Table 5), there are differences in the mean values of the groups (measurements) for site, species and treatment factors. Seedlings at Site 1 show significantly higher values of leaf perimeter than seedlings at Site 2. The difference in the mean leaf perimeter values between species is statistically significant. Seedlings of *Paulownia elongata* show significantly higher means. The difference in the mean values of leaf perimeter between seedlings of different treatments is also statistically significant. Seedlings of the group fed with a large amount of fertiliser have the highest mean values and the lowest in the control group. Interactions between all three examined factors are not statistically significant.

For the property **leaf lamina length** (Table 5), the differences in the mean values of the groups (measurements) depend on the site and treatment, but not the species. Mean values of leaf lamina length differ significantly between these two sites, with the seedlings at Site 1 showing higher mean values. There is no statistically significant difference between the species in the mean value of leaf lamina length, although seedlings of *Paulownia elongata* have higher mean values. The differences in mean values between the seedlings of different treatment groups are also statistically significant, with the highest mean value of the leaf lamina length achieved by the seedlings from the group that was treated with a large amount of fertiliser, followed by the group that was treated with a small amount of fertiliser. The lowest mean value was attained by the seedlings from the control group (Table 5).

The property **central nerve length** (Table 5) shows differences in the mean values of the groups (measurements) for site and treatment factors, but not species. Seedlings of Site 1 have significantly higher mean values of the central nerve length. The difference in the mean value of the central nerve length between species is not statistically significant, although *Paulownia elongata* seedlings have higher mean values. Seedlings in the group that was treated with a large amount of fertiliser have significantly higher mean values than seedlings from the group treated with a small amount of fertiliser and the control group. Seedlings within the latter two groups do not differ significantly, although seedlings in treatment group 2 have higher mean values of the central nerve length than control seedlings. (Table 5).

Regarding the **leaf width** (Table 5), there are differences in the mean values of the groups (measurements) for site and treatment factors. As with previous properties, the species factor does not lead to any differences in the mean values of the groups (measurements). At both sites, there are significant differences between the seedlings in the mean value of leaf width which is higher at Site 1. The difference in the mean values of the property between species is not statistically significant, although seedlings of *Paulownia elongata* have higher mean values. Mean values of leaf width are significantly different between seedlings of different treatment groups. The seedlings treated with a large amount of fertiliser have the highest mean value of the leaf width property, while the control group has the lowest. (Table 5).

Regarding the **leaf width at 1 cm from the base** (Table 6), there are differences in the mean values of the groups (measurements) for site and treatment factors, but not species. There is a significant difference in the mean value of leaf width at 1 cm from the base between the seedlings at different sites. It is significantly higher in the seedlings at Site 1. *Paulownia elongata* seedlings have larger (7.24 cm) mean leaf width values than *Paulownia fortunei* seedlings, but the difference is not statistically significant. Seedlings of different treatment groups have significantly different mean values of leaf width at 1 cm from the base, whereby seedlings treated with a large amount of fertiliser have significantly higher mean values of the property compared to seedlings treated with less fertiliser and control treatment (Table 6).

Table 5. *Basic descriptive statistics parameters and three-way ANOVA for leaf properties: leaf area (cm^2), leaf perimeter (cm), leaf lamina length (cm), central nerve length (cm), leaf width (cm); for seedlings at the site in Obrenovac (Site 1) and Pambukovica (Site 2) at the end of the first growing season*

factor	level	leaf area	leaf perimeter	leaf lamina length	central nerve length	leaf width
Site (A)	Site 1	[A]57,25(45,14)^b	31,26(20,01)^b	9,30(4,50)^b	7,81(3,56)^b	8,51(3,97)^b
	Site 2	38,02(19,17)^a	24,84(13,70)^a	7,48(2,33)^a	6,12(1,90)^a	6,82(2,28)^a
		[B]$F_{1,1490}$=124,71*	$F_{1,1490}$=54,53*	$F_{1,1490}$=105,47*	$F_{1,1490}$=146,68*	$F_{1,1490}$=109,94*
Species (B)	*P. elongata*	50,06(41,50)^b	29,19(16,64)^b	8,53(4,18)	7,00(3,35)	7,75(3,06)
	P. fortunei	45,22(29,28)^a	26,91(18,15)^a	8,25(3,13)	6,93(2,54)	7,58(3,60)
		$F_{1,1490}$=8,04*	$F_{1,1490}$=7,00*	ns	ns	ns
Treatment (C)	treatment 1	57,57(35,53)^c	31,81(16,18)^c	9,28(3,01)^c	7,64(2,53)^b	8,44(3,81)^c
	treatment 2	49,30(45,38)^b	28,25(15,64)^b	8,29(3,11)^b	6,74(2,58)^a	7,74(3,46)^b
	treatment 3	36,02(18,22)^a	24,08(19,42)^a	7,60(4,56)^a	6,47(3,56)^a	6,82(2,41)^a
		$F_{2,1490}$=53,13*	$F_{2,1490}$=26,38*	$F_{2,1490}$=30,15*	$F_{2,1490}$=26,99*	$F_{2,1490}$=33,62*
interactions **(AXB)**		ns	ns	ns	ns	ns
interactions **(AXC)**		$F_{2,1490}$=7,69*	ns	ns	ns	$F_{2,1490}$=4,89*
interactions **(BXC)**		ns	ns	$F_{2,1490}$=32,13*	$F_{2,1490}$=57,34*	$F_{2,1490}$=18,87*

Table 6. *Basic descriptive statistics parameters and three-way ANOVA for leaf properties: leaf width at 1 cm from the base (cm), petiole length (cm), distance between the third and fourth nerve, number of nerves - left and number of nerves - right for seedlings at the site in Obrenovac (Site 1) and Pambukovica (Site 2) at the end of the first growing season*

factor	level	leaf width at 1 cm from the base	petiole length	distance between the third and fourth nerve	number of nerves - left	number of nerves - right
Site (A)	Site I	7.74(3.06)^b	6.38(3.22)^b	2.11(0.98)^b	8.49(1.04)^b	8.54(0.98)^b
	Site II	6.53(4.16)^a	4.57(1.73)^a	1.41(0.58)^a	8.27(0.91)^a	8.19(0.78)^a
		$F_{1.1490}$=42.48*	$F_{1.1490}$=223.56*	$F_{1.1490}$=319.79*	$F_{1.1490}$=24.23*	$F_{1.1490}$=74.99*
Species (B)	*P. elongata*	7.24(4.01)	5.88(2.79)^b	1.74(0.92)	8.51(1.02)^b	8.44(0.97)^b
	P. fortunei	7.03(3.36)	5.07(2.62)^a	1.78(0.84)	8.24(0.93)^a	8.30(0.84)^a

factor	level	leaf width at 1 cm from the base	petiole length	distance between the third and fourth nerve	number of nerves - left	number of nerves - right
		ns	$F_{1.1490}$=46.68*	ns	$F_{1.1490}$=36.60*	$F_{1.1490}$=11.88*
Treatment (C)	treatment 1	7.88(4.58)[c]	6.37(2.90)[c]	2.00(0.87)[c]	8.45(1.15)	8.46(1.08)[b]
	treatment 2	7.19(2.94)[b]	5.29(2.88)[b]	1.75(0.81)[b]	8.35(0.79)	8.34(0.81)[a]
	treatment	6.32(3.21)[a]	4.76(2.10)[a]	1.53(0.89)[a]	8.34(0.98)	8.31(0.80)[a]
		$F_{2.1490}$=23.71*	$F_{2.1490}$=61.76*	$F_{2.1490}$=46.27*	ns	$F_{2.1490}$=5.08*
***interactions* (AXB)**		ns	$F_{1.1490}$=28.58*	$F_{1.1490}$=8.01*	$F_{1.1490}$=132.14*	$F_{1.1490}$=103.36*
***interactions* (AXC)**		ns	$F_{2.1490}$=20.26*	$F_{2.1490}$=7.65*	$F_{2.1490}$=22.61*	$F_{2.1490}$=25.10*
***interactions* (BXC)**		$F_{2.1490}$=8.21*	$F_{2.1490}$=57.52*	$F_{2.1490}$=32.08*	$F_{2.1490}$=96.22*	$F_{2.1490}$=124.15*

* Three-way analysis of variance (ANOVA III). Factor A (site) with 2 levels: Site 1 (Obrenovac) and Site 2 (Pambukovica); factor B (species) with 2 levels: species 1 (*P. elongata*) and species 2 (*P. fortunei*); factor C (treatment) with 3 levels: treatment 1 (high amount of fertiliser), treatment 2 (low amount of fertiliser), and treatment 3 (control), and their interactions. Aggregate sample size (number of aggregate sample elements), n=1500 (2 sites x 2 species x 3 treatments x 125 = 1500). [A] =mean value (standard deviation); [B]= F-test indicator with numbers of degrees of freedom; ns = non-significant difference between the mean values of the populations (P> 0.05); * = statistically significant difference ($P\leq$ 0.05).

As for the **petiole length** (Table 6), there are differences in the mean values of the groups (measurements) for the location, species and treatment factors. Seedlings at Site 1 have significantly higher mean values of petiole length. Seedlings of *Paulownia elongata* have significantly higher mean values of petiole length. The difference in the mean value of the petiole length between the seedlings with different treatments is significant. The mean value of the petiole length is the highest in the seedlings treated with a large amount of fertiliser and the smallest in the seedlings from the control group.

For the **distance between the third and fourth nerve of the leaf** (Table 6), there are differences in the mean values of the groups (measurements) for the site and treatment factors, but not species. Seedlings at Site 1 show significantly higher values of the distance between the third and fourth nerve of the leaf. There is no statistically significant difference between the species in the mean value of this property, although seedlings of the *Paulownia fortunei* have higher mean values. There is a statistically significant difference in the mean values of the distance between the third and fourth nerves between the seedlings of different treatment groups. Seedlings from the group treated with a large amount of fertiliser show the highest mean values and the control treatment group the lowest.

Regarding the **number of nerves on the left side of the leaf** (Table 6), the mean values of the groups (measurements) differ depending on the site and species factors, but not treatment. Seedlings at Site 1 have significantly higher mean values of the number of nerves on the left side of the leaf. *Paulownia elongata* seedlings have significantly higher mean values of the number of nerves on the left side of the leaf. There is no statistically significant difference in the number of nerves between seedlings of different treatments. The highest mean values of the number of nerves on the left side of the leaf are shown by seedlings from the group treated with a large amount of fertiliser and the least by the control group.

As for the **number of nerves on the right side of the leaf** (Table 6), there are differences in the mean values of the groups (measurements) depending on the site, species and treatment factors. Seedlings at Site 1 have a significantly higher mean number of nerves on the right side of the leaf. *Paulownia elongata* seedlings have significantly higher mean values of the number of nerves on the right side. Between seedlings in different treatment groups, the difference in the mean value of the number of nerves on the right side of the leaf is significant. Seedlings from the group treated with a large amount of fertiliser have significantly higher mean values of the number of nerves than seedlings from the group treated with a small amount of fertiliser and from the control group (8.31) which are not significantly different from each other.

The results of the analysis of variance in the first growing season reveal significant differences in the morphometric characteristics of the leaves between the seedlings at both sites (Table 5 and Table 6). The most significant difference is between the parameters that determine the leaf size. The mean value of the leaf lamina length of the seedlings at Site 1 is 9.30 cm and 7.48 cm at Site 2. The mean values of petiole length are 6.38 cm and 4.57 cm, respectively. The leaf size achieved by plants at both sites is far below the values that Paulownia can reach (Graves, 1989; Šijačić-Nikolić, et al., 2009). The shape and structure of leaves depend significantly on a range of factors (Fender et al., 2011; Stojnić, 2013). The morphometric characteristics of the seedling leaves at both sites are a result of their adaptation to the unfavourable environmental conditions in which the seedlings have grown. At Site 2, the content of nitrogen, phosphorus and potassium in the soil (also reflected on the leaves) is lower than at Site I, which makes the conditions for plant growth and leaf development less favourable. Although the average values of precipitation in the growing season were higher at Site 2, the seedlings did not have enough moisture in the soil, because atmospheric precipitation quickly ran off from the sloping plot, and the leaves were consequently smaller. In their research, Ozturk et al. (2014) state that the size of leaves depends on climatic factors and are smaller in drier environmental conditions (Pedrol et al., 2000; Otieno et al., 2005).

There are differences in the leaf morphometric characteristics between the seedlings of the analysed species, as indicated in literature (Šilić, 1990; Cvjetićanin and Perović, 2009), whereby the *Paulownia elongata* seedlings have higher mean values of all parameters compared to the *Paulownia fortunei* seedlings at both sites.

The effects of fertilisation can be seen in differences between leaf morphometric parameters. Seedlings that are fed with a large amount of fertiliser have the highest mean values. These findings are in agreement with the results obtained by Boughalleb et al. (2011) and Adejobi et al. (2014) that feeding had a positive effect on leaf size.

5. CONCLUSIONS

The analysis of leaf morphological parameters of *Paulownia elongata* S. Y. Hu. and *Paulownia fortunei* Seem. Hemsl. planted at different sites and treated with different amounts of fertilisers indicates that the type of site affects leaf morphological parameters and fertilisation has a positive effect on leaf parameters and leaf size in the first year after planting.

All measured parameters are significantly higher at the site in Obrenovac (Site 1) than Pambukovica (Site 2), as expected since the soil at Site 1 has better physical properties, contains more humus and has more favourable carbon to nitrogen (C/N) ratio.

The leaves of seedlings treated with a larger amount of fertiliser (240 g per plant) have significantly higher values of all analysed parameters than the leaves of seedlings fed with a smaller amount of fertiliser (120 g per plant) and the leaves of plants in the control area with no treatment. Compared to the leaves from the control area, the plants fed with a smaller amount of fertiliser had significantly higher values of all the parameters of the leaves except for the length of the central nerve, where the difference is not statistically significant.

The analysis of leaf morphological parameters of the investigated species shows that in *Paulownia elongata* S. Y. Hu, the mean values are higher and statistically significant for the properties of leaf area, leaf perimeter, petiole length, the distance between the third and fourth leaf nerves, the number of nerves on the left side of the leaf and the number of nerves on the right side of the leaf. On the other hand, these differences are not statistically significant for leaf lamina length, central nerve length, leaf width, and leaf width at 1 cm from the base.

Based on the obtained results, we can conclude that when introducing these species, we must ensure that the soil is loose and well-aerated. Since this is a fast-growing species, the amount of nutrients added through fertilisation should be adjusted to the physical and chemical properties of the soil so that it contains the right amount. The obtained results point to the potential of these species, and research should be expanded to the subsequent development of the plants until they are harvested in energy plantations where the use of these species can be expected.

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MORPHOMETRIC CHARACTERISTICS OF *PAULOWNIA ELONGATA* S. Y. HU. AND *PAULOWNIA FORTUNEI* SEEM. HEMSL. LEAVES AND FERTILISATION IN DIFFERENT SITES

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Saša EREMIJA, Renata GAGIĆ-SERDAR, Snežana STAJIĆ

Summary

The introduction of new species in the territory of Serbia has become important considering the climatic changes that have become evident in the early decades of the 21st century. These changing environmental conditions have made certain species from different regions of the world suitable for the introduction. Numerous research studies have been conducted to find out whether it is possible and justified to introduce paulownia species. We selected *Paulownia elongata* and *Paulownia fortunei,* species of the *Paulownia* Sieb. & Zucc. genus from the Paulowniaceae family for our research because we already had a plantation established in 1993 near Bela Crkva in Vojvodina to collect seeds for the production of plants that were analysed at other sites. The analysis of the morphological parameters of the leaves of these two Paulownia species was carried out as part of the research dealing with their adaptability to the environmental conditions at two different sites in Serbia. Leaf size and characteristics are important for the process of photosynthesis and the production of nutrients that are directly correlated with the production of the entire plant biomass. Leaves have another important role – acting as filters that clean the air. Based on these facts, a comparative analysis of ten main leaf characteristics was performed (Morphological leaf analysis was carried out following the modified protocol for "Assessments of oak leaf morphology") relative to the soil conditions and different amounts of fertiliser used to feed the plants in the first year after planting. The analysis of the obtained data about the morphological parameters of the leaves of *Paulownia elongata* S. Y. Hu. and *Paulownia fortunei* Seem. Hemsl. planted at different sites and treated with different amounts of fertiliser indicate that the type of site affects leaf morphological parameters and fertilisation has a positive effect on leaf parameters and leaf size in the first

year after planting. In both sites and in all treatments, better results were recorded for *Paulownia elongata* S. Y. Hu. The obtained results reveal the potential of these species. Plantations should be established on loose and well-aerated soil. When introducing this species, care should be taken, given that this is a fast-growing species, that the amount of nutrients added matches the chemical properties of the soil so that plants have enough nutrients for growth and development. Research should be continued in the second year of plant development until harvest in energy plantations where these species are expected to be used.

MORFOMETRIJSKE KARAKTERISTIKI LISTOVA VRSTA *PAULOWNIA ELONGATA* S. Y. HU. I *PAULOWNIA FORTUNEI* SEEM. HEMSL. U ODNOSU NA PRIHRANJIVANJE NA RAZLIČITIM STANIŠTIMA

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Rezime

Introdukcija novih vrsta na području Srbije je od značaja ako imamao u vidu klimatske promene koje su evidentne u prvim dekadama 21 veka. U okviru novonastalih uslova sredine pojedine vrste iz različitih regiona u svetu ukazuju da je njihova introdukcija moguća. U okviru istraživanja koja treba da pokažu da li je introdukcija vrsta paulovnija moguća i opravdana vršena su različita istraživanja. Vrste *Paulownia elongata* i *Paulownia fortunei* roda *Paulownia* Sieb. & Zucc. iz familije Paulowniaceae su odabrane za naše istraživanje jer kod nas već postoji osnovana plantaža u1993. godine kod Bele Crkve u Vojvodini. sa koje je i prikupljeno seme za proizvodnju biljaka koje su analizirane na drugim staništima. Analiza morfoloških parametara listova navedene dve vrste paulovnije vršena je u sklopu istraživanja adaptibilnosti ovih vrsta na uslove sredine dva različita lokaliteta u Srbiji. Veličina i karakteristike lista su od značaja za fotosintetičke procese i produkciju hranljivih materija koje su u direktnoj korelaciji sa produkcijom celokupne biomase biljaka. Značajna je i uloge lista kao filtera za prečišćavanje vazduha. Polazeći od ovih činjence izvršena je komparativna analiza deset osnovnih obeležja lista (Morfološka analiza lista rađena je prema modifikovanom protokolu ”Assessments of oak leaf morphology”) u odnosu na pedološke ulove i prihranjivanja biljaka u prvoj godinirazvoja nakon sadnje sa različitim količinama đubriva. Analiza mernih podataka morfoloških parametara listova vrsta *Paulownia elongata* S. Y. Hu. i *Paulownia fortunei* Seem. Hemsl. posađenih na različitim staništima i tretiranih različitim količinama đubriva ukazuju da tip staništa utiče na morfološke parametre lista i da prihranjivanje pozitivno utiče parametre lista i veličinu listova u prvoj godini nakon sadnje. Na oba lokaliteta i u svim tretmanima bolji rezultati su evidentirani kod vrste *Paulownia elongata* S. Y. Hu. Dobijeni rezultati ukazuju na potencijal ovih vrsta. Plantaže treba formirati na rastresitom i dobro aerisanom zemljištu. Kod introdukcije ove vrste treba voditi računa, obzirom da je ovo brzorastuća vrsta, da se količina hranljivih materija koje se dodaju đubrenjem usklade sa hemijskim osobinama zemlišta kako bi ih bilo u dovoljnoj meri za razvoj i razvitak biljaka. Sa istraživanjima treba nastaviti i u drugoj godini razvoju biljaka sve do žetve u energetskim zasadima gde se može očekivati upotreba ovih vrsta.

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VARIABILITY OF CHARACTERISTICS OF SESSILE OAK (*Quercus petraea (Matt.) Liebl*) SEEDLINGS FROM THE AREA OF OUTSTANDING NATURAL LANDSCAPE "AVALA"

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Abstract: *The research of the variability within the population based on morphometric characteristics of seedlings had been conducted to preserve the available gene pool of the Sessile oak population located in the Area of Outstanding Natural Landscape (AONL) "Avala" and the controlled use of the genetic resources.*

Fifty best-quality trees based on the phenotypic characteristics, the carriers of the Sessile oak (Quercus petraea (Matt.) Liebl) reproductive material production were selected at the population level. Approximately 3 kg of apparently healthy and undamaged acorns were collected from each tree, separated by mother trees, and used for seedling production in the nursery under uniform environmental conditions. The root collar diameter and the height of the randomly selected 50 seedlings per half-sib line were measured at the end of the first growing season, and the sturdiness quotient was calculated based on the measured values.

The obtained mean values of the morphometric characteristics indicate a high variability among the tested genotypes. This is also confirmed by the analysis of variance which determined statistically significant differences between the analyzed half-sib lines for all observed morphometric characteristics.

The obtained results represent a good starting point for future research on breeding, long-term preservation, and improvement of the ecological adaptability and evolutionary potential of the Sessile oak population by applying adequate in-situ and ex-situ conservation measures. Based on the research results, it can be recommended to use this

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important species for reintroduction in optimal microclimatic conditions, as well as for the selection of the best individuals for reintroduction.

Key words: seedlings, variability, gene pool, population.

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VARIJABILNOST SVOJSTAVA SADNICA KITNJAKA (*Quercus petraea (Matt.) Liebl*) SA PODRUČJA PIO „AVALA“

Izvod: *Istraživanje intrapopulacijske varijabilnosti na osnovu morfometrijskih svojstava sadnica sprovedeno je u cilju očuvanja raspoloživog genofonda hrasta kitnjaka u populaciji na području predela izuzetnih odlika Avala i kontrolisanog korišćenja genetičkih resursa.*

Pedeset stabala najboljeg kvaliteta na osnovu fenotipskih karakteristika, nosilaca proizvodnje reproduktivnog materijala hrasta kitnjaka (Quercus petraea (Matt.) Liebl) odabrano je na nivou populacije. Po svakom stablu sakupljeno je oko 3 kg okularno zdravog i neoštećenog žira, od koga su odvojeno po materinskim stablima u rasadniku, u ujednačenim uslovima sredine proizvedene sadnice. Na kraju prvog vegetacionog perioda na slučajnom uzorku od 50 sadnica po liniji polusrodnika mereni su prečnik u korenovom vratu i visina sadnica, a na osnovu izmerenih vrednosti izračunat je koeficijent jedrine.

Srednje vrednosti morfometrijskih karakteristika dobijene u istraživanju ukazuju na visoku varijabilnost među ispitivanim genotipovima. Ovo potvrđuje i analiza varijanse kojom su utvrđene statistički značajne razlike između analiziranih linija polusrodnika za sve posmatrane morfometrijske karakteristike.

Dobijeni rezultati predstavljaju dobru polaznu osnovu za buduća istraživanja oplemenjivanja, dugoročnog očuvanja i unapređenja ekološke prilagodljivosti i evolutivnog potencijala populacije hrasta kitnjaka primenom adekvatnih mera in situ i ek situ očuvanja. Na osnovu rezultata istraživanja mogu se dati preporuke za korišćenje ove značajne vrste u njenoj reintrodukciji u optimalnim mikroklimatskim uslovima, kao i u selekciji najboljih individua za ponovnu reintrodukciju.

Ključne reči: sadnice, varijabilnost, genofond, populacija.

1. INTRODUCTION

The Sessile oak (*Quercus petraea /Matt./ Leibl.*) represents, right after the Pedunculate oak (*Quercus robur*), the most valuable oak species in the growing stock of the Republic of Serbia. Its share in the total volume is 5.9%, that is, it occupies an area of 173.200 ha. Pure stands are represented by 57.5%, mixed stands by 42.5%, while coppice stands are dominant on about 75% of the surface (Banković et al. 2009). The Sessile oak mainly occurs on warmer, southern exposures within the Quercion petraeae-cerris association (Laksh. and Job. 1980). The Sessile oak forests in Serbia are located within a special oroclimatogenic altitudinal zone, above the climatogenic Turkey and Hungarian oak forests. The Sessile oak forest complex includes the upper part of the hill range and the lower mountain range, at an elevation of 300 - 1300 m (Stojanović, Lj., et al., 2005). In the last few decades, the dieback of the Sessile oak stands, groups, and individual trees almost in the entire area have been identified due to causes that have not yet been sufficiently studied and systematized. The occurrence is most likely conditioned by the influence of a complex of factors whose effect is cumulative (Marinković, P., et al., 1990). What is evident is that negative activities in the near and distant past caused major changes in natural ecosystems, which gradually led to the decline of populations, and their habitats were destroyed or reduced (BOROVICS AND MATIAS, 2013; TORRES-RUIZ et al., 2019; ŠIJAČIĆ-NIKOLIĆ et al., 2020). Based on the recent research results achieved related to the phenomenon of Sessile oak dieback, it can be considered that it is a consequence of the following: global climate change, changes in the population structure in the Sessile oak forests, air pollution, plant diseases, insect gradations, etc. (Isaev, V., et al 2005).

Genetic improvement programs include the individual selection of plus trees from the most valuable populations and the testing of their progeny in comparative experiments at different sites (Wright, 1976). The long-term survival of species is closely related to their genetic diversity (Gapare, 2014). Under the influence of changed environmental conditions, biotic agents of disease and damage, the survival and evolution of species depend on the level of genetic diversity (Reed and Frankham, 2003). Genetic diversity research that identifies populations with high genetic variability can help reduce the risk of biodiversity loss (Souto et al., 2015). Determining the level of population variability can be used to provide guidelines and recommendations for the conservation and directed use of genetic resources (Popović et al. 2021a). By combining the knowledge of meteorology, and genetics, and examining phenotypic plasticity, the above-mentioned programs strive to predict the dynamics of species evolution, preserve indigenous species, and select the most resistant and successful individuals. In this respect, Sessile oak is a species of choice for future mixed stands of European forests that will adapt to climate change and survive in dry conditions, and it is expected for this species to increase its share in forest stands (Kohler et al., 2020). Sessile oak trees in the forest ecosystem of the Area of Outstanding Natural Landscape “Avala”, near the capital of Serbia - Belgrade, are exposed to a higher level of human threats, due to their specific location and surroundings (ALVEY, 2006; FAO, 2016). The goals of multipurpose silviculture in special-purpose forests can be achieved by applying close-to-nature silviculture, where the natural site potential is optimally used to preserve their naturalness, biodiversity, and genetic variability, improve the condition, and increase productivity (Stajić et al. 2020).

The research aim was to determine the variability within the Sessile oak population in the Area of Outstanding Natural Landscape “Avala” based on the morphological characteristics of the seedlings. The results obtained in the research can help to get a preliminary understanding of the genetic variability of the studied population and propose measures for the preservation of the available gene pool and improvement of the quality of seed and planting material production.

2. MATERIAL AND METHODS

The one-year-old seedlings produced from acorns collected in 2019 from the Sessile oak test trees in the Area of Outstanding Natural Landscape “Avala” were used for the research presented in this paper. To determine the genetic variability and assess the condition of genetic resources in the Area of Outstanding Natural Landscape “Avala”, 50 Sessile oak trees (*Quercus petraea (Matt.) Liebl*) were selected and sampled. Representative, phenotypically best-quality trees, bearers of production of reproductive material in good health were sampled. The trees are evenly distributed over the entire surface of the protected area, at least 50 m apart from each other to avoid relatedness. About 3 kg of apparently healthy and undamaged acorns regardless of dimensions were collected per tree. After the collection, the acorns were dried to 35% moisture content and stored at the temperature of 3-5 ºC. The seeds were collected from the tree to breed the half-sib lines, where the mother is known but not the other parent, according to the method of genetic analysis of the trees (Isajev and Mančić, 2001). Acorns were sown in April 2020, separately by mother trees, in the seedling nursery of the Institute of Forestry in Belgrade. The seedlings were produced in uniform environmental conditions in hotbeds of dimensions 1x50 meters. The row spacing in the hotbed was 15 cm, and the rows were parallel to the shorter side of the hotbed.

Analyzes of measured and derived morphometric characteristics were performed on a random sample of 50 seedlings per mother tree, at the end of the first vegetation season. The root collar diameter and the height of the seedlings were measured and based on the obtained values, the sturdiness quotient was calculated according to Roller 1977. The root collar diameter was measured with a vernier caliper with an accuracy of 0.1 mm, and the seedling height with a ruler with an accuracy of 0.5 cm.

Morphological characteristics of seedlings were described by descriptive statistical indicators: arithmetic means (x), standard deviation (SD), and coefficient of variability (CV %). The analysis of variance (ANOVA) was used to determine the variability within the population. The source of the analyzed variability factors was the tree. All the statistical analyzes were performed by using STATISTICA 7.0 software (StatSoft Inc. 2004).

3. RESULTS AND DISCUSSION

Table 1 shows the parameters of descriptive statistics for the studied seedling characteristics.

The mean value of the seedling root collar diameter is 4.4 mm and it ranges from 3.3 mm (half-sib line 22) to 5.6 mm (half-sib line 41). The mean value of the seedling height is 22.9 cm and it ranges from 12.1 cm (half-sib line 22) to 35.5 cm (half-sib line 47). The mean value of the ratio of height to root collar diameter of seedlings is 5.3 and it ranges from 3.4 (half-sib line 19) to 7.5 (half-sib line 46). The mean value of the coefficient of variability for the root collar diameter of seedlings is 25.1% and it ranges from 12.7% (test tree 10) to 47.3% (test tree 28). The mean value of the coefficient of variability for seedling height is 35.6% and it ranges from 19.1% (test tree 9) to 60.4% (test tree 37). The mean value of the coefficient of variability for the sturdiness quotient according to Roller is 33.2% and it ranges from 16% (test tree 47) to 68.1% (test tree 28).

The most variable characteristic at the level of the studied half-sib lines is the seedling height (35.6%), while the root collar diameter is the least variable characteristic (25.1%).

Table 1. *Descriptive statistics for the measured morphological characteristics of the seedlings*

Tree	d (mm)					h (mm)					h/d				
	M	SD			CV	M	SD			CV	M			SD	CV
1	3.6	2.5	8.1	1.2	32.4	25.5	13.0	38.0	6.2	24.2	7.3	3.7	10.8	1.9	26.5
2	5.1	3.8	7.1	1.0	19.1	23.9	15.0	36.5	6.6	27.7	4.8	3.1	8.4	1.5	30.8
3	3.9	2.1	6.4	1.1	29.0	20.7	13.0	32.5	5.1	24.7	5.6	4.0	9.0	1.3	22.8
4	4.6	3.4	6.0	0.8	17.1	21.2	10.0	34.0	6.2	29.2	4.7	2.5	7.6	1.3	28.1
5	4.3	2.6	6.5	0.9	21.8	21.4	13.0	38.0	6.7	31.3	5.1	2.6	8.6	1.7	33.8
6	4.5	3.4	6.1	0.8	17.4	22.5	8.0	33.5	6.7	29.8	5.0	2.3	8.6	1.4	27.9
7	5.0	2.5	7.9	1.5	29.1	23.5	15.0	45.5	8.4	35.8	4.9	2.3	7.4	1.6	31.9
8	4.6	2.9	6.0	0.8	16.5	23.8	7.5	36.5	8.8	37.0	5.1	1.6	7.5	1.7	33.6
9	4.2	2.2	5.4	0.9	21.4	25.1	18.0	36.0	4.8	19.1	6.4	4.6	13.2	2.2	34.8
10	4.9	3.8	5.9	0.6	12.7	22.9	13.0	35.0	6.2	27.2	4.7	2.8	6.9	1.2	25.7
11	4.5	2.6	6.0	1.0	21.3	24.7	12.0	35.0	5.6	22.5	5.6	3.2	8.8	1.5	26.0
12	4.4	3.0	6.5	1.1	25.1	24.1	10.0	42.5	8.8	36.5	5.6	2.2	9.6	1.8	31.9
13	3.6	2.2	5.3	0.9	24.3	18.1	9.0	30.0	6.3	34.9	5.1	2.7	8.3	1.4	27.9
14	3.9	2.8	5.5	0.8	20.7	17.5	6.5	31.0	7.5	42.8	4.4	2.0	7.3	1.5	33.9
15	4.6	1.8	7.5	1.3	28.3	18.6	10.0	29.0	6.1	32.7	4.2	2.0	6.8	1.3	30.9
16	4.0	2.3	5.2	0.7	17.7	17.9	7.0	37.5	8.5	47.4	4.5	1.8	8.6	1.9	42.4
17	4.9	3.2	6.7	1.1	22.6	26.2	11.0	51.0	9.2	35.2	5.7	2.2	9.5	2.4	41.0
18	4.9	3.5	6.5	1.0	19.6	23.3	13.0	41.0	7.5	32.1	4.9	2.8	7.8	1.5	30.9
19	3.7	2.4	5.1	0.8	21.5	12.5	4.0	30.0	6.6	52.5	3.4	1.4	6.5	1.5	45.0
20	3.9	2.6	5.5	0.8	21.4	15.0	7.5	27.0	5.5	36.8	3.9	1.9	6.5	1.2	29.9
21	3.8	2.0	5.9	1.1	28.0	17.1	7.0	27.5	5.7	33.5	4.7	2.6	7.5	1.6	34.6
22	3.3	2.2	4.6	0.8	25.0	12.1	6.0	30.0	5.7	47.4	3.7	1.7	6.8	1.1	29.5
23	3.8	2.2	6.5	1.3	32.9	17.4	8.0	34.5	8.0	45.8	4.6	2.4	6.6	1.2	26.9
24	3.3	2.1	4.7	0.8	23.4	13.1	6.0	20.0	4.0	30.4	4.1	1.9	6.2	1.2	29.8
25	3.5	2.2	5.4	0.7	20.0	15.4	7.0	27.0	5.5	35.6	4.6	1.9	9.2	1.9	40.5
26	4.1	2.6	6.0	0.8	20.1	18.2	6.0	28.0	5.8	31.7	4.5	1.5	6.9	1.2	27.6
27	4.0	1.4	6.1	1.3	32.3	15.0	8.0	27.5	5.6	37.2	4.0	1.4	7.4	1.5	38.1
28	3.9	1.2	7.8	1.8	47.3	22.4	10.0	43.0	9.7	43.3	7.0	2.7	19.8	4.8	68.1
29	4.7	2.5	7.8	1.4	29.1	22.1	11.0	42.5	8.9	40.4	4.7	2.6	7.0	1.2	25.4
30	4.2	1.9	6.1	1.1	27.1	20.7	7.5	33.0	6.9	33.5	5.0	3.1	7.9	1.2	23.8
31	4.6	1.3	8.2	1.7	36.2	21.7	7.0	51.5	10.9	50.4	5.2	1.8	15.9	3.2	61.8
32	3.6	1.3	6.3	1.4	39.5	19.2	9.0	36.5	7.4	38.7	6.2	2.6	14.2	3.6	58.6
33	4.5	3.0	6.5	0.9	19.0	21.8	12.0	33.0	4.8	22.1	5.0	2.7	8.1	1.5	29.3
34	4.0	2.5	5.8	1.0	24.9	21.2	8.0	45.0	9.3	44.0	5.2	2.2	8.0	1.4	27.0
35	4.7	3.1	6.9	0.9	19.6	26.9	10.0	47.5	12.3	45.6	5.5	2.4	8.9	1.8	33.3
36	4.5	2.9	7.0	1.1	24.1	25.3	10.0	61.0	12.0	47.5	5.6	2.3	8.7	1.9	34.2
37	4.3	2.4	7.0	1.1	26.2	20.4	7.5	48.0	12.3	60.4	4.6	1.9	7.8	2.0	43.1
38	4.6	2.5	7.9	1.3	28.1	21.9	10.0	38.0	6.4	29.2	5.0	1.8	10.1	1.9	38.2
39	5.3	3.6	7.0	1.0	19.4	23.3	7.5	39.5	9.4	40.4	4.4	1.9	7.0	1.5	33.4
40	4.9	3.5	6.8	0.9	19.0	24.5	9.0	43.5	9.8	39.9	4.9	2.0	7.5	1.4	29.3
41	5.6	3.1	9.1	1.4	25.3	33.3	13.0	44.0	8.4	25.3	6.1	2.6	8.4	1.3	21.9
42	5.6	3.3	13.6	2.1	37.5	26.0	13.0	41.0	9.3	35.9	4.9	1.6	8.2	1.7	34.6
43	4.9	2.7	8.1	1.5	30.2	26.3	9.0	44.5	10.6	40.3	5.4	2.5	8.3	1.6	30.4
44	5.4	3.9	6.7	0.9	17.1	32.1	14.5	48.5	10.9	34.1	5.9	3.6	9.5	1.6	26.7
45	4.9	2.6	8.7	1.4	27.5	29.7	12.5	56.0	14.2	48.0	6.0	2.7	10.0	2.3	38.6
46	4.5	1.4	7.3	1.5	32.6	31.6	20.0	45.5	7.8	24.7	7.5	4.5	15.6	2.6	34.1
47	5.4	3.5	8.8	1.3	23.2	35.5	25.0	60.0	8.3	23.4	6.7	4.5	8.8	1.1	16.0
48	5.2	2.1	7.6	1.3	25.8	34.2	13.5	51.0	10.8	31.6	6.7	3.7	10.5	1.8	26.8
49	4.8	2.8	8.5	1.4	28.1	33.3	14.5	56.5	10.6	32.0	7.1	3.5	14.4	2.3	32.2
50	4.7	1.8	6.3	1.2	26.3	32.8	18.0	52.0	9.8	29.8	7.3	5.1	13.3	2.2	30.5
Mean	4.4	2.6	6.8	1.1	25.1	22.9	10.7	39.5	8.0	35.6	5.3	2.6	9.1	1.7	33.2

Note: d-root collar diameter; h- seedling height; h/d-height: root collar diameter ratio

Table 2. *Analysis of variance for the measured morphological characteristics of the seedlings*

Parameter	SS Effect	df Effect	MS Effect	F	p
d	49	347.33	7.09	5.41	0.0000
h	49	32084.4	654.8	9.521	0.0000
h/d	49	946.07	19.31	5.519	0.0000

To confirm the existence of a satisfactory level of genetic variability, the one-way analysis of variance (ANOVA) was performed based on the measured values, where the source of variability was the test tree. The results of the conducted analysis show that the trees within the population differ significantly at the significance level of $p<0.01$ for all observed morphological characteristics of seedlings (Table 2).

The existence of statistically significant differences between the studied half-sib lines for all analyzed morphological characteristics of seedlings indicates genetic differentiation and a high degree of variability within the population. Based on the obtained statistical parameters, it can be confirmed the existence of genetic variability both within and between the analyzed half-sib lines. The analyzed seedling characteristics are quantitative and controlled by polymer genes whose effects are added together. The variability of quantitative characteristics is wide and has a continuous character, and it is conditioned by the interaction of polymeric genes and environmental factors. The occurrence of a high degree of variability within the population is characteristic of most species of forest trees and can be explained by the process of gene migration and a low degree of local adaptation (Bogdan, S., 2009). As the presented results confirm the assumption of high variability within the population, the very population can be used in breeding processes and as a potential source of quality reproductive material. Statistically significant differences determined between individual parent trees (genotypes) in the analysis of morphological characteristics of acorns (Popović et al. 2021b) and morphological characteristics of leaves (Popović et al. 2020) also indicated a high level of genetic diversity within the population. A high level of genetic diversity was determined between the analyzed trees in this population of Sessile oak by using seven SSR markers (Popović et al. 2022).

A prerequisite for the successful preservation and improvement of the gene pool of forest woody species is knowledge of genetic diversity and population structure. For the survival and stability of populations, adequate ecological management is necessary with the aim of preservation and implementation of *in situ* conservation measures, along with monitoring and improving genetic diversity (Bruschi et al. 2003). Considering climate change, the adaptive potential of forest tree populations is largely determined by individual levels of relatedness (Lloret and García. 2016). The long-term survival of populations and losses of genetic resources are threatened by uncontrolled logging and the irrational use of resources (Gilpin and Soule. 1986). The reduction of populations leads to the decline of genetic diversity and the appearance of inbreeding, which in the long run can affect the reduction of heterozygosity and stability. Gene flow between and within populations depends on the orographic habitat conditions, the degree of population isolation, and the movement of pollen and seeds (Bruschi et al. 2003). Populations showing tolerance to drought stress, genetically improved, will be very important in the future to deal with the consequences of climate change (Apostol et al. 2020).

Based on the conducted research, it can be concluded that there is a high level of variability in the observed morphological characteristics of seedlings of the studied Sessile oak population. The obtained results are the basis for the continuation of the research that needs to be carried out to provide guidelines and recommendations for the conservation and directed use of genetic resources.

4. CONCLUSION

The results obtained in this research showed a high level of genetic variability at the level of the studied population. Satisfactory genetic diversity recommends this population for the dynamic conservation of Sessile oak genetic resources in Serbia. To provide additional security for the preservation of the gene pool, the establishment of *ex situ* conservation facilities is recommended. Considering the pronounced genetic variability, it can be assumed that the studied population has resistance to deterioration and adaptive potential in terms of changes caused by climatic conditions.

The determined variability of the seedlings' morphological characteristics can serve as an indicator of the further development of the selected half-sib lines' seedlings and can be useful for the improvement of the production of high-quality Sessile oak seed material.

The measures that would ensure the natural regeneration of the Sessile oak natural populations with constant monitoring of the genetic structure and timely implementation of measures to maintain natural genetic diversity should be included in the management of the Sessile oak natural populations.

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VARIABILITY OF CHARACTERISTICS OF SESSILE OAK (*Quercus petraea (Matt.) Liebl*) SEEDLINGS FROM THE AREA OF OUTSTANDING NATURAL LANDSCAPE "AVALA"

Vladan POPOVIĆ, Aleksandar LUČIĆ, Sanja JOVANOVIĆ, Ljubinko RAKONJAC

Summary

The Sessile oak (*Quercus petraea /Matt./ Leibl.*) represents, right after the Pedunculate oak (*Quercus robur*), the most valuable oak species in the growing stock of the Republic of Serbia. Its share in the total volume is 5.9%, that is, it occupies an area of 173.200 ha. The Sessile oak forests are located within a special oroclimatogenic altitudinal zone, above the climatogenic Turkey and Hungarian oak forests and cover the upper part of the hill range and the lower mountain range, at an elevation of 300 - 1300 m). In the last few decades, the dieback of the Sessile oak stands, groups, and individual trees almost in the entire area have been identified due to causes that have not yet been sufficiently studied and systematized.

The research aim was to determine the variability based on morphometric characteristics of seedlings within the Sessile oak population located in the Area of Outstanding Natural Landscape (AONL) "Avala". The results obtained in the research can help to get a preliminary understanding of the genetic variability of the studied population and propose measures for the preservation of the available gene pool and improvement of the quality of seed and planting material production.

The one-year-old seedlings produced from acorns collected in 2019 from the 50 Sessile oak test trees in the Area of Outstanding Natural Landscape "Avala" were used for the research presented in this paper. Analyzes of measured and derived morphometric characteristics were performed on a random sample of 50 seedlings per mother tree, at the end of the first vegetation season. The root collar diameter and the height of the seedlings were measured and based on the obtained values, the sturdiness quotient was calculated.

The following mean values were obtained at the level of the studied half-sib lines: the mean value of the seedling root collar diameter is 4.4 mm and it ranges from 3.3 mm to 5.6 mm; the mean value of the seedling height is 22.9 cm and it ranges from 12.1 cm to 35.5 cm; the mean value of the ratio of height to root collar diameter of seedlings is 5.3 and it ranges from 3.4 to 7.5. The existence of statistically significant differences between the studied half-sib lines for all analyzed morphological characteristics of seedlings indicates genetic differentiation and a high degree of variability within the population. Based on the obtained statistical parameters, it can be concluded that there is genetic variability both within and between the analyzed half-sib lines.

Results obtained in this study showed a high level of genetic variability in the researched population. Satisfactory genetic diversity recommends this population for the dynamic conservation of genetic resources of the Sessile oak in Serbia. To provide additional security for the preservation of the gene pool, the establishment of ex situ conservation facilities is recommended. Considering the pronounced genetic variability, it can be assumed that the studied population has resistance to deterioration and adaptive potential to changes caused by climatic conditions.

VARIJABILNOST SVOJSTAVA SADNICA KITNJAKA (*Quercus petraea (Matt.) Liebl*) SA PODRUČJA PIO „AVALA“

Vladan POPOVIĆ, Aleksandar LUČIĆ, Sanja JOVANOVIĆ, Ljubinko RAKONJAC

Rezime

U šumskom fondu Republike Srbije, kitnjak (*Quercus petraea /Matt./ Leibl.*) posle lužnjaka predstavlja najvredniju vrstu hrasta. U ukupnoj zapremini učestvuje sa 5,9%, odnosno zauzima površinu od 173.200 ha. Šume kitnjaka u nalaze se u okviru posebnog oroklimatogenog visinskog pojasa, iznad klimatogene šume sladuna i cera, obuhvataju gornji deo brdskog pojasa i niži planinski pojas, na nadmorskim visinama od 300 – 1300 m. U poslednjih nekoliko decenija sastojine, grupe i pojedinačna stabla kitnjaka gotovo na čitavom arealu se suše iz do sada još uvek nedovoljno proučenih i sistematizovanih uzroka.

Cilj istraživanja u ovom radu bio je da se utvrdi unutarpopulaciona varijabilnost kitnjaka u populaciji na području PIO „Avala“ prema morfološkim svojstvima sadnica. Dobijeni rezultati u istraživanju mogu da posluže za preliminarno upoznavanje genetičkog varijabiliteta proučavane populacije, prelog mera očuvanja raspoloživog genofonda i za unapređenje proizvodnje kvalitetnog semenskog i sadnog materijala.

Za istraživanja u ovom radu upotrebljene su jednogodišnje sadnice proizvedene od žira iz uroda 2019. godine, sakupljenog sa 50 test stabala kitnjaka u PIO „Avala“. Analize merenih i izvedenih morfometrijskih svojstava vršene su na slučajnom uzorku koji je činilo 50 sadnica po svakom materinskom stablu, na kraju prvog vegetacionog perioda. Mereni su prečnik u korenovom vratu i visina sadnica, a na osnovu izmerenih vrednosti izračunat je koeficijent jedrine.

