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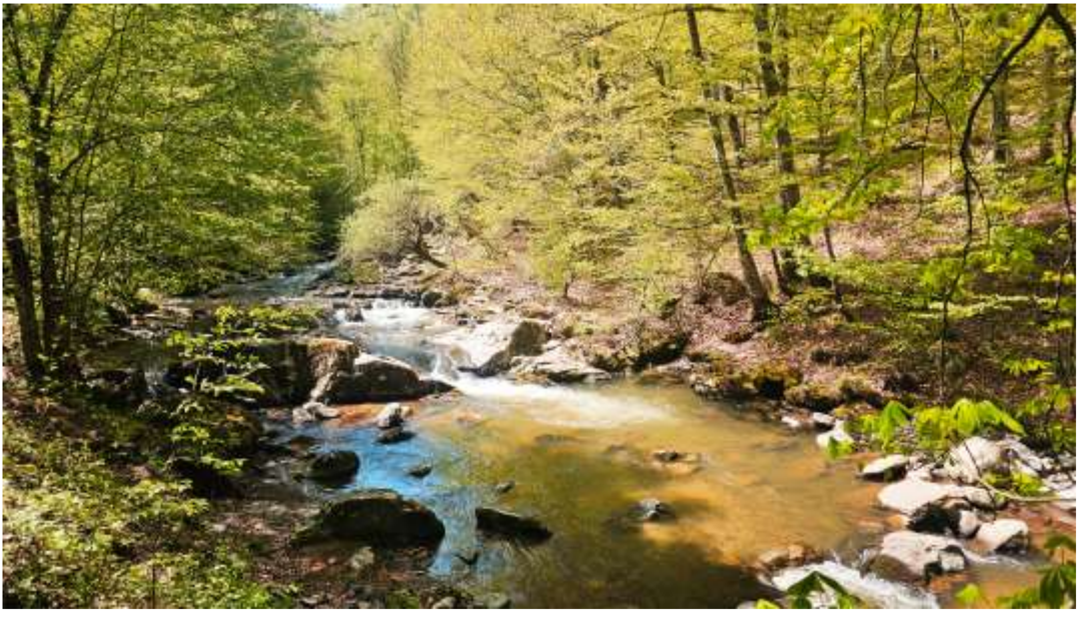

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CONTENT SADRŽAJ

Vol. 92

Snežana STAJIĆ, Vlado ČOKEŠA, Violeta BABIĆ, Suzana MITROVIĆ, Marija MILOSAVLJEVIĆ, Saša EREMIJA, Jelena BOŽOVIĆ
BEECH FORESTS OF KOSMAJ AS A NATURAL RESOURCE OF MEDICINAL PLANTS 1

Vladan POPOVIĆ, Sanja LAZIĆ, Aleksandar LUČIĆ, Ljubinko RAKONJAC, Radojica PIŽURICA, Boris IVANOVIĆ, Aleksandra PETROVIĆ
SELECTION OF SESSILE OAK (*Quercus petraea* (Matt.) Liebl.) PLUS TREES FOR SEED ORCHARD ESTABLISHMENT 11

Suzana MITROVIĆ, Milorad VESELINOVIĆ, Snežana STAJIĆ, Zoran PODUŠKA, Vanja STOJANOVIĆ, Natalija MOMIROVIĆ, Marija MILOSAVLJEVIĆ
EFFECT OF FERTILIZATION ON LEAF MORPHOMETRIC CHARACTERISTICS OF *Paulownia elongata* S. Y. Hu AND *Paulownia fortunei* Seem. Hemsl. IN THE SECOND YEAR OF GROWTH 29

Tatjana ĆIRKOVIĆ-MITROVIĆ, Dragica VILOTIĆ, Milan REBIĆ, Ljiljana BRAŠANAC-BOSANAC
EFFECTS OF A CONTROLLED-RELEAS FERTILISER ON HEIGHT GROWTH OF TWO-YEAR-OLD TRANSPLANTED (1+1) WILD CHERRY (*Prunus avium* L.) SEEDLINGS 47

Aleksandar VEMIĆ, Sanja LAZIĆ, Katarina MLADENOVIĆ, Jelena BOŽOVIĆ, Danilo FURTULA, Bojan KONATAR, Radojica PIŽURICA
THE EFFECT OF TEMPERATURE AND NUTRIENT MEDIUM ON GROWTH OF *Fistulina hepatica* 61

Miloš RAČIĆ, Nenad PETROVIĆ, Nikola MARTAĆ, Jovan DOBROSAVLJEVIĆ, Janko LJUBIČIĆ, Ivana RAČIĆ, Branko KANJEVAC
LIVE CROWN RATIO AND SLENDERNESS COEFFICIENT AS INDICATORS OF BEECH TREE STABILITY 71

Nikola MARTAĆ, Nemanja LAZAREVIĆ, Miloš RAČIĆ, Nenad PETROVIĆ, Ivana RAČIĆ, Natalija MOMIROVIĆ, Branko KANJEVAC
COMPARATIVE ANALYSIS OF SILVICULTURAL TREATMENTS IN EVEN-AGED HUNGARIAN OAK STANDS 85

Ivana ŽIVANOVIĆ, Aleksandar LUČIĆ, Nenad ŠURJANAC, Goran ČEŠLJAR, Ilija ĐORĐEVIĆ, Filip JOVANOVIĆ
RELATIONSHIP BETWEEN THE VISUAL TREE RATINGS AND WOOD SOUND VELOCITY OF POPLAR TREES 97

Suzana MITROVIĆ, Milorad VESELINOVIĆ, Snežana STAJIĆ, Nemanja LAZAREVIĆ, Katarina MARINKOVIĆ, Radmila ĐURAŠINOVIĆ, Marija MILOSAVLJEVIĆ
VISUAL ASSESSMENT OF TREES IN THE URBAN FOREST IN BELGRADE: A CASE STUDY OF THE AREA PLANNED FOR THE CONSTRUCTION OF THE MULTIFUNCTIONAL HALL OF THE INSTITUTE FOR SPORT AND SPORTS MEDICINE OF THE REPUBLIC OF SERBIA 107

Polina LEMENKOVA
SPATIAL CLUSTERING OF PROTECTED FORESTS IN ITALY FOR STRATEGIC NATURE CONSERVATION 117

Uroš DURLEVIĆ, Nina ČEGAR, Ljiljana BRAŠANAC-BOSANAC
SPATIO-TEMPORAL ANALYSIS OF LARGE WILDFIRES IN SERBIA BASED ON GIS AND VIIRS REMOTE SENSING DATA 133

Emina JEREMIĆ MARKOVIĆ, Doloris BEŠIĆ-VUKAŠINOVIĆ
THE IMPORTANCE OF THE ENGLISH LANGUAGE IN FORESTRY 145

Miroslava MARKOVIĆ, Renata GAGIĆ-SERDAR, Bojan KONATAR, Jelena BOŽOVIĆ, Vanja STOJANOVIĆ, Ljubinko RAKONJAC, Aleksandar LUČIĆ
ASSESSMENT OF THE POTENTIAL OF ALBINO BEECH COMPARED TO PIGMENTED BEECH AS A BIOINDICATOR OF ENVIRONMENTAL CONDITIONS 151

A GUIDE FOR WRITING RESEARCH PAPER 159

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

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

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

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

UPOREDNI PRIKAZ RAZLIČITIH GAZDINSKIH TRETMANA U SASTOJINAMA SLADUNA ISTE STAROSTI

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

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

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

1. INTRODUCTION

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

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

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

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

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

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

2. MATERIAL AND METHODS

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