Na nivou istraživanih linija polusrodnika dobijene su sledeće prosečne vrednosti: prečnik u korenovom vratu iznosi 4,4 mm (od 3,3 do 5,6 mm), visina sadnica iznosi 22,9 cm (od 12,1 do 35,5 cm), koeficijent jedrine sadnica iznosi 5,3 (od 3,4 do 7,5). Postojanje statistički značajnih razlika između proučavanih linija polusrodnika za sva analizirana morfološka sadnica, jasno ukazuju na genetsku diferencijaciju i visok stepen unutarpopulacione varijabilnosti. Na osnovu dobijenih statističkih parametara može se zaključiti da postoji genetička promenljivost kako unutar, tako i između analiziranih linija polusrodnika.

Rezultati dobijeni u ovom istraživanju pokazali su visok nivo genetske varijabilnosti na nivou istraživane populacije. Zadovoljavajući genetski diverzitet preporučuje ovu populaciju za dinamično očuvanje genetičkih resursa kitnjaka u Srbiji. U cilju dodatne sigurnosti očuvanja genofonda preporučuje se uspostavljanje ex situ objekata konzervacije. S obzirom na izraženu genetsku varijabilnost, može se pretpostaviti da proučavana populacija ima otpornost na propadanje i adaptivni potencijal u pogledu promena izazvanih klimatskim uslovima.

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REMOVAL OF ORGANIC MATTER IN FLOATING TREATMENT WETLAND

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Abstract: *Organic matter is considered one of the main sources of water pollution caused by the discharge of wastewater of different categories directly into rivers. The increased content of organic matter serves as a source of food for water microorganisms and significantly lowers dissolved oxygen of the recipient. Floating treatment wetlands (FTW) are an innovative green technology that removes excess organic matter from water. This paper shows the effectiveness of floating treatment wetlands in removing organic matter from the water of a polluted urban river. Cells with floating islands had BOD reduced by 84-91%, COD in the range of 57-65% and TOC by 16-20%. The highest efficiency in COD and TOC reduction was achieved in Cell I where P. australis was planted, and BOD in Cell II where C. indica was planted. The results of these studies showed that after 6 days of treatment of polluted water, a high reduction of BOD and COD was achieved, as well as a satisfactory reduction of TOC concentration.*

Key words: phytoremediation, microorganisms, plants, polluted water, urban river.

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UKLANJANJE PATOGENIH MIKROORGANIZAMA U BIOLOŠKOM SISTEMU SA PLUTAJUĆIM OSTRVIMA

Izvod: *Organske materije se smatraju jednim od glavnih izvora zagađenja vode uzrokovanog izlivanjem različitih kategorija otpadnih voda direktno u reke. Povećani sadržaj organske materije poslužiće kao izvor hrane za mikroogranizme prisutne u vodi, što će dovesti do značajnog pada koncentracije kiseonika u vodi recipijenta. Biološki sistemi sa plutajućim ostrvima (FTW) su inovativna zelena tehnologija, koja omogućava uklanjanje viška organskih materija iz vode. Ovaj rad prikazuje efikasnost biološkog sistema sa plutajućim ostrvima u uklanjanju organskih materija iz vode zagađene urbane reke. U okviru bazena sa plutajućim ostrvima ostvarena je redukcija BOD od 84-91%, COD u granicama 57-65% i TOC od 16-20%. Najveća efikasnost redukcije COD i TOC je ostvarena u bazenu 1 u kome je bila posađena P. australis, a BOD u bazenu 2 u kome se nalazila C. indica. Rezultati ovih istraživanja su pokazali da je posle 6 dana tretmana zagađene vode postignuta visoka redukcija BOD i COD, kao i zadovoljavajuće smanjenje koncentracije TOC.*

Ključne reči: fitoremedijacija, mikroorganizmi, biljke, zagađena voda, urbana reka.

1. INTRODUCTION

Organic matter plays a crucial role in the functioning of aquatic ecosystems because it affects various biogeochemical processes, nutrient cycling, biological availability, chemical transport, and interactions in these processes. However, when municipal or industrial wastewater with a high content of organic matter is discharged directly into rivers without prior pre-treatment, the concentration of oxygen in the water of the recipient significantly decreases (Chapman, 2021). The increased content of organic matter serves as a food source for water microorganisms. Aerobic bacteria use significant amounts of oxygen to decompose organic compounds into less complex organic substances up to carbon dioxide and water (Kadlec and Wallace, 2009). If the amount of organic matter is high, the rate at which microorganisms consume dissolved oxygen exceeds the rate at which it can be recovered from the atmosphere and produced by photosynthesis. Eventually, the water becomes anaerobic (US EPA, 2001). Furthermore, the increased content of organic matter in the water favours the growth of algae and aquatic plants that consume large amounts of dissolved oxygen for their growth. Anaerobic bacteria accelerate the decomposition of organic matter caused by the death of aquatic flora and fauna and lead to further eutrophication of water. However, since the environment is now anaerobic, toxic compounds such as hydrogen sulphide are formed when microorganisms break down organic matter (US EPA, 2000). With the lack of oxygen, these compounds have devastating effects on fish populations and other aquatic organisms.

Based on everything that has been said, it can be conclude that besides preventing the introduction of a large amount of organic matter into rivers or lakes, their timely removal from the recipients is another valuable instrument for maintaining good quality and ecological status of water. Floating treatment wetlands (FTW) are an innovative green technology that uses a range of natural processes and mechanisms to remove excess organic matter from water (Yeh *et al.*, 2015; Dodkins and Mendzil, 2014; Vymazal, 2011; Prasad and de Oliveira Freitas, 2003; Davis, 1995). These nature-based solutions (NBS) are modified constructed wetlands with certain advantages over other alternative water treatment technologies (Masters, 2012; Stewart et al., 2008). Floating islands are very simple to construct. They consist of the mash platform that contains the substrate for growing terrestrial and aquatic plants (Sharma *et al.*, 2021; Chance *et al.*, 2019; Benvenuti *et al.*, 2018). Having been planted, they develop a significant mass of the root system which is in direct contact with the water. This system allows better absorption of pollutants from the water, better removal of solid matter, more spots where useful microorganisms can be bound, etc. (Van de Moortel *et al*., 2010).

The Topčiderka River is an urban river that has been long used as a collector of municipal and industrial wastewater, as well as agricultural run-off that carries a range of organic matter. According to most of its chemical, physical and microbiological parameters for water quality assessment, this highly polluted river is classified in water category V (Čule *et al.*, 2017). To investigate the possibility of using floating islands to remove different categories of pollutants from this river, a floating treatment wetland (FTW) was installed on its bank. The constructed pilot system was highly efficient in the removal of chromium and nickel (Čule *et al.*, 2021a), sodium (Čule *et al*., 2022), pathogenic microorganisms (Čule *et al*., 2021b), phosphorus and nitrogen (Čule *et al*., 2020). This paper deals with the efficiency of organic matter removal in this biological system. To achieve this, we examined possible reductions in the concentration of total organic carbon (TOC), which measures the total amount of organic matter in water, chemical oxygen demand (COD), which gives the amount of organic matter subject to chemical oxidation, and biological oxygen demand (BOD) or the amount of biodegradable organic matter.

2. MATERIAL AND METHODS

The floating treatment wetland (FTW) consisted of a collection tank (5.0 m^3) and four cells with floating islands (each 3.0 m^2 in area and 3.0 m^3 in volume). The collection tank and cells were placed on the levelled ground and connected with plastic pipes (Čule *et al.*, 2017). Each of the four cells had three floating islands (1.0 m x 1.0 m). Since the cells were 100% covered with floating islands, anaerobic conditions were expected. The mash platform of the floating islands was made of light thermoplastic materials, with handles and circular openings at the bottom. Rock wool was used as a growing substrate. Each island had 25 (Cells I-III) and 30 (Cell IV) seedlings planted. *Phragmites australis* (Cav.) Trin. ex Steud was planted in Cell I, *Canna indica* L. in Cell II, while Cell III had a mixture of *P. australis* and *C. indica* in the ratio 12:13. Each island of Cell IV contained mixed plantings of *Iris pseudacorus* L. (8 seedlings), *Iris sibirica* 'Perry's Blue' (5 seedlings), *Alisma plantago - aquatica* L. (5 seedlings), *Lythrum salicaria* L. (5 seedlings) and *Menyanthes trifoliata* L. (6 seedlings).

After a month and a half of establishing the FTW, monitoring of its effectiveness in removing pollutants began. The treatment cycle began by bringing water from the river into the collection tank using a pump and distributing it, by gravity flow, simultaneously to Cells I-IV. The hydraulic retention time (HRT) in the cells was six days. After that time, the water treatment was completed, and the purified water was released into the river.

To examine the quality of polluted and treated water based on the content of organic matter, the following parameters were determined: five-day biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). Polluted water needed for the analysis was sampled according to the SRPS ISO 5667-4:1997 method and treated water according to the SRPS ISO 5667-6:1997 method. Polluted water samples were taken at the beginning of the treatment cycle at the entrance to the FTW. After 6 days, the water was sampled in Cells I-IV. The water sample represented 1 litre of water collected at five spots in each cell (each corner and the centre). Water samples were brought to the laboratory in coolers and stored according to the prescribed protocol before the analysis.

Biochemical oxygen demand (BOD) was determined using the SRPS EN 1899-1:09 method. Chemical oxygen demand (COD) was determined using a method based on the manuals for the use of COD reactor ET 108 (Lovibond), RD 125 thermoreactor (Lovibond) and COD Vario photometer (Lovibond). The concentration of total organic carbon (TOC) was determined by the SRPS ISO 8245:07 method. The obtained results are expressed in mg/l.

3. RESULTS AND DISCUSSION

Organic matter found in polluted and wastewater contains about 45-50% carbon which serves as a source of energy for various microorganisms that inhabit the rhizosphere (DeBusk, 1999b). Therefore, the key mechanism for the removal of organic matter in the floating treatment wetland (FTW) was the metabolism of microorganisms, which in an aerobic environment use dissolved oxygen to oxidise and decompose organic matter (Shahid *et al.*, 2018; U.S. EPA, 2000). Plants also had an important role in removing excess organic matter. Thanks to the well-developed root system, they provided a large area for the development of a biofilm, i.e., rhizosphere that hosted aerobic microorganisms (Prajapati *et al.*, 2017). The large biomass of roots, which were hanging free in the water, enabled the filtration of solid particles of organic matter and their deposition on the surface of the root system or at the bottom of the cell (Van de Moortel *et al.*, 2010). Finally, the organic matter, which was broken down by microorganisms into simple nutrients, was taken up by the plants directly from the water (Shahid *et al.*, 2018). Outside the plant rhizosphere, in the anaerobic environment of the cells, the content of organic matter in the water could also be reduced by the processes of fermentation (with the production of lactic acid or ethanol), methanogenesis (with the production of CH_4), sulphate reduction (with the production of CO_2 and H_2S), and denitrification (with the production of CO_2 and N_2) (Dodkins and Mendzil, 2014). Kadlec and Wallace (2009) state that the process of decomposition and deposition of organic carbon is very fast in biological systems with plants and BOD is reduced by 50% within six hours.

Table 1 shows the results related to the concentration of organic matter in polluted and treated water, as well as the efficiency of FTW in their removal. According to the results of the analysis of the efficiency of the removal of the organic matter, after six days of treating polluted water in cells with plants, a high reduction in biological oxygen demand (BOD) and chemical oxygen demand (COD) was achieved, as well as a satisfactory reduction in the concentration of total organic carbon (TOC). Extremely lower BOD values (0.50 - 0.90 mg/L) were recorded in the cells compared to the BOD value in the inlet (5.70 mg/L). The highest BOD removal efficiency of 91% was recorded in Cell II where *C. indica* was planted. The BOD reduction efficiency was 88% in Cell IV with mixed plantings of decorative macrophytes, 86% in Cell I with *P. australis*, and 84% in Cell III with mixed plantings of *P. australis* and *C. indica*. The initial influent COD value (10.00 mg/L) was reduced to 3.50 mg/L - 4.30 mg/L in the cells, and the highest removal efficiency of 65% was recorded in Cell I with *P. australis*. It was followed by Cell III with 61% efficiency, Cell IV with 58% and Cell II with 57%. The initial concentration of total organic carbon (TOC) in the cells was reduced to 3.97 mg/L - 4.19 mg/L. The maximum efficiency of total organic carbon (TOC) removal was achieved in Cell I with *P. australis* and amounted to 20%. The efficiency was 19% in Cell II with *C. indica*, 18% in Cell III with *C. indica* and *P. australis*, and 16% in Cell IV with decorative macrophytes.

Table 1. *Biological oxygen demand, chemical oxygen demand and concentration of total organic carbon in polluted and treated water and efficiency of FTW*

		BOD	COD	TOC
Influent to FTW (mg/L)	Tank	5.70	10.00	4.97
Effluent of a single cell (mg/L)				
	Cell I	0.80	3.50	3.97
	Cell II	0.50	4.30	4.05
	Cell III	0.90	3.90	4.06
	Cell IV	0.70	4.20	4.19
Reduction in a single cell (mg/L)				
	Cell I	4.90	6.50	1.00
	Cell II	5.20	5.70	0.92
	Cell III	4.80	6.10	0.91
	Cell IV	5.00	5.80	0.78
Single-cell efficiency (%)				
	Cell I	86	65	20
	Cell II	91	57	19
	Cell III	84	61	18
	Cell IV	88	58	16

Each value represents the value of a composite sample taken from 5 spots in each cell. BOD - biological oxygen demand (mg/L), COD - chemical oxygen demand (mg/L), TOC - concentration of total organic carbon (mg/L). 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.

Biological systems for the treatment of waste and polluted water generally have high efficiency in removing organic matter (DeBusk, 1999a). Chen *et al.* (2016) emphasize that the efficiency of BOD and COD reduction in FTW has a very wide range of limits, i.e., 36-90% for BOD and 17-84% for COD. In the experimental FTW established by Prajapati *et al.* (2017) the efficiency of BOD reduction was 87-94%, COD 50-57% and TOC 48-53%. According to the authors, these results point to a significant reduction of organic matter in FTW. Comparing the efficiency achieved in our research with these results, we can see that BOD reduction was almost the same amounting to 84-91%, while COD reduction was slightly higher and ranged from 57-65%. The reduction of TOC concentration was slightly lower with an achieved efficiency of 16-20%. The comparison of the effectiveness of FTW in our research with the results presented by other authors (White and Cousins, 2013; Van de Moortel *et al*., 2010; Yang *et al*., 2008b; Stewart *et al*., 2008) for a similar type of FTW shows that the wastewater treatment system was more efficient in removing different forms of organic matter.

The efficiency of a FTW in the removal of different forms of organic matter can also be tested by comparing the content of BOD, COD and TOC as parameters for assessing the ecological status of water (Official Gazette of RS, 2011) in the FTW influent and effluent water. Based on the content of BOD (5.70 mg/L), the influent water belonged to class III and based on the concentrations of COD (10.00 mg/L) and TOC (4.97 mg/L) to class II (Official Gazette of RS, 2012). After the water had passed through the FTW, the concentrations of organic matter decreased and based on the content of BOD (0.50 - 0.90 mg/L) and COD (3.50-4.30 mg/L) the effluent water was class I (water with excellent ecological status), while regarding the TOC content (3.97-4.19 mg /L), it was class II (water with good ecological status) (Official Gazette of RS, 2012).

5. CONCLUSION

Organic matter is considered as one of the main sources of water pollution caused by the discharge of various categories of wastewater directly into rivers. An excess of organic matter in the water poses a threat to the aquatic world because microorganisms use dissolved oxygen in the water to decompose the pollutants. Floating treatment wetlands (FTW) are a relatively new and innovative technology. They are very similar to constructed wetlands which enable efficient treatment of wastewater and polluted waters of rivers, lakes and other water bodies. The key advantages of this nature-based solution (NBS) are the large free surface of the root system in the water and the adjustability of floating islands to different water levels and depths. Besides the main function of removing pollutants, FTW also have other functions, which can be significant at some treatment sites. They can become a habitat for a range of animal species (birds, insects, reptiles, fish, etc.), increase the aesthetic value of an often-degraded landscape, easily fit into the surrounding landscape, encourage the scientific community to conduct research there and achieve the education in line with sustainable development by promoting the importance of environmental protection and water conservation. The results of this study showed that the FTW installed on the banks of the Topčiderka River proved to be effective in removing excess organic matter from polluted water. The highest reduction efficiency of COD (65%) and TOC (20%) was achieved in cell I where *P. australis* was planted, and BOD (91%) in cell II with *C. indica*. Given that microorganisms play an important role in decomposing organic pollutants, future research should identify species of microorganisms adequate for specific types of pollutants and examine their capacity to break down organic matter, activities that encourage plant growth, their performances, and synergistic interactions with plants, which can help improve the efficiency of FTW.

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REMOVAL OF ORGANIC MATTER IN FLOATING TREATMENT WETLAND

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Summary

Organic matter is considered as one of the main sources of water pollution caused by the discharge of wastewater of different categories directly into rivers. The increased content of organic matter serves as a source of food for microorganisms in the water. Aerobic bacteria decompose organic compounds into less complex organic substances up to carbon dioxide and water, and in doing so use significant amounts of dissolved oxygen. If the amount of organic matter is high, the rate at which microorganisms consume dissolved oxygen exceeds the rate at which it can be recovered from the atmosphere and produced by photosynthesis. Eventually, the water becomes anaerobic which poses a threat to the aquatic world. Besides preventing the introduction of large amounts of organic matter into rivers or lakes, their timely removal from recipients is another valuable instrument for maintaining the good quality and ecological status of water. Floating treatment wetlands (FTW) are innovative green technology that uses different natural processes and mechanisms to remove excess organic matter from water. The Topčiderka River is an urban river, which has long been used as a collector of municipal and industrial wastewater and agricultural run-off that carries a range of organic substances. To examine the possibility of using floating islands to remove different categories of pollutants from this river, a FTW was installed on its bank. It consisted of a collection tank and four cells with floating islands. There were 3 floating islands in each cell. *Phragmites australis* (Cav.) Trin. ex Steud, *Canna indica* L., *Iris pseudacorus* L., *Iris sibirica* 'Perry's Blue', *Alisma plantago - aquatica* L., *Lythrum salicaria* L. and *Menyanthes trifoliata* L were used to form the islands' vegetation. This paper shows the efficiency of organic matter removal in the mentioned FTW. According to the results, BOD was reduced by 84-91%, COD by 57-65% and TOC by 16-20%. The highest efficiency in COD and TOC reduction was achieved in cell I where *P. australis* was planted, and BOD in cell II with *C. Indica* plants. Owing to microorganisms and plants, i.e., processes of decomposition, filtration, sedimentation,

fermentation, methanogenesis, sulphate reduction and denitrification, after six days of treating polluted water in FTW, a high reduction of BOD and COD was achieved, as well as a satisfactory reduction of TOC concentration. The efficiency of FTW in removing different forms of organic matter is reflected in the fact that the polluted water belonged to class III (based on BOD) and class II (based on COD and TOC), while after the treatment, it had the characteristics of class I water (water with excellent ecological status) based on BOD and COD, and class II (water with good ecological status) based on TOC concentration.

UKLANJANJE ORGANSKIH MATERIJA U BIOLOŠKOM SISTEMU SA PLUTAJUĆIM OSTRVIMA

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Rezime

Organske materije se smatraju jednim od glavnih izvora zagađenja vode uzrokovanog izlivanjem različitih kategorija otpadnih voda direktno u reke. Povećani sadržaj organske materije poslužiće kao izvor hrane za mikroogranizme prisutne u vodi. Aerobne bakterije će organska jedinjenja razlagati na manje složene organske supstance, sve do ugljen dioksida i vode, a pri tome će koristiti značajne količine kiseonika. Ukoliko je količina organskih materija visoka, brzina trošenja rastvorenog kiseonika od strane mikroorganizama će nadmašiti brzinu kojom rastvoreni kiseonik može da se nadoknadi iz atmosfere i fotosintezom i na kraju će voda postati anaerobna, što predstavlja opasnost za akvatični svet. Pored prevencije unosa velike količine organske materije u reke ili jezera, njihovo blagovremeno uklanjanje iz recipijenata, predstavlja važan instrument za održavanje dobrog kvaliteta i ekološkog statusa voda. Biološki sistemi sa plutajućim ostrvima (FTW) su inovativna zelena tehnologija, koja na osnovu različitih prirodnih procesa i mehanizama omogućava uklanjanje viška organskih materija iz vode. Topčiderka je urbana reka, koja se dugi niz godina koristi kao kolektor komunalnih, industrijskih i poljoprivrednih otpadnih voda, koje sa sobom nose različite organske materije. Kako bi se ispitala mogućnost korišćenja plutajućih ostrva za uklanjanje različitih kategorija polutanata iz ove reke, na njenoj obali je postavljen biološki sistem, koji se sastojao od sabirnog tanka i četiri bazena sa plutajućim ostrvima. U svakom bazenu su se nalazila po 3 plutajuća ostrva. Za formiranje vegetacije ostrva korišćene su vrste *Phragmites australis* (Cav.) Trin. ex Steud, *Canna indica* L., *Iris pseudacorus* L., *Iris sibirica* 'Perry's Blue', *Alisma plantago - aquatica* L., *Lythrum salicaria* L. i *Menyanthes trifoliata* L. Ovaj rad prikazuje efikasnost uklanjanja organskih materija u pomenutom FTW. Rezultati istraživanja pokazuju da je ostvarena redukcija BOD od 84-91%, COD u granicama 57-65% i TOC od 16-20%. Najveća efikasnost redukcije COD i TOC je ostvarena u bazenu 1 u kome je bila posađena *P. australis*, a BOD u bazenu 2 u kome se nalazila *C. indica*. Zahvaljujući mikroorganizmima i biljkama odnosno procesima razlaganja, filtracije, taloženja, fermentacije, metanogeneze, redukcije sulfata i denitrifikacije, posle 6 dana tretmana zagađene vode u FTW je postignuta visoka redukcija BOD i COD, kao i zadovoljavajuće smanjenje koncentracije TOC. Na dobru efikasnost FTW u uklanjanju različitih formi organskih materija može da se ukaže i činjenica da je zagađena voda pripadala III klasi (na osnovu BOD) i II klasi (na osnovu COD i TOC), a da je po završenom tretmanu imala karakteristike vode klase I (voda sa odličnim ekološkim statusom) na osnovu BOD i COD odnosno klase II (voda sa dobrim ekološkim statusom) na osnovu koncentracije TOC.

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Review paper

RADIAL VARIABILITY OF WOOD DENSITY AND FIBRE LENGTH IN THE RED OAK TREES (*Quercus rubra* L.)

Nebojša TODOROVIĆ[1], Ivana ŽIVANOVIĆ [2], Dragica VILOTIĆ[1], Goran MILIĆ[1]

Abstract: *Wood density and fibre length are two wood properties that are important in determining the quality of wood for commercial use. The fibre length of red oak has not been studied to the same extent as in other oak species. The aim of this paper is to explore the anatomical variation and wood density of red oak wood, as valuable information for researchers in other fields. Samples were taken in a 60-year-old red oak stand in the south part of Belgrade on the site of Stepin Lug. Along the south radius, the disc samples of 20 x 20 mm were cut from the sapwood, mature and juvenile wood. Oven-dry density and fibre length were measured from the pith to the bark. According to the obtained data, the average oven-dry density of wood per radius is 0.694 g/cm*^{3}*. The lowest is in the juvenile wood and ranges from 0.628 to 0.681 g/cm*^{3}*, then in the part of sapwood - 0.662 g/cm*^{3}*, and the highest is in the mature wood where the density ranges from 0.707 to 0.740 g/cm*^{3}*. The presented values show certain differences, but also conform to literature data on the density of some industrial species from the genus Quercus L. The obtained results of the wood fibre length show that it varies from 0.99 to 1.33 mm which was measured in mature wood. The average length in a mature zone is 1.26 (1.16-1.33) mm, while in a juvenile area the average length is 1.02 (0.85-1.23) mm. Based on the known wood fibre length, it is possible to determine the density of red oak wood. In this research, a positive influence was determined in both parts of the tree, juvenile and mature, but a better mathematical dependence was obtained in the mature zone.*

Keywords: red oak, wood density, fibre length, juvenile wood

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RADIJALNA VARIJABILNOST GUSTINE DRVETA I DUŽINE VLAKANA U DRVETU CRVENOG HRASTA (*Quercus rubra* L.)

Izvod: *Gustina drveta i dužina vlakana su dva svojstva drveta koje su od značaja za određivanje kvaliteta drveta za komercijalnu upotrebu. Dužina vlakana crvenog hrasta nije proučavana u istoj meri kao kod drugih vrsta hrasta. Cilj ovog rada je istraživanje anatomske varijacije i gustine drveta crvenog hrasta, kao dragocene informacije za istraživače u drugim oblastima izučavanja nauke o drvetu drveta. Uzorci su uzeti u sastojini crvenog hrasta starog 60 godina u južnom delu Beograda na lokalitetu Stepin Lug. Po južnom polupręčniku diska sečeni su uzorci 20 x 20 mm od beljike, zrelog i juvenilnog drveta. Gustina drveta u apsolutno suvom stanju vlažnosti i dužina vlakana merene su od srži do kore. Prema dobijenim podacima, prosečna gustina drveta iznosi 0,694 g/cm3. Najniža je u juvenilnom drvetu i kreće se od 0,628 do 0,681 g/cm3, zatim u delu beljike - 0,662 g/cm3, a najveća je u zrelom drvetu gde se gustina kreće od 0,707 do 0,740 g/cm3. Prikazane vrednosti pokazuju određene razlike, ali su i u skladu sa literaturnim podacima o gustini pojedinih industrijskih vrsta iz roda Quercus L. Dobijeni rezultati dužine drvnog vlakna pokazuju da ona varira od 0,99 do 1,33 mm koliko je izmerena kod zrelog drveta. Prosečna dužina u zreloj zoni je 1,26 (1,16-1,33) mm, dok je u juvenilnom području prosečna dužina 1,02 (0,85-1,23) mm. Na osnovu poznate dužine drvenih vlakana moguće je odrediti gustinu drveta crvenog hrasta. U ovom istraživanju utvrđen je pozitivan uticaj u oba dela stabla, juvenilnom i zrelom, ali je bolja matematička zavisnost dobijena u zoni zrelog drveta.*

Ključne reči: crveni hrast, gustina drveta, dužina vlakana

1. INTRODUCTION

Oak (*Quercus* spp.) holds a high reputation as a strong, durable timber. It is traditionally used for high-grade construction work in much of Europe, and for boat and shipbuilding, fencing, interior woodwork, exterior joinery, flooring, coffins, beer casks and domestic furniture (Rendie, 1969). Oak wood anatomy is therefore of considerable interest with special attention to the strength properties, water relations and anatomical variation (Gasson, 1987). This paper aims to explore the anatomical variation in the wood of red oak(*Quercus rubra* L.), as valuable information for researchers in other fields.

Wood fibre length in red oak has not been studied to the same extent as in other oak species. As red oak is a ring-porous species, the growth ring properties have a great influence on the physical and mechanical wood properties. Gričar *et al*. (2013) point out that the change in the growth ring structure and its variability by radius is the most important indicator of oak wood quality. Tsoumis (1991) declares that this variability is more important than the structural and chemical changes during heartwood formation. Due to the above, in the literature, we can find different average values for the properties of species from the genus *Quercus* L.

Through earlier studies, it was determined that the wood density of European oaks is positively related to the ring width and negatively to the ring number from pith to bark. Ring-porous wood found in oak species is characterized by the division of each annual ring into low-density earlywood and high-density latewood zones. Latewood contains a lower number of tracheae and therefore a higher proportion of wood fibres than earlywood (Rao *et al.*, 1997). Within a tree, earlywood width and density are generally constant in pith to bark profiles, while latewood fiber width and wood density vary with ring number and ring width (Zhang *et al*., 1993; Degron *et al*., 1996).

In the literature, information on the density and properties of sessile oak (*Quercus petrea* L.) and pedunculate oak (*Quercus robur* L.) are more prominent through their presence in European forests (Zhang *et al*., 1993; Degron, 1996). The density value for red oak was published by Alden (1995) and it amounts 0.660 g/cm^3 for specimens from North America. For samples grown in European conditions, Merele and Čufar (2013) showed that red oak species have a higher density than white oak species. Gohre and Wagenknecht (1955) found a very similar density to Alden, i.e., 0.666 g/cm3. Other authors mention values close to 0.660 g/cm3 (Wagenfuhr 2000), but even higher than the value determined in this work is shown by Genet *et al*. (2013) in the amount of 0.760 g/cm3 for wood from natural stands and 0.734 g/cm3 for wood that was produced in trees from plantations.

Anatomical wood properties significantly influence wood quality (Richter, 2015). The influence of anatomical parameters of red oak on the quality of its wood was investigated mainly by authors in North America (Guiher, 1965; Hamilton and Knaus, 1986; Tardif *et al*., 2006; Genet *et al*., 2013). The juvenile zone is a part of the tree that differs significantly from its anatomical characteristics and properties compared to the mature tree (Zobel and Buijtenen, 1989; Hernandez *et al*., 2006). The influence of location on the anatomical characteristics of red oak was investigated by Maeglin (1974), Tainter *et al.* (1990) and Tardif *et al*. (2006).

Wood fibres are involved in the structure of the red oak tree as mechanical elements. The domestic species of oaks (sessile oak, pedunculate oak and Turkey oak) also have fibrous tracheids as additional elements (Šoškić and Popović, 2002). The arrangement of wood fibres and their length from the pith to the bark, as well as their participation, are very important for knowing the quality of the wood. Fibres (40-60%) have the largest area in the structure of the oak wood. Accordingly, the vessel surface in early wood is 40%, and in latewood 8%, while the ray surface is 15-30% (Wagenfuhr and Scheiber, 2006).

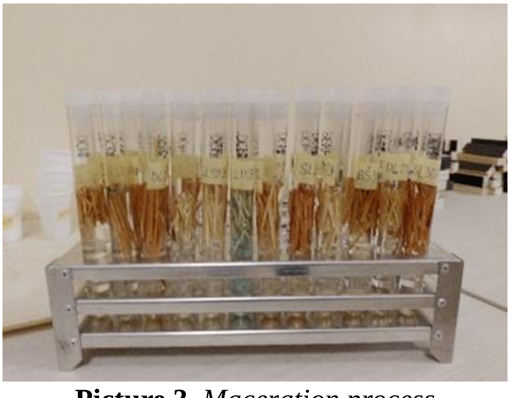
The aim of the work was to research the radial variability of wood density and fibre length in red oak trees. These properties were assessed for juvenile, mature and sapwood. Considering that anatomical elements affect the quality of wood, in this paper the dependence between fibres and wood density, from the pith to the bark, was investigated.

2. MATERIALS AND METHODS

Samples were taken in a 60-year-old red oak stand in the south part of Belgrade, the capitol of Serbia, Europe, on the site of Stepin Lug (Picture 1). After measuring the diameter, at tree breast height, a disc was taken.

Picture 1. *Site map*

Picture 2. *Cross section*



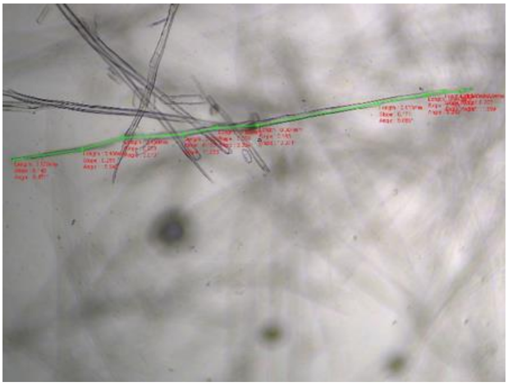
Picture 3. *Maceration process*

Along the south radius of the disc (Picture 2), samples of 20 x 20 mm were cut from the sapwood part, mature part and juvenile part of the tree cross-section. The radial length was divided into eight zones (1-6; 7-13; 14-20; 21-27; 28-34; 35-44; 45-52; 53-60) according to the growth rate and the number of tree-rings. From the whole width of each of the mentioned parts, the material was taken for maceration.

The length of the axial anatomical elements was measured on macerates obtained using a 1:1 ratio mixture of glacial acetic acid and 30% hydrogen peroxide solution (Picture 3). The maceration was performed at 60°C for 48 hours (Parharn and Grey, 1982). The macerated elements were washed several times with water, and then gently separated.

The length of the fibres was measured using a microscope Bio Blue with enlargement 40x (Picture 4), in each mentioned part of the wood cross-section 30 vessel elements were measured, including tails (Picture 5). The measurements were made with an accuracy of 0.001 mm.

Picture 4. *Wood fibres under microscope*



Picture 5. *Measured wood fibre*

In addition, the width of all the growth rings was measured. The ring width was measured with a microscope Bio Blue with enlargement 10x.

The wood density was expressed as oven-dry weight per unit green volume. The wood density was determined on samples having 20x20x40 mm. The wood density (ρ_0) at 0% moisture content was determined according to the following equation (SRPS ISO 13061-2):

$$\rho_0 = m_0/V_0 \text{ [g /cm}^3\text{]};$$

(1) where m_0 is the weight of the test specimen at 0% wood moisture content (kg) and
(2) V_0 is the volume of the test specimen at 0% wood moisture content (g/cm^3).

To obtain absolutely dry wood, the test specimens were dried in a laboratory kiln at 103 ± 2 °C until weight stabilization was reached.

A significance level of 95% was used for all statistical analyses. A t-test was used to evaluate the differences between the two tested samples. The ANOVA and Turkey’s multiple-range tests were applied to evaluate the statistically significant differences among the other evaluated factors. The linear regression model was used to evaluate the dependence of fibre length density on the width of annual rings and proportion of latewood for both types of oaks.

3. RESULTS AND DISCUSSION

The variation of wood density and fibre length per radius is shown in Table 1.

Table 1. *The variation of oven-dry density and fibre length per radius of red oak wood*

Anatomical properties of wood	The number of tree-rings from the pith to the bark								
		Juvenile wood		Mature wood					Sapwood
	Statistical indicators	1-6	7-13	14-20	21-27	28-34	35-44	45-52	53-60
Fibre length (mm)	N_{mean} (mm)	0.99	1.04	1.16	1.21	1.26	1.33	1.33	1.27
	S_d (mm)	0.16	0.16	0.15	0.17	0.28	0.33	0.15	0.17
	C_v (%)	15.9	15.2	13.0	13.9	21.9	24.7	11.3	14.9
Wood density (g/cm^3)	N_{mean}	0.628	0.651	0.707	0.706	0.718	0.729	0.740	0.712
	S_d	0.07	0.03	0.05	0.05	0.04	0.08	0.09	0.05
	C_v	10.4	4.7	7.2	6.6	5.5	11.5	12.8	7.7

According to the results obtained in this research, the average wood density per radius is 0.694 g/cm^3. The lowest is in the juvenile wood and ranges from 0.628 to 0.681 g/cm^3, then in the part of sapwood - 0.662 g/cm^3, and the highest is in the mature zone where the density ranges from 0.707 to 0.740 g/cm^3. The presented values show certain differences, but also conform to the literature data for the density of some industrial species from the genus *Quercus*. Except for information that the 60 years old red oak tree located in Lipovačka Šuma stand had a wood density of about 0.724 g/cm^3 (Živanović *et al.*, 2021), the red oak density values in the local literature are very scarce. Up to now, mainly the sessile oak wood density has been published, as the most important domestic industrial species from the oak genus. In comparison with the density of red oak from this work, Todorović (2006) obtained a similar density value (0.688 g/cm^3), while Šoškić *et al*. (2005) showed a significantly lower value of 0.651 g/cm^3 density for sessile oak from the area of Debeli Lug (Serbia). Examining the density of white oak from the forests of the apea Đerdap (Serbia), Popović *et al*. (2007) obtained data (0.720 g/cm^3) which shows a higher density compared to the red oak density from this study.

The obtained results of the length of the wood fibres show that it varies from 0.99 to 1.33 mm which was measured in mature wood. The average length in a mature tree is 1.26 (1.16-1.33) mm, while in a juvenile the average length is 1.02 (0.85-1.23) mm. On the basis of statistical analysis shown in Table 1, it was determined that zones 1 and 2 of the growth ring differ significantly in terms of fibre length and wood density from all zones that are further to the bark. Taylor (1976) showed that red oak wood fibres are longer in mature wood compared to juvenile wood. The same author studied the correlation between the position in the growth ring by radius and the wood fibre length and showed a functional quadratic dependence. In some studies (Mladenova *et al.*, 2017; Nazari *et al*., 2020) fibre characteristics have been investigated, mainly fibre length in the wood of different oak species. The results showed a great dependence of its dimensions on location conditions.

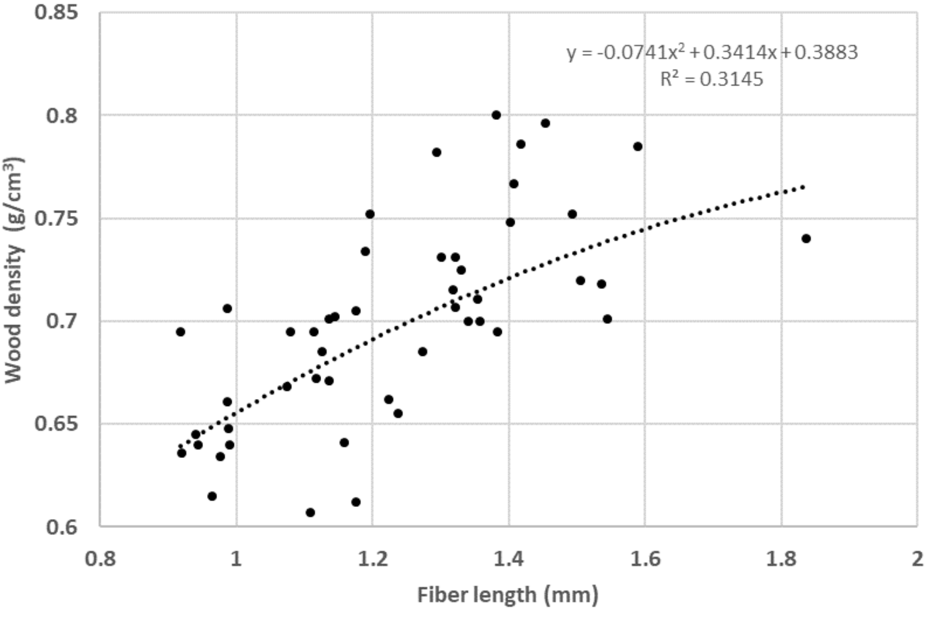
Raczkowska and Fabisika (1999) published that the fibre lengths increase from the pith to the bark and it is 0.99 mm in juvenile wood and 1.13 mm in the mature zone. The same authors pointed out that there is a negative correlation between the anatomical elements, length and the growth ring width for species from the genus *Quercus*. Mladenova *et al.* (2017) stated that the fibre length of 1,306 mm was measured for different oaks, while for red oak Wagenfuhr and

Scheiber (1985) stated a length of 1,300 mm, and for white oak, the same authors published a value of 1,360 mm. Nazari *et al*. (2020) reported that the fibre length in the wood of Persian oak (*Quercus macranthera* Fisch. et Mey.) was less than 1 mm while the average value was 0.87 mm. The differences shown are a consequence of genetic influences and the fact that the anatomical characteristics of wood can vary even within the same forest stand and are largely dependent on the microenvironment and hydrological conditions (Gričar *et al.*, 2013; Jokanović *et al.*, 2022), as well as variations in the structure of the growth ring by radius (Genet *et al.*, 2013).

Table 2. *Statistically significant differences in wood density and fibre length between zones by tree radius (+ fibre length;* * wood *density) (p≤0,05)*

Rings by tree radius	1-6	7-13	14-20	21-27	28-34	35-44	45-52	52-60
1-6			+*	+*	+*	+*	+*	+*
7-13			+*	+*	+*	+*	+*	+*
14-20	+*	+*						
21-27	+*	+*						
28-34	+*	+*						*
35-44	+*	+*						*
45-52	+*	+*						*
53-60	+*	+*			*	*	*	

The dependence between fibres and wood density in the juvenile part (not shown) of the tree was weaker compared to the mature wood zone (Graph 1). In the interval of fibres length from 0.96 to 1.8 mm, the wood density changes positively and according to the following equation form: $y=0,074x^2+0,3414x+0,3883$ ($R^2=0,3145$). This positive trend of wood density change with fibre length is in agreement with the previous results (Stringer and Olson, 1985; Yanchuk and Micko, 1990; Zobel and Sprague, 1998; De Bell *et al.*, 2004). Also, it should be pointed out that this trend cannot be observed separately from changes in the structure of the radial growth. Namely, in the juvenile wood, a larger ring growth was noted and with a greater share of latewood; however, the wood density is the lowest there. This indicates that in the late part of the growth ring in juvenile wood fibres are shorter with thinner walls compared to fibres in mature wood. Longer fibre dimensions with less participation of latewood indicate higher wood density. Therefore, the length of the fibres, latewood proportion and the double thickness of the fibre walls (Gričar *et al.*, 2013; Genet *et al.*, 2013) are the most important parameters that affect the density of the wood and its strength.



Graph 1. *Effect of fibre length on the density of red oak wood*

It should be noted that in the sapwood zone, a lower density was confirmed compared to mature wood, but higher compared to the area around the heartwood. This result largely coincides with that published by Todorović (2006) but contradicts the claims made by Merela and Čufar (2013). The authors showed that there is no significant difference between the sapwood and the heartwood properties for the sessile oak, pedunculate oak, and turkey oak, but statistically significant differences were found between, on one hand, the properties of the white oaks – sessile oak and pedunculate oak, and red oak and turkey oak, on the other hand. These differences may be a consequence of the positions of early and late wood zones and their anatomical elements ratio, as a result of climatic and locational conditions (Carlquist, 1988; Gričar *et al.*, 2013).

4. CONCLUSION

In this research, the average density of wood per radius of 0.694 g/cm3 was obtained. In the juvenile zone, a part of the tree with large variations in anatomical characteristics and properties, the dependence between fibre length and wood density was weaker than in the mature wood zone. The radial variation of fibre length and wood density in red oak was investigated, and the following results were obtained:

- The age of a tree and the variation of the growth ring structure by radius affect the change in the wood fibre length and the wood density;
- The wood fibre length increases from the pith to the bark, and it is lower in juvenile wood (1.02 mm), whereas it is higher in the mature zone (1.26

mm.) There is no difference between the heartwood and sapwood wood fibre lengths;

– Wood density decreases from pith to bark in the heartwood zone but, unlike wood fibres, density decreases again in the sapwood zone. The average density in juvenile wood is 0.654 (0.519-0.741) g/cm^3, in mature wood is 0.712 (0.595-0.865) g/cm^3, and in sapwood is 0.662 (0.514-0.832) g/cm^3.
– Based on the known length of wood fibres, it is possible to determine the density of red oak wood. In this paper, a positive influence was determined in both parts of the tree, juvenile and mature, but a better mathematical dependence was obtained in the mature zone.

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RADIAL VARIABILITY OF WOOD DENSITY AND FIBRE LENGTH IN THE RED OAK TREES (*Quercus rubra* L.)

Nebojša TODOROVIĆ, Ivana ŽIVANOVIĆ, Dragica VILOTIĆ, Goran MILIĆ

Summary

As a strong, durable timber, traditionally used for different household products, oak is one of the most favourable materials for the wood processing industry. The anatomy of wood has a great influence on its mechanical properties, so it is important to analyze the basic physical and anatomical wood properties, wood density and fibre length as valuable information for mechanical properties prediction.

The red oak wooden disk was taken from the tree that was located in the south part of Belgrade, Stepin Lug stand. Oven-dry density was measured on oven-dried 20x20x40 mm samples from pith to bark. Fibres were separated in the chemical process of maceration and measured with a microscope. The results are statistically analyzed.

The average density of wood per radius obtained in this research is 0.694 g/cm^3. The lowest is in the juvenile wood and ranges from 0.628 to 0.681 g/cm^3, then in the sapwood area - 0.662 g/cm^3, and the highest is in the mature wood where the density ranges from 0.707 to 0.740 g/cm^3. The presented values show certain differences, but also conform to literature data on the density of some industrial species from the genus *Quercus*. The results of wood fibre length show that it varies from 0.99 to 1.33 mm in mature wood. The average length in a mature zone is 1.26 (1.16-1.33) mm, while in a juvenile the average length is 1.02 (0.85-1.23) mm. There is no difference between the heartwood and sapwood wood fibre length.

Summarising all results obtained and available literature data, it can be concluded that based on the length of wood fibers it is possible to determine the density of red oak wood. In this research, a positive influence was determined in both parts of the tree, juvenile and mature, but a better mathematical dependence, square-shaped, was obtained in the mature zone.

RADIJALNA VARIJABILNOST GUSTINE DRVETA I DUŽINE VLAKANA U DRVETU CRVENOG HRASTA (*Quercus rubra* L.)

Nebojša TODOROVIĆ, Ivana ŽIVANOVIĆ, Dragica VILOTIĆ, Goran MILIĆ

Rezime

Kao tvrdo, trajno drvo, tradicionalno korišćeno za različite proizvode za domaćinstvo, hrast je jedan od najtraženijih materijala za drvnu industriju. Anatomija drveta ima veliki uticaj na mehanička svojstva tako da je za svako drvo, kao budući materijal za proizvodnju, značajno istražiti osnovna fizička i antomska svojstva drveta, gustinu drveta i dužinu vlakana kao značajnu informaciju za procenu drugih mehaničkih svojstava.

Kotur drveta crvenog hrasta uzet je sa stabla koje se nalazilo u južnom delu Beograda, sastojina Stepin lug. Gustina u apsolutno suvom stabnju vlažnosti merena je od srži do kore na uzorcima 20x20x40 mm. Drvna vlakna su odvojena u hemijskom procesu maceracije i merena mikroskopom. Rezultati su statistički analizirani.

Prosečna gustina drveta po radijusu dobijena u ovom istraživanju iznosi 0,694 g/cm^3. Najniža je u juvenilnom delu i kreće se od 0,628 do 0,681 g/cm^3, zatim u delu beljike - 0,662 g/cm^3, a najveća je u zrelom drvetu gde se gustina kreće od 0,707 do 0,740 g/cm^3. Prikazane vrednosti pokazuju određene razlike, ali i slaganje sa literaturnim podacima o gustini pojedinih industrijskih vrsta iz roda *Quercus*. Rezultati dužine drvnih vlakana pokazuju kod zrelog drveta varijaciju od 0,99 do 1,33 mm. Prosečna dužina u zreloj zoni je 1,26 (1,16-1,33) mm, dok je kod juvenilnog drveta prosečna dužina 1,02 (0,85-1,23) mm. Ne postoji razlika između dužine drvnih vlakana srži i beljike.

Sumirajući sve rezultate i literaturne podatke, zaključuje se da je na osnovu dužine drvnih vlakana moguće odrediti gustinu drveta crvenog hrasta. U ovom istraživanju utvrđen je pozitivan uticaj u oba dela stabla, juvenilnom i zrelom, ali je bolja matematička zavisnost, kvadratnog oblika, dobijena u zoni zrelosti.

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TRANSVERSAL STRESS WAVE VELOCITY IN THE TREE OF SERBIAN SPRUCE (Picea omorika (Pančić) Purkyně)

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Abstract: *In this paper, transversal stress wave velocity was measured in 30 trees of Serbian spruce (Picea omorika /Pančić/ Purk.) using a 2D sonic tomograph. Tomograms were analyzed and speed loss and average speed for Serbian spruce were calculated. Since there is no reference value for this species, in this research the reference value for stress wave velocity of Norway spruce (Picea abies /L./ H. Karst.) was used for comparison. The relative difference between referent and measured stress wave velocity indicates the amount of decay between the two sensors. The largest number of cross-sections had a speed loss of up to 10%, but there were also cross-sections with a speed loss of more than 50% in the transversal direction. This result shows that there are defects and damages in this direction that will reduce the strength of the wood. Summarizing data for trees with speed loss of less than 10%, the average stress wave velocity at the cross-sections is 1635 (1205-2170) m/s. Compared to Norway spruce, this velocity is higher, but not significantly.*

Key words: Serbian spruce, 2D tomography, stress wave velocity, tree health evaluation

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BRZINA TRANSVERZALNIH ZVUČNIH TALASA U STABLIMA PANČIĆEVE OMORIKE (*Picea omorika* (Pančić) Purkyně)

Izvod: *U ovom radu merena je brzina transverzalnih zvučnih talasa na 30 stabala Pančićeve omorike (Picea omorika /Pančić/ Purk.) korišćenjem 2D zvučnog tomografa. Analizirani su tomogrami i izračunati su gubici brzine i prosečna brzina zvučnih talasa za Pančićevu omoriku. S obzirom da za ovu vrstu ne postoji referentna vrednost, u ovom istraživanju je za poređenje korišćena referentna vrednost brzine talasa kod smrče (Picea abies /L./ H. Karst.). Relativna razlika između izmerene i referentne vrednosti brzine talasa ukazuje na količinu oštećenja između dva senzora. Najveći broj poprečnih preseka imao je gubitak brzine do 10%, ali je bilo i preseka sa gubitkom brzine više od 50% u poprečnom pravcu. Ovaj rezultat pokazuje da u ovom pravcu postoje devastacije i oštećenja koja će smanjiti čvrstoću drveta. Sumirajući podatke za stabla sa gubitkom brzine manjim od 10%, prosečna brzina talasa napona na poprečnim presecima je 1635 (1205-2170) m/s. U poređenju sa smrčom, ova brzina je veća, ali ne značajno.*

Ključne reči: Pančićeva omorika, 2D tomografija, brzina zvučnih talasa, procena zdravstvenog stanja drveta

1. INTRODUCTION

Today, wood is an irreplaceable raw material for many products, where the properties of wood significantly determine the application of final wood products, as well as their economic value. The development of new methods for non-destructive analysis of living trees has greatly helped to determine the future of the tree in relation to its quality and properties of wood as a material.

As a part of the project "Monitoring the habitat of the Serbian spruce (*Picea omorika* Pancic) in NP Tara", trees of Serbian spruce were inspected with a 2D sonic tree tomography. The speed of sound waves is used, as a non-destructive method, in the prediction of internal damage in wood. Many researchers have studied the relationship between wood mechanical properties and wave speed (Ishiguri *et al.*, 2013: Tannert *et al.*, 2014; Yue *et al.*, 2019). Damage in the wood often results in lower quality and speed of acoustic wave propagation, therefore sound wave propagation time provides usefuinforns on the physical-mechanical properties of wood (Goh *et al.*, 2018). Instruments for this purpose generally measure the speed of ultrasonic or sound waves in wood. The speed of sound propagation depends on the species and its characteristics, and it is necessary to establish reference speeds of sound wood to set criteria for each species. According to the results so far, the speed of sound is the highest in the axial direction, and the largest number of tests was done by monitoring the correlation between the longitudinal speed of sound and the properties of wood. In recent years, tomography techniques that were developed for engineering or medical applications have been evaluated for their applicability in standing trees. Investigations on trees showed great success in using tomography techniques to detect internal decay (Mahon *et al.*, 2007). Instruments for this purpose usually measure the speed of waves or sound traveling through the wood. Given that wood is a solid medium, the speed of the wave in it is much higher than in air and depends on the type of wave and the elasticity and density of the material. Damaged wood often results in a modified speed of propagation of the acoustic wave, so that the propagation time of the sound wave provides useful information about the mentioned properties of wood (Goh *et al.*, 2018). This means that wood quality can be assessed *in situ* and that the methods and devices in question can help us make the right decisions. Still, it must be pointed out that all the methods and devices used are only measuring and quantifying tools, and practical human experience cannot be replaced by any measuring tools (Živanović *et al.*, 2019). Arbotom is a device for pulse tomography that enables an internal examination of the condition of trees and tree trunks. Hidden rot, invisible cavities, and cracks, as well as their dimensions become visible with this device that uses sound signals. The software package of this tomograph will provide a graphic display of the measurement results (i.e., tomogram) showing differently colored cross-sectional zones depending on the degree of wood decay.

Serbian spruce is an endemic species with a fragmented natural distribution range, which is limited to the areas along the central part of the river Drina. In Bosnia and Herzegovina, it occurs in 13 localities (Petrović, 2018). In Serbia, there are several smaller populations and scattered groups of trees in the Tara Mts., and a single large population in the valley of the river Mileševka (Vidaković, 1991). Serbian spruce is a mountain species with an altitudinal range between 800 and 1550 m a.s.l. It requires a mountain climate with mean annual temperatures of 4 to 6 °C and annual precipitation of around 1000 mm. Even at high elevations, the occurrences are limited to steep north-facing slopes and deep ravines with abundant fogs and a high snow cover. Within its natural range, it grows mainly on scree fields and calcareous rocks with shallow soils. Natural populations of Serbian spruce have been under legal protection since 1964, and the species has been listed in the IUCN Red List of Threatened Plants as a vulnerable species in the restricted area since 1997. In many European countries, it is grown as a decorative plant or in commercial forest plantations (Ballian, 2006).

In this paper transversal stress wave velocity was measured in 30 trees of Serbian spruce using Arbotom, in order to evaluate the internal damage and health of Serbian spruce in Serbia and to determine an average stress wave velocity for this species.

2. MATERIALS AND METHODS

Thirty Serbian spruce trees in the protected zone, located in the Crvena Stena area, were examined. The stand resides on a slope with a greater incline, on very shallow soil with a high portion of stones. A high number of fallen trees was noticed. The standing trees were examined with a sound tomograph in one or two cross-sections at different heights from the ground (pictures 1 and 2). The internal wood decay was measured using a portable Sonic Tomograph (ARBOTOM® Rinntech Inc. Heidelberg, Germany).

Picture 1. *Arbotom measurements*

Picture 2. *Examined Serbian spruce trees*

The relative difference between the reference and the measured velocity indicates the amount of decay between the two sensors.

The relative decrease of stress wave velocity is determined in a percent:

$$\Delta Vrel = \frac{Vref - Vmes}{Vref} * 100$$

where $\Delta Vrel$ is the relative decrease of sound velocity, Vref is the reference velocity, and Vmes is the measured velocity (Dackermann, 2014).

3. RESULTS AND DISCUSSION

The measurement results for the cross-section devastation and sound velocity in 30 trees of Serbian spruce are shown in table 1. Based on these results, the values of the share of damaged wood were obtained, ranging from 50% for tree number V33, while as many as 14 trees were without any damage.

Table 1. *Cross-section devastation and sound velocity in 30 Serbian spruce trees*

No.	Tree mark	Dia-metar (cm)	Cross section devastation (%)			Stress wave velocity (m/s)			Mean reference value for stress wave velocity *	ΔVrel
			Sound wood	Partly damaged	Damaged	Vmin	Vavg	Vmax	(m/s)	(%)
1.	T40	17	80	20	--	310	1205	2100	931 – 1310	8.02
2.	V19T42	40	95	5	--	330	730	1130	931 – 1310	44.27
3.	T41	20	70	30	--	730	1395	2060	931 – 1310	0.00
4.	T11V15	35	75	5	20	320	1395	2470	931 – 1310	0.00
5.	T44	30	40	25	35	300	1495	2690	931 – 1310	0.00
6.	T45	40	10	--	--	150	580	1010	931 – 1310	55.73
7.	T43	40	100	--	--	690	940	1190	931 – 1310	28.24
8.	T12	65	35	30	35	120	565	1010	931 – 1310	56.87
9.	T9	60	95	5	--	150	580	1000	931 – 1310	55.73
10.	T10	60	95	5	--	150	580	1000	931 – 1310	55.73
11.	T7	50	100	--	--	50	580	1110	931 – 1310	55.73
12.	T5	45	100	--	--	630	950	1270	931 – 1310	27.48
13.	T8	20	100	--	--	700	1445	2190	931 – 1310	0.00
14.	T6	35	50	20	30	430	2170	3910	931 – 1310	0.00
15.	T4	50	100	--	--	260	690	1120	931 – 1310	47.33
16.	T33	15	70	30	--	140	1635	3130	931 – 1310	0.00
17.	T35	30	100	--	--	370	780	1190	931 – 1310	40.46
18.	T27	22	70	5	25	720	2025	3330	931 – 1310	0.00
19.	T24	20	100	--	--	130	1250	2310	931 – 1310	4.58
20.	T25	40	100	--	--	310	720	1130	931 – 1310	45.04
21.	T28	40	70	30	--	310	985	1660	931 – 1310	24.81
22.	T31V28	15	100	--	--	1300	1850	2400	931 – 1310	0.00
23.	T32	45	100	--	--	200	675	1070	931 – 1310	48.47
24.	V29	50	70	30	--	280	864	1550	931 – 1310	34.05
25.	V33	30	40	10	50	300	2115	3350	931 – 1310	0.00
26.	T29	45	100	--	--	870	1130	1390	931 – 1310	13.74
27.	T38	30	100	--	--	360	775	1190	931 – 1310	40.84
28.	T37	25	100	--	--	830	1120	1410	931 – 1310	14.50
29.	T36	35	100	--	--	830	1120	1410	931 – 1310	14.50
30.	T39	15	65	35	--	50	1020	1900	931 – 1310	22.14

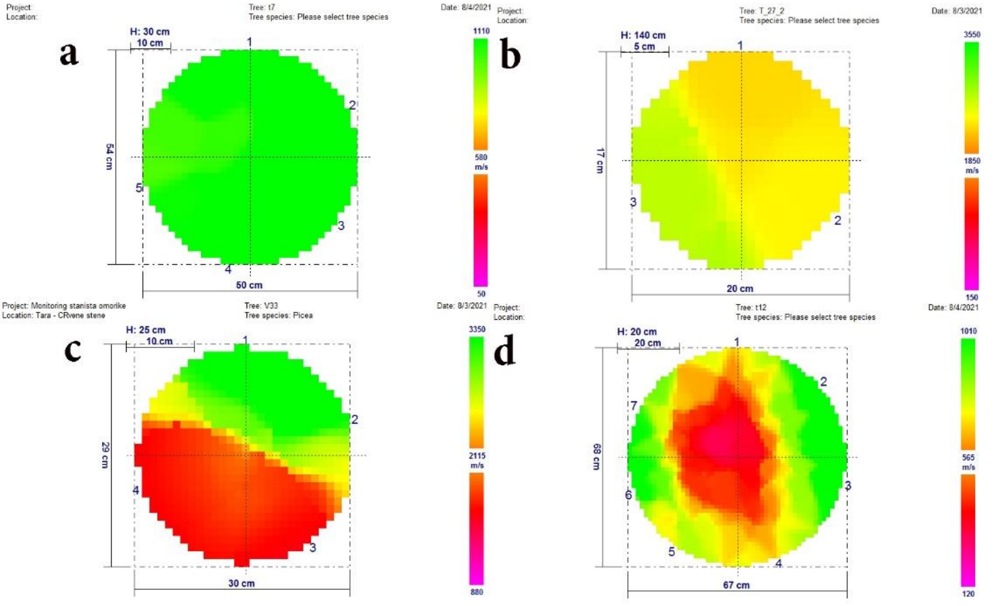
Since the speed of sound propagation greatly depends on the species and water content and density of the wood, the table gives average reference values for healthy trees of the genus *Picea*. By comparing these values with the measured values between individual sensors, the place of damage, rot, cavities, etc. were located. For sound wood, the stress wave velocities for longitudinal (parallel to the grain) and radial (perpendicular to the grain) orientations are listed for various wood species in table 2 by Dackermann (2014). These reference velocities can be used to evaluate the measured wave velocity and assess the internal condition of the timber specimen.

Table 2. *The stress wave velocities for longitudinal and transverse directions (Dackermann, 2014)*

Species	Species Stress wave velocity (m/s)	
	Longitudinal	Transverse
White ash	3,968–5,076	
Ash*		1,162–1,379
Beech*		1,670
Red beech*		1,206–1,412
Birch	4,695–5,747	1,140–1,479
Yellow birch	4,348–5,556	
Black cherry	4,831–5,435	1,451–1,613
Horse chestnut*		873–1,557
Sweet chestnut*		1,215–1,375
Fir*		910–1,166
Black fir*		1,480
Douglas-fir*		905–1,675
Japanese fir*		1,450
Silver fir*		1,360
Larch*		1,023–1,490
Lime*		940–1,183
Linden*		1,690
Black locust*		934–1,463
Maple*		1,006–1,690
Sugar maple	3,906–5,155	
Oak*		1,382–1,610
Live oak		627–1,631
White oak 1,258		1,258
Red oak	3,311–5,650	1,548–1,751
Pine*		1,066–1,146
Scotch pine*		1,470
Southern pine	5,000–5,882	
Plane*		950–1,033
Black poplar*		869–1,057
Pine poplar*		967–1,144
Silver poplar*		821–1,108
Yellow poplar	5,155–5,747	1,399–1,479
Spruce*		931–1,310
Sitka spruce	5,882	
Willow*		912–1,333

* Measured on a tree

For sound wood, the longitudinal stress wave velocities generally range between 3,500 and 5,000 m/s, while the velocity of transverse stress waves falls in the range of 1,000–1,500 m/s. Since there is no reference value for Serbian spruce, in this research value for the reference stress wave velocity of Norway spruce was used for comparison instead.



Picture 3. *Tomograms of different Serbian spruce trees cross-sections: a)sound wood, b) initial devastation, c and d) devastated wood*

Since longitudinal stress waves travel along the vertically oriented cells with only a few or no boundaries to pass, they have a higher velocity, while transverse waves encounter numerous interfaces and boundaries at the cell walls and travel at slower velocities. In picture 3, four different tomograms are shown. The first one (picture 3a) is for the wood with no damage. The second tomogram (picture 3b) is showing the sound speed loss and the beginning of devastation on the whole cross-section. The remaining two tomograms (pictures 3c and 3d) are for damaged and possibly rotten wood. Stress wave velocity was measured between all sensors on the cross-section. It was determined that the average stress wave velocity at the cross-sections is 1112 (565-2170) m/s.

Table 3. *Relationship between relative velocity decrease and decayed area (Fakopp Enterprise, 2011)*

Relative velocity decrease (%)	**Decayed area ratio (%)**
0–10	No decay
10–20	10
20-30	20
30-40	30
40-50	40
≥ 50	≥ 50

The relative difference indicates the amount of decay between the two sensors. The relationship between the relative velocity decrease and the decayed area is shown in table 3. The largest number of cross-sections had a speed loss of up to 10%, but there were also cross-sections with a speed loss of more than 50%

in the radial direction. This result shows that there are defects and damages in this direction that will reduce the strength of the wood.

Summarizing data for trees with less than 10% speed loss, the average stress wave velocity at the cross-sections is 1635 (1205-2170) m/s. Compared to Norway spruce, this velocity is higher, but not significantly. This value could be used as a reference value for Serbian spruce.

4. CONCLUSIONS

Stress wave velocity was measured between all sensors on the cross-section. It was determined that the average stress wave velocity at the cross-sections is 1112 (565-2170) m/s. Summarizing data for trees with less than 10% speed loss, the average stress wave velocity at the cross-sections is 1635 (1205-2170) m/s. Compared to Norway spruce, this velocity is only slightly higher. The relative difference between the reference and measured speed was used to assess the wood quality. The relative difference indicates the amount of decay between the two sensors. Based on the obtained results, the largest number of cross-sections had a speed loss of up to 10%, but there were also cross-sections with a speed loss of more than 50% in the radial direction. This result shows that there are defects and damages in this direction that will reduce the strength of the wood.

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TRANSVERSAL STRESS WAVE VELOCITY IN THE TREE OF SERBIAN SPRUCE (*Picea omorika* (Pančić) Purkyně)

Ivana ŽIVANOVIĆ, Nenad ŠURJANAC, Ilija ĐORĐEVIĆ, Goran ČEŠLJAR

Summary

Serbian spruce (*Picea omorika* /Pančić/ Purk.) is a endemic mountain species of the eastern part of Bosnia and Herzegovina and the western part of Serbia, which attracts the attention of researchers from all over the world. Natural populations of Serbian spruce have been under legal protection since 1964, and the species has been listed in the IUCN Red List of Threatened Plants as a vulnerable species in the restricted area since 1997.

As a part of the project "Monitoring the habitat of the Serbian spruce (*Picea omorika* Pancic) in NP Tara", 30 Serbian spruce trees were analyzed using sound tomography. Changes in the speed of sound waves and variations in wood density caused by rots were successfully detected. Based on the obtained results, the largest number of cross-sections had a speed loss of up to 10%, but there were also cross-sections with a speed loss of more than 50% in the radial direction. This result shows that there are defects and damages in this direction that will reduce the strength of the wood. The average speed of sound waves for Serbian spruce was also determined, which until now did not exist in the literature as a reference value and it is 1635 m/s.

The results presented in scientific papers show a good correlation between the speed of sound waves and the density of wood, as well as its other properties. Based on the measurement of the speed of sound flow through the wood, data on the health condition and properties of the wood is obtained. In this way, science and practice get significant data on the vitality and quality of wood, and the consumption of materials is minimized.

BRZINA TRANSVERZALNIH ZVUČNIH TALASA U STABLIMA PANČIĆEVE OMORIKE (*Picea omorika* (Pančić) Purkyně)

Ivana ŽIVANOVIĆ, Nenad ŠURJANAC, Ilija ĐORĐEVIĆ, Goran ČEŠLJAR

Rezime

Pančićeva omorika (*Picea omorika* (Pančić) Purkyně) je endemska planinska vrsta istočnog dela Bosne i Hercegovine i zapadnog dela Srbije, koja privlači pažnju istraživača iz celog sveta. Prirodne populacije srpske omorike su pod zakonska zaštita od 1964. godine, a vrsta je od 1997. godine navedena na Crvenoj listi ugroženih biljaka IUCN-a kao ranjiva vrsta u ograničenom području.

U okviru projekta „Monitoring staništa pančićeve omorike (*Picea omorika* Pančić) u NP Tara", zvučnom tomografijom je analizirano 30 stabala omorike. Uspešno su otkrivene promene u brzini zvučnih talasa i varijacije u gustini drveta izazvane truljenjem. Na osnovu dobijenih rezultata najveći broj poprečnih preseka imao je gubitak brzine do 10%, ali je bilo i preseka sa gubitkom brzine više od 50% u radijalnom pravcu. Ovaj rezultat pokazuje da u ovom pravcu postoje nedostaci i oštećenja koja će smanjiti čvrstoću drveta. Utvrđena je i prosečna brzina zvučnih talasa za pančićevu omoriku, koja do sada nije postojala u literaturi kao referentna vrednost i iznosi 1635 m/s.

Rezultati prikazani u naučnim radovima pokazuju dobru korelaciju između brzine zvučnih talasa i gustine drveta, kao i njegovih drugih svojstava. Na osnovu merenja brzine proistiranja zvuka kroz drvo dobijaju se podaci o zdravstvenom stanju i svojstvima drveta. Na ovaj način nauka i praksa dobijaju značajne podatke o vitalnosti i kvalitetu drveta, a utrošak materijala je minimiziran.

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Original scientific paper

COMPARISON OF FLORISTIC COMPOSITION OF SUBMONTANE BEECH FOREST AND ARTIFICIAL ESTABLISHED STANDS OF NORWAY SPRUCE ON Mt. KOSMAJ

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Abstract: *The paper presents the comparative characteristics of the floristic composition in the association of the submontane beech forest* **(***Helleboro odori-Fagetum moesiacae Soo & Borhidi 1960.) and artificially established spruce stands (Picea abies (L.) Karst.) in the area of Kosmaj. According to the obtained results, the cover in the shrub and ground flora layers of the artificially established spruce stands increased significantly compared to the autochthonous beech forests, but the floristic diversity decreased. Regarding the spectrum of floral elements, a higher percentage of mesophilic (51%) and frigophilic plants (11%) was observed in the artificially established spruce stands compared to the beech forests. Significant differences could also be observed regarding the spectrum of life forms since there were twice as many phanerophytes in the artificially established spruce stands (48%) than in the beech forests (23%). This resulted from the open canopy of artificially established spruce stands and the influx of a greater amount of light, which made conditions favourable for an abundant shrub layer to develop in this community. A comparative study of the mean plant indicator values showed that in the artificially established spruce stands, the mean values of the ecological factors for moisture, light and soil nitrogen supply increased, while the value of the ecological factors for temperature and soil acidity decreased compared to the beech forests.*

Key words: *Fagus sylvatica*, substitution, floristic diversity, Kosmaj

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POREĐENJE FLORISTIČKOG SASTAVA BRDSKE BUKOVE ŠUME I VEŠTAČKIH PODIGNUTIH SASTOJINA SMRČE PODRUČJU KOSMAJA

Izvod: *U radu su prikazane uporedne karakteristike florističkog sastava zajednice brdske bukove šume* **(**Helleboro odori-Fagetum moesiacae Soo & Borhidi 1960.) *i veštački podignute sastojine smrče (*Picea abies *(L.) Karst.) na području Kosmaja. Rezultati su pokazali da se u veštački podignutoj sastojini smrče znatno povećala pokrovnost u spratu žbunja i prizemne flore u odnosu na autohtone šume bukve, ali se floristički diverzitet smanjio. U spektru flornih elemenata veštački podignute sastojine smrče uočava se veće procentualno učešće mezofilnih (51%) i frigorifilnih biljaka (11%) u odnosu na bukove šume. Prema spektru životnih oblika značajne razlike se ogledaju u prisustvu fanerofita, kojih ima duplo više u veštački podignutoj sastojini smrče (48%), nego u šumi bukve (23%). Ovo je posledica nesklopljenosti veštački podignutih sastojina smrče i priliva veće količine svetlosti, što je uslovilo bogat sprat žbunja u ovoj zajednici. Uporedna analiza srednjih indikatorskih vrednosti biljaka, pokazuje da se u veštački podignutoj sastojini smrče u odnosu na bukove šume, povećala prosečna vrednost ekološkog faktora za vlagu, svetlost i količinu azota, dok se vrednost ekološkog faktora za temperaturu i kiselost zemljišta smanjila.*

Ključne reči: *Fagus sylvatica*, supstitucija, floristički diverzitet, Kosmaj

1. INTRODUCTION

Recent disturbances in biological diversity worldwide and in Serbia have reached seriously worrying proportions. The most visible sign of the decline in biodiversity is the extinction of species with the increasing threat to the living world and its habitats. At the global level, the area of naturally regenerated forests has decreased, while there has been an obvious increase in the area of artificially established stands of various species (FAO, 2020). Reforestation with new tree species can do more harm than good to the ecosystem. It can, among other things, change the floristic composition and decrease floristic diversity (van Oijen *et al.*, 2005; Atauri *et al.*, 2005). It can further change soil properties and decrease its productivity (Van Calster *et al.*, 2007; Miletić *et al.*, 2013; 2020).

Our research was conducted in the territory of the Kosmaj Protected Area. Kosmaj was proclaimed a landscape of outstanding features in 2005. Since the mid-20th century, these coppice forests have been replaced with different conifer tree species, such as Austrian pine – *Pinus nigra* Arn., Scots pine–*Pinus sylvestris* L., Douglas fir – *Pseudotsuga menziesii* (Mirb.) Franco, Atlas cedar–*Cedrus atlantica* (Endl.) Carrière, Norway spruce (*Picea abies* (L.) Karst), etc. The introduction of tree species with decorative and aesthetic effects certainly improves the functions that forests in protected areas should have. However, this type of forest resources management entails certain environmental risks. Our research aimed to determine to what extent the establishment of artificial stands of Norway spruce (*Picea abies* (L.) Karst) on the site of the submontane beech forest (*Helleboro odori-Fagetum moesiacae* Soo & Borhidi 1960) in this area changed the floristic composition and diversity of these forests.

2. STUDY AREA, MATERIAL AND METHODS

Kosmaj is a relatively low mountain massif (626 m) that belongs to the Šumadija Mountain Range. According to Thornthwaite climate classification, the prevailing climate in the area is subhumid moist – C_2 type (Stajić, S., 2016). The mean annual air temperature is 12.3°C, and the mean annual precipitation is 696 mm.

Kosmaj has specific bedrock that consists of Neogene sands and clays, marls, limestones, breccias, sandstones and serpentinite. This type of bedrock has brought about significant pedological diversity in the area. Regarding phytogeography, this area belongs to the Balkan floristic province within the Central European region.

The floristic composition of the community of the submontane beech forest and the artificially established spruce stand was studied using 12 relevés collected in the submontane beech forest (*Helleboro odori-Fagetum moesiacae* Soo & Borhidi 1960) and three relevés in the spruce stand (*Picea abies* (L.) artificially established on this site. In doing so, we applied the Braun-Blanquet approach (Braun-Blanquet, 1964). Plant species were determined based on the following literature sources: Flora of Serbia IX (Josifović *et al*. 1972-1977, Sarić *et al*. 1986;1992; Stevanović *et al*. 2012). The spectra of floral elements were defined based on the systematisation of phytogeographical elements according to Gajić (1980) and the spectra of life forms using the method of Kojić *et al*. (1997). Plant indicator values and ecological optimums were determined using the method of Kojić *et al*. (1997).

3. RESULTS AND DISCUSSION

3.1 Floristic composition

Submontane beech forests (*Helleboro odori-Fagetum moesiacae* Soo & Borhidi 1960) typically occur at lower altitudes, in the climax zone of oaks, and are greatly conditioned by orographic conditions. They are found on cold slopes or in sheltered, shaded valleys with a specific microclimate (Tomić and Rakonjac, 2013). This community is widespread on Kosmaj, occurring at altitudes from 375 to 561 m above sea level and predominantly in cool exposures (Stajić *et al*., 2018). The ground flora cover ranges from 0.1 to 0.7. A total of 73 species were recorded within the submontane beech community (Table 1). Besides beech (*Fagus sylvatica*), the typical group includes the following species: *Lamium galeobdolon* (L.) Crantz, *Cardamine bulbifera* (L.) Crantz, *Acer campestre* L., *Helleborus odorus* Waldst. & Kit., *Mycelis muralis* (L.) Dum., *Circaea lutetiana* L., *Stachys sylvatica* L., *Carex sylvatica* Huds. and *Moehringia trinervia* (L.) Clairv.

Based on the analysis of the floristic composition, we can conclude that the investigated stands of Norway spruce (*Picea abies* (L.) Karst) were established on the site of the submontane beech forest (*Helleboro odori-Fagetum moesiacae* Soo & Borhidi 1960). Their altitude ranged from 460 to 470 m, the aspect was northeastern, and the slope was 10-14°. The ground flora cover ranged from 0.9 to

1.0, with a total of 27 species registered. The canopy closure was incomplete (0.6), which caused a higher presence of weed species in the shrub and ground flora layers, such as *Sambucus ebulus* L., *Rubus hirtus* Wald. & Kif., *Urtica dioica* L., *Rubus canescens* DC.

Table 1. *Floristic characteristics of the investigated stands*

Species	*B*	*NS*	*Species*	*B*	*NS*
Acer campestre	+	+	*Lathyrus vernus*	+	
Acer platanoides		+	*Lilium martagon*	+	
Ajuga reptans	+		*Luzula pilosa*	+	
Alliaria officinalis	+		*Melica uniflora*	+	
Allium ursinum	+		*Melittis melissophyllum*	+	
Asarum europaeum	+		*Mercurialis perennis*	+	
Asperula odorata	+		*Moehringia trinervia*	+	+
Athyrium filix femina	+	+	*Mycelis muralis*	+	
Atropa belladonna	+		*Neottia nidus avis*	+	
Bilderdykia convolvulus	+		*Picea abies*		+
Brachypodium pinnatum	+		*Pinus nigra*		+
Calamintha vulgaris	+		*Poa nemoralis*	+	
Cardamine bulbifera	+	+	*Polygonatum odoratum*	+	
Cardamine impatiens	+		*Polystichum setiferum*	+	
Campanula trachelium	+		*Prunus avium*	+	+
Carex pendula	+		*Pteridium aquilinum*	+	
Carex pilosa	+	+	*Pyrus pyraster*	+	
Carex sylvatica	+		*Quercus cerris*	+	
Carpinus betulus	+		*Quercus farnetto*	+	
Chaerophyllum hirsutum	+		*Quercus petraea*	+	+
Chaerophyllum temulum	+		*Ranunculus cassubicus*	+	
Chelidonium majus	+		*Ranunculus polyanthemos*	+	
Circaea lutetiana	+	+	*Rubus hirtus*	+	+
Cornus sanguinea		+	*Rubus canescens*		+
Crataegus monogyna		+	*Ruscus aculeatus*	+	
Clematis vitalba	+		*Ruscus hypoglossum*	+	
Dryopteris filix-mas	+	+	*Sambucus nigra*	+	+
Euphorbia amygdaloides	+		*Sambucus ebulus*		+
Fagus sylvatica	+	+	*Scrophularia nodosa*	+	
Festuca drymea	+		*Scrophularia vernalis*	+	
Fraxinus excelsior	+		*Stellaria media*	+	
Fraxinus ornus	+		*Stachys silvatica*	+	
Galeopsis speciosa		+	*Stenactis annua*	+	
Galium silvaticum	+		*Tamus communis*	+	+
Geranium robertianum	+	+	*Urtica dioica*	+	+
Glechoma hirsuta	+		*Veronica montana*	+	
Hedera helix	+	+	*Viola alba*	+	
Helleborus odorus	+		*Viola hirta*	+	
Juglans regia	+	+	*Viola odorata*	+	
Lamium galeobdolon	+	+	*Viola silvestris*	+	+
Lathyrus venetus	+				

Legend: B- Beech forests; NS-artificially established stands of Norway spruce

3.2 Spectrum of floral elements

The spectrum of floral elements (Table 2) indicated the dominance of mesophilic plants (Central European and Sub-Atlantic range of distribution types) in the investigated communities. A slightly higher percentage of these distribution types was recorded in the artificially established spruce stands (51%) than in the beech forest (48%). Also, a slightly higher share of xerothermophilic plants (Pontic, sub-Mediterranean and Balkan distribution types) can be observed in the mountain beech community (17%) compared to the artificially established spruce stands (15%), where some of the thermophilic species of the oak zone were absent. Artificially established spruce stands had a greater share of frigophilic plants (floral elements of northern regions and circumpolar). It amounted to 11%, compared to beech forests where it was as little as 4%. The share of plants with a wide ecological amplitude (Eurasian and cosmopolitan distribution types) was also higher in the beech forests (26%).

Table 2. *Spectrum of floral elements*

Range of distribution types	Beech		Norway spruce	
	Share (%)			
Pontic	4	17	7	15
Sub-Mediterranean	10		4	
Balkan	3		4	
Central European	38	48	44	51
Sub-Atlantic	10		7	
Desert	1	1	4	4
Eurasian	19	26	11	19
Cosmopolitan	7		8	
Circumpolar	7	7	7	11
Northern regions	-		4	
Adventive	1	1	-	-

3.3 Spectrum of life forms

Regarding the spectrum of life forms, both communities had dominant shares of phanerophytes and hemicryptophytes (Table 3). The beech forest had the highest share of hemicryptophytes (38%) which are also the largest group of life forms in our region (Diklić, 1984). The share of geophytes, whose presence indicates favourable soil conditions (moisture, soil structure and depth), was 25% in the beech community, while in the artificially established spruce stands, it was significantly lower (15%). Significant differences were reflected in the presence of phanerophytes, which were twice as many in the artificially established spruce stands (48%) than in the beech forest (23%). A larger share of phanerophytes resulted from the open canopy of Norway spruce stands and the greater influx of light, which made conditions favourable for a rich layer of shrubs to be formed in this community.

Table 3. *Spectrum of life forms*

Life forms	Beech		Norway spruce	
	Share (%)			
Phanerophytes	16	23	33	48
Nanophanerophytes	6		11	
Phanerophytic lianas	1		4	
Herbaceous chamaephytes		3		4
Hemicryptophytes		38		22
Geophytes		25		15
Therophytes		1		4
Therophytes / Chamaephytes		10		7

3.4 Plant ecological indices

Classification of plants into ecological groups was done based on their indicator values of the analysed ecological factors (moisture, soil acidity, soil nitrogen supply, light and heat). The mean indicator values of the studied ecological factors showed that regarding the moisture, the submontane beech community (*Helleboro odori-Fagetum moesiacae* Soo & Borhidi 1960.) was mesophilic; regarding the acidity of the soil, neutrophilic with an increased share of basophilic plants compared to acidophilic ones; regarding the soil nitrogen supply, it is mesotrophic; regarding the light sciophilous to semi-sciophilous; regarding the heat, it has a mesothermal character (Stajić *et al*., 2018).

A comparative study of the mean indicator values of some ecological factors (Table 4) shows that the mean value of the ecological factors for moisture, light and soil nitrogen supply increased in artificially established spruce stands compared to natural beech forests, while the value of the ecological factors for temperature and soil acidity decreased.

Table 4. *Mean plant indicator values*

	Moisture	Soil reaction	Nitrogen	Light	Temperature
Beech	2.99	3.25	2.99	2.56	3.37
Spruce	3.07	3.24	3.21	2.69	3.22

As a sciophilous species, spruce was accompanied by species adapted to cold and humid microsite conditions. On the other hand, the open canopy that resulted from tree dieback was favourable for the occurrence of plant species tending to be heliophytes and thus increased the mean value of the ecological factor for light. Given that the value of the ecological factor for soil acidity did not decrease significantly, we still cannot be sure if soil acidification has occurred.

The study of the floristic composition of the submontane beech forest and the artificially established spruce stands on Mt. Kosmaj point to notable differences between the observed communities. Norway spruce (*Picea abies* (L.) Karst.) is a conifer least used in the establishment of forest plantations in the area of Mt. Kosmaj. It is not unusual considering its main bioecological characteristics (alpine, mesophilic and sciophilic species). Given that Kosmaj, as a relatively low mountain massif, did not prove to be a site favourable for the growth of this species, artificially established spruce stands were in very poor condition and individual trees had died back. Their death resulted in the partial opening of the stand canopy, which caused an abundant ground flora layer. Although the coverage of the ground flora in the artificially established spruce stand was much higher, the number of recorded species of vascular flora was significantly lower than in the natural beech forest.

Replacement of autochthonous beech forests with coniferous tree species has in most cases decreased the floristic diversity. Investigations in artificially established spruce stands on the site of submontane beech in the area of Bukovo (Cvjetićanin and Bjelanović, 2007) and Maljen (Kostić *et al*., 2012) also revealed a decrease in floristic diversity compared to autochthonous species of beech forests. Another research showed that the substitution of a natural beech forest with spruce affects soil degradation processes, i.e., the soil shows elements of podzolization to a smaller or greater extent (Knežević, 1992; Kostić *et al*., 2012). Norway spruce was found to have the most unfavorable impact on the soil, because this species, besides its unfavorable composition of forest litterfall, as shade-loving species, makes microclimatic conditions not favorable for the decomposition of organic matter (Knežević, 1992).

5. CONCLUSIONS

This paper presents the results of comparing the floristic composition of the submontane beech forest and Norway spruce stands (*Picea abies* (L.) Karst) artificially established on the beech site on Mt. Kosmaj. According to the results, artificially established spruce stands had a significantly higher cover in the shrub and ground flora layers than the autochthonous beech forests, but the floristic diversity decreased and many plant species typical of natural beech forests were missing. The spectrum of floral elements pointed to the dominance of mesophilic plants (Central European and sub-Atlantic distribution types) in the investigated communities and a higher share of frigophilic plants (floral elements of northern regions and circumpolar floral elements) in artificially established spruce stands (11%) compared to beech forests (4%). Regarding the spectrum of life forms, significant differences were noticed in the presence of phanerophytes, which were twice as many in the artificially established spruce stands (48%) than in the beech forest (23%), as a result of the spruce canopy opening and the influx of a greater amount of light. A comparative analysis of the mean indicator values for the ecological factors showed that the mean value of the ecological factors for moisture, light and soil nitrogen supply increased in the artificially established spruce stands, while the value of the ecological factor for temperature and soil acidity decreased.

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. The introduction of spruce into the site whose conditions were not suitable for its growth led to the poor health condition of the artificially established stands that were overwhelmed by weeds and decreased the number and coverage of species typical of beech forests.

Should they use conifer tree species, native or introduced, future reconstruction of coppice forests in this area should be done in smaller areas taking into account the bioecological characteristics of these conifer species.

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COMPARISON OF FLORISTIC COMPOSITION OF SUBMONTANE BEECH FOREST AND ARTIFICIAL ESTABLISHED STANDS OF NORWAY SPRUCE ON Mt. KOSMAJ

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Summary

The paper presents the comparative characteristics of the floristic composition in the submontane beech forest **(***Helleboro odori-Fagetum moesiacae* Soo & Borhidi 1960.) and artificially established stands of Norway spruce (*Picea abies* (L.) Karst.) on this site in the area of Mt. Kosmaj. The aim of the study was to determine to what extent the establishment of artificial spruce stands on the site of the submontane beech forest changed the floristic composition and floristic diversity of these forests.

The results showed that in the artificially established spruce stand, the cover of shrubs and ground flora increased significantly compared to the autochthonous beech forests, but the floristic diversity decreased. The spectrum of floral elements indicated the dominance of mesophilic plants (Central European and sub-Atlantic distribution types) in the investigated communities and higher participation of frigophilic plants (floral elements of northern and circumpolar regions) in artificially established spruce stands (11%) compared to beech forests (4%). According to the spectrum of life forms, significant differences were noticed in the presence of phanerophytes, which were twice as many in the artificially established spruce stand (48%) than in the beech forest (23%). This was due to the opening in the canopy of artificially established spruce stands and the influx of a greater amount of light, which made favourable conditions for an abundant shrub layer to be developed in this community. A comparative study of the mean indicator values of some ecological factors showed that the mean value of the ecological factors for moisture, light and soil nitrogen supply increased in artificially established spruce stands, while the value of the ecological factors for temperature and soil acidity decreased compared to natural beech forests.

The establishment of artificial spruce stands of in this area changed the floristic composition of these forests, as the number of vascular flora species decreased compared to the natural beech forests. The introduction of spruce into the site whose conditions were not suitable for its growth led to the poor health condition of the artificially established stands that were overwhelmed by weeds and decreased the number and coverage of species typical of beech forests.

The introduction of tree species with decorative and aesthetic effects certainly improves the functions that forests in protected areas should have. However, this type of forest resources management entails certain environmental risks. Therefore, if in the future reconstruction of coppice forests, conifer tree species (native or introduced) are used, they should be used in smaller areas taking into account the bioecological characteristics of the selected conifer species.

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EFFECTS OF DIFFERENT MEDIA ON THE MYCELIAL GROWTH OF *Cryphonectria parasitica* (Murrill) M.E. Barr

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Abstract: *It is a well-known fact that a large number of parasitic and saprophytic fungi grow on sweet chestnut trees. However, the greatest damage is caused by C . parasitica which causes "sweet chestnut blight" and leads to its dieback. Hosts other than Castanea species include the following families: Aceraceae, Betulaceae, Fagaceae, Anacardiaceae, Juglandaceae u Magnoliaceae, where it grows as a saprophyte. The exception, according to some authors, is oak, where it can also occur as a parasite. Mycelial growth of C. parasitica was tested on media made of the bark of sweet chestnut (Castanea sativa), manna ash (Fraxinus ornus), sycamore maple (Acer pseudoplatanus), sessile oak (Quercus petraea), common yew (Taxus baccata), hazel (Corylus avellana), small-leaved linden (Tilia cordata), Norway maple (Acer platanoides) and English walnut (Juglans regia).*

After 28 days, the medium was not completely overgrown only in the variants with sycamore maple and Norway maple bark added to the medium.

Key words: *C. parasitica*, sweet chestnut, bark, mycelia

UTICAJ RAZLIČITIH PODLOGA NA PORAST MICELIJE GLJIVE *Cryphonectria parasitica* (Murrill) M.E. Barr

Izvod: *Poznato je da se na pitomom kestenu razvija veliki broj parazitskih i saprofitskih gljiva. Ipak, najveće štete izaziva C. parasitica koja izaziva "rak kore kestena", dovodeći do njegovog potpunog sušenja. Pored vrsta roda Castanea ostali domaćini gljive*

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C. parasitica pripadaju familijama: Aceraceae, Betulaceae, Fagaceae, Anacardiaceae, Juglandaceae i Magnoliaceae. Na vrstama ovih familija javlja se kao saprofit. Izuzetak, po nekim autorima predstavlja hrast, na kom se može javiti i parazitski. Porast micelije C. parasitica ispitivan je na podlogama napravljenim od kore: pitomog kestena (Castanea sativa), crnog jasena (Fraxinus ornus), javora (Acer pseudoplatanus), hrasta kitnjaka (Quercus petraea), tise (Taxus baccata), leske (Corylus avellana) sitnolisne lipe (Tilia cordata), mleča (Acer platanoides) i oraha (Juglans regia).
Posle 28 dana podloga nije u potpunosti obrasla samo u varijantama kada je podlozi dodavana kora javora i mleča.

Ključne reči: *C. parasitica,* pitomi kesten, kora, micelija

1. INTRODUCTION

Sweet chestnut (*Castanea sativa* Mill.) is a tree species of considerable economic value. Therefore, it has often been the subject of numerous research studies worldwide. It is one of the most useful and economically important forest tree species, with a very high use value in all developmental stages (from saplings to mature stands).

The occurrence of the parasitic fungus *Cryphonectria parasitica* (causing sweet chestnut blight) has markedly decreased the use value of sweet chestnut trees. *C. parasitica* was first recorded in the New York area in 1904 (probably transferred from East Asia) and then quickly spread over the entire distribution area of the American chestnut (*Castanea dentata*). Within 40 years, it practically devastated the American chestnut in North America. More than 3.5 billion American chestnut trees were estimated to be destroyed in the US alone. It was introduced to Europe from North America in 1938, and the European chestnut (*Castanea sativa*) immediately proved very sensitive to the infections caused by this pathogen.

According to Krstić (1950), sweet chestnut blight was first detected in Yugoslavia in 1950 in the Slovenian "Panovac" forest. Its presence in Croatia was first recorded by Halambek in 1955 in the vicinity of Opatija (cited by KRSTIN et al., 2008). In Bosnia and Herzegovina, the blight was first noticed by UŠČUPLIĆ in 1961. According to MIJUŠKOVIĆ (1973), the first signs of chestnut disease in Montenegro were observed by B.Sc. Danilo Stamatović in 1968 in the place known as "Matića Gvozd" at the foot of Rumija, and Mijušković registered it in Boka Kotorska in 1973 (in a chestnut forest above Stolivo). Sweet chestnut bark blight was first recorded in Macedonia in 1974 (PAPAZOV et al., 1974) and in Kosovo and Metohija in 1975 (cited by MARINKOVIĆ and KARADŽIĆ 1985).

C. parasitica was first described in 1906 as *Diaporthe parasitica* Murr. and was renamed *Endothia parasitica* (Murrill) P. J. Anderson & H. W. Anderson in 1912. The taxonomy of the *Endothia* genus was modified by Barr (1978) in his monograph named Diaporthales. Based on the composition and structure of the fruiting body and the appearance of the spores (shape and septation), *Cryphonectria* and *Endothia* were separated (Roane et al., 1986).

Recent taxonomic revisions have restricted the name *Cryphonectria* (*sensu stricto*) only to the following four species: *C. parasitica* (Murr.)

Barr., *C. radicalis* (Schwein.: Fr.) M.E. Barr, *C. macrospora* (Tak. Kobay. & Kaz. Ito) M.E. Barr and *C. nitschkei* (G.H.Otth) M.E. Barr (GRYZENHOUT et al., 2006a, b). Of the four species, only *C. parasitica* is a dangerous plant pathogen.

C. parasitica occurs on all known species of chestnut, causing the most considerable damage to American chestnut *Castanea dentata*. European chestnut *Castanea sativa* is also sensitive, while the Asian species *Castanea crenata* and *Castanea molissima* are more resistant. It grows as a saprophyte on other tree species on which it has been observed. Other hosts of *C. parasitica*, as stated by NASH и STAMBAUGH (1982), TURCHETTI et al. (1991), DALLAVALLE and ZAMBONELLI (1999), and RADOCZ and TARCALI (2005), belong to the families of *Aceraceae*, *Betulaceae*, *Corylaceae*, *Fagaceae*, *Anacardiaceae*, *Juglandaceae* and *Magnoliaceae*.

2. MATERIAL AND METHODS

The growth of mycelia was examined on media made from the bark of different tree species. We used the isolate *C. parasitica* (CS3) recovered from the bark of the sweet chestnut growing in the locality of Sobina near Vranje. The bark of sweet chestnut (*Castanea sativa*), manna ash (*Fraxinus ornus)*, sycamore maple (*Acer pseudoplatanus*), sessile oak (*Quercus petraea*), common yew (*Taxus baccata*), hazel (*Corylus avellana*), small-leaved linden (*Tilia cordata*), Norway maple (*Acer platanoides*) and walnut (*Juglans regia*) was used. Besides the bark, the medium made from sweet chestnut fruit was also used. The bark and the fruit of sweet chestnut trees were dried to a constant value and ground. The medium was prepared from 10 g of powder ground in this way and 20 g of agar per liter of water. Mycelium growth was measured after 2, 4, 6, 8, 15 and 28 days. The results are expressed as a percentage of mycelial growth relative to the radius of the Petri dish at the time of measurement. We also registered the moment when the fruiting body emerged.

The data relating to the growth of *C. parasitica* mycelia on different media were processed using the STATISTICA 6.0 software package. (StatSoft, Inc).

3. RESULTS AND DISCUSSION

The table below (Table 1) shows the mycelium growth in the study period.

Table 1. *Media and mycelial growth of C. parasitica*

Medium	X ± SE	X ± SE	X ± SE	X ± SE	X ± SE	X ± SE
	2nd day	4th day	6th day	8th day	15th day	28th day
Oak	7.6±0.68 d	26.7±1.66 e	42.8±1.60 de	63.8±1.76 e	100.0±0.00 e	100.0±0.00 b
Manna ash	4.5±0.40c	10.0±0.90 c	22.8±1.48 c	36.5±1.58 c	83.8±1.41 c	100.0±0.00 b
Sycamore maple	0.0±0.00a	0.0±0.00 a	0.0±0.00 a	1.6±0.30 a	7.6±0.68 a	14.7±0.68 a
Chestnut bark	10.9±0.45e	33.9±0.68 f	54.2±0.68 f	75.2±0.52 fg	100.0±0.00 e	100.0±0.00 b
Chestnut fruit	6.7±0.45 d	21.2±1.63 d	44.6±1.84 e	71.3±1.81 f	100.0±0.00 e	100.0±0.00 b
Hazel	11.1±0.42e	34.4±1.12 f	57.3±1.26 f	80.0±1.40 g	100.0±0.00 e	100.0±0.00 b
Linden	7.4±0.46 d	24.9±1.12 de	44.0±1.57 e	73.6±1.85 f	100.0±0.00 e	100.0±0.00 b
Norway maple	2.6±0.16b	5.1±0.31 b	8.9±0.44 b	10.5±0.55 b	15.6±1.12 b	15.6±1.12 a
Walnut	6.7±0.39 d	25.8±1.04 de	44.9±1.71 e	56.8±1.17 d	90.2±0.92 d	100.0±0.00 b
Yew	6.7±0.46 d	22.0±1.21 de	36.9±1.20 d	51.6±1.14 d	90.4±0.94 d	100.0±0.00 b
F	133.08	219.88	374.82	448.34	1772.32	6990.42
P	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

After two days, no mycelial growth was observed on the medium with the addition of sycamore maple, while the highest growth was recorded on the media with the addition of hazel bark and sweet chestnut bark.

After four days, there was still no mycelial growth of *C. parasitica* on the medium with the addition of sycamore maple bark, while the medium with the addition of hazel bark and chestnut bark had the highest growth.

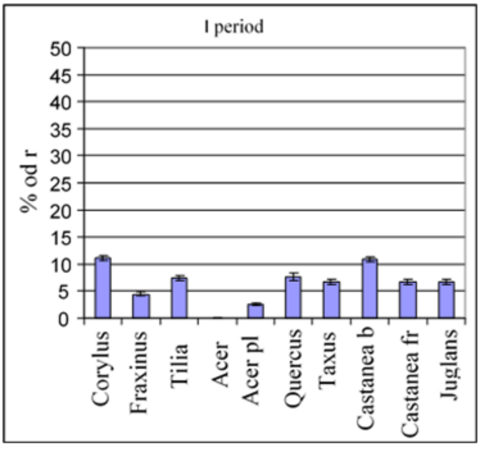
On the sixth day, the greatest increase was still achieved on the bark of hazel and sweet sweet chestnut. Mycelia still did not grow on the sycamore maple, while on the Norway maple it reached 8.9% of the Petri dish radius.

On the eighth day, the mycelium of *C. parasitica* started to grow on the medium with the addition of sycamore maple bark. The highest increase in mycelial growth was recorded on the medium with the addition of hazel bark and sweet chestnut bark. We also noted considerable growth on the medium with the addition of linden bark (73.6%).

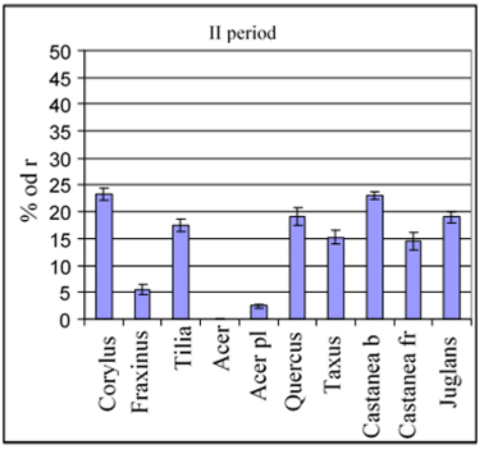
On the fifteenth day, Petri dishes were completely filled on the media with the addition of sessile oak, sweet chestnut, hazel, and linden bark, as well as sweet chestnut fruit. The lowest growth was recorded on the medium with the addition of sycamore maple (7.6%), followed by Norway maple (15.6%), and manna ash (83.8%). On the media with the addition of walnut and yew bark, the increase was approximately the same and amounted to 90%.

After 28 days, the only media that were not completely grown in mycelia were the ones with the addition of sycamore maple and Norway maple bark.

The research results related to the growth rate of *C. parasitica* mycelia in different periods are shown in the graphs below (1-6). Period 1 refers to the mycelial growth from the beginning of the experiment to the measurement conducted on the second day. Period 2 shows the growth from the second to the fourth day, Period 3 from the fourth to the sixth, Period 4 from the sixth to the eighth, Period 5 from the eighth to the fifteenth, and Period 6 from the fifteenth to the twenty-eighth day. Results are shown as a percentage of the Petri dish radius.



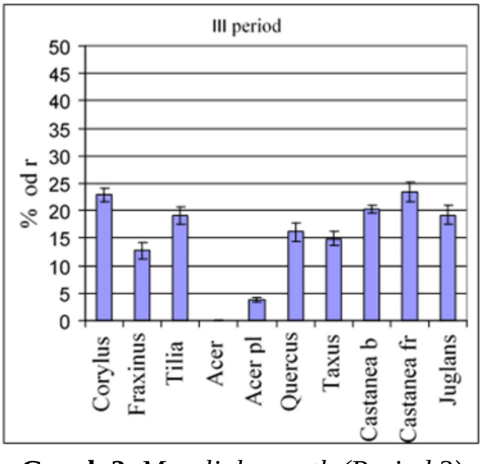
Graph 1. *Mycelial growth (Period 1)*



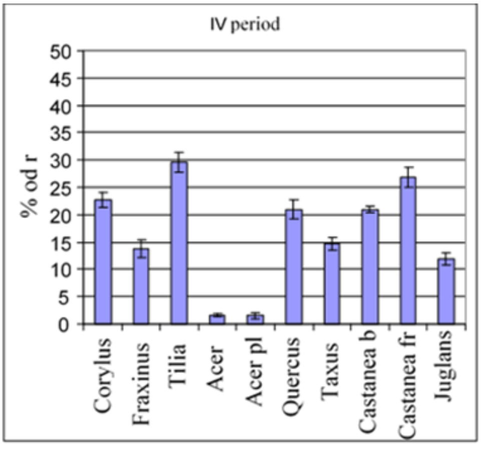
Graph 2. *Mycelial growth (Period 2)*

The highest mycelial growth increase in the first period was recorded on the medium with hazel bark, while it was slightly lower on the medium with sweet chestnut bark. In this period, the mycelium began to grow on all media, except for the medium with the addition of sycamore maple bark.

In the second period, the highest increase in growth was again noted on the medium with the addition of hazel bark and the medium with the addition of sweet chestnut bark. In this period, the mycelium was still not growing on the medium with the addition of sycamore maple bark.



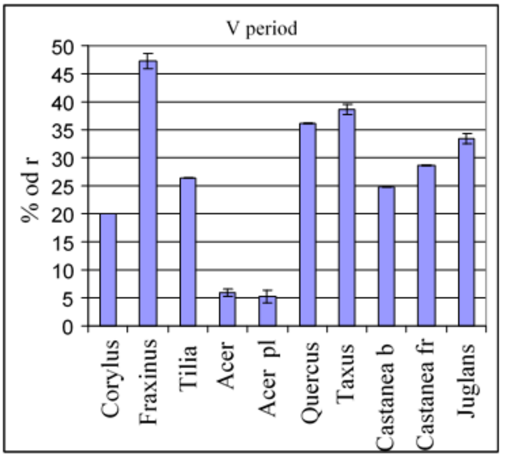
Graph 3. *Mycelial growth (Period 3)*



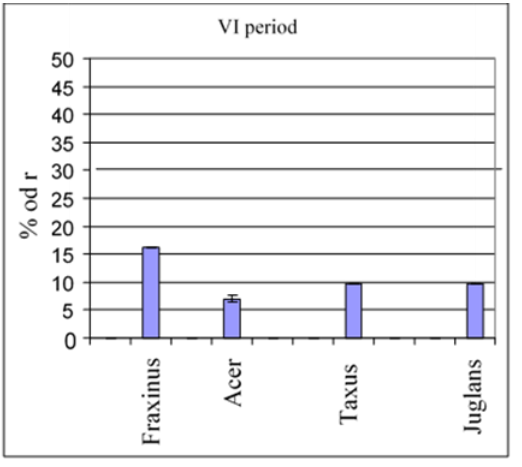
Graph 4. *Mycelial growth (Period 4)*

In the third period, the mycelium had the greatest growth on the medium with the addition of sweet chestnut fruit, followed by the medium with the addition of hazel bark. Even in this period, the mycelium did not start growing on the medium with the addition of sycamore maple bark. Significant mycelial growth was achieved on the media with the addition of chestnut, linden and walnut bark.

The fourth period saw the greatest mycelial growth on the medium with the addition of linden bark, followed by sweet chestnut fruit, hazel and oak. It was in this period that the mycelium began to grow on the medium with the addition of sycamore maple bark.



Graph 5. *Mycelial growth (Period 5)*

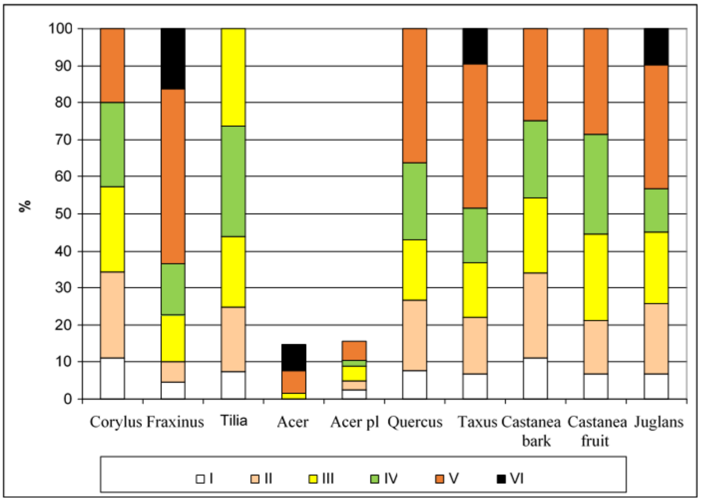


Graph 6. *Mycelial growth (Period 6)*

In the fifth period, the greatest growth was on the medium with the addition of manna ash bark, followed by yew, oak and walnut bark. The lowest growth was observed on the Norway maple and sycamore maple media.

After the fifth period (on the fifteenth day), the mycelia filled the Petri dishes on the media with the addition of hazel, linden, oak, sweet chestnut bark, as well as chestnut fruit. In the sixth period, mycelial growth on the medium with the addition of Norway maple bark stopped (it was the same as in the previous measurement). In this period, mycelial growth continued on the media with the addition of ash, yew, walnut and sycamore maple.

The graph below (Graph 7) shows the mycelial growth for each investigated variant by period.



Graph 7. *Mycelial growth for each tested variant by period*

Regarding the variant with the addition of hazel bark, the growth of mycelia was roughly equal in all periods (20-23.9%). A slightly smaller growth was observed only in the first period (11.06%). The variant with the addition of manna ash bark had low growth in all periods, except for Period 5 (with approximately half of the total growth, 47.31%). Regarding the variant with the addition of linden bark, the most significant growth was attained in Period 4 (29.65%) and the lowest in Period 1 (7.41%) period.

Regarding the variant with the addition of sycamore maple bark, the mycelium had not begun to grow until Period 4, while the growth was the same in Periods 5 and 6. The variant with the addition of Norway maple had low growth in the first four periods, while it was the highest (3.88%) in Period 5 and then stopped in Period 6. Regarding the variant with the addition of oak bark, the weak growth in the first period was followed by three fairly even periods, and the highest growth was in Period 5 (36.24%). In the case of the variant with the addition of yew bark, the highest growth was recorded in Period 5 (36.71%), and the lowest was in Periods 1 (6.91%) and 6 (9.65%). The variant with the addition of chestnut bark had the most invariable mycelial growth across periods (from 20.31-24.63%). It was the lowest in Period 1 (10.90%). The variant with the addition of chestnut fruit had the lowest growth in the first period (6.69%), and with each subsequent period, mycelial growth kept increasing slightly (from 14.49% in Period 2 to 28.67% in Period 5). The variant with the addition of walnut bark had the highest growth in Period 5 (33.41%), and the lowest in Period 1 (6.71%).

The survival of sweet chestnut has been threatened in the entire territory of Serbia and unfortunately, its area has been constantly decreasing from year to year. According to the research by GLIŠIĆ (1975), chestnut is autochthonous (of relict origin) but rare in Serbia today. It grows in Vojvodina – on Vršački Breg and a few localities on Fruška Gora, in central Serbia on Gučevo, Kostajnik near Krupanj, Hisardžik near Prijepolje, localities near Vranje, Gorica and Saličevica near Niš. In Kosovo and Metohija, there are several chestnut sites near Kosovo Polje, Peć, Dečani, Đakovica, Prizren, Žar Planina, etc. The present-day fragmented sites or individual trees of sweet chestnut are the remnants of the former stronger presence of chestnut forests in our area. Hence it is necessary to protect and rehabilitate the existing natural chestnut sites and then gradually expand the area to sites optimal for its cultivation in Serbia. At the same time, due to the spread of the fungus *C. parasitica*, it is necessary to take care of other tree species that grow with sweet chestnuts in communities.

4. CONCLUSIONS

After 28 days of investigating the growth rate of *C. parasitica* mycelia on media made from the bark of different tree species, the following results were obtained:

- After two days, no mycelial growth was observed on the medium with the addition of sycamore maple bark, while the media with the addition of hazel bark and chestnut bark had the highest growth recorded.
- After four days, there was still no mycelial growth of *C. parasitica* on the medium with the addition of sycamore maple bark, while the media with the addition of hazel and chestnut bark recorded the highest growth.
- After six days, the greatest growth increase was still on the hazel and chestnut bark; the maple medium still had no growth, while 8.9% of the Petri dish radius was covered in the hazel medium.
- After eight days, the mycelium of *C. parasitica* began to grow on the medium with the addition of maple bark, while it had the highest growth increase on the medium with the addition of hazel bark and chestnut bark. We noted a large increase on the medium with the addition of linden bark (73.6%).
- On the fifteenth day, the Petri dishes were completely filled on the media with the addition of oak, chestnut, hazel and linden bark, as well as chestnut fruit. The lowest growth was recorded on the medium with the addition of sycamore maple (7.6%), followed by Norway maple (15.6%), and manna ash (83.8%). On the media with the addition of walnut and yew bark, the increase was approximately 90%.
- After 28 days, the media not completely overgrown were only in the variants in which sycamore maple and Norway maple bark were added.
- The largest number of pycnidia were formed on the media with the addition of sweet chestnut and sessile oak bark (formed in concentric circles), and chestnut fruit (formed over the entire surface of the medium).

The obtained results indicate that some tree species that grow together with sweet chestnuts can be infected with *C. parasitica* and become a potential source of further infection. However, due to the small number of pycnidia formed on these media, the dispersion of ascospores is very small, so the infectious potential is low. Based on this research and bearing in mind that regarding the natural conditions in our country, this fungus has only been found on sessile oak trees, the highest risk when afforesting with sweet chestnut occurs in the localities where sessile oak trees are already present.

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EFFECTS OF DIFFERENT MEDIA ON THE MYCELIAL GROWTH OF *Cryphonectria parasitica* (Murrill) ME Barr

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Summary

The occurrence of the parasitic fungus Cryphonectria *parasitica* (causing bark blight) has significantly reduced the use value of sweet chestnut trees. *C. parasitica* was first observed in the New York area in 1904 (probably introduced from East Asia), and then quickly spread over the entire distribution area of the American chestnut (*Castanea dentata)*. Fungus *C. parasitica* occurs on all known species of chestnut, but it causes the greatest damage to the American chestnut *Castanea dentata*. The European chestnut *Castanea sativa* is also sensitive, while the Asian species *Castanea crenata* and *Castanea molissima* are more resistant. It occurs as a saprophyte on other tree species, with the exception of oak, where it develops as a parasite. Other hosts of the fungus *C. parasitica* belong to the families of *Aceraceae*, *Betulaceae*, *Fagaceae*, *Anacardiaceae*, *Juglandaceae* and *Magnoliaceae*. Mycelial growth of *C. parasitica* was examined on media made from the bark of different tree species. We used the isolate *C. parasitica* (CS3) recovered from the bark of the sweet chestnut growing in the locality of Sobina near Vranje. The bark of sweet chestnut (*Castanea sativa*), manna ash (*Fraxinus ornus)*, sycamore maple (*Acer pseudoplatanus*), sessile oak (*Quercus petraea*), common yew (*Taxus baccata*), hazel (*Corylus avellana*), small-leaved linden (*Tilia cordata*), Norway maple (*Acer platanoides*) and English walnut (*Juglans regia*). Besides the bark, we used a medium made from the fruit of the sweet chestnut trees. Statistically significant differences in the growth of mycelia On the media made from the bark of different tree species were determined between the experimental groups after 15 days. By that time, the Petri dishes had been completely filled on the media with the addition of oak, chestnut, hazel, linden and bark, and chestnut fruit. The lowest growth was recorded on the medium with the addition of sycamore maple (7.6%), followed by Norway maple (15.6%), and manna ash (83.8%). The media with the addition of walnut and yew bark had the same growth rate that amounted to about 90%. After 28 days, the media was not completely overgrown only in the variants with the addition of sycamore maple and Norway maple bark. On the medium with the addition of sycamore maple bark, the mycelium hadn't begun to grow until after eight days and had the slowest growth (14.7%). Based on this research and bearing in mind that regarding the natural conditions in our country, this fungus has only been found on sessile oak trees, the highest risk when afforesting with sweet chestnut occurs in the localities where sessile oak trees are already present.

UTICAJ RAZLIČITIH PODLOGA NA PORAST MICELIJE GLJIVE *Cryphonectria parasitica* (Murrill) M.E. Barr

Zlatan RADULOVIĆ, Ivan MILENKOVIĆ, Aleksandar VEMIĆ, Katarina MLADENOVIĆ

Rezime

Zbog pojave parazitne gljive *Cryphonectria parasitica* (izaziva rak kore) upotrebna vrednost kestena je znatno umanjena. *C. parasitica* prvi put je primećena u okolini Njujorka 1904. godine (verovatno prenešena iz istočne Azije), a zatim se brzo proširila preko celog areala rasprostranjenja američkog kestena (*Castanea dentata*). Gljiva *C. parasitica* javlja se na svim poznatim vrstama kestena, ali najveće štete pričinjava na američkom kestenu *Castanea dentata*. Osetljiv je i evropski kesten *Castanea sativa*, dok su azijske vrste *Castanea crenata* i *Castanea molissima* otpornije. Na ostalim vrstama drveća na kojima je konstatovana javlja se kao saprofit, izuzev hrasta na kome se razvija parazitski. Ostali domaćini gljive *C. parasitica* pripadaju familijama: *Aceraceae, Betulaceae, Corylaceae*, *Fagaceae*, *Anacardiaceae*, *Juglandaceae* i *Magnoliaceae.* Porast micelije *C. parasitica* ispitivan je na podlogama napravljenim od kore različitih vrsta drveća. Korišćen je izolat *C. parasitica* (CS3) dobijen iz kore pitomog kestena sa stabla na lokalitetu Sobina kod Vranja. U ovim ispitivanjima je korišćena kora: pitomog kestena (*Castanea sativa*), crnog jasena (*Fraxinus ornus*), javora (*Acer pseudoplatanus*), hrasta kitnjaka (*Quercus petraea*), tise (*Taxus baccata*), leske (*Corylus avellana*) sitnolisne lipe (*Tilia cordata*), mleča (*Acer platanoides*) i oraha (*Juglans regia*). Pored kore korišćena je i podloga napravljena od ploda pitomog kestena. Na veštačkim podlogama napravnjenim od kore različitih vrsta drveća posle 15 dana utvrđeno je postojanje statistički značajnih razlika među ekperimentalnim grupama u porastu micelije. U ovom periodu Petri posude su skroz popunjene na podlogama sa dodatkom kore hrasta, kestena, leske, lipe i ploda kestena. Najmanji porast je zabeležen na podlozi sa dodatkom javora (7,6%), potom mleča (15,6%), pa jasena (83,8%). Na podlogama sa dodatkom kore oraha i tise porast je isti, i iznosi oko 90%. Posle 28 dana podloga nije u potpunosti obrasla samo u varijantama kada je podlozi dodavana kora javora i mleča. Na podlozi sa dodatkom kore javora micelija počinje sa rastom tek posle osam dana i na ovoj podlozi ima najmanji porast (14,7%). Na osnovu ovih istraživanja, a imajući u vidu činjenicu da je ova gljiva kod nas do sada u prirodnim uslovima konstatovana samo na kitnjaku, najveći rizik pri pošumljavanju pitomim kestenom pretstavljaju lokaliteti na kojima je već prisutan kitnjak.

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THE EPIZOOTIC CASE CAUSED BY *Entomophthora muscae* (Cohn) Fresen IN THE CZECH REPUBLIC

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Abstract: *In this article we present the epizootic case of dipteran insects in a park in the Czech Republic caused by a fungus of the order Entomophthorales. Through field and laboratory investigations we confirmed the presence of the entomopathogenic fungus Entomophthora muscae (Cohn) Fresen, which caused the death of 73 flies at a single site. This is the first report of a higher mortality rate in this region.*

Key words: Diptera, Entomophthorales, biological control, epizootiology.

SLUČAJ EPIZOOCIJE IZAZVAN *Entomophthora muscae* (Cohn) Fresen U ČEŠKOJ REPUBLICI

Izvod: *U radu predstavljamo epizootski slučaj insekata dvokrilaca u parku u Češkoj Republici uzrokovanih gljivom iz reda Entomophthorales. Terenskim i laboratorijskim istraživanjima potvrđeno je prisustvo entomopatogene gljive Entomophthora muscae (Cohn) Fresen, koja je izazvala uginuće 73 jedinki na jednom mestu. Ovo je prvi nalaz o većoj stopi mortaliteta u navedenom regionu, koja je izazvala uginuće 73 jedinki na jednom mestu.*

Ključne reči: Diptera, Entomophthorales, biološka kontrola, epizootiologija.

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1. INTRODUCTION

The fungi of the Entomophthorales order are known to be obligate pathogens capable of causing epizootics in populations of numerous arthropods (Hajek 1994, 1999, Tabakovic - Tosic et al 2018). With a new phylogenetic classification, the former class Zygomycetes was distributed among the phylum Glomeromycota and four subphyla: Mucoromycotina, Kickxellomycotina, Zoopagomycotina, and Entomophthoromycotina (Hibbett et al 2007, Humber 2012). From the family Entomophthoraceae Nowakowski 1877, more than 300 species are known to infest different hosts, especially in the subfamily Entomophthoroideae Keller 2005, and there are several genera that are being studied as potential pest control agents, e.g. Entomophaga maimaiga, E,aulicae, Entomophthora musca (Hajek 2007:Tabakovic 2014, Tabakovic -Tosic et al 2018, Tabakovic -Tosic et al 2019 Pilarska et al, 2001; Pilarska et al, 2016; Elya, 2021).

One of the most common features of Entomophtora fungi is the manipulation of the host, such as commanding it to climb to an elevated position and stand still in one place, so that the fungus is able to produce rhizoids to ensure that the insect's cadaver has a better distribution of spores (Hayek,1999). This previously infected cadaver allows the fungus to spread and infect the next insect. It breaks through the cuticle to access the hemolymph, consumes non-vital organs that keep an insect alive until all resources are used up, and manipulates the host again to climb to an elevated position and remain there.

In the summer of 2022, a group of Diptera flies was observed on the leaves of small-leaved lime in Stromovka Park in the Czech Republic. The immobile flies were actually cadavers with characteristic symptoms of Entomophthora muscae (Cohn) Fresen.

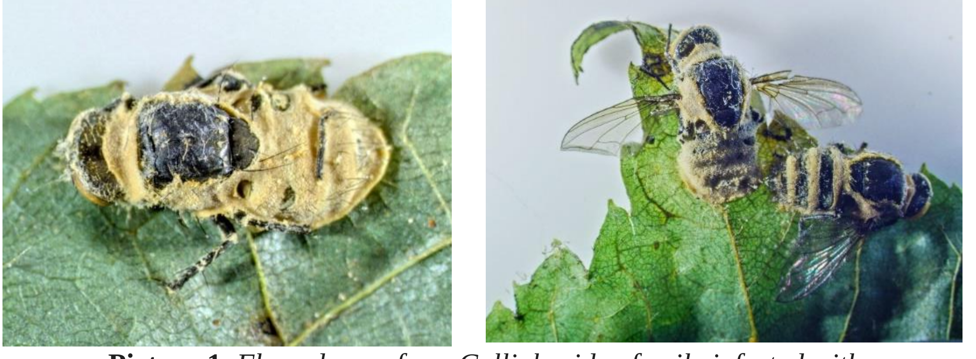
2. MATERIAL AND METHODS

The study was conducted in the town of České Budějovice, South Bohemia, in Stromovka Park (48° 96' N, 14° 27 ' E) (www.budweb.cz). Stromovka Park is the town’s largest park with an area of 68 ha, and serves as a recreational area. It is covered with grassland and mainly broad-leaved tree types, such as: small-leaved lime (*Tilia cordata* Mill.), English oak (*Quercus robur* L.), beech (*Fagus sylvatica* L.), birch (*Betula* spp.), alder (*Alnus glutinosa* L.), Canadian poplar (*Populus* × *canadensis* Moench), willow (*Salix* spp.), sycamore (*Acer pseudoplatanus* L.), Norway maple (*Acer platanoides* L.), *Platanus acerifolia* 'Alphens Globe', swamp Spanish oak (*Quercus palustris* Münchh.), and some conifer species: fir (*Abies alba* Mill), Norway spruce (*Picea abies* (L.) H. Karst.).

The infected flies were collected in sterile bags and taken to the laboratory for further examination. Microscopic examinations of the infected flies were performed using a MOTIC optical trinocular, model BA210E. The identification of the species was based on suitable literature with the key for the species (Cohen, 1855, Keller and Petrini, 2005). To photograph the infected flies, we used an Olympus SZX16 with an Olympus SDF Plapo 1XPF lens and a PROMICRA 3-5CP camera together with QuickPHOTO software MICRO 3.2.

3. RESULTS AND DISCUSSION

Outbreaks of infection with *E. muscae* most often occur in the spring and autumn. *E.* muscae have been observed to infect a broad range of dipteran hosts, while epizootics have been observed in adult Diptera in the families Muscidae, Calliphoridae, Sarcophagidae, Tachinidae, Drosophilidae, Anthomyiidae and Culicidae (Steinkraus and Kramer 1987). During our research we observed 73 flies in the summer of 2022 (Picture 1).



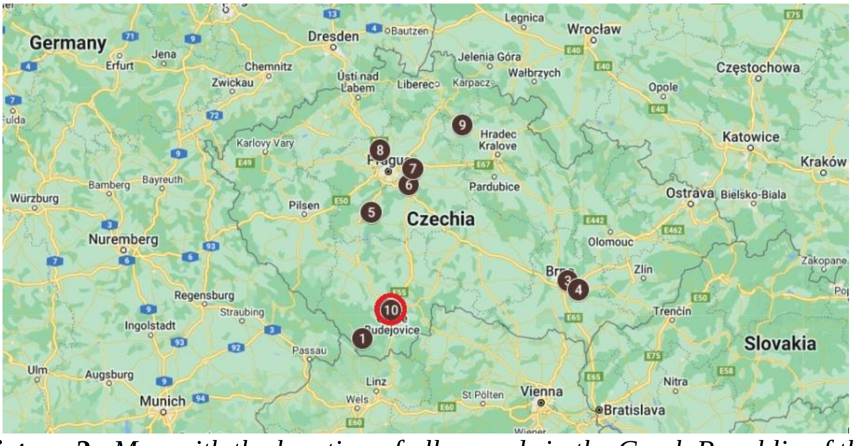
Picture 1. *Fly cadavers from Calliphoridae family infected with Entomophthora muscae*

The infected flies were collected from a single small-leaved lime tree (T. cordata Mill.), on the leaves, one meter above the ground (Table 1). Based on the infestation and impacted specimens, it was concluded that infected species belong to Calliphoridae family. Distribution of the recorded E. musca observations based on iNaturalist data (https://www.inaturalist.org/) accessed on Sept, 12, 2022 was combined with our location of epizootic case (Table 1, Picture 2). However, the data from iNaturalist have no other information and scientific confirmation than photographs and location. Nevertheless, the site No.2 is in the same region of the epizootic case, and the date shows the presence of E.muscae in a spring time.

Table 1. *Information on location where E.musacae was observed*

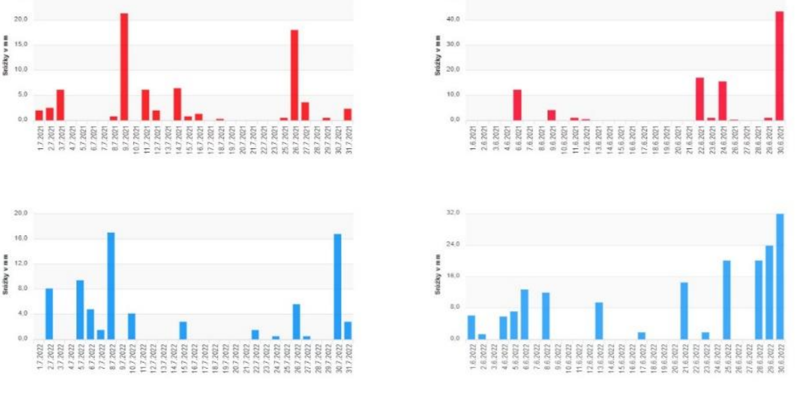
No	Location	Coordinates (Longitude Latitude)	Number of infected flies	Date	Confirmation other than morphological similarity
1	Černá v Pošumaví	48.734336 14.100645	1	Aug 19,2021	No
2	České Budějovice	48.975108 14.43825	1	May 25, 2022	No
3	Brno	49.202843 16.694113	1	Nov 24, 2021	No
4	Hrušky	49.129532 16.83083	1	Oct 22, 2021	No
5	Rybníky	49.752773 14.206691	1	Nov 19, 2021	No
6	Tehov	49.973659 14.677795	1	Aug 30,2020	No
7	Horoušany	50.096564 14.732605	1	Jul 25, 2020	No

No	Location	Coordinates (Longitude Latitude)	Number of infected flies	Date	Confirmation other than morphological similarity
8	Jičín	50.248211 14.31868	1	Jun 30, 2022	No
9	Kralupy nad Vltavou	50.442224 15.357671	1	Sept 19, 2020	No
10	České Budějovice	48.967579.14 14.455779	73	Jul 11, 2022	Yes



Picture 2. *Map with the location of all records in the Czech Republic of the presence of infected flies (*Location number 2 is behind the number 10, but it is not visible due to the short distance between them. Source: Google Map)*

The environmental conditions, such as humidity, have an influence on the sporulation of conidia, germination, and also infection. It has been found (Kramer, 1980) that higher humidity results in greater germination. Comparing the rainfall during the months of June and July of 2021 and 2022, there is a difference of 17.68% in favor of 2022 (Graph. 1).



Graph 1. *Comparison of the precipitation between 2021 (red) and 2022(blue) for June and July*

4. CONCLUSIONS

The Entomophthoraceae family have been one of the most powerful natural suppressants of the insect abundance in the nature (e.g. Entomophaga maimaiga, E,aulicae, Entomophthora musca ect.). Entomophthora muscae is a well-known fungal disease of adult Diptera with a wide range of potential hosts, first described by Cohn in 1855 from an epizootic of house flies (M.domestica L.). For many years it has been recognized as a potential biological agent, however, as a fastidious organism it cannot be easily cultured artificially. The direct fly-to-fly contact is the best way to transmit the fungus. This epizootic case of natural occurrence in this region was the first one to be reported.

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THE EPIZOOTIC CASE CAUSED BY *Entomophthora muscae* (Cohn) Fresen IN THE CHECH REPUBLIC

Marija MILOSAVLJEVIĆ, Mara TABAKOVIĆ-TOŠIĆ, Danilo FURTULA, Miroslava MARKOVIĆ, Renata GAGIĆ-SERDAR, Natalija MOMIROVIĆ

Summary

Species of the genus Entomophthora are fungal pathogens of a variety of insects, most of which alter the behaviour of their host. Entomophthora is a genus of obligate insect pathogens with *Entomophthora muscae* (originally named *Empusa muscae*) as the first species described in the scientific literature by Cohn in 1855. E. muscae is a pathogen of adult Diptera that causes epizootics in populations of economically important pest flies, such as the housefly, *Musca domestica* L. *E. muscae* infects a wide range of dipteran hosts, and epizootics have been observed in adult in the families Muscidae, Calliphoridae, Sarcophagidae, Tachinidae, Drosophilidae, Anthomyiidae and Culicidae. In the summer of 2022, we observed an epizootic case of E. muscae in Stromovka Park in the Czech Republic. Based on the infestation and impacted specimens, it was concluded that infected species belong to Calliphoridae family.

SLUČAJ EPIZOOCIJE IZAZVAN *Entomophthora muscae* (Cohn) Fresen U ČEŠKOJ REPUBLICI

Marija MILOSAVLJEVIĆ, Mara TABAKOVIĆ - TOŠIĆ, Danilo FURTULA, Miroslava MARKOVIĆ, Renata GAGIĆ - SERDAR, Natalija MOMIROVIĆ

Rezime

Vrste iz roda Entomophthora su patogeni raznih insekata, od kojih većina menja ponašanje svog domaćina. Entomophthora je rod obligatnih patogena sa *Entomophthora muscae* (prvobitno nazvan *Empusa muscae*) kao prvom vrstom koju je Cohn opisao u naučnoj literaturi 1855. *E. muscae* je patogen odraslih Diptera koji izaziva epizoociju u populacijama ekonomski važnih štetočina kao što je kućna muva, *Musca domestica* L. *E. Muscae* inficira širok spektar domaćina dvokrilaca, a epizoocije su primećene kod adulta u familijama Muscidae, Calliphoridae, Sarcophagidae, Tachinidae, Drosophilidae, Anthomyiidae i Culicidae. U leto 2022. primetili smo epizootski slučaj *E. muscae* u parku Stromovka u Češkoj. Na osnovu infestacije i determinisanih primeraka, zaključeno je da zaražene vrste pripadaju familiji Calliphoridae.

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Original scientific paper

AFFORESTATION IN THE REPUBLIC OF SERBIA: SCOPE AND TRENDS FROM 2002 TO 2021

Tatjana ĆIRKOVIĆ-MITROVIĆ[1], Ljiljana BRAŠANAC-BOSANAC[1], Sabahudin HADROVIĆ[1], Saša EREMIJA[1], Snežana STAJIĆ[1], Ilija ĐORĐEVIĆ[1], Ljubinko RAKONJAC[1]

Abstract: *The issue of the annual volume of afforestation directly affects changes in the degree of forest cover and represents one of the most topical and complex activities of the forestry profession. Therefore the main aim of this research was to determine the current trends in the scope of afforestation and make projections about future courses by monitoring multi-year trends.*

Norway spruce and Austrian pine are coniferous forest species most frequently used in afforestation in Serbia. Oaks are broadleaved species most frequently used in afforestation, although beech forests are the most common forests in Serbia. For that reason, we analysed the trends in the scope of afforestation with these tree species in the period from 2002 to 2021. All species, except for beech, recorded a negative trend in the scope of afforestation.

The analysis of data related to the extent of afforestation, together with the data related to the level of subsidisation provided by the state for afforestation, gives an insight into the dynamics of afforestation, based on which recommendations and guidelines can be given for planning and carrying out work on further afforestation, the establishment of new forests, which would, in turn, increase the degree of forest cover.

Keywords: afforestation trend, annual afforestation rates, state subsidizing.

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POŠUMLJIVANJE U REPUBLICI SRBIJI: OBIM I TRENDOVI U PERIODU OD 2002. DO 2021. GODINE

Izvod: *Pitanje godišnjeg obima pošumljavanja direktno utiče na promene stepena šumovitosti i predstavlja jedan od najaktuelnijih i najkompleksnijih aktivnosti šumarske struke. Zato je osnovni cilj ovih istraživanja utvrđivanje kretanja obima pošumljavanja, ali i predviđanje njihovih daljih tokova na osnovu praćenja višegodišnjih trendova.*

Smrča i crni bor su najzastupljenije i najčešće korišćene četinarske šumske vrste za pošumljavanje u Srbiji. Vrste koje se najviše koriste kod pošumljavanja lišćarima jesu hrastovi, dok su šume bukve najzastupljenije šume u Srbiji. Zato je analizirano i kretanje obima pošumljavanja navedenim vrstama drveća u periodu 2002-2021. Kod svih vrsta, osim bukve, konstatovan je negativan trend obima pošimljavanja.

Analizom podataka o obimu pošumljavanja i analizom podataka o stepenu učešća države u subvencionisanju pošumljavanja dobija se uvid u dinamiku, na osnovu koje se mogu dati preporuke i smernice za planiranje i izvođenje radova na daljem pošumljavanju, sprovođenju radova na podizanju novih šuma, samom tim na povećanje stepena šumovitosti.

Ključne reči: trend pošumljavanja, godišnje stope pošumljavanja, subvencija države.

1. INTRODUCTION

It is a well-known fact that the establishment of new forests and the improvement of existing ones enhance their climatic, protective, erosion control, aesthetic-environmental, tourist-recreational and other roles and increase the yield of other resources of forests and forest areas.

The annual rate of afforestation directly affects the degree of forest cover. The high degree of soil degradation caused by erosion, the lack of water, the increasing need for wood production, recreation, etc., as well as the fact that the forest cover in Serbia used to be as much as 80% (Dražić, 1992), call for the increase of areas under forest in Serbia.

Afforestation is one of the most topical and complex activities of the forestry profession. According to the data of the Statistical Office of the Republic of Serbia, an average of 1,762 ha were reforested annually from 2016 to 2021. Norway spruce and Austrian pine were the most common coniferous species, while broadleaved species used for afforestation mainly included oak species.

Therefore the main aim of this research was to determine the current trends in the scope of afforestation and make projections about future courses by monitoring multi-year trends. Data on the annual scope and trends of afforestation will be analysed in order to develop the trend models related to the total afforested area and the area afforested with the broadleaved and coniferous species most frequently used for afforestation in the specified period. Analysing these data, together with the data related to the subsidization provided by the state for afforestation, gives an insight into the dynamics of afforestation. Based on the results obtained, we can put forward recommendations and guidelines for planning and conducting work on further afforestation and the establishment of new forests, which would, in turn, increase the degree of forest cover.

2. METHODOLOGY

The basic principle underlying this research was to use the methods of analysis and synthesis, induction and deduction to develop trend models that would study the intensity and scope of afforestation, analyse the existing and projected state of afforestation within forest complexes and ecosystems, and based on the results produce the most satisfactory solutions and proposals related to the extent of afforestation.

Data on the state and privately-owned forested and barren areas and the scope of afforestation were obtained from the Statistical Office of the Republic of Serbia, the Forest Directorate of the Ministry of Agriculture, Forestry and Water Management, SE "Srbijašume", SE "Vojvodinašume", as well as relevant scientific papers, studies, projects and monographs on this topic.

Data were obtained and regression models of the trends were developed and verified (using the coefficient of determination R^2) using the Statistica 7 software and the Microsoft Office package.

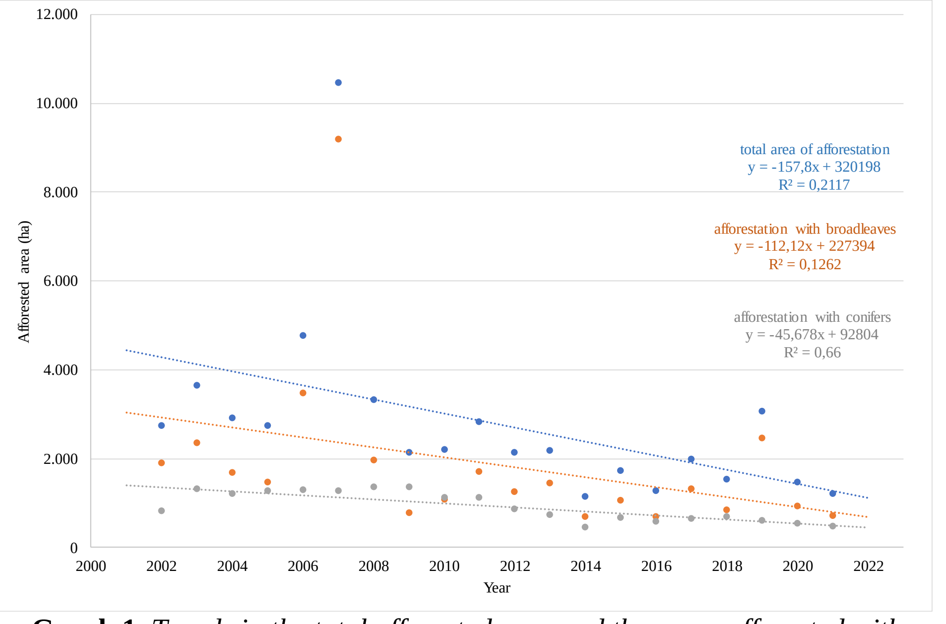
3. RESULTS AND DISCUSSION

The relationship between economic growth and environmental deterioration was first placed on the international agenda in 1972, at the UN Conference on the Human Environment, held in Stockholm. After the Conference, Governments set up the United Nations Environment Programme (UNEP[1]), which today continues to act as the core of the action in the fight against climate change. Increasing the area of forest cover by encouraging the activities and by providing assistance for the afforestation of the land on which it is economically and ecologically feasible to raise forests (degraded soil, abandoned agricultural land, barren forest land, etc.) regardless of the ownership is one of the main goals for population (Nevenić et al., 2007).

Afforestation can transform vulnerable forests into diverse, productive, and climate-resilient forests (Bolte et al., 2009; Reyer et al., 2015). Afforestation also entails the active involvement of actors from forestry, conservation, and nursery business (Hazarika et al., 2021). Furthermore, forest services are changed from an industrial one, focusing on timber production, to a postindustrial one, in which forest services become more important to timber production.

A linear regression function was used to develop a model of the afforestation trend in the Republic of Serbia from 2002 to 2021, both taking all species into account and separately for broadleaved and coniferous species (Graph 1).

[1] https://www.unep.org/

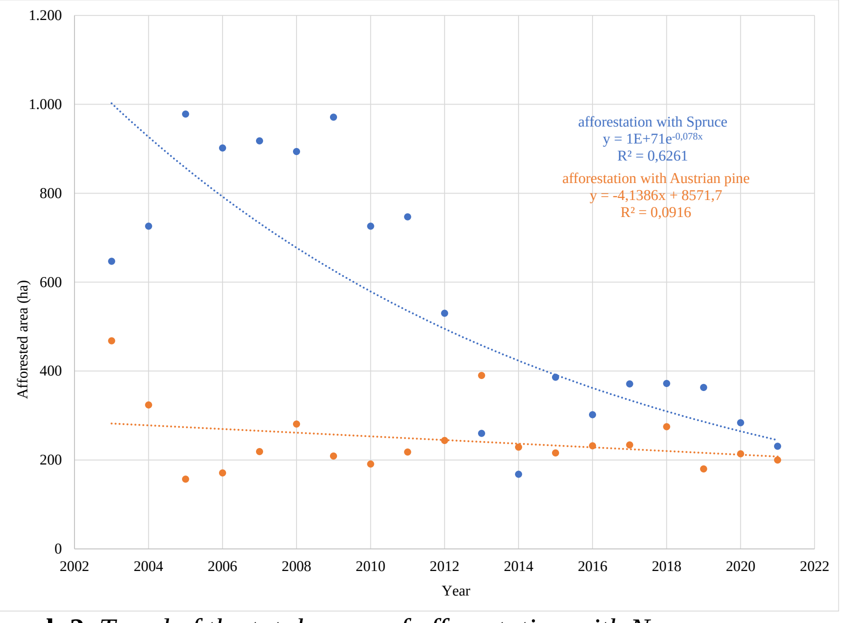


Graph 1. *Trends in the total afforested area and the areas afforested with broadleaves and conifers in the Republic of Serbia from 2002 to 2021*

A decreasing linear trend, i.e., a decreasing trend in afforested areas in Serbia, can be noticed throughout the study period. The scope of afforestation, i.e., the afforested area decreased in this period by an average of 157.8 ha (5.39%) per year. A decreasing trend could be noted in afforestation with both broadleaved and conifer species. It was more evident in broadleaved species, whose annual scope of afforestation decreased on average by 5.71%. The scope of conifer afforestation decreased by an average of 4.70% per year.

Data on afforestation for 2003-2016 in the Republic of Serbia (Ćirković-Mitrović et al., 2018) also revealed a negative trend, with a larger annual average decrease in the scope of afforestation, amounting to 203.73 ha. The research by Ranković (2009) states that the scope of afforestation in Serbia in the period from 2000 to 2007 was characterised by exponential growth, with an annual increase in the afforested area of 804 ha (average annual growth rate of 17.4%). This difference in the research results was caused by the high degree of afforestation performed in 2007 when the afforestation was several times above the average for the last twenty years (Ćirković-Mitrović et al., 2018).

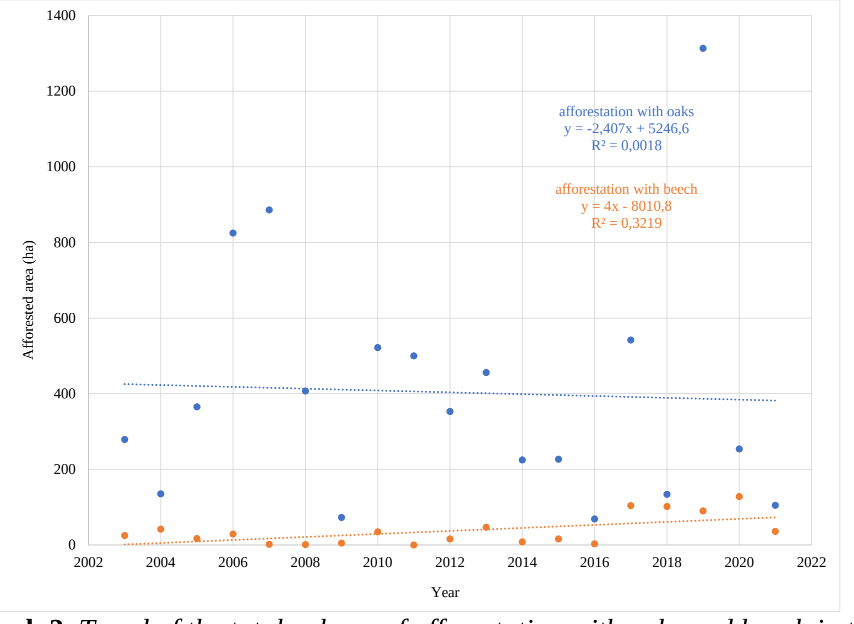
Norway spruce and Austrian pine were the most common and most frequently used coniferous forest species for afforestation in Serbia. Therefore, we studied the trend in the scope of afforestation with these species in the period from 2002 to 2021 (Graph 2).



Graph 2. *Trend of the total scope of afforestation with Norway spruce and Austrian pine in the Republic of Serbia from 2002 to 2021*

The model of the trend in the afforestation with Norway spruce used the exponential function and the model developed for Austrian pine used the linear function. A negative trend of afforestation with Norway spruce could be observed from the beginning of the study period, with the scope of afforestation decreasing exponentially. Norway spruce was more frequently used in afforestation than Austrian pine in the first ten years of the study period. The area afforested annually with Norway spruce decreased by an average of 7.32% (by 6.90% per year in the first ten years and by 8.11% per year in the next ten years). Regarding the afforestation with Austrian pine, a uniform decrease in the scope of afforestation by about 4.14 ha per year was observed from the beginning of the study period. The area reforested annually with Austrian pine decreased by an average of 1.60% (1.39% per year in the first ten years and 1.83% per year in the next ten years). In the last ten years, the trendlines got closer to each other because the spruce trendline showed a more significant decline than the Austrian pine trend line.

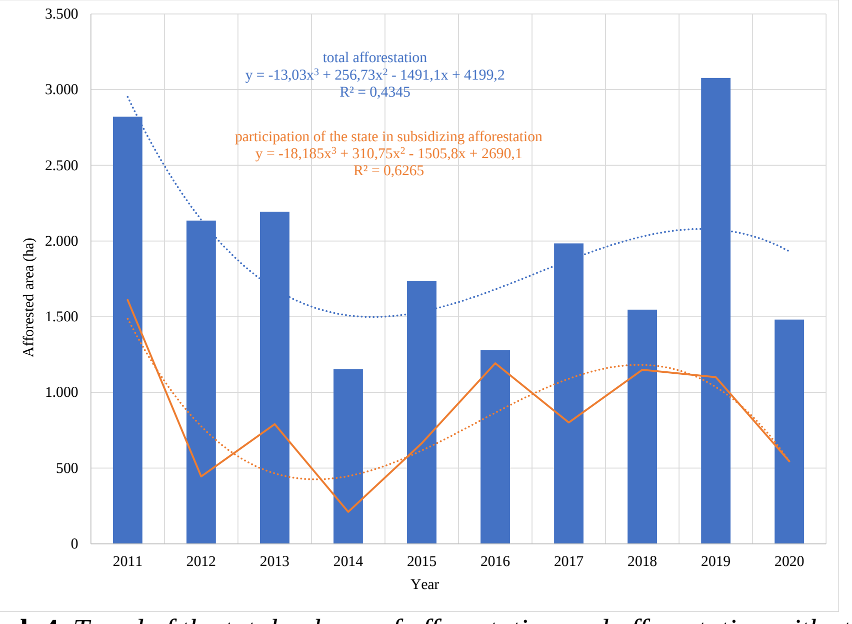
Oaks were the broadleaved species most frequently used in afforestation, although beech forests are the most common forests in Serbia. Therefore, we analysed the trends in the scope of afforestation with oak and beech trees from 2002 to 2021 (Graph 3).



Graph 3. *Trend of the total volume of afforestation with oaks and beech in the Republic of Serbia from 2002 to 2021*

The linear function was used to model the trend of afforestation with oaks and beech. While the volume of afforestation with oaks decreased, the volume of afforestation with beech increased, thus decreasing the difference between their afforested areas. The same pattern can be noticed in the trends of the share of afforestation with oak and beech. On average, the area afforested with oaks annually decreased by 0.56%, and the area afforested with beech increased by 10.19%. Tomaz et al. (2013) in their research on changes in forest cover and afforestation in Portugal stated that the multi-year trend of afforestation with the most common autochthonous oak species did not show a significant increase in the area afforested by these species.

The absolute values and the trend of afforestation in the ten-year period (2011-2022), including the share of incentives provided by the state (subsidies from the Forest Directorate of the Ministry of Agriculture, Forestry and Water Management) are shown in Graph 4.



Graph 4. *Trend of the total volume of afforestation and afforestation with state subsidies in the Republic of Serbia from 2011 to 2020*

The polynomial regression function of the third degree was selected for the model. A decrease in the scope of afforestation could be noted until the middle of the study period when more intensive afforestation began and lasted until 2019. A significant decrease occurred in 2020, which can be explained by aggravating circumstances and the state of emergency in the country due to the COVID pandemic. The trend of the volume of afforestation with state subsidies follows the total volume of afforestation trend, and the average volume of afforestation with subsidies from the Forest Directorate was about 45% of the total afforested area.

Afforestation in Serbia can be increased by afforesting unutilised agricultural land and arable land categorised as class VI, VII and VIII, changing regulations, facilitating the conversion of agricultural land into forests, and enabling subsidised or free afforestation of these categories of agricultural land.

4. CONCLUSIONS

Recent research and analysis show the differences and potential changes in the extent of afforestation and trends in different time intervals from 2002 to 2021.

By analysing the changing trends, we can notice that both the total afforested area and the area of individual species decreased. Beech forests were the exception, which can be explained by the choice of sites suitable for afforestation with this species. Another reason was the reduced afforestation of extreme sites or the ones with unfavourable production characteristics where Austrian pine was planted.

The obtained data and projections related to the afforestation trend behaviour in the following period are very important for the management and implementation of measures to establish new forests. They also have an important role in planning and increasing the forest cover in the future. The application of modern technologies in future afforestation makes it easier to collect, process, present, and apply data needed for logistics in hardly accessible areas. Information can be used to improve the planning workflow efficiency (by cutting costs and saving time). There is great potential in monitoring the entire workflow and the qualitative and quantitative measurements of the performed work (Šurjanac, 2019).

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AFFORESTATION IN THE REPUBLIC OF SERBIA: SCOPE AND TRENDS FROM 2002 TO 2021

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Summary

The main goal of this research was to determine the course and project trends in the scope of afforestation for 2002-2021 in order to gain insight into their dynamics. Based on the obtained trends and dynamics, we can provide recommendations and guidelines for planning and implementing future afforestation.

By analysing the trend of change both in the total afforested area and the area afforested with individual species, a decrease can be observed. Beech was the exception, which could be explained by the choice of sites suitable for afforestation with this species, and reduced afforestation of extreme sites or the ones with unfavourable production characteristics where Austrian pine was planted.

The absolute values and trends of afforestation in the ten-year period (2011-2022), including the participation of including the share of incentives provided by the state (subsidies from the Forest Directorate of the Ministry of Agriculture, Forestry and Water Management), indicate a decline in the scope of afforestation until the middle of the study period when more intensive afforestation began and lasted until 2019. A significant decrease occurred in 2020, which can be explained by aggravating circumstances and the state of emergency in the country due to the COVID pandemic. The trend of the volume of afforestation with state subsidies follows the total volume of afforestation trend, and the average volume of afforestation with subsidies from the Forest Directorate was about 45% of the total afforested area.

The economic, social and political situation reduced the funding and incentive measures, which would have had a positive effect in terms of increasing the scope of afforestation and the forest cover of the Republic of Serbia. That is why it is necessary to plan adequate means and measures so that these negative trends in the scope of afforestation change their direction.

POŠUMLJIVANJE U REPUBLICI SRBIJI: OBIM I TRENDOVI U PERIODU OD 2002. DO 2021. GODINE

Tatjana ĆIRKOVIĆ-MITROVIĆ, Ljiljana BRAŠANAC-BOSANAC, Sabahudin HADROVIĆ, Saša EREMIJA, Snežana STAJIĆ, Ilija ĐORĐEVIĆ, Ljubinko RAKONJAC

Rezime

Osnovni cilj ovih istraživanja bio je da se utvrde tokovi i predvide trendovi kretanja obim pošumljavanja u periodu 2002-2021. godina, kako bi se stekao uvid u njihovu dinamiku. Na osnovu trendova i dinamike mogu se dati preporuke i smernice za planiranje i sprovođenje radova na budućem pošumljavanju.

Analizom trenda promene, kako ukupne pošumljene površine, tako i po pojedinim vrstama, može se konstatovati smanjenje ove površine, izuzev kod bukve, što se može objasniti izborom staništa pogodnih za pošumljavanje ovom vrstom, ali i smanjenjem pošumljavanja ekstremnih staništa, odnosno staništa lošijih proizvodnih karakteristika, na kojima se sadi beli bor.

Apsolutne vrednosti i trend pošumljavanja u desetogodišnjem periodu (2011-2022), uključujući učešće podsticajnih sredstava koje daje država (subvencije Uprave za šume Ministarstva poljoprivrede, šumarstva i vodoprivrede), ukazuju na pad obima pošumljavanja do sredine posmatranog perioda, kada počinju intenzivnija pošumljavanja do 2019. godine, sa značajnim padom u 2020. godini, što se može objasniti otežavajućim okolnostima i vanrednim stnjem u državi usled COVID pandemije. Trend obima pošumljavanja uz subvencije države prati ukupan obim pošumljavanja, a prosečni obim pošumljavanja uz subvencije Uprave za šume bio je na oko 45% ukupne pošumljene površine

Ekonomska, socijalna i politička situacija uticala je na smanjenje finansiranja i podsticajnih mera, koje bi dale pozitivan efekat u pogledu povećanja obima pošumljavanja, samim tim i šumovitosti Republike Srbije. Zato je neophodno isplanirati adekvatna sredstva i mere kako bi ovi negativni trendovi obima pošumljavanja promenili svoj smer.

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Original scientific paper

CHANGE IN THE GROWING STOCK CONDITION OF THE MORAVIAN FOREST AREA AS A CONSEQUENCE OF ICE DISASTERS IN THE WINTER 2014

Branka PAVLOVIĆ[1], Violeta BABIĆ[2] , Vlado ČOKEŠA[1], Nikola MARTAĆ[1], Branko KANJEVAC[2] , Đorđe JOVIĆ[1]

Abstract: *The area of eastern Serbia was hit by a natural disaster, specifically an ice disaster, in the winter of 2014 which caused great damage to forest trees. The subject of this research is the state-owned natural forests and artificially raised stands within the Moravian Forest Area which are managed by Public Enterprize (PE) "Srbijašume" Belgrade. The data summarized as of December 31, 2013, and December 31, 2021, were parallelly analyzed to determine whether and to what extent the ice disaster affected the growing stock condition of the Moravian Forest Area. For that purpose, the comparative analysis of the following indicators was carried out: origin-based forest condition, preservation, diversity, tree species, stand affiliation, and coeno-ecological affiliation. Having in mind that the ice disaster highly damaged some parts of the Moravian Forest Area (Forest Management Unit (FMU) „Obla Glava", FMU "Kamenički Vis I", FMU "Kamenički Vis II", FMU "Bukovik - Mratinja", FMU "Rtanj", FMU "Svrljiško - Gulijanske Planine" and FMU "Devica") which consequently led to clean-cuttings at large areas (app.1000 hectares of forest stands), the research aim was to determine if the significant changes occurred in the growing stock at the whole area level.*

Key words: Moravian Forest Area, growing stock, natural disaster, ice disaster

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PROMENA STANJA ŠUMSKOG FONDA U MORAVSKOM ŠUMSKOM PODRUČJU KAO POSLEDICA LEDOLOMA U ZIMU 2014. GODINE

Izvod: *U zimu 2014. godine, područje istočne Srbije je pogodila elementarna vremenska nepogoda koja je pričinila velike štete na šumskom drveću u vidu ledoloma i ledoizvala. Predmet ovog istraživanja su obrasle površine Moravskog šumskog područja (prirodne šume i veštački podignute sastojine) u državnom vlasništvu kojima gazduje JP „Srbijašume" Beograd. Uporedo su analizirani podaci svedeni na dan 31.12.2013. godine i* podaci *svedeni na dan 31.12.2021. godine, kako bi se utvrdilo da li su i u kojoj meri ledolomi uticali na stanje šumskog fonda Moravskog ŠP. U tu svrhu, vršena je uporedna analiza pojedinih pokazatelja stanja šumskog fonda Moravskog ŠP (stanje šuma po poreklu, očuvanosti, mešovitosti, vrstama drveća, sastojinskoj pripadnosti i cenoekološkoj pripadnosti. Obzirom da su elementarne vremenske nepogode u pojedinim delovima Moravskog ŠP (GJ "Obla Glava", GJ "Kamenički Vis I", GJ "Kamenički Vis II", GJ "Bukovik – Mratinja", GJ "Rtanj", GJ "Svrljiško - Gulijanske Planine" i GJ "Devica") pričinile velike štete u vidu ledoloma i ledoizvala, usled čega su morale biti izvršene čiste seče na velikim površinama (oko 1000 ha šumskih sastojina), cilj istraživanja je da se utvrdi da li je došlo do bitnih promena u stanju šumskog fonda na nivou područja.*

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

1. INTRODUCTION

A Forest Area (FE) is an environmental and spatial geographical unit within which forest management is planned and functional sustainability is ensured (Jović et al., 1991). In the geographical sense, these are mainly clearly defined mountain massifs or macro-environmental units in the plain area which dominate the space. One forest area extends within the same macro-environmental (ecoclimatic) area. There are a total of thirteen macro-environmental (ecoclimatic) areas in Serbia, which, if each had the same degree of forest cover, could also represent organizational units (Medarević M., 2006).

The Moravian Forest Area was named after the Morava River that flows through this area. It covers the area of the Niško - Aleksinac basin from which rise the following mountains: Bukovik (part), Rtanj (part), Slemen (part), Devica, Ozren, Tresibaba (part), Svrljiške mountains, Belava (part), Šljivovački vis, Suva planina (part), Babička gora (part), Selicevica, Mali Jastrebac, and Veliki Jastrebac (Savić M., 2021).

The ice deposition on various objects and forest trees is a common phenomenon during the winter due to the continental climate which prevails in the Moravian Forest Area. In the winter of 2014, the extremely cold air masses penetrated from the east and the Carpathians, causing the appearance of large ice deposits on infrastructure facilities and forest trees in most parts of eastern Serbia. The ice disaster affected the entire area east of Morava River, and especially east of the Čestobrodica and Crni vrh pass. Practically, for a long period of time, this area was bound by ice. Forest trees could not withstand large amounts of ice (even several tons per tree), so the ice made damage to large areas (Marković et al., 2018).

According to Baković et al., (2015), larger-scale damages occurred in the forest areas of Timok (FE Boljevac), Morava (FE Niš), Severnikučaj (FE Kučevo), Rasina (FE Kruševac), and Južnikučaj (FE Despotovac) based on data of "An action plan for the rehabilitation of state and privately-owned damaged forests for the period 2015-2018" published by PE "Srbijašume". According to this action plan, the damage was recorded on an area of 43,305.78 ha, and 1,874,046 m3 of damaged trees were recorded. The clear-cutting was planned on an area of 1,077.40 ha, and the vegetative and artificial regeneration is intended to be performed for most of the said area.

Table 1. *Overview of damaged areas per forest area*

Forest area	State-owned forests		Private-owned forests		Total for rehabilitation	
	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
Morava	6,744.22	569,775	1,818	41,946	8,562.22	611,721
Severnikučaj	1,612.60	7,868	460.00	3,850	2,072.60	11,718
Rasina	827.10	39,317	-	-	827.10	39,317
Južnikučaj	175.14	11,339	20.00	400.00	195.14	11,739
Total	**19,419.78**	**1,607.981**	**23,886.00**	**266,065**	**23,886.00**	**1,874,046.00**

Source: "*An action plan for the rehabilitation of state and privately-owned damaged forests for the period 2015-2018" published by PE "Srbijašume".*

In the Moravian Forest Area, the following Forest Management Units (FMU) suffered the greatest damage: "Obla Glava", "Kamenički Vis I", "Kamenički Vis II", "Bukovik - Mratinja", "Rtanj", "Svrljiško - Gulijanske Planine" and "Devica".

2. THE RESEARCH SUBJECT, MATERIAL AND METHODS

According to "An action plan for the rehabilitation of state and privately-owned damaged forests for the period 2015-2018" the total area under forest and other land amounts to 329,333 ha of which 140,471 ha is the stocked forest land and 188,862 ha is non-stocked forest land with 30,872 ha of forest land which can be afforested taking into account the existing projections in the Spatial Plan of the Republic of Serbia and the Draft Forestry Development Program of the Republic of Serbia. The forest coverage of the Moravian Forest Area is 42.6%. The state-owned land in this forest area is 55,911 ha of which forest and forest land occupy 49,058 ha or 87.7%, and another land occupies 6,852 ha or 12.3%. Forests occupy an area of 47,726 ha, and artificially established stands occupy an area of 561 ha, i.e. the total stocked forest land owned by the state is 48,287 ha. The total non-stocked forest land owned by the state is 7,623 ha.

The subject of this research is only the stocked forest land of the Moravian Forest Area (natural forests and artificially established stands) state-owned and managed by PE "Srbijašume" Belgrade. For that purpose, the comparative analysis of the following forest condition indicators was carried out: origin-based forest condition, preservation, diversity, tree species, stand affiliation, and coeno-ecological affiliation.

Given that natural disasters in the form of ice disasters, in some parts of the Moravian Forest Area (FMU "Obla Glava", FMU "Kamenički Vis I", FMU "Kamenički Vis II", FMU "Bukovik - Mratinja", FMU "Rtanj", FMU "Svrljiško - Guljanske Planine" and FMU "Devica") caused great damage, as a result of which clear cuttings had to be carried out on large areas (about 1000 ha of forest stands), the research aims to determine whether there have been significant changes in the growing stock condition at the area level.

Picture 1. *Ice break damage in natural beech stands*

Picture 2. *Ice break damage in artificially raised conifer stands*

The forest management data from the database of the Public Enterprise "Srbijašume" Belgrade for 20 forest management units managed by this enterprize were used for the analysis of certain parameters of the Moravian Forest Area growing stock (FMU "Veliki Jastrebac", FMU "Mali Jastrebac II", FMU "Suva Planina", FMU "Šljivovački Vis", FMU "Rinjska Planina", FMU "Babička Gora", FMU "Obla Glava", FMU "Seličevica – Koritnik", FMU "Kamenički Vis I", FMU "Kamenički Vis II", FMU "Suva Planina I – Rakoš", FMU "Suva Planina III", FMU "Bukovik – Aleksinački", FMU "Bukovik – Mratinja", FMU "Rtanj", FMU "Svrljiško - Gulianske Planine", FMU "Mali Jastrebac I", FMU "Lipovačko - Crnobarske šume", FMU "Ozren - Leskovik" and FMU "Devica"). The data summarized as of December 31, 2013, and December 31, 2021, was parallelly analyzed to determine whether and to what extent the ice disaster affected the growing stock condition of the Moravian Forest Area.

Some data on forest condition indicators (qualitative and quantitative) were obtained from the Development Plan of Moravian Forest Area (2012-2021) and available theoretical and professional sources related to this issue.

The most used methods in the research included the method of analysis and synthesis, the comparative method, as well as the method of induction and deduction.

3. RESEARCH RESULTS AND DISCUSSION

3.1. Origin-based stand condition in the Moravian Forest Area

In the growing stock of the Moravian Forest Area according to data summarized as of December 31, 2013 (Tabela 2), high natural stands occupy 13.1% of the area, with a share in volume of 30.9% and a share in volume increment with 23.7%. The most represented are coppice stands which occupy 34.6% of the area, with a share in volume of 53.5% and a share in volume increment with 53.1%. Artificially raised conifer stands occupy 10.7% of the area, with a share in volume of 12.3% and a share in volume increment of 20.7%. Shrubs and thickets occupy 39.6% of the area, while other forms (mixed stands by origin, artificially established hardwood stands) occupy about 2% of the stocked area.

Table 2. *Origin-based stand condition in the Moravian Forest Area according to data summarized as of December 31, 2013*

Stand origin	Area		Volume		Volume increment	
	ha	%	m^3	%	m^3	%
High natural stands of hardwoods	6326.63	13.1	1905598.5	30.9	41936.8	23.7
Coppice natural stands of hardwoods	16651.08	34.6	3297207.9	53.5	93948.2	53.1
Origin-based mixed stands	871.53	1.8	193760.8	3.1	4080.8	2.3
Artificially raised hardwood stands	82.65	0.2	6324.6	0.1	184.1	0.1
Artificially raised stands of soft deciduous trees	5.37	0.0	1547.8	0.0	49.2	0.0
Artificially raised conifer stands	5171.48	10.7	756760.2	12.3	36667.2	20.7
Total	**29108.74**	**60.4**	**6161199.8**	**100.0**	**176866.4**	**100.0**
Shrubs	6155.50	12.8				
Thickets	12915.64	26.8				
Total	**19071.14**	**39.6**				
Total	**48179.88**	**100.0**				

Source: Database of PE “Srbijašume” as of December 31, 2013 and author's calculations

In the growing stock of the Moravian Forest Area according to data summarized as of December 31, 2021 (Table 3), high natural stands occupy 15.1% of the area, with a share in volume of 33.7% and a share in volume increment with 26.1%. The coppice stands occupy 35.5% of the area, with a share in volume of 53.0% and a share in volume increment with 53.9%. Artificially raised conifer stands occupy 8.2% of the area, with a share in volume of 13.2% and a share in volume increment with 19.8%. Shrubs and thickets occupy 40.8% of the area, while other forms (artificially established hardwood and soft deciduous trees stands) occupy about 0.5% of the stocked area.

Table 3. *Origin-based stand condition in the Moravian Forest Area according to data summarized as of December 31,2021*

Stand origin	Area		Volume		Volume increment	
	ha	%	m^3	%	m^3	%
High natural stands of hardwoods	7279.00	15.1	2177650.76	33.74	48271.26	26.12
Artificially raised stands of soft deciduous trees	5.71	0.0	2044.21	0.03	65.79	0.04
Coppice natural stands of hardwoods	17135.32	35.5	3417750.87	52.95	99635.01	53.91
Coppice natural stands of soft deciduous trees	3.50	0.0	340.13	0.01	14.13	0.01
High natural stands of conifers	2.03	0.0	0.00	0.00	0.00	0.00
Artificially raised hardwood stands	178.83	0.4	4508.74	0.07	157.51	0.09
Artificially raised stands of soft deciduous trees	6.30	0.0	1962.38	0.03	49.53	0.03

Stand origin	Area		Volume		Volume increment	
	ha	%	m³	%	m³	%
Artificially raised conifer stands	3936.45	8.2	850327.10	13.17	36633.82	19.82
Total	**28547.14**	**59.2**	**6454584.19**	**100.00**	**184827.05**	**100.00**
Shrubs	7366.98	15.3				
Thickets	12343.62	25.6				
Total	**19710.60**	**40.8**				
Total	**48257.74**	**100.0**				

Source: Database of PE "Srbijašume" as of December 31, 2021 and author's calculations

From tables 2 and 3 it can be seen that after the natural disaster in 2014, the share of artificially raised conifer stands significantly decreased. Exactly these stands suffered the most from the ice disaster and clear-cutting was carried out consequently. At the expense of artificially raised conifer stands, the share of artificially raised hardwood stands increased. This is a consequence of emphasizing artificial regeneration with deciduous trees after clear-cutting.

The share of thickets has also increased significantly (by about 500-600 ha) which could mean that certain areas after clear-cutting failed to be completely artificially restored so they turned into thickets. Apparently, according to the new Inventory, between 500 and 600 ha of shrubs was reclassified as thickets. However, these thickets are often composed of pioneer and autochthonous species of the parent stand of vegetative origin. As artificial restoration on these surfaces has partially succeeded it can be expected in the future to be raised the origin-based mixed stands if the cultivation measures of illuminating and cleaning as well as the thining would be performed.

3.2. Preservation-based forest condition in the Moravian Forest Area

In the growing stock of the Moravian Forest Area according to data summarized as of December 31, 2013, the forest condition is unsatisfactory. The most represented are preserved stands that occupy 55.8% of the area, with a share of 97.1% in volume and 97.2% in volume increment. Insufficiently stocked stands occupy 3.1% of the area. 2.0% volume and 1.8% volume increment while unwanted forms (devastated stands, shrubs and thickets) occupy 41.1% of the area with a share of 0.9% in the total standing tree volume.

A large share of devastating stands, shrubs and thickets (41.1%) represents a potentially large work-site and a significant issue. It should be borne in mind that in this area a large share is occupied by shrubs which represent a permanent stage of vegetation in contrast to thickets which are a degradation stage.

Table 4. *Preservation-based forest condition in the Moravian Forest Area according to data summarized as of December 31, 2013*

Preservation	Area		Volume		Volume increment	
	ha	%	m³	%	m³	%
Preserved stands	26896.82	55.83	5981551.77	97.08	171959.82	97.23
Insufficiently stocked stands	1479.42	3.07	124959.19	2.03	3268.32	1.85
Devastating stands	732.50	1.52	54688.85	0.89	1638.31	0.93
Total	**29108.74**	**60.42**	**6161199.81**	**100.00**	**176866.44**	**100.00**
Shrubs and thickets	19071.14	39.58				
Total	**19071.14**	**39.58**				
Total	**48179.88**	**100.00**				

Source: Database of PE "Srbijašume" as of December 31, 2013 and author's calculations

In the growing stock of the Moravian Forest Area according to data summarized as of December 31, 2021, the preserved stands are also the most represented with a share of 52.7% in the area, 93.3% in volume and 94.4% in volume increament. Insufficiently stocked stands occupy 2.4% of the area, with a share of 2.1% in volume and 2.0% in volume increment while devastating stands, shrubs and thickets occupy 44.9% of the area with a share of 4.6% in the total standing tree volume.

Table 5. *Preservation-based forest condition in the Moravian Forest Area according to data summarized as of December 31, 2021*

Preservation	Area		Volume		Volume increment	
	ha	%	m³		ha	%
Preserved stands	25449.20	52.74	6024564.73	93.29	175065.83	94.41
Insufficiently stocked stands	1149.60	2.38	136159.70	2.11	3635.55	1.96
Devastating stands	2116.23	4.39	296965.36	4.60	6725.42	3.63
Total	**28715.03**	**59.51**	**6457689.79**	**100.00**	**185426.79**	**100.00**
Shrubs and thickets	19541.28	40.49				
Total	**19541.28**	**40.49**				
Total	**48256.31**	**100.00**				

Source: Database of PE “Srbijašume” as of December 31, 2021 and author's calculations

Tables 4 and 5 show that after the ice disaster in 2014, the share of preserved stands decreased by approx. 1,450 ha and the share of devastating stands increased by the same amount and that between 500 and 600 ha became overgrown. Perhaps all this is not the result of the natural disaster, but according to existing records, clean-cutting was still carried out on approx. 1000 ha of forest stands damaged by ice.

The presence of insufficiently stocked and devastated stands, shrubs and thickets on almost half of the total stocked area with all the negative effects resulting from it (reduced ecological stability, insufficiently utilized habitat potential, reduced productivity concerning preserved stands, etc.) is one of the basic, long-term issues of forest management (Banković et al. 2009).

3.3. Diversity-based forest condition in the Moravian Forest Area

According to data summarized as of December 31, 2013, pure stands occupy 18,106.72 ha, namely 37.6% of the area. Their share in volume is 69.7% (4,292,169.6 m3) and in volume increment 66.8% (118,164.7 m3). The mixed stands occupy 11,002.02 ha (22.8%) with a share of 30.3% (1,869,030.2 m3) in volume and 33.2% (58,701.8 m3) in volume increment. The rest of the area of 19,071.14 ha (39.6%) is overgrown with shrubs and thickets where diversity, volume, and volume increment have not been determined (table 6).

The dominance of pure stands, as environmentally, functionally, and even productively inferior stand forms, is another strategic issue that burdens the forests of Serbia (Banković et al. 2009). The mixed stands represent more stable forest ecosystems and they are more resistant to negative abiotic and biotic influences, therefore the spread of monocultures should be limited.

Table 6. *Diversity-based forest condition in the Moravian Forest Area according to data summarized as of December 31, 2013*

Diversity	Area		Volume		Volume increment	
	ha	%	m³	%	m³	%
Pure stand	18106.72	37.58	4292169.60	69.66	118164.67	66.81
Mixed stand	11002.02	22.84	1869030.21	30.34	58701.76	33.19
Total	**29108.74**	**60.42**	**6161199.81**	**100.00**	**176866.43**	**100.00**
Shrubs and thickets	19071.14	39.58				
Total	**19071.14**	**39.58**				
Total	**48179.88**	**100.00**				

Source: Database of PE "Srbijašume" as of December 31, 2013 and author's calculations

According to data summarized as of December 31, 2021, pure stands occupy 18,231.57 ha, namely 37.8% of the area. Their share in volume is 71.2% (4,597,510.5 m^3) and in volume increment 67.0% (124,190.1 m3). The mixed stands occupy 10,483.46 ha (21.7%) with a share of 28.8% (1,860,179.3 m3) in volume and 33.0% (61,236.7 m3) in volume increment. The rest of the area of 19,541.28 ha (40.5%) is overgrown with shrubs and thickets where diversity, volume, and volume increment have not been determined (table 7).

Table 7. *Diversity-based forest condition in the Moravian Forest Area according to data summarized as of December 31, 2021*

Diversity	Area		Volume		Volume increment	
	ha	%	m³	%	m³	%
Pure stand	18231.57	37.78	4597510.48	71.19	124190.14	66.98
Mixed stand	10483.46	21.72	1860179.31	28.81	61236.66	33.02
Total	**28715.03**	**59.51**	**6457689.79**	**100.00**	**185426.79**	**100.00**
Shrubs and thickets	19541.28	40.49				
Total	**19541.28**	**40.49**				
Total	**48256.31**	**100.00**				

Source: Database of PE "Srbijašume" as of December 31, 2021 and author's calculations

The reduced share of mixed stands and a slight increase in share of pure stands should certainly not be the result of the natural disaster, because mixed stands are more stable. This condition may occur as they were spatially more affected by this natural disaster, or that they were renamed into pure stands during another arrangement.

3.4. Forest condition based on the tree species in the Moravian Forest Area

In the stand inventory of forests managed by PE "Srbijašume", 75 tree species were recorded (59 are deciduous and 16 coniferous species). The number of tree species is extremely important from the biodiversity conservation point of view (Banković et al. 2009).

From the following Table 8, it can be concluded that in the Moravian Forest Area before the natural disaster, the deciduous species dominated. They were represented by volume at 87.7% and by growth at 79.2%. Conifer stands were represented by volume only at 12.3% and by growth at 20.8%. These are exclusively artificial stands, established by the afforestation of bare forests and the reclamation of devastated deciduous forests with spruce and pine species, Douglas fir, and larch. The most common species is beech which participates in the total standing tree volume with 66.9% and the current volume increment with 57.3%. A significant share in the standing tree volume also has the following deciduous tree species: Turkey oak (8.4%), Sessile oak (6.8%) hornbeam (1.5%), black locust (1.3%), Hungarian oak (0.7%), maple (0.4%). Other deciduous species are symbolically represented.

The most important conifer species are spruce with 6.7% share in volume and 10.1% in volume increment, Austrian pine with 3.3% volume and 6.7% volume increment, and Scots pine with 1.4% volume and 2.6% volume increment, Douglas fir (0.5% of volume, i.e. 0.9% of volume increment) and larch (0.3% of volume, i.e. 0.4% of volume increment).

The determined large number of tree species represents great biodiversity and biological wealth and has multiple importances for the environment.

Table 8. *Forest condition based on the tree species in the Moravian Forest Area according to data summarized as of December 31, 2013*

Tree species	Volume		Volume increment	
	m³	%	m³	%
Beech	4121314.5	66.9	101337.9	57.3
Turkey oak	520435.2	8.4	14760.6	8.3
Sessile oak	416615.2	6.8	12530.6	7.1
Common hornbeam	91585.1	1.5	2461.7	1.4
Black locust	82982.3	1.3	4591.3	2.6
Other hardwoods	46240.3	0.8	1064.5	0.6
Hungarian oak	40754.1	0.7	1462.6	0.8
Maple	27279.7	0.4	399.1	0.2
Black ash	10201.4	0.2	224.4	0.1
Large-leaved linden	9779.7	0.2	331.6	0.2
White ash	9217.2	0.1	207.1	0.1
Field maple	6989.4	0.1	175.1	0.1
Turkish hazel	5850.6	0.1	163.6	0.1
Norway maple	4492.1	0.1	122.0	0.1
Mountain maple	4476.3	0.1	44.5	0.0
Aspen	3045.4	0.0	126.7	0.1
American maple	2296.5	0.0	10.0	0.0
Silver linden	925.4	0.0	27.1	0.0
Black poplar	221.4	0.0	0.0	0.0
Other soft deciduous trees	160.0	0.0	0.2	0.0
Hardwood trees	**5404861.9**	**87.7**	**140040.5**	**79.2**
Norwaz spruce	413551.0	6.7	17803.0	10.1
Austrian pine	203826.2	3.3	11789.4	6.7
Scots pine	88494.4	1.4	4676.7	2.6
Douglas fir	30666.6	0.5	1587.7	0.9
European larch	15961.4	0.3	707.8	0.4
Eastern white pine	3278.1	0.1	241.4	0.1
Fir	560.3	0.0	20.0	0.0
Conifers	**756337.9**	**12.3**	**36825.9**	**20.8**
Total	**6161199.8**	**100.0**	**176866.4**	**100.0**

Source: Database of PE “Srbijašume” as of December 31, 2013 and author's calculations

The participation of species that have the status of relict, endemic, rare, and endangered species according to the IUCN - TBFRA 2000 category (International Union for Conservation of Nature – Temperate and Boreal Forest Resource Assessment), i.e. protected and strictly protected species according to the Rulebook 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) is of particularly great importance. In that sense, special attention should be paid to the Turkish hazel, mountain maple, various forest fruits such as walnut, wild service tree, true service tree, etc.; to bushy species such as species of the genus Daphne, and several herbaceous species such as sage, Ramonda, etc.

From the following Table 9 it can be concluded that the the growing stock condition by tree species is almost unchanged after a natural disaster. Deciduous species are represented by volume with 87.2% and by growth 80.5%. Conifer stands are represented by volume only 12.8% and by growth with 19.5%. The most abundant species is also beech which participates in the total standing tree volume with 65.5% and in the current volume increment with 55.7%.

Similarly as in the previous management period, from deciduous species, a significant share in the standing tree volume has the following species: Turkey oak (8.3%), Sessile oak (4.4%), hornbeam (1.6%), black locust (1.4%), and maple (0.6%) with the fact that a slightly higher share of Hungarian oak (3.1%) was recorded.

The share of the most important coniferous species as well as their representation by volume and volume increment has not changed significantly.

Table 9. *Forest condition based on the tree species in the Moravian Forest Area according to data summarized as of December 31, 2021*

Tree species	Volume		Volume increment	
	m³	%	m³	%
Beech	4229595.1	65.5	102857.0	55.7
Turkey oak	534588.1	8.3	15905.5	8.6
Sessile oak	281110.8	4.4	8426.3	4.6
Hungarian oak	199269.5	3.1	6664.8	3.6
Common hornbeam	104143.5	1.6	3561.1	1.9
Black locust	88355.6	1.4	5055.1	2.7
Other hardwoods	65322.0	1.0	2497.6	1.4
Maple	38957.3	0.6	1134.3	0.6
Black ash	18834.7	0.3	694.0	0.4
Field maple	16904.6	0.3	533.5	0.3
Large-leaved linden	12669.5	0.2	502.4	0.3
Turkish hazel	7880.7	0.1	225.1	0.1
White ash	6839.3	0.1	206.0	0.1
Aspen	5113.5	0.1	186.8	0.1
Norway maple	4563.3	0.1	119.5	0.1
Oriental hornbeam	2166.9	0.0	114.7	0.1
Cherry	1918.2	0.0	0.3	0.0
Silver linden	1557.7	0.0	55.6	0.0
Red oak	1454.6	0.0	61.7	0.0
Mountain maple	1110.8	0.0	30.4	0.0
American maple	891.9	0.0	1.8	0.0
Wild service tree	636.9	0.0	0.0	0.0
Bleck poplar	569.4	0.0	0.0	0.0
Black walnut	542.6	0.0	19.6	0.0
Other soft deciduous trees	401.0	0.0	6.6	0.0
Hardwood trees	**5625397.3**	**87.2**	**148859.8**	**80.5**
Norway spruce	451345.83	7.0	17409.5	9.4
Austrian pine	233875.61	3.6	12446.0	6.7
Scots pine	89615.94	1.4	3983.9	2.2
Douglas fir	32060.96	0.5	1377.6	0.7
European larch	14506.48	0.2	342.2	0.2
Fir	3948.46	0.1	115.4	0.1

Tree species	Volume		Volume increment	
	m³	%	m³	%
Eastern white pine	3833.59	0.1	292.7	0.2
Conifers	**829186.89**	**12.8**	**35967.3**	**19.5**
Total	**6454584.2**	**100.0**	**184827.1**	**100.0**

Source: Database of PE "Srbijašume" as of December 31, 2021 and author's calculations

3.5. Forest condition based on the stand affiliation in the Moravian Forest Area

In accordance with the instructions given in the framework of the National Forest Inventory (Banković et al. 2009) all forests are also differentiated by individual stand categories defined according to the main type of trees in the stand regardless of the participation of other species. In accordance with this criterion, the national inventory registered 20 stand categories in the forests of Serbia from the belt of willow forests along the banks of the rivers to the belt of spruce forests at the upper limit of the distribution of forest communities.

Based on data summarized as of December 31, 2013, the most represented category of forests based on the area coverage is thickets and thickets which occupy an area of 19,071.14 ha (39.6%) (Table 10).

The dominant category of forests in relation to this indicator is beech forests which cover 35.5% followed by spruce forests at 7.2%, Turkey oak forests at 6.1%, Sessile oak forests at 5.0%, pine forests at 3.0%, forests of black locust, aspen and birch at 2.4%, hornbeam forests at 0.3%, Hungarian oak forests at 0.2% of the total covered area to the linden forests, maple and ash forests, poplar forests, which are slightly present in the total forest area. The dominance of beech forests is even more pronounced if the participation in the total volume and volume increment is observed, which amounts to 70.2% for volume, that is, to 60.0% for volume increment followed by Turkey oak forests with a volume share of 9.2% and volume increment of 9.4%, spruce forests with 8.4% share in volume and 13.5% share in volume increment, Sessile oak forests with a volume share of 6.1% and volume increment of 6.3%, pine forests with 3.1% share in volume and 5.9% share in volume increment, forests of black locust, aspen and birch with 1.5% share in volume and 2.7% in volume increment. Forests of hornbeam, Hungarian oak, poplar, linden, willow, and forests of other broadleaves and conifers have an insignificant share in the volume and volume increment (Table 10).

Table 10. *Forest condition based on the stand affiliation in the Moravian Forest Area according to data summarized as of December 31, 2013*

Stand unit	Area		Volume		Volume increment	
	ha	%	m³	%	m³	%
Beech forests	17087.04	35.5	4326327.3	70.2	106179.9	60.0
Turkey oak forests	2919.34	6.1	566201.7	9.2	16644.3	9.4
Sessile oak forests	2401.93	5.0	373977.6	6.1	11070.2	6.3
Hungarian oak forests	90.77	0.2	14996.5	0.2	513.2	0.3
Norway spruce forests	3486.31	7.2	520117.2	8.4	23831.4	13.5
Pine forests	1432.72	3.0	189693.7	3.1	10508.3	5.9
Black locust, aspen, and birch forests	1153.95	2.4	91702.4	1.5	4861.3	2.7
Hornbeam forests	162.77	0.3	18413.8	0.3	513.6	0.3
Fir forests	2.46	0.0	508.3	0.0	17.1	0.0
Poplar forests	4.46	0.0	377.6	0.0	3.1	0.0

Stand unit	Area		Volume		Volume increment	
	ha	%	m³	%	m³	%
Linden forests	37.31	0.1	5890.7	0.1	216.1	0.1
Forests of other broadleaves	60.93	0.1	3744.1	0.1	95.2	0.1
White willow forests	0.96	0.0	188.2	0.0	2.2	0.0
Ash and maple forests	11.52	0.0	1033.0	0.0	30.2	0.0
Forests of other conifers	256.27	0.5	48027.9	0.8	2380.3	1.3
Total (without shrubs and thickets)	**29108.74**	**60.4**	**6161199.8**	**100.0**	**176866.4**	**100.0**
Total (shrubs and thickets)	**19071.14**	**39.6**				
Total	**48179.88**	**100.0**				

Source: Database of PE "Srbijašume" as of December 31, 2013 and author's calculations

Based on data summarized as of December 31, 2021, the most represented category of forests based on the area coverage is also thickets and thickets which occupy an area of 19.710.60 ha (40.8%) (Table 11).

The dominant category of forests in relation to this indicator is beech forests which cover 35.5% followed by spruce forests at 7.2%, Turkey oak forests at 6.1%, Sessile oak forests at 5.0%, pine forests at 3.0%, forests of black locust, aspen and birch at 2.4%, hornbeam forests at 0.3%, Hungarian oak forests at 0.2% of the total covered area to the linden forests, maple and ash forests, poplar forests, which are slightly present in the total forest area. The dominance of beech forests is even more pronounced if the participation in the total volume and volume increment is observed, which amounts to 70.2% for volume, that is, to 60.0% for volume increment followed by Turkey oak forests with a volume share of 9.2% and volume increment of 9.4%, spruce forests with 8.4% share in volume and 13.5% share in volume increment, Sessile oak forests with a volume share of 6.1% and volume increment of 6.3%, pine forests with 3.1% share in volume and 5.9% share in volume increment, forests of black locust, aspen and birch with 1.5% share in volume and 2.7% in volume increment. Forests of hornbeam, Hungarian oak, poplar, linden, willow, and forests of other broadleaves and conifers have an insignificant share in the volume and volume increment (Table 11).

Table 11. *Forest condition based on the stand affiliation in the Moravian Forest Area according to data summarized as of December 31, 2021*

Stand unit	Area		Volume		Volume increment	
	ha	%	m³	%	m³	%
Beech forests	17416.54	36.1	4428206.4	68.6	108694.0	58.8
Turkey oak forests	2839.35	5.9	560344.7	8.7	17573.0	9.5
Sessile oak forests	1606.23	3.3	287767.1	4.5	8936.3	4.8
Hungarian oak forests	1084.88	2.2	178558.9	2.8	5841.9	3.2
Norway spruce forests	2094.98	4.3	469212.9	7.3	18039.7	9.8
Pine forests	1635.49	3.4	324375.8	5.0	16312.5	8.8
Black locust, aspen, and birch forests	1196.18	2.5	103357.5	1.6	5567.2	3.0
Hornbeam forests	205.52	0.4	26137.0	0.4	903.2	0.5
Fir forests	15.00	0.0	4443.7	0.1	129.5	0.1
Poplar forests	3.79	0.0	660.5	0.0	1.1	0.0
Linden forests	46.94	0.1	8551.0	0.1	339.0	0.2
Forests of other broadleaves	52.22	0.1	188.2	0.0	2.2	0.0
White willow forests	107.06	0.2	2681.0	0.0	81.3	0.0
Ash and maple forests	49.95	0.1	7804.8	0.1	254.1	0.1
Forests of other conifers	193.01	0.4	52294.7	0.8	2152.2	1.2
Total (without shrubs and thickets)	**28547.14**	**59.2**	**6454584.2**	**100.0**	**184827.1**	**100.0**
Total (shrubs and thickets)	**19710.60**	**40.8**				
Total	**48257.74**	**100.0**				

Source: Database of PE "Srbijašume" as of December 31, 2021 and author's calculations

3.6. Forest condition based on coeno-ecological affiliation in the Moravian forest area

The coeno-ecological affiliation is an ecological characteristic of forests that does not change significantly from one management period to another. It is defined by habitat and phytocenological affiliation. However, it should be said that this is not an unchangeable category but such changes require a much longer period. On the other hand, a change in the coeno-ecological unit can occur due to climate change. However, they are long-term and gradual, and this situation is about weather extremes that occur in certain years and as such cannot individually have much effect on the habitat and potential vegetation. Extreme climate disasters can only temporarily throw an ecosystem out of balance. If the habitat has not been significantly changed, it returns to balance through the succession of vegetation.

This process is not short though, so it is the task of the forest professionals to speed it up through artificial regeneration. In this way, some stages in the succession would be skipped and the end stages of climazonal and oroclimatic conditioned forest communities would be created more quickly. However, it should be noted that artificial restoration has failed in some cases, so we have the appearance of pioneer tree species or vegetative regeneration from stumps and shoots.

Table 12. *Forest condition based on coeno-ecological affiliation in the Moravian Forest Area as of December 31, 2013*

Coeno-ecological unit	Area	
	ha	%
Typical montane beech forest (*Fagetum moesiace submontanum typicum*) on medium to deep brown soils and diluvium	10894.94	22.6
Forest of Oriental hornbeam and oak(*Carpino orientalis- Polyquercetum*) on skeletal acidic brown soil	6948.05	14.4
Forests of Turkey and Sessile oak with a rich layer of shrubs (*Quercetum petraeae-cerris galietosum*) on the ridges, pararendzinas, browned pararendzinas, shallow eutric brown soils and alluvial soils - Total	6939.86	14.4
Forest of Oriental hornbeam and Pubescent oak with lilac (*Carpinetum orientalis syringosum*) on mottled rankers on andesite	5362.33	11.1
Alpine beech forests (*Fagetum moesiacae montanum typicum*) on acidic brown soil	4131.75	8.6
Subalpine beech forests (*Fagetum moesiacae submontanum typicum*) on acidic brown to lessive acid brown soil	3349.11	6.9
Subalpine beech forest with hammer sedge (*Fagetum moesiace submontanum caricetosum pilosae*) on skeletal acid brown soil	1910.48	4.0
Ecological unit of Turkey and Sessile oak forest with Oriental hornbeam (*Quercetum frainetto-cerris carpinetosum orintalis*) on shallow acid brown soils on schist	1697.43	3.5
Forest of Oriental hornbeam and oak (*Carpino orientalis - Polyquercetum*) on soils from pararendzina on loess to shallower (drier) cambisol	1155.16	2.4
Alpine beech forests (*Fagetum moesiacae montanum typicum*) on distric and eutric brown soils	879.91	1.8
Forests of Sessile oak and Hungarian oak (*Quercetum petraeae-cerris pauperum*) on acidic brown soil	785.59	1.6
Forests of Sessile oak and hornbeam (*Querco-carpinetum montanum typicum*) on eutric humus-silicate soil (mottled rankers)	751.38	1.6
Forests of Sessile oak and hornbeam on limestone (*Hordelymo- Querco-Carpinetum typicum*) on humus and shallow brown soil on limestone	747.69	1.5
Forests of Sessile oak and hornbeam with black ash (*Querco- Carpinetum montanum ornetosum*) on skeletal acid brown soil	521.48	1.1
Forests of Sessile oak with Poa annua L. (*Quercetum montanum poetosum nemoralis*) on humus-silicate and on skeletal acid brown soil	362.10	0.8
Turkey and Hungarian oak forest (*Quercetum farnetto-cerris*) on acidic brown soils on conglomerates and sandstones	353.16	0.7
Sessile oak and hornbeam forest (*Querco-Carpinetum moesiacum montanum*) on medium deep eutric brown soils	199.88	0.4
Sessile and Turkey oak forest (*Quercetum petraeae-cerris serpentinicum*) on brown and loess brown soil on serpentinite	193.45	0.4
Typical Turkey and Sessile oak forest (*Quercetum petraeae- cerris typicum*) on distric and eutric brown soils	193.42	0.4
Alpine beech forest with drymetosum (*Fagetum moesiacae montanum drymetosum*) on skeletal acid brown soils	165.64	0.3
Sessile oak and hornbeam forest (*Querco-Carpinetum serpentinicum*) on loess brown soil on serpentinite	116.06	0.2
Sessile oak and hornbeam forest (*Querco-Carpinetum montanum typicum*) on skeletal acid brown soil and acidic brown soil	96.26	0.2
Hungarian and Turkey oak forest with Sessile oak (*Quercetum frainetto-cerris petraetosum*) on medium deep brown soils	80.98	0.2
Environmental units of typical forest of Hungarian and Turkey oak (*Quercetum frainetto-cerris typicum*) on medium deep to deep brown soils	79.12	0.2
Sessile and Turkey oak forests with Hungarian oak (*Quercetum petraeae-cerris frainettosum*) on loess acid brown soil	45.03	0.1
Typical alpine beech forest (*Fagetum moesiacae submontanum typicum*) on deep acidic brown soil	44.61	0.1
Sessile oak, hormbeam, and Turkey oak (*Carpino-Quercetum petraeae - cerris pauperum*) on lessive acid brown soil	38.92	0.1
Forest of Sessile oak with flowering ash (*Quercetum montanum ornetosum*) on loess pararendzina on loess	37.41	0.1
Mountain beech forest with noble deciduous trees (*Fagetum moesiace submontanum ceretosum*) on deep eutric brown soils	33.50	0.1
Sessile and Turkey oak forests (*Quercetum petraeae-cerris typicum*) on loess cambisol	28.25	0.1
Forest of different oak species and hornbeam (*Carpino- Polyquecetum typicum*) on soil interval from deep pararendzinas on loess to loess cambisol	24.83	0.1
Typical forest of Hungarian and Turkey oak (*Quercetum farnetto- cerris aculeatetosum*) on lessive cambisol	22.26	0.0
Sessile and Turkey oak forests (*Quercetum petraeae-cerris*) on cambic pararendzina to humus cambisol	15.32	0.0

Coeno-ecological unit	Area	
	ha	**%**
Forest of Turkey, Hungarian and Sessile oak with Festuca (*Quercetum frainetto-cerris petraetosum fac. festucetosum heterophyllae*) on the medium-deep acidic brown soils	12.36	0.0
Forest of beech and hornbeam (*Fagetum moesiacae montanum carpinetosum betuli*) on rankers (humus silicate soils)	11.30	0.0
Sessile, Turkey oak and hornbeam forests (*Quercetum petraeae-cerris calcicolum*) lessive acid brown soil on limestone	9.54	0.0
Sessile and Turkey oak forests (*Carpino-Quercetum petraeae-cerris*) on pararendzinas on loess and marl	8.28	0.0
Forest of beech and Sessile oak (*Querco-Fagetum typicum*) on medium-deep eutric and distric brown soils	7.80	0.0
Typical forest of Sessile oak (*Quercetum montanum typicum*) on acidic brown soil	2.14	0.0
Forest of Sessile oak and hornbeam with European bladdernut (Querco- Carpinetum staphyletosum) on acidic brown soils	0.96	0.0
Total	**48257.74**	100.0

4. CONCLUSION

The natural disaster that happened in the winter of 2014 had an impact on the growing stock and the forest condition in certain parts of the Moravian Forest Area. The following forest management units were more affected by this disaster: FMU “Obla Glava”, FMU “Kamenički Vis I”, FMU “Kamenički Vis II”, FMU “Bukovik – Mratinja”, FMU “Rtanj”, FMU “Svrljiško - Gulianske Planine” and FMU “Devica”. It should be noted that the neighboring Timočka forest area which is located north of the Moravian Forest Area was affected to an even greater extent by this natural disaster.

On that occasion, the cooled-down air masses from the north, northeast, and east created an ice crust of greater thickness on the trunks of forest trees. Under the weight of the ice and the influence of the wind, there were breaks in different stand situations in the mentioned forest management units. The damages were of different intensity but on about 1,000 ha, they were so large that clear-cutting had to be carried out. This certainly led to a change in the growing stock condition in the mentioned forest management units.

Because of this climate disaster the artificially raised stands were almost completely destroyed. Natural stands that were on the way of this ice wave that moved in the direction Svrliško - Guljanske Mountains - Tresibaba - Kamenički vis - Devica - Ozren - Obla glava also were destroyed. Parallel to this direction, the natural disaster also moved on the other side of Moravica River from Knjaževac via Slemen and mountain Rtanj towards mountain Bukovik. This natural disaster affected all stands and structural forms in the zone between 600 and 900 m above sea level.

In the research period, the share of the preserved forests decreased and the share of devastated forests and thickets increased. During artificial renewal in the areas where the clear-cutting was performed the emphasis was put on hardwoods. This increased the share of artificially raised hardwood stands and reduced the share of artificially raised conifer stands that suffered the most due to cold weather. The artificial restoration did not completely succeed in some parts of the destroyed area and thickets overgrown the surfaces. However, these thickets are often of vegetative origin, composed of pioneer and autochthonous species of the cut mother stand with some number of species of generative origin. Those areas will become autochthonous stands of mixed origin in the future through succession, cultivation measures of cleaning and illuminating, and thinning.

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CHANGE IN THE GROWING STOCK CONDITION OF THE MORAVIAN FOREST AREA AS A CONSEQUENCE OF ICE DISASTERS IN THE WINTER 2014

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Summary

The area of eastern Serbia was hit in the winter of 2014 by natural disaster, specifically ice disaster, which caused great damage to forest trees. The subject of this research is the state-owned natural forests and artificially raised stands within the Moravian Forest Area which are managed by Public Enterprize (PE) “Srbijašume” Belgrade. Given that natural disasters in the form of ice disasters, in some parts of the Moravian Forest Area caused great damage, as a result of which clear-cuttings had to be carried out on large areas (about 1000 ha of forest stands), the research aims to determine whether there have been significant changes in the condition of the growing stock at the level of the area.

Natural stands that were on the way of this ice wave that moved in the direction Svrliško - Guljanske Mountains - Tresibaba - Kamenički vis - Devica - Ozren - Obla glava also were destroyed. Parallel to this direction, the natural disaster also moved on the other side of Moravica River from Knjaževac via Slemen and mountain Rtanj towards mountain Bukovik. This natural disaster affected all natural stands and structural forms in the zone between 600 and 900 m above sea level. Artificially raised stands were almost completely destroyed.

In the research period, the share of the preserved forests decreased and the share of devastated forests and thickets increased. During artificial renewal in the areas where the clear-cutting was performed the emphasis was put on hardwoods. This increased the share of artificially raised hardwood stands and reduced the share of artificially raised conifer stands that suffered the most due to cold weather.

The artificial restoration did not completely succeed in some parts of the destroyed area and thickets overgrown the surfaces.

PROMENA STANJA ŠUMSKOG FONDA U MORAVSKOM ŠUMSKOM PODRUČJU KAO POSLEDICA LEDOLOMA U ZIMU 2014. GODINE

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Rezime

U zimu 2014. godine područje istočne Srbije je pogodila elementarna vremenska nepogoda u vidu ledene kiše koja je pričinila velike štete na šumskom drveću. Predmet ovog istraživanja su obrasle površine Moravskog ŠP (prirodne šume i veštački podignute sastojine) u državnom vlasništvu kojima gazduje JP „Srbijašume“ Beograd. Obzirom da su elementarne vremenske nepogode u pojedinim delovima Moravskog ŠP pričinile velike štete u vidu ledoloma i ledoizvala. usled čega su morale biti izvršene čiste seče na velikim površinama (oko 1000 ha šumskih sastojina). cilj istraživanja je da se utvrdi da li je došlo do bitnih promena u stanju šumskog fonda na nivou područja.

Od prirodnih sastojina stradale su one koje su se našle na udaru ove ledene stihije koja se kretala pravcem: Svrliško - Guljanske planine Tresibaba - Kamenički vis - Devica - Ozren - Obla glava. Paralelno sa ovim pravcem. elementarna nepogoda se kretala i drugom stranom Moravice od Knjaževca preko Slemena i Rtnja ka Bukoviku. Od prirodnih šuma.

elementarnom nepogodom su zahvaćeni svi sastojinski i strukturni oblici u pojasu između 600 i 900 m nadmorske visine. Veštački podignute sastojine. zahvaćene vremenskom nepogodom stradale su gotovo u celosti.

U analiziranom periodu naročito se smanjilo učešće očuvanih, a povećalo učešće devastiranih šuma i šikara. Prilikom veštačkog obnavljanja. na mestima čiste seče. akcenat je stavljen na tvrde lišćare. Time se povećao udeo veštački podignutih sastojina tvrdih lišćara. a smanjio udeo veštački podignutih sastojina četinara koje su najviše stradale u vremenskoj nepogodi.

Na pojedinim mestima veštačko obnavljanje nije u potpunosti uspelo, te su se površine zašikarile.

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CHARACTERISTICS OF STRUCTURE AND PRODUCTION IN *VINATOVAČA* VIRGIN FOREST

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Abstract: *The paper presents the results of the research conducted in the "Vinatovača" virgin forest in northeastern Serbia. The investigated stands belong to the complex of mesophilic beech forest types. These stands haven't had any management treatments carried out since 1957 when the virgin forest was placed under state protection as a strict natural reserve of beech with the character of a virgin forest. The results of this research were obtained by selecting homogeneous parts of the virgin forest and surveying sample plots established evenly over the entire surface of the virgin forest. Beech is the dominant tree species in all sample plots. Besides beech, there are individual specimens of maple, common ash, cherry, hornbeam, manna ash and Norway maple in the virgin forest area. The investigated stands have a structure typical of virgin forests with the highest number of trees found in the lowest diameter degrees. The investigated stands have a similar volume as other beech virgin forests in Serbia. The obtained value of the stand volume indicates the high production potential of beech forests in northeastern Serbia*.

Key words: virgin forests, beech, northeastern Serbia, structure.

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STRUKTURNE I PROIZVODNE KARAKTERISTIKE PRAŠUME VINATOVAČA

Izvod: *U radu su predstavljeni rezultati istraživanja prašume „Vinatovača" koja se nalazi u severoistočnoj Srbiji. Sastojine koje su predmet ovog istraživanja pripadaju kompleksu mezofilnih bukovih tipova šuma. U predmetnim sastojinama ne sprovode se nikakavi gazdinski tretmani još od 1957. godine, kada je prašuma stavljena pod zastitu države kao strogi prirodni rezervat bukve prašumskog karaktera. Rezultati ovog rada nastali su na osnovu, izdvajanja homogenih delova prašume a zatim i premera stacioniranih oglednih polja postavljenih ravnomerno na čitavoj površini prašume. Na svim primernim površinama bukva je dominantna vrsta drveta, pored bukve na području prašume stablimično javljaju se još javor, beli jasen, trešnja, grab, crni jasen i mleč. Struktura istraživanih sastojina odgovara tipičnoj strukturi za šume prašumskog karaktera pri čemu je najveći broj stabala skoncentrisan u najslabijim debljinskim stepenima. Vrednosti zapremine u istraživanim sastojinama su približne zapremini ostalih prašuma bukve na teritoriji Srbije, ovakva vrednost zapremine sastojina ukazuje na visoki proizvodni potencijal bukovih šuma na području severoistočne Srbije.*

Ključne reči: prašuma, bukva, severoistočna Srbija, struktura.

1. INTRODUCTION

Virgin forests are completely natural ecosystems undisturbed by human activity. They are under the strictest protection regime, which besides logging, forbids any human interference in the natural flows of the living and non-living world. Not only is it forbidden to extract any natural resources from these forests, but the human footprint is also undesirable. They serve primarily for scientific and research purposes. The strict protection regime doesn't apply only to living and dead trees but to the whole living and non-living world.

Untouched nature can give us answers to many questions about forest growth and development. Virgin forests reveal the laws by which forest stands grow and regenerate. There, we can learn that forest stands are nature's eternal attempt to adapt the living to the dead space. They have an inherent dynamism with stand images changing before our very eyes. There are no indications of a permanent balance between the dead and living parts of nature (Mlinšek, 1968).

The virgin forest is an undisturbed primeval natural ecosystem that develops according to its specific laws that have not been fully studied yet. That is why research conducted in virgin forest stands is of great importance both for fundamental science and practical disciplines of forestry (Bucalo et al., 2008).

The research conducted in intact ecosystems has an important role in determining site potentials. Given the state of our forests, intact ecosystems can only be found in nature reserves (Stamenković et al., 1988).

The site and stand conditions affect the growth of stand trees with varying intensity. Precisely, different courses in the growth of individual trees in a stand contribute to the differentiation of trees in terms of thickness, height and other structural elements and thus produce a specific stand structure.

Everything that has been said above emphasises the importance of studying virgin forests. They give us deeper insight into natural flows and facilitate decision-making in forest management. Our research deals with a virgin forest of the most common tree species in the growing stock of Serbia, which gives it additional value.

In the Balkans, beech virgin forests were mostly studied from the thirties to the seventies of the twentieth century (Miletić, 1930; Milin, 1954; Drinić, 1957).

2. STUDY AREA, MATERIAL AND METHODS

The research was conducted in the “Vinatovača” General Nature Reserve (Figure 1) in northeastern Serbia. It is situated on the north-facing slopes of the Kučaj Mountains in the Resava Gorge (Upper Resava). No feeling has ever been conducted in the virgin forest, nor has the natural forest ecosystem been disturbed in any way. The reserve is located between 19° 22' and 19° 30' east longitude and 44° 02' and 44° 05' north latitude. It is managed by the “Srbijašume” State Enterprise, “Južni Kučaj” Despotovac Forest Estate, Despotovac Forest Administration. According to the spatial division of forests (Special Forest Management Plan for 2015-2024), this nature reserve is located in MU “Vinatovača-Vrtačelje”, compartment 22 (sections b and c) and compartment 23 (sections a and b). The total area of the reserve is 37.43 ha. The terrain is of a gorge type. The lower part of the slope (sections 22b and 23a) at 640-800 m above sea level has a uniformly steep slope of 26-35°, while the upper part of the slope (sections 22c and 23b) at 800-870 m above sea level has a very steep slope of 35-47°. Practically the entire stand faces the northeast.

To study the production characteristics of the virgin forest, its homogeneous parts were first selected. The forest was then divided into two parts – the lower part that is less steep and grows in deep and fresh soil over chlorite-sericite shales and the upper one with steep terrain and shallow soil over limestone.

The investigated stands can be classified into the group of the montane beech forest (*Fagetum moesiacae montanum*) on different brown soils, with the lower wide part located on medium to deep, and the upper narrow part of the virgin forest on shallow soil. We established 14 sample plots in the lower (wide) part and two sample plots in the upper (narrow) part of the virgin forest, evenly distributed over the entire surface area (Figure 2). All sample plots were circular and 10 a in size.

Cross diameter at breast height and the total height of all trees whose diameter was above 10 cm were measured in all sample plots.

Besides measuring forest estimation elements, we collected descriptive attributes that characterised the investigated stands.

The method of constructing tree volume tables was used to calculate the volume. The current volume increment was determined by the percentage increment method since we could not extract cores in a virgin forest. Different functions were tested to model the height curve, and the final model was selected based on statistical parameters of regression and correlation analysis and the degree of coincidence between weighted and empirical data. Data were processed using Microsoft Excel and Statgraphics.

Figure 1. *Location of Vinatovača*

Figure 2. *Layout of sample plots*

3. RESEARCH RESULTS AND DISCUSSION

Considering that there were significant differences between the lower and the upper part of the virgin forest, the two parts were separated in the field, and the results are presented accordingly. Table 1 shows the values of the main forest estimation elements for the lower part named Sample Plot 1 (SP 1) and the upper part named Sample Plot 2 (SP 2). It should also be noted that all other species recorded in the virgin forest were classified in the category of other hardwoods (ohw) due to their small number.

Table 1. *Forest estimation elements*

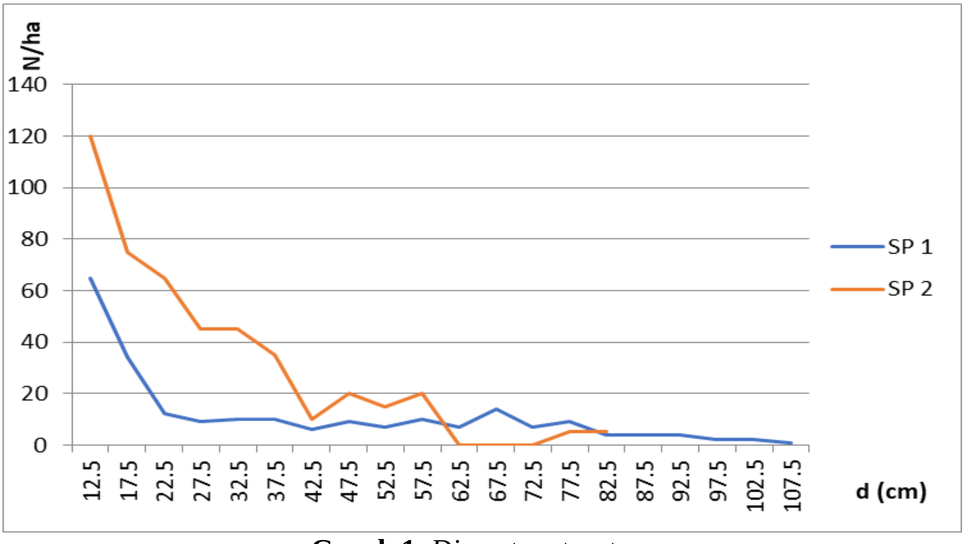
Area	Number of trees N/ha			Basal area G (m^2/ha)			Volume V (m^3/ha)			Volume increment Iv (m^3/ha)		
	beech	ohw	total	beech	ohw	total	beech	ohw	total	beech	ohw	total
SP 1	224	2	226	35.0	0.9	35.9	628.1	1.7	629.8	9.25	0.15	9.4
SP 2	420	40	460	30.3	4.2	34.5	340.4	16.6	357.0	6.38	0.2	6.58

The data in the table above prove that there were significant differences between the upper and lower parts of the virgin forest and that it was necessary to divide them into two units. Extreme site conditions resulted in a greater number of tree species in the upper part of the virgin forests, where, besides beech, there were Norway maple, common ash, sycamore maple, manna ash, hornbeam and cherry, while the lower part of the virgin forests registered only hornbeam besides beech. Looking at the total volume values, it is evident that the upper part of the virgin forests had a smaller volume than that typical of virgin forests, while the lower part had a volume similar to other virgin forests in Serbia. If we compare the values of the forest estimation elements given for the lower part of the virgin forest with the results of earlier research, it is evident that this stand has a slightly higher number of trees compared to the number of trees in the virgin forests of "Danilova Kosa", "Kukavica" and "Busovata" (Ostojić et al., 2008) and smaller compared to the "Felješana" and "Golema Reka" virgin forests. It is interesting to compare the results of the research conducted in "Vinatovača" in 2008 (Ostojić et al., 2008) and today. The number of trees per hectare was 177 back then, and the volume amounted to 709 m^3/ha. Today, the number of trees is slightly higher but the volume is smaller. The basal area of the investigated stands is also lower than the basal area obtained in previous studies conducted in other beech virgin forests in Europe, one of them being "Dobra" in lower Austria with a basal area of 39.7 m^2/ha (Mayer & Reimoser 1978). Looking at the volume of the investigated stand and the volume obtained by previously conducted research in beech virgin forests in Serbia, we can conclude that, as was the case with the number of trees, the researched stand has a medium volume per hectare. The achieved volume increment values in the investigated stands can be explained in two ways. Namely, the lower part of the virgin forest has high volume increment values, although still lower than some economically managed stands. As shown in the research conducted in beech stands, the volume increment of these stands in the area of Kukavica amounted to 10.7 m^3/ha and 10.49 m^3/ha in East Boranja (Čokeša et al., 2008). The reason may be a high number of large-diameter trees that have long passed their culmination period. On the other hand, the volume increment values in the upper part of the virgin forest once again indicate the extreme site conditions that prevail there.

3.1. Diameter structure

The number of trees is the structural element that we first determine when we measure the diameter at breast height of all trees above the measurement limit. The number of trees varies, above all, with the silvicultural form, developmental phase, tree species, site quality class, biological and silvicultural measures provided by the management system, and other biotic and abiotic factors.

More precisely, as the investigated stands are virgin forests, the number of trees directly depends on the site quality class and the development phase of the virgin forest.

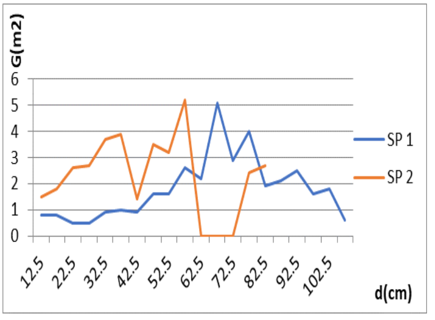


Graph 1. *Diameter structure*

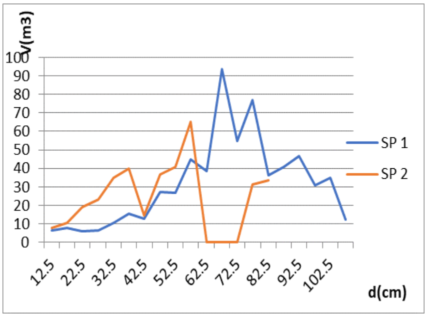
Looking at Graph 1, we see that in the lower part of the stand, the highest number of trees, or 45% of the total number of trees are in the first two diameter degrees. The diameter degrees of 22.5-77.5 cm have approximately the same number of trees, except for the 67.5 cm degree, which has a slightly larger number of trees, i.e., 6% of the total number. From the diameter degree of 82.5 cm to 107.5 cm, the number of trees decreases, and only 8% of the total number of trees can be found in these degrees. As for the upper part of the virgin forest, the largest number of trees are in the smallest-diameter degrees, which indicates that this part of the virgin forest is mostly in the initial phases of development. However, we should have a bit broader view of this. The largest number of trees in smaller-diameter degrees does not result only from natural regeneration, but from extreme site conditions too. Consequently, some diameter degrees (62.5-72.5) have no trees due to the conditions in which trees reached their maximum and died. In contrast, only about 10% of the total number of trees are found in this diameter degree in the lower part of the virgin forest. There are only individual trees in the highest diameter degrees in the upper part of the virgin forest. Most of them are in poor health.

Similar results were obtained in the study of tree diameter distribution in the virgin forests of Eastern, Central and Southern Europe by other authors (Meyer et al. 2003, Commarmot et al. 2005, Drössler & Lüpke 2007, Bilek et al. 2011, Kucbel et al. 2012)

3.2. Basal area and volume structures in investigated stands



Graph 2. *Basal area structure*



Graph 3. *Volume structure*

Looking at the graphs presenting the structure of the basal area and volume (Graphs 2 and 3), it is evident that in the lower part of the virgin forest, the trees that make up most of the basal area and the volume are in the diameter classes of 67.5 and 77.5 cm, which is correlated with the greater number of trees in these diameter degrees. We can also see that the investigated stand is all-aged. It is important to note that this state has resulted primarily from the spontaneous development of the stand and the presence of different development phases in it. Regarding the upper part of the virgin forest, the data on the structure of the basal area and the volume are correlated with the greater number of trees in the diameter degree of 57.5.

3.3. Diameter and height of mean and dominant tree per basal area

Since the field data collection included the measurement of the height of all trees in the sample plots, it was necessary to produce height curves for the investigated stands and flatten them by diameter degrees to make a more detailed analysis. When generating the height curves, statistical parameters were taken into account. Hence, function 1, with a correlation coefficient of R=0.89, was used for the lower part of the stand, and function 2, where the correlation coefficient was R=0.87, for the upper part of the virgin forest.

$$H = d^2 / (1.407183 + 0.1472828 * d)^2 \quad (1)$$

$$H = d^2 / (1.380326 + 0.177082 * d)^2 \quad (2)$$

Table 2. *Mean* d_g *and dominant tree diameter* $d_{g\,max}$ *per basal area*

Sample plot	Tree species	d_g (cm)	$d_{g\,max}$ (cm)
SP 1	Beech	45.1	54.6
SP 2	Beech	31.4	79.4

The values of the mean and dominant tree diameter per basal area indicate different stand conditions and different productivity of the sites in the upper and lower parts of the virgin forest. Comparing these values with the values of the mean tree diameter per basal area produced by the research carried out in the area of the virgin forests "Danilova Kosa" where dg was 61.1 cm and "Kukavica" with a dg of 50.2 cm (Matović et al., 2018), it is obvious that these stands have slightly smaller values of the mean stand diameter per basal area. On the other hand, they are higher than the values of the mean stand diameter per basal area in the beech virgin forests of the northwestern Carpathians, where it was 42.5 cm in the "Badin" virgin forest and 43.2 cm in the "Rožok" virgin forest (Kucbel et al., 2012).

Table 3. *Vrednosti visina srednjeg* h_g *i dominantnog stabla po temeljnici* $h_{g\,max}$

Sample plot	Tree species	h_g (m)	$h_{g\,max}$ (m)
SP 1	Beech	31.4	36.7
SP 2	Beech	20.5	24.4

The values of the mean and dominant tree height per basal area confirm the diversity of site conditions in the investigated virgin forest. If we compare these values with the values produced by previous research, it is evident that they are slightly lower than that measured in the "Danilova Kosa" virgin forest, where it was 39.2 m, and "Kukavica" 32.3 m (Matović et al., 2018).

4. CONCLUSIONS

The results of earlier research on the number of trees and the total volume indicate that more trees are in the "initial phase" of development in the total area of the virgin forest today than 15 years ago. We presume that at that time, there were more large trees in the maturity and decline phases and they died in the meantime.

The diameter structure of the investigated stand corresponds to the diameter structure of typical virgin forests. The structure of the basal area and the volume, as well as the values of the mean and dominant tree diameter and height per basal area in the lower part (SP 1) and the upper part (SP 2) of the virgin forest, call for further study of the entire area of the virgin forest, which was not the case before. Namely, earlier research obviously covered only the lower, more productive part of the virgin forest, while this research deals with the upper, more extreme and from the aspect of production less attractive part of the virgin forest

Based on the above, it is evident that the investigated virgin forest is in different development phases, which is reflected in its structure. In other words, the highest number of trees in the first two degrees, and slightly lower values of the diameter and height of the mean and dominant tree per basal area indicate the strong presence of the initial phase. An even number of trees in the highest number of diameter degrees also indicates the frequent presence of the optimal phase, and a slightly smaller number of trees in the strongest diameter degrees indicates a smaller presence of the aging phase.

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CHARACTERISTICS OF STRUCTURE AND PRODUCTION IN *VINATOVAČA* VIRGIN FOREST

Nikola MARTAĆ, Vlado ČOKEŠA, Snežana STAJIĆ, Danilo FURTULA, Branka PAVLOVIĆ, Miloš RAČIĆ

Summary

This paper studies the characteristics of the structure and production in the “Vinatovača” virgin forest in northeastern Serbia.

The investigated stands belong to the beech mesophilic forest complex and a group of ecological units (ecological types) – montane beech forest (*Fagetum moesiacae montanum*) on different brown soils. Regarding its function, the forest is a strict nature reserve.

The total number of trees in the investigated stands ranges from 224 to 420 trees per ha, with beech being dominant in all parts of the stands. The mean volume of the investigated stands in the lower part of the virgin forest is 629.8 m^3/ha, while it is 357.0 m^3/ha in the upper part of the virgin forest. The share of other tree species in the total volume is below 10%, with a significantly higher number of trees registered in the upper part of the virgin forest. The volume increment in the investigated stands ranges from 6.58 m^3/ha to 9.25 m^3/ha. The volume of the investigated stands, especially in the lower part of the virgin forest, is significantly larger than the volume of the surrounding stands where regular management is carried out.

The forest estimation parameters obtained through this research indicate the stability of the investigated virgin forest. Compared to data from other beech virgin forests in Serbia, they have somewhat lower values, but this is due to the different stages of development in the investigated and other beech virgin forests in Serbia. This statement was also confirmed by the results of research studies carried out in Europe, according to which forest estimation parameters also fluctuate from one virgin forest to another. On the other hand, the typical virgin forest structure indicates its stability.

The part of northeastern Serbia where the virgin forest of this research is located is known as a special site refugium for beech, both in pure or mixed stands. The investigated stand certainly provides guidelines on how and what to do in adjacent stands that are regularly managed by implementing the necessary silvicultural measures. In order to conduct deeper analyses that will provide specific guidelines for managing beech forests based on natural processes that occur in virgin forests, it is necessary to carry out more detailed research, especially with reference to the processes of natural reproduction and regeneration of these forests.

STRUKTURNE I PROIZVODNE KARAKTERISTIKE PRAŠUME VINATOVACA

Nikola MARTAĆ, Vlado ČOKEŠA, Snežana STAJIĆ, Danilo FURTULA, Branka PAVLOVIĆ, Miloš RAČIĆ

Rezime

U radu su proučavane strukturne i proizvodne karakteristke prašume „Vinatovača“ u severoeistočnoj Srbiji.

Istraživane sastojine pripadaju kompleksu bukovih mezofilnih šuma, grupi ekoloških jedinica (ekoloških tipova) – planinska šuma bukve (*Fagetum moesiacae montanum)*) na različitim smeđim zemljištima. Osnovna funkcija ove šume je strogi rezervat prirode.

Ukupan broj stabala u istraživanim sastojinama se kreće od 224 do 420 stabala po ha, pri čemu je bukva dominantno zastupljena u svim delovima sastojina. Prosečna zapremina istraživanih sastojina u donjem delu prašume iznosi 629,8 m^3/ha, a gornjem delu prašume 357,0 m^3/ha sa učešćem drugih vrsta drveća u ukupnoj zapremini ispod 10%, s tim da je u gornjem delu prašume registrovan znatno veći broj vrsta šumskog drveća. Zapreminski prirast u istraživanim sastojinama kreće se od 6,58 m^3/ha do 9,25 m^3/ha. Zapremina istraživanih sastojina posebno donjeg dela prašume je znatno veća od zapremine okolnih sastojina u kojima se sprovodi redovno gazdovanje .

Taksacioni pokazatelji dobijeni ovim istraživanjem ukazuju na stablinost predmetne prašume i u porođenju sa podacima iz drugih prašuma bukve na teritoriji Srbije imaju nešto niže vrednosti ali to je posledica prisustva razlićitih faza razvoja u predmetnoj i drugim prašumama bukve u Srbiji. Potvrda ove konstatacije nalazi se u rezultatima sprovedenih istraživanja na području Evrope gde je takođe, evidentno određeno osciliranje taksacionih pokazatelja od jedne do druge prašume, ali s druge strane struktura koja je karakteristična prašumama ukazuje na njenu stabilnost.

Deo severostočne Srbije gde se i nalazi prašuma obuhvaćena ovim istraživanjem predstavlja poseban stanišni refugijum za bukvu, bilo da se radi o čistim ili mešovitim sastojinama. Istraživana sastojina svakakao mora biti pokazatelj kako i šta raditi u sastojinama koje se nalaze u okolini a sa kojima se pritom redovno gazduje sprovođenjem neophodnih uzgojnih mera. Za potrebe dubljih analiza i davanje određenih smernica za gazdovanje bukovim sumama utemeljenih na prirodnim procesima koji se dešavaju u prašumama neophodno je vršiti još detaljnih istraživanja posebno sa osvrtom na tokove podmlađivanja i obnove ovih šuma.

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Original scientific paper

APPLICATION OF MULTISPECTRAL SENSOR IN QUANTIFICATION OF SOIL PROTECTION COEFFICIENT (XA) IN EROSION POTENTIAL METHOD

Nenad ŠURJANAC[1], Vukašin MILČANOVIĆ[2], Siniša POLOVINA[2], Jovana CVETKOVIĆ[1] Ivana ŽIVANOVIĆ[1]

Abstract: *In this paper, Soil Protection Coefficient (Xa) was quantified through the approach of high resolution multispectral orthomosaic segmentation and classification. The approach was presented in the example of ski lane in ski center Kopaonik. The data collection was performed through application of Unmanned Aerial System equipped with 5-band multispectral sensor and RGB sensor. Data processing was performed with digital photogrammetric and Object Based Image Analyses software. The Soil Protection Coefficient represents the descriptive and very sensitive parameter of Erosion Potential Method. Application of 5 spectral bands, of which 2 bands are very sensitive to the type of land use /land cover allowed precise detection, delineation and classification of different land cover/use types. These types were directly tied to the values of Xa coefficient which were originally proposed by the author of the Erosion Potential Method, professor Slobodan Gavrilović. The final result was a georeferenced digital map classified with both land cover/use and Xa values classes. This approach created the potential to use such maps for further analyses, planning, and modeling of erosion protection measures.*

Key words: Erosion Potential Method, Soil protection coefficient (Xa), Unmanned Aerial Systems, Multispectral sensors, Erosion protection, Object-Based Image Analyses

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PRIMENA MULTISPEKTRALNIH SENZORA U KVANTIFIKOVANJU KOEFICIJENTA UREĐENOSTI SLIVA (XA) U METODI POTENCIJALA EROZIJE

Izvod: *U ovom radu je izvršeno kvantifikovanje Koeficijenta Uređenosti Sliva (Xa) putem segmentacije i klasifikacije multispektralnog ortomozaika visoke rezolucije na primeru ski staze ski centra Kopaonik. Terensko prikupljanje podataka je izvršeno bespilotnom letelicom opremljenom 5-kanalnim multispektralnim senzorom i RGB senzorem. Obrada podataka je izvršena digitalnim fotogrametrijskim softverom i softverom za analizu slika na nivou objekata. Koeficijent Uređensti Sliva predstavlja opisni i veoma osetljiv koeficijent Metode Potencijala Erozije. Primenom 5 spektralnih kanala, od kojih su 2 veoma osetljiva na različite načine korišćenja zemljišta odnosno zemljišnog pokrivača omogućena je precizna detekcija, delineacija i klasifikacija različitih tipova korišćenja i zemljišnog pokrivača. Ovi tipovi su direktno povezani sa vrednostima Xa koeficijenta koje je izvorno predložio tvorac Metode Potencijala Erozije, profesor Slobodan Gavrilović. Krajnji rezultat prikupljanja i obrade podataka predstavlja georeferencirana digitalna karta sa klasifikacijom načina korišćenja/tipa zemljišnog pokrivača, i vrednosti koeficijenta Xa. Ovaj pristup je stvorio mogućnost za potencijalnu upotrebu takvih tematskih karti za dalju analizu, planiranje i modelovanje mera za zaštitu zemljišta od erozije.*

Ključne reči: Metod potencijala erozije, Koeficijent uređenosti sliva (Xa), Bespilotne letelice, Multispektralni senzori, Zaštita od erozije, Analiza slika na osnovu objekata.

1. INTRODUCTION

Soil erosion by water represents the naturally occurring process and geological phenomenon closely tied and an inseparable part of the hydrological cycle. The erosion process gradually increased activity that causes the detachment of the soil particles under the influence of water, which eventually leads to the deterioration of the quality of the soil (Jazouli et al.).

The soil is defined as a surface layer of the hard Earth’s crust, more or less affected and changed under the influence of the hydrosphere, atmosphere, and biosphere. Soil is the main naturally occurring, limited, and non-renewable resource. As a consequence of intense urbanization, industrialization, and exploitation, soil fund is continuously damaged and destroyed at a global level. In the Republic of Serbia, most of the pressure on the soil comes from erosion by water, landslides, and the reduction of organic matter in the most productive layers of the soil. The change in land use has a huge impact on the soil. It was estimated that various degrees of erosion processes affect 80% of the territory of the Republic of Serbia. (Vodič za održivo upravljanje zemljištem na lokalnom nivou u Republici Srbiji, 2018).

The impacts of erosion are multiple. The nature of the impact depends on the positioning of the in-situ and off-site erosion processes – displacement and sedimentation. The erosion processes may have different outcomes in different areas. The erosion in mountain areas may lead to the degradation of the entire ecosystems while the erosion in arable land may lead to loss of soil productivity and reduced crop yield. Even though these are very different outcomes the mechanism of the erosion and the approach to quantify and predict the erosion is the same. (Garcia-Ruiz, J.M, 2010)

For the risk assessment from erosion and assessment of the production of erosion material, there are numerous prediction models in use.

The Erosion Potential Method (EPM) has been widely used in former Yugoslavia and in present Serbia for mapping erosion processes. EPM is a complex methodology designed for usage in the field of Integrated Water Resources Management (Globevnik et al., 2003) This method was based on the Method for Quantitative Classification of Erosion developed in 1954 (Amini et al, 2010). This method allows the assessment of different types of erosion – surface, fluvial, and lateral (Dragičević et al, 2014) It also encompasses erosion mapping, sediment quantity estimation, and torrent classification (Gavrilović et al, 2006).

According to de Vente, the EPM can be considered a semi-quantitative methodology with the inclusion of both descriptive and quantitative factors (de Vente and Poesen, 2005). The descriptive factors are the coefficient of erosion ability of soil, coefficient of protection of soil with vegetation, and coefficient of visible and clearly defined erosion processes in the observed area.

The Erosion Potential Method underwent multiple modifications for various applications. For this purpose, the modification done by Tošić and Dragičević in 2012 (Tošić and Dragićević,2012) is of the most interest. This modification was performed in order to adjust the EPM to the GIS environment. The idea was to apply GPS PDA (handheld positioning device) for the detection and georeferencing of visible erosion processes (**φ**)**.** This modification would especially aim at the geometry of the terrain which would affect the **φ** coefficient of EPM. (Dragičević et al., 2016)

Besides this modification, there were multiple modifications that targeted the values for other descriptive coefficients in EPM (Globevnik et al., 2003), Fanetti and Vezzoli, 2007). In the paper written by Tošić and Dragičević (Tošić and Dragićević,2012), it was presented the idea of application of maps of higher resolution supplemented with digital elevation model (DEM) information. It was proposed that those would allow a more detailed classification of areas of interest. (Tošić and Dragićević,2012) In addition to this premise, high-resolution imagery may prove as a highly beneficial source of information for planning and logistics for field works. (Šurjanac et al. 2019)

The Soil Protection Coefficient (Xa) of the EPM represents the level of vegetative protection of the basin or erosion area. This coefficient is the function of vegetation land cover which covers and protects the land surface from atmospheric effects and erosion forces. This coefficient represents a two-component coefficient. The "X" component represents natural protection while the "a" component represents artificial protection through erosion protection work in a field (construction or bio-technical). The product of these two components is the coefficient that ranges from 0.01 for a well-protected area to 1.0 for bare, unprotected soil. According to (Dragičević et al. 2017 and Ballio et al. 2010) Xa coefficient is one of the most sensitive coefficients in EPM. Dragičević et al tested different sources of land use/cover information (Xa) and noted a very high deviation of the results of the model.

The purpose of this paper is to explore the possibility of airborne multispectral sensors and a set of software solutions to develop an approach for the automatic delineation and classification of various land cover types on high-resolution orthomosaics. This will directly affect the spatial distribution and values of the Xa coefficient of EPM. The idea was to introduce the quantification of otherwise descriptive coefficients and to limit or remove the arbitrary impact of the human factor from the qualification of coefficients. It will also explore the relationship between Xa values and various Vegetation Indices (VI) although the quality of various land cover types and relationship with VI's is out of the scope of this paper.

2. MATERIALS AND METHODS

Study area selected for this purpose is the mountain area in Kopaonik mountain. The area is part of the ski center Kopaonik. Ski lanes are of particular risk for surface erosion. Due to the high slopes and physical exploitation during the winter season ski lanes are very prone to erosion once the vegetation cover is reduced and removed. The development of ski lanes induces soil and vegetation degradation. (Ristić et al, 2012)

The choice of ski lanes as a data source for this paper was due to the fact that ski lanes are prone to erosion processes. They also have various land cover types present which makes them suitable and demanding for high-precision land cover delineation and classification.

The methodology consisted of two main and several sub-processes. The main processes were data collection and data processing.

Instead of relying on satellite and manned aircraft data, this paper required data collected with the unmanned aerial system – UAS, commonly known as a drone. It was equipped with two sensors – RGB and multispectral. The total amount of mapped area was ~28ha. The image acquisition was done between 11 am and 12 pm during the clear weather which resulted in images with high contrast and deep and dark shadows.

RGB refers to Red-Green-Blue channels or colors. It is a 3-channel Bayer pattern[2] sensor that collects the data in the visible part of the light spectrum. This sensor allowed image collection with 256 levels of intensity per channel effectively delivering images with 16 million colors.

Multispectral sensor of choice was MicaSense RedEdge M. This multispectral sensor allowed the simultaneous collection of 5 discrete, narrow-band images, with 65536 levels of intensity per channel. Unlike the RGB sensor, the used multispectral sensor had narrowband channels with a larger total spectral span. Center wavelengths for each of the 5 sensors are – 475, 560, 668, 717, 842. The first three wavelengths correspond with the Blue, Green, and Red parts of the spectrum, while the latest two spectral wavelengths correspond with the Red Edge

[2] Bayer pattern which is a technique whereby instead of requiring each pixel to have its own individual three color planes (requiring 24 bits in total), an array of color filters is placed over the camera sensor requirement for data bits per pixel to a single 8-bit byte (with a known color filter in place)

and Near Infra-Red parts of the spectrum. The last two wavelengths are not visible by the human eye but vegetation, especially alive, dense and healthy vegetation shows a high intensity of reflectance in these areas of the light spectrum. This makes it suitable for differentiation between different types of land cover (Campbell and Randolph 2011).

All collected data was in a form of individual images. All images are georeferenced with geospatial data in WGS 84 geographic coordinate system. The main input for land cover delineation and classification was RGB and 5-channel multispectral orthomosaics shown in image 1.

The first level of processing was digital photogrammetry. The used software was Agisoft Metashape. The products of photogrammetry were colorized point clouds, digital elevation models, and orthomosaics. Multispectral images were co-registered and calibrated through the application of a calibrated spectral panel of which images were taken while collecting the data in the field. Orthomosaics were exported and geospatial information was transformed into a projected coordinate system ETRS89 UTM zone 34N.

The second level of processing was done on produced RGB and multispectral orthomosaics. The Ground Sample Distance (GSD) for RGB orthomosaic was 3.3cm/pixel, while multispectral orthomosaic and Digital Terrain Model- DTM and Digital Surface Model-DSM GSD of 8.4cm/pixel. For the purpose of development of workflow and algorithms for automatic delineation and classification and the drawing of vectors (objects), Object-Based Image Analyses (OBIA) software was used. Trimble eCognition software allowed input of 5-channel orthomosaic and segmentation of the image into small objects. Created objects consisted of groups of pixels with similar contextual values of individual pixels. The segmentation criteria and weight values were set on each of the 5 channels.

The channels with the highest weights were RedEdge and Near Infrared due to their high sensitivity to different land cover types(Šurjanac et al 2015). An example of the resulting segmentation process is shown in image 4.

Initial segmentation resulted in ~1,451,000 objects. The part of orthomosaics with objects after initial segmentation is shown in image 4. All objects have assigned values for 9 initial attributes. These values were reflectance values for 5 spectral channels. Additional information was elevation values in the form of Digital Terrain Model (DTM) and Digital Surface Model (DSM) which are shown in image 2. The next process requested calculations of vegetation indices which used all 5 channel values to assign numerical values to each of the segmented objects. Vegetation indices that were used for differentiation of all present types of land cover were Normalized Difference Vegetation Index(NDVI), Normalized Difference Red Edge (NDRE), and Visible Atmospheric Resistance Index (VARI).

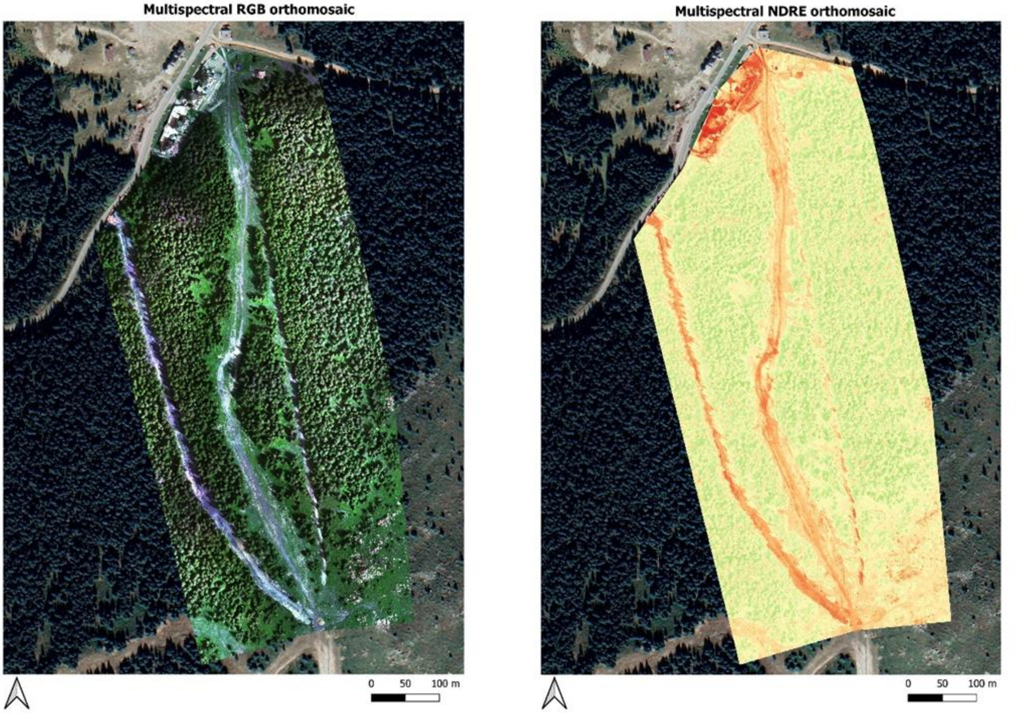

Image 1. *Multispectral orthomosaics RGB and NDRE*

NDVI index required reflectance values in NIR and RED channels, NDRE required NIR and Red Edge values, while VARI required RED, GREEN, and BLUE channels. DTM and DSM elevation models were used to produce a normalized Digital Elevation Model (nDEM) which effectively represented the height of the objects in the field. The raster file with the information on height is shown in image 3. In order to classify Non-Vegetated surfaces and Bare rock surfaces two conditions were supposed to be fulfilled. The height should be less than 0.3m for Non-Vegetated and 2 m for Bare rocks and the VARI index should be lower than -3500 for Bare-Rocks and lower than -300 for Non-Vegetated surfaces.

For vegetation classification NDVI and NDRE values alongside nDEM values were used to classify vegetation as Sparse vegetation (nDEM<0.3m, NDRE<0.3), Low Vegetation (nDEM<0.3m, NDVI>0.5), High Vegetation (nDEM>0.3m, NDVI>0.5).

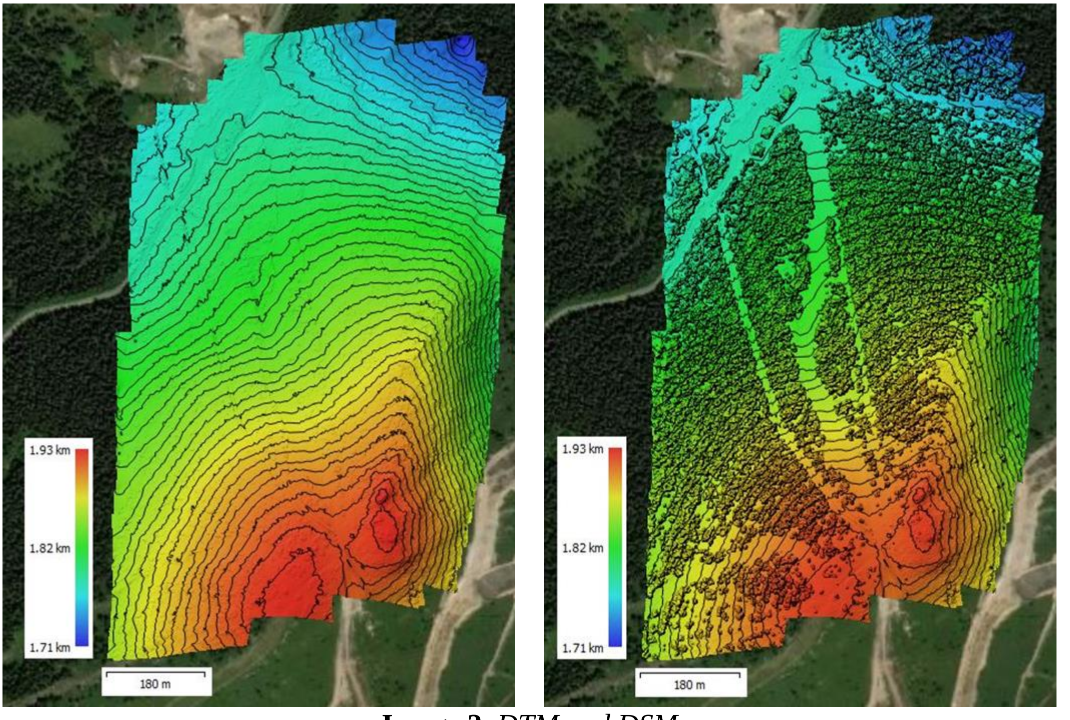

Image 2. *DTM and DSM*

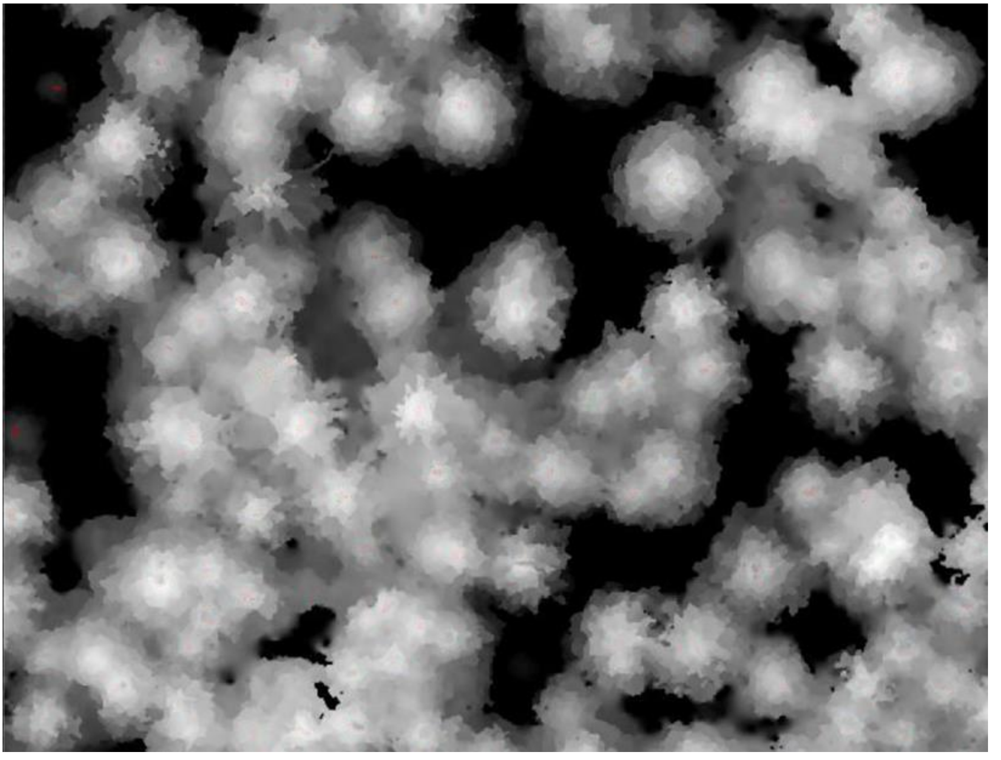

Image 3. *nDEM*

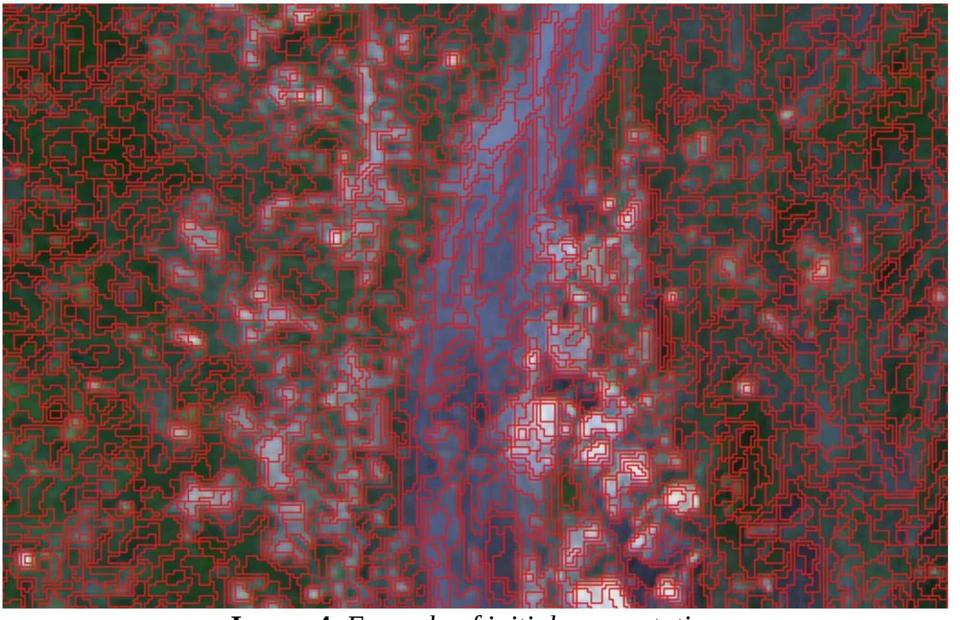

Image 4. *Example of initial segmentation*

3. RESULTS AND DISCUSSION

Initial segmentation resulted in ~1.451 million vectored objects. Classification and merging of adjacent objects of the same classes resulted in ~91 thousand polygons exported in the form of a .shp file. The example of resulting vectors is presented in image 5.

The classification of the objects is shown in image 6. Classification resulted in 5 classes – Bare rocks and disturbed soils, Non-Vegetated areas, Sparse vegetation (low-quality grassland), Low vegetation (good-quality grassland), and High vegetation (trees, forest).

These classes were directly related to the original values defined by Gavrilović (Gavrilović, 1972). The “a” component was 1, since there was no erosion protection work in the area. This meant that classes could be directly transformed into Xa coefficient values. Corresponding Xa values to the aforementioned classes are 1.0 for Bare rocks and disturbed soils, 0.9 for Non-Vegetated areas, 0.6 for Sparse vegetation, 0.4 for Low vegetation, and 0.05 for Trees. This is shown in image 5.

Area which each class occupy is: Trees 172665.332m^2, Sparse vegetation 4332.41 m^2, Non- vegetated 23821.201 m^2, Low vegetation 73303.331 m^2, Bare rock and disturbed soils 7688.704 m^2

The distribution of area classified in each class and Xa values are presented in Chart 1.

The resulting vectors (objects) show high precision of detection and delineation of different land covers/land uses. This is shown in image 6. This image shows multispectral orthomosaic overlaid with automatically generated vectors with 16 attributes.

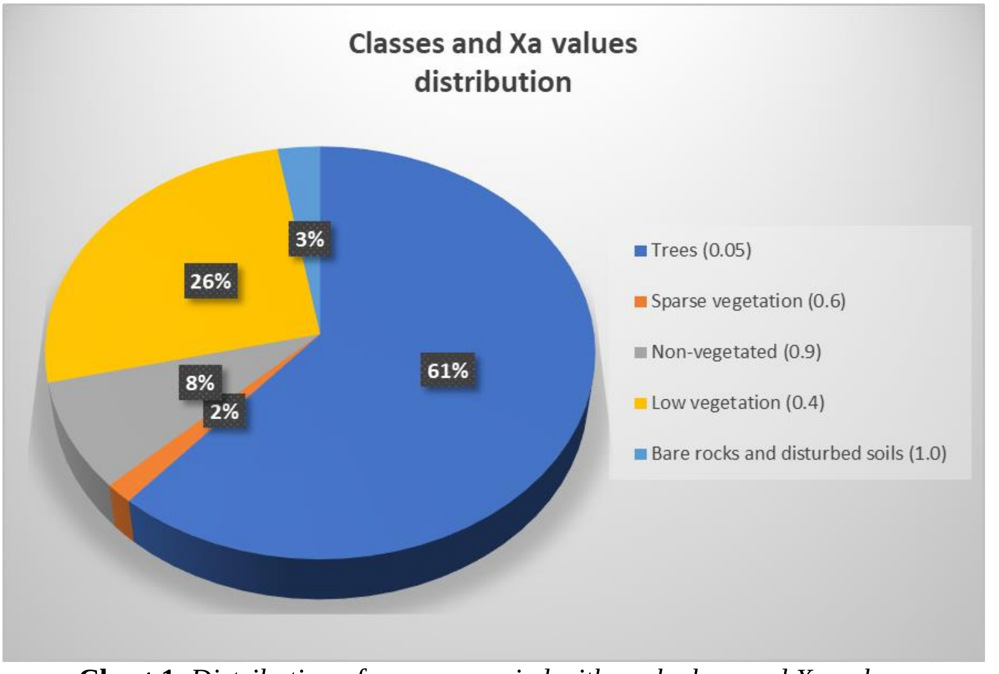

Chart 1. *Distribution of areas occupied with each class and Xa values*

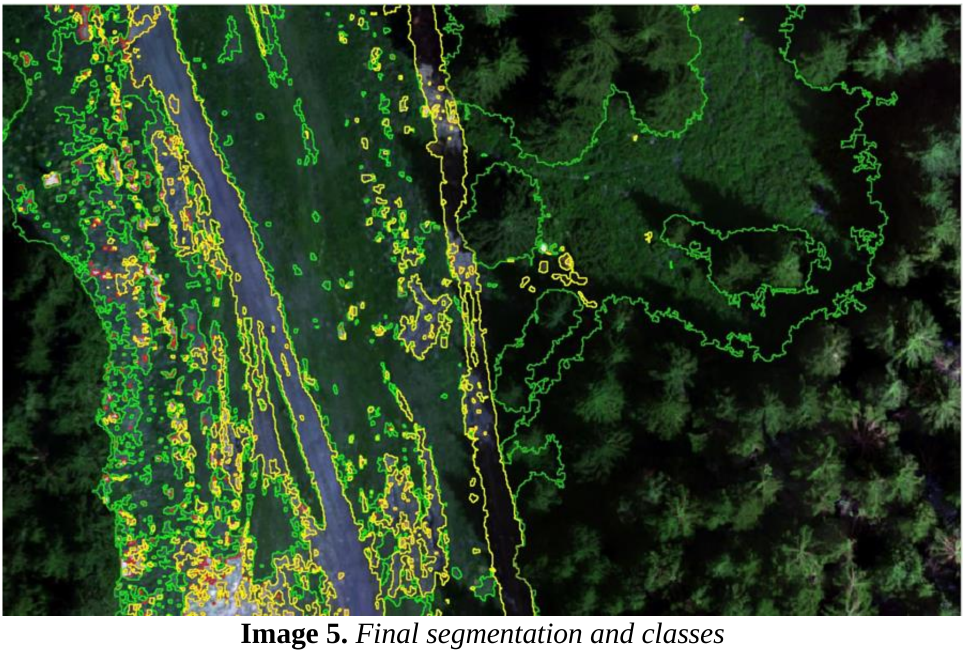

Image 5. *Final segmentation and classes*

The areas of individual objects range from 0.5 meters or below to hundreds and thousands of square meters. The resulting resolution of 8cm/pixel allows the creation of a high variety of sizes of objects and polygons which can be scaled up and/or down to find the most suitable size which is the most usable for calculations of the erosion coefficient Z on a local level. The value of localization and georeferencing of parameters of EPM is in the ability to perform ground truth data collection which can be done with absolute precision. This would also allow planning of erosion protection that can target the areas which are the most critical for sediment production and slope stability which will affect the quality of the ski lane.

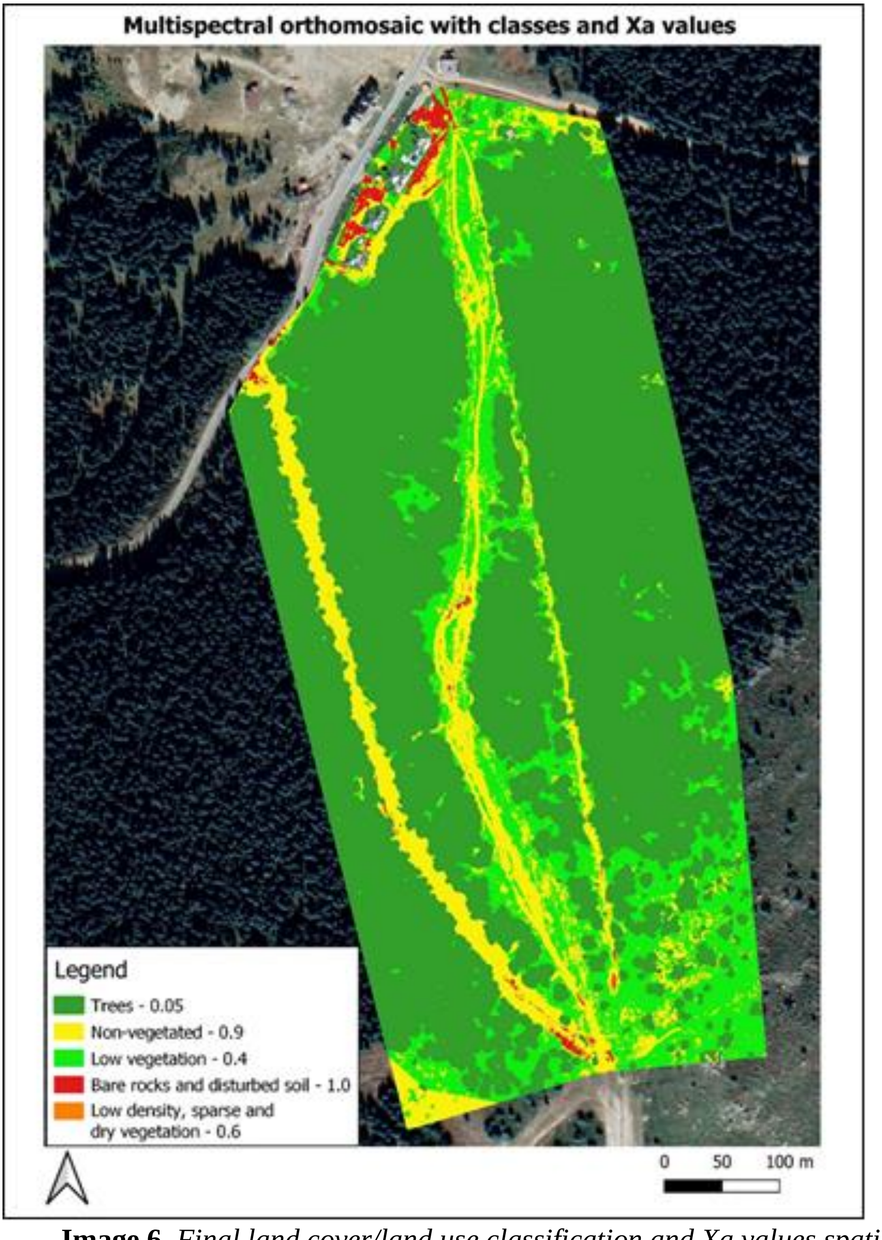

Image 6. *Final land cover/land use classification and Xa values spatial distribution*

4. CONCLUSION

The ability to perform the segmentation of the orthomosaic based on values in an individual channel and classify the created objects on the ground of values which are directly associated with Xa coefficient creates the potential to segment the orthomosaic on the ground of the parameter of digital elevation models and slope which will directly affect other descriptive coefficients of the EPM.

This approach can provide the ability to quantify the descriptive parameters based on spectral values and geometries, rather than on the varying experience of the individual engineers in the field. Combination of RGB and multispectral data provides the ability to verify the multispectral classification of land use/land cover on 2-3cm/pixel RGB orthomosaic. RGB orthomosaic provides ability to detect fine level of detail and delineation of various land cover types. However, for features that affect the results of EPM that might be hidden below the canopy field verification may be required. This kind of field data acquisition, data processing, classification, and analysis allows not only adequate and precise planning of protection measures and modeling, but it allows the inclusion of more environmental parameters for a holistic approach and provides the basis for frequent and regular monitoring of the development of erosion processes and effect of proposed measures and models.

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APPLICATION OF MULTISPECTRAL SENSOR IN QUANTIFICATION OF SOIL PROTECTION COEFFICIENT (XA) IN EROSION POTENTIAL METHODOLOGY

Nenad ŠURJANAC, Vukašin MILČANOVIĆ, Siniša POLOVINA, Jovana CVETKOVIĆ, Ivana ŽIVANOVIĆ

Summary

Erosion processes pose a danger to ski lanes. Ski lanes in the ski center Kopaonik are heavily exploited during the winter season. During the late spring and summer season, the ski lanes are used for hiking and quad bike enthusiasts. This puts additional pressure on the slopes already prone to water erosion processes. The prevalent methodology for erosion mapping is Erosion Potential Method defined by professor Gavrilović. This is an empirical semi-quantitative method that relies on 3 descriptive coefficients. One of these is the Soil Protection Coefficient (Xa). This coefficient is represented by numerical values which describe the type of land use/land cover present in the observed area.

This paper presented the approach of automatic quantification of Xa values based on spectral and geometrical characteristics of the groups of pixels in digital orthomosaics. The paper presented the entire pipeline from field data collection over processing to the final classification and digital map production.

Field data was collected with UAS (drone) equipped with RGB and 5-band multispectral sensor. These data were used for automatic object extraction, delineation, and classification of land use/land cover types present in the observed area. This approach resulted in the generation of the digital georeferenced map that presents the high-resolution spatial distribution of Xa coefficient values which is ready for application in the Erosion Potential Method, and planning of erosion protection measures. The approach presented in the paper is also applicable to the automatic extraction, delineation, and classification of other descriptive coefficients in the Erosion Potential Method.

PRIMENA MULTISPEKTRALNIH SENZORA U KVANTIFIKOVANJU KOEFICIJENTA UREĐENOSTI SLIVA (XA) U METODI POTENCIJALA EROZIJE

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Rezime

Erozioni procesi predstavljaju opasnost za ski staze. Ski staze u skijaškom centru Kopaonik se veoma aktivno koriste tokom zimske sezone. Tokom prolećne i letnje sezone skistaze se koriste za pešačenje i za vožnju kvadova. Ovo dodatno opterećuje padine koje su već izložene erozionim rizicima. U Republici Srbiji i okolnim zemljama preovlađajuća metoda za kartiranje erozionih procesa je Metoda Potencijala Erozije koja je razvijena od strane profesora Gavrilovića. U pitanju je empirijska polu-kvantitativna metoda koja u se oslanja na 3 opisna keoficijenta. Jedan od njih je Koeficijent uređenja sliva (Xa). Ovaj keoficijent je predstavljen brojčanim vrednostima koje opisuju način na koji se koristi zemljište, odnosno tip zemljišnog pokrivača u posmatranom području.

U ovom radu je predstavljen pristup za automatsku kvantifikaciju Xa vrednosti na osnovu spektralnih i geometrijskih karakteristika grupisanih piksela na multispektralnom ortomozaiku. Rad predstavlja kompletan pristup od terenskog prikupljanja podataka preko obrade podataka do krajnje klasifikacije i izrade digitalne karte.

Terensko prikupljanje podataka je izvršeno bespilotnom letelicom (dronom) sa RGB i multispektralnom kamerom. Ovi podaci su korišćeni za automatsko definisanje poligona i klasifikaciju načina korišćenja zemljišta/tipova zemljišnog pokrivača u posmatranom području. Ovaj pristup je rezultirao u izradi digitalne georeferencirane karte koja predstavlja prostorni raspored Xa vrednosti visoke rezolucije, koja je spremna za dalju primenu u Metodi Potencijala Erozije, i planiranje protiv erozionih radova. Pristup prikazan u radu takođe je pogodan za definisanje poligona i klasifikaciju i drugih opisnih parameter Metode Potencijala Erozije.

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APPLICATION OF RETAINING STRUCTURES IN REHABILITATION OF LANDSLIDE ON STOLICE – KRUPANJ REGIONAL ROAD

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Abstract: *Landslides can be triggered by different factors including changeable weather conditions, prolonged heavy rains, complex terrain, traffic loads, etc. This paper deals with the problem of landslide rehabilitation on the Stolice-Krupanj regional road that resulted from vehicle loads and soil saturated with water. The technical measures used in the rehabilitation of the landslide included a concrete retaining wall and a geogrid-reinforced soil structure. Based on data related to soil obtained from laboratory tests, slope stability before and after applying rehabilitation measures was tested in the GEO5 Geotechnical software. The stability of the concrete wall was examined analytically by calculating the factors of safety against toppling and horizontal displacement. Both technical measures of given physical-mechanical properties increased the stability of the slope.*

Key words: landslide rehabilitation, concrete wall, geogrid-reinforced soil structure, GEO5.

PRIMENA POTPORNIH KONSTRUKCIJA U SANACIJI KLIZIŠTA NA REGIONALNOM PUTU STOLICE – KRUPANJ

Izvod: *Na pojavu klizišta mogu uticati mnogi faktori: promenljivi klimatski uslovi; velika količina padavina u kratkom periodu; složenost strukture terena; opterećenja od saobraćaja, itd. Rad se bavi problemom sanacije klizišta na regionalnom putu Stolice – Krupanj, koje je nastalo usled opterećenja od vozila i zasićenja zemljišta vodom. Tehničke mere koje su primenjene za sanaciju klizišta su: betonski potporni zid i potporna konstrukcija*

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od tla i geomreže. Na osnovu podataka o zemljištu iz laboratorijskih ispitivanja izvršene su provere stabilnosti kosina pre i posle primenjenih mera sanacije u programu GEO5, dok je stabilnost betonskog zida ispitivana analitičkim proračunom faktora sigurnosti na prevrtanje i horizonatalno pomeranje. Obe tehničke mere, zadatih fizičko mehaničkih karakteristika, povećale su stabilnost padine.

Ključne reči: sanacija klizišta, zid od betona, potporna konstrukcija od tla i geomreže, GEO5

1. INTRODUCTION

Landslides are among the most common hazards both in our country and worldwide. Most landslides are triggered by heavy rain and/or snowmelt, earthquakes and human activities. They can have substantial socioeconomic impacts and often cause the loss of human lives (Mitrović, 2014). Many case studies indicate that landslides can cause extensive damage (Kesseli, 1943; Campbell, 1975; Govi and Sorzana, 1980; Govi and Mortara, 1981; Sidle and Swanston, 1982; Ellen and Wieczorek, 1988).

Landslide rehabilitation requires the engagement of a wide range of resources. There are various measures and means to conduct the rehabilitation of landslides. They can be classified into several categories, such as changes in slope geometry, replacement of existing soil with better physical and mechanical properties, drainage of the terrain, and/or removal of surface water, retaining structures and internal reinforcement of slopes (Popescu, 2002, Mitrović, 2014), as well as the use of vegetation in shallow landslides (Marković et al., 2018). Landslide rehabilitation is often performed to protect a building or road (Marković et al., 2019). The application of technical measures, such as retaining structures made of concrete or geogrid-reinforced soil, is a solution that significantly increases the stability of newly designed slopes (Jotić et al., 2007, Niroumand et al., 2012). If several potential solutions are examined, a multi-criteria decision-making method should be applied to choose the most efficient solution (Cvetković, 2020).

The paper presents the analysis of proposed solutions for the rehabilitation of a landslide with retaining structures and the effects of the measures on the change in the stability of the terrain on the Stolica-Krupanj regional road. The paper aimed to elaborate on applying modern and traditional technical solutions for the rehabilitation of landslides in this locality.

2. MATERIAL AND METHOD

2.1. Material

A landslide on a section of the regional road R-211 Stolice-Krupanj in western Serbia at km: 0+578.6 - 0+605.690 was selected for the research area (Figures 1a and 1b).

The most important data on the landslide, including slope geometry, lithological layers, geotechnical profiles and results of physical and mechanical parameters of the soil, were taken from the “Elaborate on geotechnical conditions of landslide rehabilitation”, hereinafter –Elaborate (Institute of Geotechnics).

2.1.1. Study area

Regarding its configuration, the terrain is mountainous and hilly. This part of the road is located between the absolute terrain elevations of 425-460 m above sea level. Regarding the bedrock, the wider research area belongs to the Jadar tectonic area. The landslide was triggered by the movement of different materials, including the embankment of the road body and the deluvial silty clay to fine-grained surface cover and the physiochemically altered impermeable zone of clay shale in the bedrock. The landslide caused deformations on a section of the roadway and the slope under the road. The average width of the resulting landslide was 20.0 m, and the length was about 30.0 m. The depth to the sliding plane in the central part of the landslide was 4.0 to 4.5 m. The height difference from the top of the main scarp to the foot was 15.0 m. The main scarp was very pronounced, reaching a height of 1.5 m on the roadway itself.

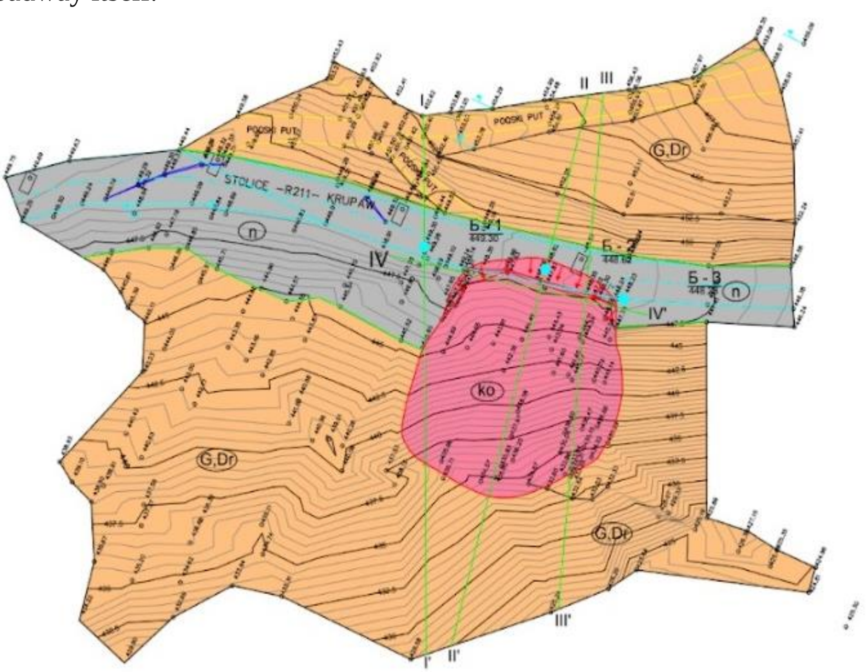

Figure 1a. *Part of the engineering geological map showing the landslide (Source: Elaborate)*

Figure 1b. *Legend for the part of the map shown in Figure 1a (Source: Elaborate)*

The analysis of the slope stability and the calculation of the stability of the applied solutions was performed on profile II - II' (Figure 2). This profile was chosen as typical or critical, as it was the longest and steepest and showed the landslide in the direction of sliding.

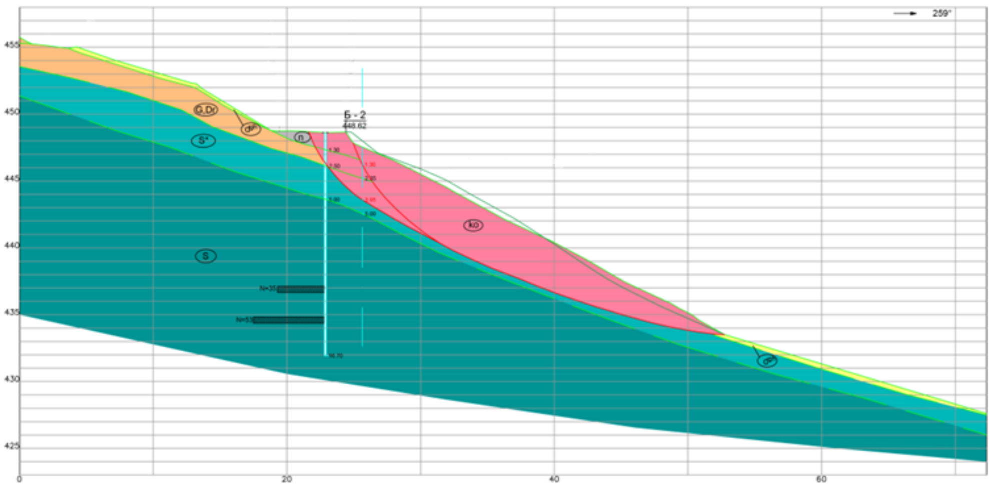

Figure 2. *Characteristic geotechnical section of terrain II-II` (Source: Elaborate)*
Legend: n-embankment and roadway structure; co-colluvium, G, Dr-clay with crushed fines; S-clay shale; S-clay shale; dgh-humus clay*

2.1.2. Physical and mechanical parameters of lithological layers

Table 1. *Geotechnical data of lithological layers used in calculations (Source: Elaborate)*

	Layer thicknes [m]	γ [kN/m^3]	φ_{usl} [˚]	φ_r [˚]	φ [˚]	c [kPa]	c_r [kPa]	Mv [kPa]
Embankment and roadway structure (n)	0.2-1.0	21.0			32	0,0		$25 \cdot 10^3$
Colluvium (co)	1.2-3.5	19.0	28	15	22	5.0	3.0	$5 \cdot 10^3$
Clay with fines[1] (G, Dr)	1.1-2.2	18.5		18	22 - 28	5.0 – 20.0	7.0	$1\text{-}3 \cdot 10^4$
Clay shales (S*)	0.5-3.0	21.0		15 - 22	25	22.0	3.0 - 4.0	8
Clay shale (S)	>3.5	23.0			32	30.0		$4 \cdot 10^4$

Legend: 1 – clay with crushed fines to limestone fines in a silty clay base; γ – volumetric weight; φ – angle of internal friction; c - cohesion; Mv – bulk modulus; φ_{usl} – value of mobilised friction angle determined by back analysis; φ_r – residual value of shear stress parameter determined under laboratory conditions; c_r – residual value of cohesion obtained under laboratory conditions.

Table 1 shows the values of physical and mechanical parameters of the lithological layers defined by exploratory drilling. The residual values of the shear stress parameters were adopted because they were disturbed after the landslide triggering.

In order to achieve complete stability of the slope and the road, it is necessary to terrace the slope (landslide body). The adopted values of soil parameters that are required to calculate the stability of designed terraces:

- volumetric weight γ =19.0 kN/m^3,
- angle of internal friction φ= 22˚,
- cohesion c=12.0 kPa

The maximum traffic load expected on a regional road adopted for the calculation amounted to120 kN/m^2.

2.2. Methods

To achieve the optimum solution for landslide rehabilitation, it is necessary to study:

- the stability of the displaced slope (before applying the solution),
- dimensioning of the retaining structures and
- terrain stability with technical measures applied.

We studied two solutions proposed for landslide rehabilitation:

1. traditional – a gravity retaining wall made of concrete and
2. modern – a retaining structure made of geogrid-reinforced soil.

Both solutions required the planning or terracing of the slope under the selected structures. Software package *Geotechnical Software GEO5* (Fine spol. s r.o, Czech Republic) was used to study the stability of the slope before the application of technical measures based on the adopted parameters obtained from the analysis of the existing documentation (Table 1). The same software was used to study the dimensioning of the retaining structure made of geogrid-reinforced soil. After adopting the optimum dimensions for both solutions using the GEO5 software, the local stability of the slope with retaining structures was tested, as well as the general stability of the terrain levelling solution (terracing) together with retaining structures (Solution 1 and Solution 2).

2.2.1. Slope stability analysis

The methods of Bishop and Yanbu were used to estimate slope stability. AW Bishop's method is applied to test the stability of slopes with the slip surface shaped as an arc of a circle. It was applied to test the partial (local) stability of designed slopes. The safety factor for the slip surface is obtained by the following equation (Todorović, 1991):

$$F_s = \frac{1}{\sum W \, sin\alpha} \cdot \sum\{[c'b + W(1 - r_u)tg\varphi'] \frac{1}{m_\alpha}\} \quad (1)$$

Wherein:
W_1 – weight of non-submerged part of the slip, α – angle of inclination of the main slip to the horizontal, b – slip width, c – cohesion, φ – internal friction angle, U_s – pore water pressure, F_o – assumed safety coefficient, X_n and X_{n+1} – vertical shear forces along the sides of the slips, E_n and E_{n+1} – horizontal shear forces on the sides of the slips.

Yanbu's method is an analytical solution applicable to the slip surface with slips of arbitrary shape. In our study, it was applied to examine the general stability of the slope. The following equation was used to estimate this stability (Todorović, 1991):

$$F = \frac{f_0 \frac{\sum[c' + (p-u)tg\,\varphi']\Delta x}{n\alpha}}{p \cdot tg_\alpha \Delta x + Q} \quad (2)$$

Wherein:
f_0 and $n\alpha$ – coefficients determined by the diagram, c' effective cohesion, φ' – effective angle of internal friction, p – mean vertical pressure at the base of the slip, Δx – slip width, u – pore pressure, Q – horizontal force (tensile force, horizontal seismic force, etc.)

The safety factor for capital structures is Fs=1.3-1.5 and for other structures Fs=1.1-1.3 (Todorović, 1991). Since the analysed road is regional, we adopted the safety factor of Fs =1.3-1.5 to consider the slope stable.

2.2.2. Dimensioning of the concrete retaining wall

The dimensions of the concrete wall were determined using the static analysis for the toppling stability (Todorović, 1991, Equation 3) and horizontal displacement stability (Todorović, 1991, Equation 4) of retaining structures based on the values of the active pressure obtained by the graphoanalytical procedure (Todorović, 1991).
We obtain the safety factor Fs using the following equation:

$$F_s = \frac{M_W}{M_r} \tag{3}$$

The slope is stable against toppling on the foundation contact if Fs > 1.5.

The horizontal displacement of the retaining wall under the action of the horizontal force component (Rh) can occur along the contact surface of the footing with the ground. It is defined by the stability factor Fs (source):

$$F_s = \frac{R_V \cdot tg_\varphi}{R_h} \tag{4}$$

The structure is stable if Fs>1.5.

If the given analysis shows that the wall is not stable, another stabilisation measure is introduced in the form of bevelling the footing – ω (Jevtić, 1975):

$$S' = \frac{S - 0{,}2Z}{coscos\ \omega} \tag{5}$$

$$N = R_V \cdot cos\ cos\ \omega\ + R_H \cdot sin\ sin\ \omega \tag{6}$$

$$T = -R_V \cdot sin\ sin\ \omega\ + R_H \cdot cos\ cos\ \omega \tag{7}$$

It follows that the safety factor against sliding is:

$$Kp = \frac{N \cdot F}{T} \tag{8}$$

The safety factor is met if Fs > 1.5.

2.2.3. Geostatic calculation of the retaining structure made of geogrid-reinforced soil

To calculate the safety factor, we assume that there is a resisting force at each point of the intersection between the georeinforcement and the potential sliding surface (Mitrović, 2014):

$$F_S = \frac{M_O + \sum_{i=1}^{m} T_i \cdot y_i}{M_S} \tag{9}$$

Wherein:
Ti – resistance force of geosynthetics in layer i, *yi* – arm of Ti force to the center of rotation O,

m – number of geosynthetics layers, Ms – moment of all shearing forces around the center of rotation.

For a circular cylindrical sliding plane, it is assumed that the slope is optimally stable when the stability factor ranges from 1.5 to 2.0.

3. RESULTS AND DISCUSSION

The analysis of slope stability with multiple sliding planes determined the lowest safety factor of Fs=0.86 (Equation 2). Considering the condition of stability of Fs>1.3, the analysed slope was unstable. When analysing the displaced sliding body in the segment of the road body itself (main scarp), the highest values of transfer forces were determined. Taking into account the need to rehabilitate the landslide and protect the road, the retaining structures were positioned directly below the road body (Figures 3 and 5).

3.1. Solution 1 – Concrete wall

This solution included several positions of the wall at different distances from the road, with several geometric characteristics of the wall of simple and complex construction: the width of the foundation from 3.0 m to 4.5 m, and the height of the wall from 5.0 m to 7.5 m. The volume weight of γ =24.0 kN/m ^{3} was adopted for MB30 concrete. Table 2 shows the force values based on which the concrete retaining structure was dimensioned.

The adopted dimensions with which the wall meets the condition of stability are as follows:

- Foundation width B=4.5 m
- The height of the retaining wall H=8.1 m

A simple construction made of unreinforced concrete was selected.

Table 2. *Forces acting on the retaining wall; Safety factor*

Active earth pressure	Ea=377.83 kN/m2
Horizontal component of the resultant	Rh=370 kN/m
Vertical component of the resultant	Rv=671 kN/m
Stability of retaining structure against toppling	Fs = 2.23
Stability of retaining structure against horizontal displacement (without bevelling)	Fs = 0.77
Bevelling of footing	8 °
Stability of retaining structure against horizontal displacement (with bevelling)	Fs = 1.58

The analysis of the stability of the concrete retaining structure built to reduce the risk of toppling (Equation 3) resulted in a safety factor of Fs = 2.23, which means that the stability condition was met, and the retaining wall was stable. However, the stability of the structure against horizontal displacement under the effect of the horizontal force Rh (Equation 4) was not confirmed. For this reason, the footing (ω) was bevelled by 8˚, so the height of the structure was now 8.1 m. The safety factor thus amounted to Fs = 1.58 (Equation 8) and the structure was stable regarding the horizontal displacement (Fs > 1.50).

For the rehabilitation of the part of the landslide that extended under the concrete structure terracing was proposed. The proposed width of each planum was 3 m, and the inclination of the planum to the horizontal was 3˚ (inclination down the slope). The height of the planum differed, and going in the direction from the retaining wall to the bottom of the slope, the heights were 3.0 m, 2.0 m, 2.0 m, and 4.4 m (Figures 3 and 4).

The general stability of the slope was Fs=3.55 (Figure 3), which meant that the newly designed slope was stable. The analysis of the second sliding plane that passed directly through the structure produced a safety factor that met the stability condition Fs=11.88 (Figure 4).

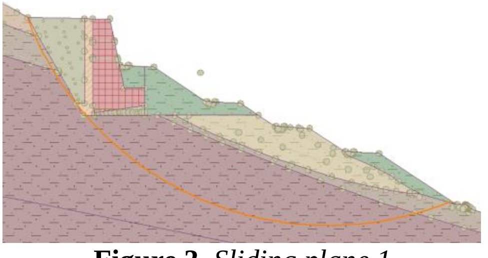

Figure 3. *Sliding plane 1*

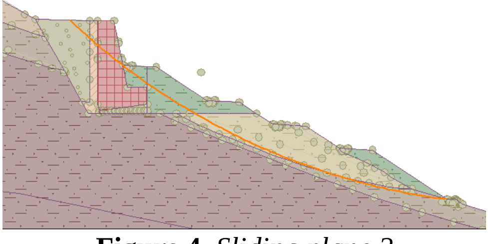

Figure 4. *Sliding plane 2*

3.2. Solution 2 – Retaining structure made of geogrid-reinforced soil

The stability was determined based on the primary geo-reinforcement that provides tensile resistance in the soil. Geogrid layers were placed at a vertical spacing of 1 m, which made the total height of the retaining structure from the ground and the geogrid amounted to 5 m. Table 3 shows the characteristics of the geogrid proposed for landslide rehabilitation.

Table 3. *Geogrid characteristics*

Ordinal number of the geogrid	Geogrid length [m]	Tensile strength Rt [kN/m]
1.	6.5	50.0
2.	7.0	50.0
3.	7.5	50.0
4.	8.0	50.0
5.	8.5	50.0

The tensile strength of the geogrid adopted for the calculation was 50 kN/m.

Table 4 shows the results of testing the local stability of the slope with a retaining structure using Bishop's method (Equation 1).

Table 4. *Local slope stability test*

Sum of active forces	Fa=527.45 kN/m
Sum of passive forces	Fp=893.96 kN/m
Moment of displacement	Ma=6424.29 kNm/m
Moment of resilience	Mp=10888.42 kNm/m
Safety factor	Fs=1.69 > 1.50

The safety factor obtained from the stability analysis (Table 4) met the stability condition (Fs>1.5), which indicates that the part of the slope covered by the sliding plane was stable (Figure 5).

Terracing was proposed as the most suitable measure to stabilise the entire landslide. The proposed width of each planum was 3 m, while the slope of the planum to the horizontal was 3° (inclination down the slope). The heights of the planum differed, and towards the bottom of the slope, they were 3.0 m, 3.0 m, 3.0 m, and 4.0 m.

The general stability of the slope for the tested sliding plane (Figure 6) was Fs=2.12, which means that the stability condition was met (Fs > 1.3), and the newly designed slope was stable with the applied measures.

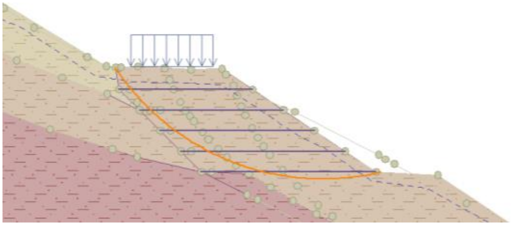

Figure 5. *Sliding plane 1*

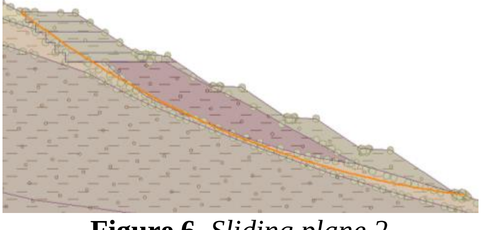

Figure 6. *Sliding plane 2*

3.3. Analysis of proposed solutions for rehabilitation

By comparing the obtained safety factors without the applied measures (Fs=0.86) and with applied measures (Solution 1 Fs=3.55 and Solution 2 Fs=2.12), we can see that a significant increase in the safety factor is achieved. Expressed as a percentage, the application of the first solution increases the safety factor by 313%, and relative to the stability condition 136%. We can say that the dimensions used in this solution are overestimated and calculations should be repeated to reduce material consumption. Regarding the second solution, the percentage increase is 146%, and relative to the stability condition, it is 41%, which means it can be adopted without repeating the calculations.

The retaining concrete wall receives the stress of the road body and the soil behind the wall and ensures their primary stability. The construction with its own weight reduces the active moment of rotation from the earth pressure and thus ensures greater stability (Fs=3.55). The analysis of the second sliding plane (Figure 4) produced a significantly higher safety factor Fs=11.88, which can be explained by the position of the sliding plane passing through the retaining structure. The retaining structure made of concrete has high values of resistance parameters, and thus the entire slope is more stable. The stability of the slope can be further enhanced with the use of vegetation on the planums, the role of which increases with time. For maximum effects of vegetation, planting arrangement should be carefully considered. (Marković et al., 2018).

Considering the current trend towards solutions that follow the concept of “soft engineering” (Popescu, 2002, Prambauer et al., 2019, Wu et al., 2020), the retaining structure made of geogrid-reinforced soil is a more acceptable solution for landslide rehabilitation. Furthermore, when choosing the most effective solution for landslide rehabilitation, it is not enough to consider only the criterion of stability. Methods of multi-criteria decision-making that include a larger number of criteria (e.g., stability, price, length of exploitation, ecological solution, etc.) provide a more reliable way to reach the optimal solution for landslide rehabilitation.

4. CONCLUSIONS

In 2011, deformations were observed on the regional road Stolice - Krupanj, which clearly indicated the existence of a landslide. The landslide also covered part of the road and thus hindered the traffic.

By analysing the stability of the slope, the value of the safety factor Fs=0.86 was obtained, which proved that the terrain was not stable.

The analysis of the stability of the slope with technical measures applied show that Solution 1 – a retaining wall made of concrete and Solution 2 – retaining structure made of geogrid-reinforced soil, together with levelling solutions (terracing) increase the safety factor. Solution 1 increases the general safety factor to Fs=3.55 and Slution 2 to Fs=2.12.

Looking at the achieved safety factors, we can conclude that both technical solutions for landslide rehabilitation meet the condition of stability.

In order to choose the best solution for landslide rehabilitation, it is necessary to conduct multi-criteria decision-making analyses. These analyses would set the criteria how to rank the solutions, for instance according to construction costs, structure lifetime, fitting into the environment, proneness to damage, etc. (Cvetković et al., 2022).

In a broader sense, it is of great importance that, in practice, landslide processes are timely recognised and addressed first with preventive and temporary, and then with long-term measures. In this way, not only do we use resources most efficiently, but also prevent the damage caused by landslides.

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APPLICATION OF RETAINING STRUCTURES IN REHABILITATION OF LANDSLIDE ON STOLICE – KRUPANJ REGIONAL ROAD

Jovana CVETKOVIĆ, Nikola ŽIVANOVIĆ, Vukašin RONČEVIĆ, Grozdana GAJIĆ, Milan KABILJO

Summary

The paper presents an analysis of slope stability on the regional road Stolice - Krupanj.

The triggering of the landslide caused deformations on a road section and the slope under the road. The average width of the landslide was 20.0 m and the length was about 30.0 m. The depth to the sliding plane in the central part of the landslide was from 4.0 to 4.5 m. The height difference from the top of the main scarp to the foot part was 15.0 m. The main scarp was very pronounced, reaching a height of 1.5 m on the roadway.

The aim of the research was to show the possibilities of applying modern and traditional technical solutions for the rehabilitation of landslides in the locality.

The following technical measures were proposed: a concrete retaining wall and a retaining construction made of geogrid-reinforced soil. In order to achieve complete stability of the slope and the road, it was necessary to terrace the slope (body of the landslide).

In order to find the optimal solution for landslide rehabilitation, the following analyses were carried out: analysis of the stability of the displaced slope (before applying the solution), dimensioning of the retaining structures and testing of the stability of the terrain with the applied technical measures.

The analysis of the slope stability as well as the calculation of the stability of the applied solutions was carried out on the profile II - II`. This profile was chosen as characteristic/critical because it showed the landslide in the direction of sliding, was the longest and had the steepest slope.

Having analysed several sliding planes, the lowest safety factor of Fs=0.86 was determined. Considering the condition of stability (Fs>1.3), the analysed slope is unstable. With the measures applied, the newly designed slope becomes stable, and with Solution 1 (a concrete retaining wall) the general safety factor increases to Fs=3.55. The dimensions with

which the wall meets the condition of stability are: the width of the foundation of 4.5 m and the retaining wall height of 8.1 m. If we apply Solution 2 (retaining construction made of geogrid-reinforced soil), the safety factor is Fs=2.12. It consists of primary geo-reinforcement placed at a vertical distance of 1 m. The total height of the retaining construction is 5 m.

It is of great importance that, in practice, landslide processes are timely recognised and addressed first with preventive and temporary, and then with long-term measures. In this way, not only do we use resources most efficiently, but also prevent the damage caused by landslides.

PRIMENA POTPORNIH KONSTRUKCIJA U SANACIJI KLIZIŠTA NA REGIONALNOM PUTU STOLICE - KRUPANJ

Jovana CVETKOVIĆ, Nikola ŽIVANOVIĆ, Vukašin RONČEVIĆ, Grozdana GAJIĆ, Milan KABILJO

Rezime

U radu je prikazana analiza stabilnosti padine na regionalnom putu Stolice - Krupanj.

Nastanak klizišta je izazvao pojavu deformacija na delu puta i kosini ispod puta. Prosečna širina klizišta je 20,0 m, dužina oko 30,0 m. Dubina do klizne ravni u centralnom delu klizišta iznosi od 4,0 do 4,5 m. Visinska razlika od vrha čeonog ožiljka do nožičnog dela je 15,0 m. Čeoni ožiljak je vrlo izražen, na kolovoznoj traci doseže visinu od 1,5 m.

Cilj istraživanja bio je da se prikažu mogućnosti primene savremenih i tradicionalnih tehničkih rešenja za sanaciju klizišta na pomenutom lokalitetu.

Predložene su sledeće tehničke mere: potporni zid od betona i potporna konstrukcija od tla i geomreže. Kako bi se postigla potpuna stabilnost padine i puta, bilo je neophodno izvršiti i terasiranje padine (tela klizišta).

Za utvrđivanje optimalnog rešenja sanacije klizišta sprovedene su sledeće analize: analize stabilnosti pokrenute padine (pre primene rešenja), dimenzionisanje potpornih konstrukcija i ispitivanje stabilnosti terena sa primenjenim tehničkim merama.

Analiza stabilnosti padine kao i proračuna stabilnosti primenjenih rešenja izvršena je na profilu II - II`. Ovaj profil je izabran kao karakteristični/kritični, s obzirom da daje prikaz klizišta u pravcu klizanja, najveće je dužine i najstrmijeg nagiba.

Analizom stabilnosti padine, uzimajući u obzir više kliznih ravni, utvrđen je najniži faktor sigurnosti koji iznosi Fs=0,86. Imajući u vidu uslov stabilnosti (Fs>1,3), analizirana padina je nestabilna. Sa primenom pomenutih mera novoprojektovana kosina postaje stabilna, pri čemu sa rešenjem 1 (potporni zid od betona) generealni faktor sigurnosti iznosi Fs=3,55. Usvojene dimenzije sa kojima zid ispunjava uslov stabilnosti su sledeće: širina temelja je 4,5 m, a visina potpornog zida je 8,1 m. Primenom rešenja 2 (potporna konstrukcija od tla i geomreže) faktor sigurnosti je Fs=2,12. Rešenje 2 se sastoji od primarne geo-armature koja je postavljena na vertikalnom rastojanju od 1 m. Ukupna visina potporne konstrukcije iznosi 5 m.

Od velikog značaja je da se, u praksi, na vreme prepoznaju procesi kliženja kako bi se blagovremeno reagovalo sa preventivnim, privremenim, a kasnije i završnim merama. Na ovaj način, ne samo da bi se optimalno iskoristili resursi, već bi se sprečile i štete koje nastaju kao posledica pojave klizišta.

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SHEME OF ORGANISATION AND PROCEDURES IN THE ACTIONS OF ENTITIES ON FOREST FIRE PROTECTION – PREVENTION AND SUPPRESSION OF FOREST FIRES

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Abstract: *Organisations and procedures play an important role in the preventive fire protection of forest as well as in the calculation of effective forest fire suppression. In order for the fight against forest fires to be successful, all entities involved in risk management in forest fire protection must know their place and role, both in the segment of preparedness, preventive action, action on forest fires and in the field rehabilitation. Knowledge of the legality of forest fires, mode of action, equipment and extinguishing agents, rapid fire detection, preparation of planning documents is very important for the actions of entities in the protection of forest from fires to be effective.*

Key words: fire protection entites, prevention, organisation sheme

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ŠEMA ORGANIZACIJE I PROCEDURA U POSTUPANJU SUBJEKATA NA ZAŠTITI ŠUMA OD POŽARA – PREVENCIJA I SUZBIJANJE ŠUMSKIH POŽARA

Izvod: *U preventivnoj zaštiti šuma od požara kao i u načunu efikasnog suzbijanja šumskih požara organizacija i procedure u postupanju imaju važnu ulogu. Da bi borba sa šumskim požarima bila uspešna svi subjekti koji učestvuju u upravljanju rizicima u zaštiti šuma od požara moraju znati svoje mesto i svoju ulogu, kako u segmentu pripravnosti, preventivnog delovanja, delovanja na nastali šumski požar i u delu sanacije terena. Poznavanje zakonitosti šumskih požara, način dejstva, korišćenje opreme i sredstava za gašenje, brzo otkrivanje požara , izrada planskih dokumenata je vrlo važno da bi postupanje subjekata u zaštiti šuma od požara bilo efikasno*.

Ključne reči: subjekti zaštite od požara, prevencija, šema organizacije.

1. INTRODUCTION

Wildfire prevention includes a whole complex of measures and activities that need to be implemented to prevent wildfire occurrence, and in case a fire does occur, it entails an organised approach to fire extinguishing and rehabilitation.

Wildfire prevention is one of the most important elements in the risk management system regarding the protection of forests against wildfire. Preventive measures taken to protect forests against wildfire are aimed at reducing the risk of wildfire occurrence, the number of fires, and the incurring damage.

The level of wildfire prevention applied in the Republic of Serbia is varying both in state-owned enterprises that manage state forests and in privately owned forest areas, where almost no preventive measures are applied to protect forests against fire.

Measures taken to prevent wildfire occurrence must be included in the wildfire protection plans for all forest areas regardless of the type of ownership. Wildfire protection plans must enlist specific measures that should enable:

- effective prevention of wildfire occurrence;
- in case it occurs, quick detection and extinguishing in the initial stage with a small number of people and simple extinguishing equipment and agents, which is also important in terms of economy.

2. METHODOLOGY AND AREA OF RESEARCH

Analysis of data with open fires in the Braničevo district, which includes the territories of the municipalities of Požarevac, Kučevo, Petrovac, Veliko Gradište, Golubac, Žagubica, Žabari and Malo Crniče. The analysis of the documentation of the Sector for Emergency Situations on the holding of classes in the field of fire protection was carried out, as well as the number of radio and television reports, professional and popular material in magazines. An analysis of the regulations on the risk of forest fires in the researched area was carried out.

Based on the analysis of the aforementioned documentation, the number of wildfires was analyzed depending on the cause (for the period from 1998 to 2008), as well as the number of reports submitted for the period of 2007 and 2015.

3. RESEARCH RESULTS WITH DISCUSSION

The largest number of fires in Serbia and other neighboring countries, i.e., over 95% of wildfires, are caused by human activity. Based on the database of the Sector for Emergency Situations - Department in Požarevac, the number of forest fires according to causes for the Braničevski district for the period 2000-2010 is presentation in Table 1. (Ratknić, T. et al., 2017; Ratknić, T. et al., 2019).

Table 1. *The number of wildfires by cause for the Braničevo administrative district from 2000 to 2010.*

Total number of wildfires	Number of wildfires caused by human activity	Number of wildfires caused by natural phenomena	The number of fires whose cause has not been determined
2220	2087	44	89
100%	94,01%	1,98%	4,01%

Therefore it is of utmost importance in wildfire prevention to plan measures against potential causes of wildfires. Little has been done in this regard in the Republic of Serbia, and the preventive effects in this area are negligible.

First of all, wildfire education is mainly overlooked at schools, and school children are not taught about the importance of forest conservation, the protection of forests against wildfires, and extinguishing when they occur.

Every country must educate schoolchildren and create habits in wildfire prevention and environmental protection in general. Schools should find methods and topics to integrate wildfire education into their curricula. Electronic and written media should be used to popularise participation in wildfire prevention. Field xperts and radio and television stations should be engaged to produce professional and popular materials to raise awareness about the importance of wildfire protection. Based on the database of the Sector for Emergency Situations - Department in Požarevac, education of children and students in schools in the field of fire protection in Braničevo District in 2009 is presentation in Table 2.

Table 2. *Education of schoolchildren and students in the field of fire protection in the Braničevo district in 2009*

Municipality	Total number of schools	Number of schools where classes in the field of wildfire protection were held	Number of schools where training was organised and fire protection equipment was demonstrated
Požarevac	15	10	8
Kučevo	5	1	1
Petrovac	6	0	0
Veliko Gradište	2	2	2
Golubac	2	1	1
Žagubica	4	2	2
Žabari	2	2	2
Malo Crnjće	3	0	0

Another form of prevention includes biological and technical protection measures, their planning and implementation, elaboration and classification of elements that can be applied in the system of biological and technical protection measures, and the factors that can hinder their application. According to Bertović (1987), as dominant biological-technical measures protection in a preventive sense, parts of biological-technical measures should be processed as:

1. mixed planting of broadleaves and conifers, application possibilities and hindering factors;
2. group mixture of broadleaves and conifers, application possibilities;
3. construction of biological fire barriers relying on natural and artificial obstacles;
4. construction of fire protection lines and breaks that suit the terrain characteristics;
5. application of different protection models, depending on the type of vegetation, terrain composition and slope, wind direction and velocity, etc.
6. proposal of the type of vegetation that would be most suitable in terms of efficient biological and technical protection and acceptable regarding the economic and technical aspects of its use.

The primary aim of biological and technical protection measures is to reduce the number of fires. However, it is even more important that, in case of fire, these measures enable rapid localisation to a small area, involvement of a small number of people and the use of simple extinguishing equipment and agents.

Furthermore, prevention should also consider the selection of the most favorable models of fire lines and breaks depending on the type of vegetation, soil composition, aspect, orography and climate.

3.1 The role of meteorology in wildfire forest protection

Meteorology has a very important role in the protection of forests against fire, both in the pre-fire stage and during the fire. The method of forecasting the wildfire hazard and, based on that, preparing man forces and resources, depending on the observed elements and specific factors, must be included in the implementation of the system for the monitoring of the risk and occurrence of wildfire (Ratknić T., et al., 2019; Ratknić, T. et al., 2019).

The wildfire danger forecast provides the following three levels of information:

- the first level of information refers to intermediate indices that analyse the data related to the factors that affect the occurrence of fire and provide the necessary prevention measures and means of suppression;
- the second level of information refers to the final index that determines the risk of fire and its spread depending on the state of the fuel material;
- the third level of information proposes the final solution to the current danger.

Organisations that participate in the implementation of wildfire hazard and warning systems must be fully aware of their role and method of action. The following institutions are engaged in the assessment of the wildfire risk and degree of threat:

- Republic Hydrometeorological Service of Serbia,
- Sector for Emergency Management,
- Public and other companies dealing with forest management and wildfire forest protection,
- State authorities of all levels,
- Local self-government bodies,
- Media companies and electronic and written media,
- Other interested institutions and bodies,
- Inspection authorities

The wildfire risk assessment system should (Đorđević, 2012):

- make sure that the means allocated for the prevention and suppression of wildfire are distributed according to the degree of threat regarding both the time and space;
- set the dates for the activities to promote prevention and inform the public about the potential fire agents;
- to raise preparedness to a higher level.
- Adequate implementation of this system can reduce the number of potential wildfires and help recover the land after the fire.

This system should also include inspection authorities (Prevention department of the Sector for emergency management, municipal police, municipal inspection, agriculture and forestry inspections, etc.) that plan their activities to identify and sanction potential fire-starters based on the fire risk levels provided by the fire risk assessment system Based on the database of the Sector for Emergency Situations - Department in Požarevac, comparative data were given before and after the implementation of Article 50 of the Fire Protection Act, which refers to the control of open burning in the Braničevo District for the years 2007 and 2015 (Table 3.)

Table 3. *Comparative data before and after the enactment of Article 50 of the Law on Fire Protection that refers to the management of open burning in the Braničevo District in 2007 and 2015*

Number of wildfires in 2007	**The number of reports submitted for open burning**	**Fires reduced (%)**
112	0	0%
Number of wildfires in 2015	**The number of reports submitted for open burning**	**Fires reduced (%)**
65	27	Око 45 %

3.2 Fire detection system in wildfire protection

Preventive measures to protect forests against fires cannot prevent their occurrence but can minimise the number of wildfires that, with good organisation, early detection and timely extinguishing, can be suppressed quickly and successfully.

The Republic of Serbia has a poor system of early detection of wildfire occurrence. It takes a long time for a detected fire to be reported, which delays the start of its extinguishing to the time when the fire is already in a raging stage, and a large number of people and heavy equipment are needed to extinguish it. Consequently, it takes a long time to extinguish the fire, and the outcomes of the interventions are often uncertain. Based on the database of the Sector for Emergency Situations - Department in Požarevac, the time from the beginning to the discovery of the fire in the Braničevo District for the period 1998-2008 is presented in Table 4.

Table 4. *Time from fire occurrence to the detection in the Braničevo District for 1998-2008*

Total number of fires	Time needed to detect a forest fire 1-15 minutes	Time needed to detect a forest fire 15-30 minutes	Time needed to detect a forest fire 30-60 minutes	Time needed to detect a forest fire 60-90 minutes	Time needed to detect a forest fire 90-120 minutes	Time needed to detect a forest fire over 120 minutes	Time of fire occurrence not determined
2220	215	282	414	408	332	202	367
% 100	9,7	12,7	18,7	18,4	14,9	9,1	16,5

In the Republic of Serbia, the segment of wildfire forest protection that relates to the early detection of wildfires is not clearly defined. It can be performed through (Đorđević, 2012) :

- observation from the ground,
- observation from the air,
- combined method of observation,
- special cameras that collect meteorological data and detect a fire
- other ways (satellite monitoring, etc.)

Each method of wildfire monitoring has its characteristics and costs that determine its efficiency and effectiveness.

Every subject involved in wildfire forest protection should study different wildfire detection systems, their applicability and cost-effectiveness in relation to the characteristics of a given area since different systems produce different results in different areas. They cannot be economical if they are not selected based on the required features. The camera surveillance systems seem to be the most effective method. However, this is not the case in our country. The actual effectiveness of the camera monitoring in our areas ranges from 35 to 40% of the territory, depending on the terrain, weather conditions, and technical requirements. The rest of the territory should be covered by other types of observation, including the most expensive one –air observation, This type of observation should mostly be implemented through regular activities of sports clubs, such as training or scheduled flights.

3.3 Entities dealing with wildfire protection and their role

The entities that are obliged to participate in wildfire forest protection, both in prevention and suppression, must be defined for each area.

A scheme of preparedness must be developed for each entity. It defines all measures that each entity participating in firefighting must undertake in different seasons and the time they should be implemented.

All entities engaged in the protection of forests against fires should make a classification of fire event levels based on the size of the fire as well as the entities that participate and take measures during each wildfire event.

A scenario for the outbreak of large wildfires that can be categorised as an emergency must be developed carefully. In case of such large fires, emergency headquarters are activated. Before this, it must be defined who establishes the headquarters, who are the members, how are decisions made, how it functions, when to declare an emergency, types of decision-making, ways of engaging people, equipment and means for fire extinguishing, etc.

In case of large fires, expert operational teams are formed to monitor, control and find solutions to overcome the emergency.

3.4 Defining the wildfire extinguishing model

Determining the methods of extinguishing wildfires is one of the most important segments of wildfire suppression. The proper selection of the method of fire extinguishing determines its effectiveness and success, the number of people involved, the means and equipment needed, and the time required to extinguish a fire.

Several methods of extinguishing wildfires are applied in practice, but the following are the most often applied ones (Vasić, 1983):

- direct extinguishing,
- indirect extinguishing,
- combined extinguishing,
- air extinguishing.

Each area has its characteristics defined by the type of fuel material, terrain configuration, type of soil, type of climatic conditions, availability of fire extinguishing means, passable roads, availability of biological and technical protection measures, etc., and the fire extinguishing scenario largely depends on this.

It is also important to determine the equipment that can be used and its effectiveness in different extinguishing methods.

The direct extinguishing method includes:

- extinguishing the front of the fire,
- extinguishing by encircling the fire,
- extinguishing by surrounding the fire from the background,
- extinguishing combined with existing natural and artificial obstacles

The indirect extinguishing of wildfires can be done by the following methods:

- removal of combustible material in front of the fire,
- plowing of combustible material,
- burning of combustible material,
- extinguishing with water and chemical substances,
- stopping the fire by digging canals and other obstacles.

3.5 Analysis of the existing infrastructure in wildfire protection

To determine the state of wildfire protection, it is important to study the existing forest infrastructure in the Republic of Serbia, assess its suitability for wildfire prevention and propose a plan to improve the infrastructure. The plan must include the timeframe for the proposed activities.

This segment implies building new roads for firefighting vehicles and equipment, firefighting lines and breaks and the most suitable access to water sources, water supply management, protection of major buildings, picnic areas, national parks, and supply of water used to extinguish fires from the air, etc.

3.6 Model of the equipment and infrastructure needed for wildfire protection

Firefighting equipment has an important role in the effective prevention and suppression of wildfires. It is wrong to think that all types of wildfires can be extinguished with the same type of equipment, without taking into account the combustible material, type of fire, climatic conditions, soil and bedrock, infrastructure, forest management, the use of obstacles in firefighting, etc. The success of wildfire extinguishing depends on the selection of firefighting equipment and fire extinguishers, which results in faster fire damage restoration, lighter equipment used, fewer people needed to extinguish the fire, less time, and lower cost of intervention that increases, which all improve the economic aspect of risk management in wildfire protection.

Besides the firefighting equipment, the accompanying fire extinguishers have to be defined because they contribute to the effectiveness of the firefighting process.

In order to select the firefighting equipment and fire extinguishers, it is necessary to know:

- what and how burns,
- who extinguishes what and how.

Classification of firefighting equipment according to the mode of operation:

- firefighting equipment with the cooling effect;
- firefighting equipment with the smothering effect;
- equipment for removing combustible material in front of the fire.

According to the location and mode of operation, firefighting equipment can be classified as:

- land firefighting equipment and
- areal firefighting equipment.

For areas at risk of wildfires, it is necessary to classify the equipment and study its effectiveness depending on the field conditions, the type of fire, the type of fuel, the soil, climatic conditions, and the supply of extinguishing agents.

Regarding the effectiveness of equipment used in aerial firefighting, it is necessary to study the time needed to discharge water and propose ways to improve the existing infrastructure and thus increase the efficiency of aerial firefighting. It is also important to map the areas that are favorable or unfavorable for aerial fire extinguishing.

We must also consider the possibility of using agents that can improve the effects of extinguishing combustible forest material, such as the application of various types of suppressants and retardants that typically penetrate into forest fuel material.

Regarding the applicable and efficient firefighting equipment, it is further necessary to map the firefighting equipment for each area, depending on:

- types of vegetation
- topography and orography
- types of fire
- arrangement of forest areas
- types and quality of roads
- soil characteristics
- openness of the forest area
- climatic factors
- supply of water and other extinguishing agents
- arrangement of water sources
- manpower available in the most unfavorable conditions
- the possibility of bringing together and mobilising people
- the possibility of extinguishing wildfires from the air
- characteristics of the equipment at the disposal
- efficacy
- delivery and distribution of equipment

3.7 Model for the preparation of wildfire protection plans – a proposal to amend the existing rulebook for the preparation of fire protection plans

Every country with a large number of wildfires, a large area of forest affected by fires and extensive material damage, endangered lives, buildings and environment seeks to find solutions to fight these issues as efficiently as possible. Planning documents such as wildfire protection plans are the starting point for proper and effective wildfire protection, both in prevention and suppression.

The current rulebook for the development of fire protection plans does not provide a specific method for their development, which impedes the preparation of these planning documents, both for forest users and inspecting authorities that carry out inspections and approve the wildfire protection plan.

The wildfire protection plan is an important document that must enhance the efficiency of wildfire protection, and determine important elements that affect the risk management system in wildfire protection. The preparation of wildfire protection plans has not provided so far a complete picture of the state of protection, and adequate measures that should be taken to make this protection better and more efficient, and the organisation of the fire suppression faster and more efficient in order to minimise the damage and costs incurred by fire suppressing and extinguishing. The creation of wildfire protection plans is a complex process, affecting and encompassing many fields (forestry, meteorology, fire protection, firefighting, biology, etc.) and in many ways different from the development of fire protection plans intended for buildings. The Rulebook on the method of development and content of the Fire Protection Plan of autonomous provinces, local self-government units and entities classified in the first and second categories of fire risk has been adopted but it does not provide the method of developing this planning document, which is a serious shortcoming, considering that the Regulation on the categorisation of buildings, activities and soil in terms of fire risk includes the areas with different types of plant cover, i.e. forest area.

3.8 Wildfire protection plans a

Fire protection plans are acts enacted by autonomous provinces, local self-government units and legal entities classified into the first and second categories of fire risk.

The Law on Fire Protection (Official Gazette of the RS No. 111/09 20/15) specifies who should adopt fire protection plans and how. For the first time in the Law on Fire Protection, the area and the type of plant cover are taken into account when categorising. This change in the Law on Fire Protection is of great importance since it deals with the land and plant cover of special interest and under a special protection regime, such as national parks. A by-law that regulates the method of preparing and the content of fire protection plans and the conditions that legal entities must fulfill for the preparation of fire protection plans was also adopted.

3.9 Proposed method of preparation and content of wildfire protection plans

The Law on Fire Protection (Official Gazette of the RS No. 111/09 and 20/15) and the Decree on the Classification of Facilities, Activities and Land into Fire Risk Categories (Official Gazette of the RS No. 76 /10) include land categorisation in terms of area and plant cover. This land categorisation requires the development of high-quality forest protection plans, not included in the Rulebook for the development of plans.

Wildfire protection plans should have the same structure as other plans. This structure should include:

1. description of the current state of fire protection,
2. fire risk assessment,
3. organisation of fire protection,
4. proposal of technical and organisational measures to eliminate deficiencies and improve the state of fire protection,
5. estimation of financial needs,
6. necessary calculation and graphs.

Regarding the content, such a soil and forest protection plan would be fairly different from other fire protection plans and would have its specific characteristics.

3.10 Description of the current state

The description of the current state should contain the following elements:

1. Land area, type of vegetation, division into compartments and sections;
2. The type of vegetation by compartment and section (coniferous forests, deciduous forests, mixed forests, degraded forests, thickets and brushwood, etc);
3. Age of forest trees by species, amount of forest litter, and silvicultural forms and classes);
4. Accessibility of forest areas in terms of the road network;
5. Condition and quality of roads leading to areas of high-quality forest and roads within areas of high-quality forest and what vehicles they are open to (fire engines, people and equipment transporters, fire-fighting machines, etc.);
6. Potential dangers and agents of fire in the given area (charcoal pits, illegal dumps, facilities with open fire, picnic areas, etc.);
7. The state of water sources and method of water supply in case of fire;
8. The state and availability of firefighting equipment (belonging to legal entities, fire departments, nearest fire rescue department, etc.).
9. Assessment of the suitability of the available firefighting equipment in the area, bearing in mind that different wildfires require different equipment.
10. 1The state of firefighting services and manpower (available to legal entities, firefighting units, units of volunteers, the nearest firefighting and rescue departments, specialised civil protection units, aircraft vehicles that can be used for surveillance, observation and extinguishing, etc.)
11. State of the observation system (method of observation, condition and number of observation posts, other observation systems)
12. Ways of detecting and reporting fires (from the ground, from the air, surveillance cameras, etc.)
13. Possibility of extinguishing fire from the air (possibility, method of water supply, etc.)
14. Biotechnical protection measures (current state – mixed forests, biological fire breaks, after-fire breaks, expansion of existing lanes, cleaning and care)

15. Types of fire barriers, roads, lanes and their state (type, number, width, state throughout the year, etc.)
16. State of the water supply system (the map of natural sources and the possibility to use artificial sources throughout the year by setting up pools that can be refilled, etc.)
17. The application of the system for wildfire danger forecast in its territory.
18. The possibility and method of communication between all entities engaged in fire protection (radio, telephone, and other types of communication and speed of establishing the connection).
19. Quick establishment of collecting points for people and equipment, use of chemical agents (retardants and suppressants);
20. Method of coordination with headquarters for emergency management (republic, district, city, municipality, etc.);
21. Method of firefighting logistical support;
22. Firefighting operational maps for certain areas of the legal entity.
23. The risk of endangering buildings, people and other goods located in the forest or near the threatened area and how to protect them quickly;
24. Ways of fighting and measures to be taken against potential causes of fire with an assessment of their effectiveness.
25. Fire events and their causes registered in the last 10 years.

3.11 Assessment of wildfire risk

Wildfire risk assessment is carried out using a special method and system of assessment that is precisely defined and the same for all entities.

The main goal of the wildfire risk assessment is:

1. to present an accurate picture of the forest wildfire risk to the institutions dealing with the protection of forests against fire.
2. to determine and classify the risks of wildfires in the observed area.
3. to determine how possible it is to protect forests against wildfires in a certain area and to apply additional protection measures.
4. to show the specialised services dealing with fire protection and participating in fire extinguishing the specific characteristics and fire dangers in the observed area.
5. to find models of supplementary protection measures and more efficient firefighting when a fire occurs in an area.

3.12 Parameters for assessing the risk of wildfires

Numerous factors affect the risk of wildfire, but for the sake of its easier application in practice, the risk assessment method takes into account only those considered to be the most important and with the strongest impact on the risk of wildfire (Ratknić, T. 2018). The most important parameters in the wildfire risk assessment are:

a) vegetation and fuel material
b) natural disasters that lead to fires
c) anthropogenic factor (human risk)

d) climate
e) drought
f) bedrock (parent material and soil type)
d) orography
h) forest management
i) fire history in the observed area

3.13 Degree of wildfire risk

The degree of wildfire risk is assessed based on the presented parameters of wildfire risk. Points are assigned for each parameter and summed up for the observed area. The method of calculation is presented in the methodology of wildfire risk assessment (Ratknić, 2018).

Numerical indicators of the wildfire risk are used to create a risk map that presents the threatened areas in different colours, namely:

First degree – red
Second degree – orange
Third degree – yellow
Fourth degree – green

Previous assessments of the risk of wildfire took into consideration only the predominant vegetation, which was not sufficient to make a comprehensive assessment of the risk. Therefore, the new method of assessing the risk of wildfire aims to achieve a more comprehensive and higher-quality assessment.

3.14 Organisation of wildfire protection

The organisation of wildfire protection should include:

1. the manner in which fire protection is organised within the entity that manages or uses forests and forest land (number of people, fire departments, communication, etc.);
2. the manner in which communication will be achieved with other entities dealing with wildfire protection (Ministry, public estates, institutes, state bodies, headquarters, etc.);
3. means and methods of communication;
4. data on the protection service, the fire department, and the number of people trained for fire protection;
5. procedures taken by all entities in forest protection and firefighting actions and procedures that regulate the implementation of preventive and repressive measures with the exact method of coordination;
6. fire extinguishing equipment, its characteristics and the possibility of its effective application in the intended area;
7. training methods and programmes in the field of wildfire protection, basic and special training.

3.15 Proposal of technical and organisational measures to eliminate deficiencies in wildfire protection

The proposal for technical and organisational measures to eliminate deficiencies in wildfire protection should contain:

1. measures to be taken to reduce the risk of wildfires and measures to improve risk management in wildfire protection (prevention, preparedness, fire emergency response and post-fire rehabilitation),
2. biotechnical measures of wildfire protection to raise the level of protection,
3. measures to fight against potential causes of fire,
4. measures to improve the wildfire forecasting system,
5. measures to upgrade the wildfire detection system, and improve the existing or introduce new modern wildfire observation and reporting systems,
6. measures to be taken to prepare for the start of fire season,
7. measures and preparedness during the wildfire season,
8. measures to build and maintain fire roads in order to conduct fire prevention and suppression,
9. measures to improve the state of the water supply needed in firefighting and arrangement of water intakes and to construct new sources of water supply used in firefighting,
10. measures for the maintenance and security of picnic and other forest areas where a large number of people gather with the aim of reducing the risk of fire,
11. measures to plan and procure firefighting equipment and means according to the characteristics of the terrain,
12. measures to organise and manage firefighting actions in order to achieve better communication between all the entities involved and the correct use of extinguishing means and equipment,
13. measures to elaborate wildfire extinguishing methods and strategies based on the characteristics of the forest areas and procedures for the application of certain extinguishing methods,
14. measures related to fire ignition and plant waste burning in open and near forest edges,
15. measures to change and upgrade the communication system,
16. development of a system for modeling wildfires in order to predict these events,
17. ability to provide quick and effective first aid to the injured while firefighting,
18. measures for the terrain rehabilitation after a fire and recovery of the burned areas,
19. application and construction of information systems to improve risk management in wildfire protection (GIS, meteorological information system, environmental protection system, Ministry of Internal Affairs information system, notification and surveillance system, etc.).

3.16 Calculation of the necessary financial resources

Calculation of the necessary financial resources should include:

1. a realistic assessment of the financial elements of the proposed technical and organisational fire protection measures,
2. the dynamics of execution of technical and organisational measures with a plan of financial resources for a period of five years.

3.17 Graphics

Graphics that display:

1. operational maps showing areas with the highest risk of wildfires,
2. maps and tables with an overview of areas according to the degree of fire hazard created using the given methodology of the system for determining the risk of wildfire with all the foreseen elements,
3. maps of roads, fire-fighting lines and canals, firefighting water supply points and facilities that must be protected as a matter of priority in the event of a fire,
4. area-specific equipment with the map of the areas where the equipment can be used effectively (manual equipment, water fire extinguishers, mechanised equipment, air fire extinguishers),
5. places with observation posts and other systems for quick fire detection and reporting,
6. climatic diagrams for specific areas,
7. a map of water supply points (managed and unmanaged), places to keep special water tanks used in case of fire, and places to refill tanks in firefighting aircraft,
8. collecting points for people, equipment and chemical extinguishers and the places most favorable for operational headquarters and emergency headquarters (close to the area, protected and safe, accessible, with logistical assistance, etc.).
9. a map of the areas particularly endangered by fire with the highest number of fires in the past 10 years.

All data in wildfire protection plans must be clear, precise, and correct. All unnecessary elements, both in terms of the text and the graphs, must be avoided.

4. CONCLUSIONS

The organisation and performance of all entities dealing with wildfire protection are of utmost importance for the proper functioning of the whole system of risk management in wildfire protection. Cooperation and mutual interaction of all entities and precisely prescribed activities both in wildfire prevention and when a fire occurs must improve all segments of fire protection. Besides the improvement of all the engaged systems (the fire hazard system, the education system at all levels, the early fire detection system, the fire prevention system, the fire extinguishing system), and the preparation of appropriate planning documents, the appropriate system of communication between all the entities in wildfire protection, the number of fires can be reduced and the efficiency in wildfire protection increased

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SHEME OF ORGANISATION AND PROCEDURES IN THE ACTIONS OF ENTITIES ON FOREST FIRE PROTECTION – PREVENTION AND SUPPRESSION OF FOREST FIRES

Goran ĐORĐEVIĆ, Mihailo RATKNIĆ, Ljubinko RAKONJAC, Tatjana DIMITRIJEVIĆ

Summary

Wildfire prevention includes a whole complex of measures and activities that need to be implemented to prevent wildfire occurrence, and in case a fire does occur, it entails an organised approach to fire extinguishing and rehabilitation. Wildfire prevention is one of the most important elements in the risk management system regarding the protection of forests against wildfire. Preventive measures taken to protect forests against wildfire are aimed at reducing the risk of wildfire occurrence, the number of fires, and the incurring damage.

The level of wildfire prevention applied in the Republic of Serbia is varying both in state-owned enterprises that manage state forests and in privately owned forest areas, where almost no preventive measures are applied to protect forests against fire.

Measures taken to prevent wildfire occurrence must be included in the wildfire protection plans for all forest areas regardless of the type of ownership. Wildfire protection plans must enlist specific measures that should enable: effective prevention of wildfire occurrence and in case it occurs, quick detection and extinguishing in the initial stage with a small number of people and simple extinguishing equipment and agents, which is also important in terms of economy.

The organisation and performance of all entities dealing with wildfire protection are of utmost importance for the proper functioning of the whole system of risk management in wildfire protection. Cooperation and mutual interaction of all entities and precisely prescribed activities both in wildfire prevention and when a fire occurs must improve all segments of fire protection. Besides the improvement of all the engaged systems (the fire hazard system, the education system at all levels, the early fire detection system, the fire prevention system, the fire extinguishing system), and the preparation of appropriate planning documents, the appropriate system of communication between all the entities in wildfire protection, the number of fires can be reduced and the efficiency in wildfire protection increased.

ŠEMA ORGANIZACIJE I PROCEDURA U POSTUPANJU SUBJEKATA NA ZAŠTITI ŠUMA OD POŽARA – PREVENCIJA I SUZBIJANJE ŠUMSKIH POŽARA

Goran ĐORĐEVIĆ, Mihailo RATKNIĆ, Ljubinko RAKONJAC, Tatjana DIMITRIJEVIĆ

Rezime

Preventivna zaštita od požara obuhvata čitav kompleks mera i aktivnosti koji trebaju da se realizuju da do požara u šumi ne dođe , a ukoliko do požara i dođe da se organizovanim načinom pristupi na sanaciji i gašenju požara. Sama preventivna zaštita šuma od požara, jedan je od najvažnijih elemenata u sistemu upravljanja rizikom u zaštiti šuma od požara. Preventivne mere u zaštiti šuma od požara imaju za cilj da se smanji rizik od nastanka požara u šumi , umanji broj nastalih požara i umanje štete koje nastaju dejstvom šumskih požara.

Nivo primenjenih preventivnih mera za zaštitu šuma od požara u Republici Srbiji je neujednačen, kao u državnim preduzećima koja gazduju državnim šumama tako i na površinama koje su u privatnom vlasništvu, gde se gotovo ne primenjuju preventivne mere na zaštiti šuma od požara.

Mere za sprečavanje nastanka šumskih požara moraju pre svega biti sadržani pre svega u planovima zaštite šuma od požara za sva područja pod šumom bilo kojoj svojini pripadaju. U planovima zaštite šuma od požara moraju da se daju konkretne mere koje trebaju da omoguće efikasno sprečavanje nastanka šumskih požara da i kada požar nastane, bude brzo otkriven i ugašen u početnom stadijumu sa upotrebom malog broja ljudi i malo opreme i sredstava za gašenje, što je važno i sa ekonomskog aspekta.

Organizacija i način postupanja svih subjekata koji se bave zaštitom šuma od požara je vrlo važna u sistemu upravljanja rizikom u zaštiti šuma od požara. Saranja i međusobna interakcija svih subjekata i tačno propisani načini delovanja kako u preduzimanju preventivnih mera zaštite , ali i delovanja kada požar nastane mora da omogući uspešnost u svim delovima zaštite. Pored usavršavanja svih uticajnih sistema: sistema opasnosti od nastanka požara, sistem edukacije na svim nivoima, sistem ranog otkrivanja požara, preventivni sistem zaštite, sistem gašenja požara pa do izrade odgovarajućih planskih dokumenata uz odgovarajući sistem povezanosti subjekata na zaštiti šuma od požara, može da smanji broj požara i poveća efikasnost u zaštiti šuma od požara.

A GUIDE FOR WRITING RESEARCH PAPER

SUSTAINABLE FORESTRY is a scientific journal which is published original scientific papers, review papers and short communications of Forestry scientific disciplines, Environmental protection, Wood processing, Landscape architecture and horticulture and Environmental engineering (Erosion Control) at least once a year.

The paper should be, in whole, written in English, and Abstract and Summary should be written in English and Serbian. The paper length, including tables, graphs, schemes, pictures and photographs can have maximum 10 typewritten pages, A4 format (Portrait), with normal line spacing (Single Space). Margins: Top 1.5cm, Left 1.5cm, Bottom 1.5cm, Right 1.5cm, Gutter 0.5 cm. The paper should be typed in *Word* format, Roman alphabet, using exclusively the *Times New Roman* Font, 11 points, Normal, First Line 1.27. LAYOUT: header 0.5 cm, footer 0.5 cm. PAPER: width 16.5 cm, height: 24 cm. If special signs (symbols) are used in the text, use the *Symbol* Font.

PAPER TITLE IN ENGLISH (capital letters, 11 points, bold, centered)
Title should be 11 Enter keystrokes below the top margin.

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With mark 1, 2 ... in superscript (with command Insert Footnote), above the name of the author is marked a Footnote in which are indicated title, name and family name, occupation and institution in which authors are employed. Also, in Footnote should be write the name, family name and e-mail of correspondence author.

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Abstract: *The abstract is written in English with three spaces below the name of the paper author. In abstract are given basic aim of research, materials and methods, more important results and conclusion (maximum 500 characters) (10 points, italic, first line 1.27).*

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Key words: in English, minimum 3, maximum 6 words (10 points, normal).

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PAPER TITLE IN SERBIAN (capital letters, 11 points, bold, normal, centered)

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Abstract: *Text of the abstract in Serbian (10 points, italic, first line 1.27)*

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Corresponding author: Name and family name, e-mail.

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11

1. INTRODUCTION (capital letters, 11 points, bold, align left)

11

The introduction should be a short review of explanation about reasons that led to the research of specific scientific issue. The introduction contains reference data of published papers that are relevant for the analyzed issue (normal, 11 points, justify, first line 1.27).

11

2. MATERIAL AND METHODS (capital letters, 11 points, bold, align left)

11

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

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3. RESULTS (capital letters, 11 points, bold, align left)

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Within this chapter there can be subtitles of first and second line. The paper results should be presented in the form of text, tables, pictures (diagrams) and, rarely, photographs. From the results should be clear whether the hypotheses have been confirmed or disproved and whether the aim and tasks have been achieved. It should not be avoided the presentation of the negative results or disproving the hypotheses.

11

3.1. Chapter title (11 points, bold, align left)

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3.1.1. Subchapter title (11 points, bold, align left, first line 1.27)

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Subchapter text (11 points, justify, first line 1.27)

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Table 1. (bold, 11 points), *Table title (11 points, italic, centered)*

	Font size in Tables is 8		

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Continuation of the text, 11 points, justify, first line 1.27

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Graph 1. (bold, 11 points), *Graph title (11 points, italic, centered)*

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Picture 1. 11 points, bold *Picture title, (11 points, italic, centered)*

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Continuation of the text, 11 points, justify, first line 1.27.

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4. DISCUSSION (capital letters, 11 points, bold, align left)

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Discussion should not be the simple repeating of obtained results. The results should be discussed by comparing them with the research results of other authors with compulsory citing of literature sources. It is very important to give discussion of the results and the opinion of the authors. Interpretation of perceived ambiguities and illogicalities should be correctly stated (11 points, justify, first line 1.27).

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5. CONCLUSION (capital letters, 11 points, bold, align left)

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Conclusions of the paper should be carefully carried out and shown clearly to the reader. Conclusions can be significantly connected with the result discussion, but in them should be given freer and wider interpretation of the paper subject and results. The special quality is the defining of suggestions for future work and identifying the issues need to be resolved (11 points, justify, first line 1.27).

11

Acknowledgements (10 points, bold)**:** *If the paper is a part of a research within a project in acknowledgement are indicated: name of the project, registration number and the full name of the institution that finances the project (10 points, justify, italic).*

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In this text a detailed structured instruction for writing papers is given. Papers that do not satisfy the propositions of this Guide will not be forwarded for review and will be returned to the author.

Categorization of papers (suggested by the author – determined by Editorial board taking into account the opinion of the reviewer):

Scientific Articles

1. Review paper (paper that contains original, detailed and critical review of the research issue or field in which the author contributed, visible on the basis of auto-citations);
2. Original scientific paper (paper which presents previously unpublished results of author's researches by scientific method);
3. Preliminary communication (Original scientific paper of full format, but small-scale or preliminary character).
4. Other known forms: scientific review, case study and others, if Editorial board finds that such paper contributes to the improvement of scientific thought.

Professional Articles

1. Professional paper (annex in which are offered the experiences for improving professional practice, but which are not necessarily based on scientific method).

This guide, as well as an example of correctly printed paper in the Journal Sustainable Forestry, can be found on the web-site of Institute of Forestry (***http:// www.forest.org.rs***).

Papers and all enclosures (photos, pictures and graphs) should be sent to the e-mail of Secretary of the Journal "Sustainable Forestry": *natalijamomirovic@rocketmail.com*

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Godišnje. - Je nastavak: Zbornik radova - Institut za šumarstvo = ISSN 0354-1894
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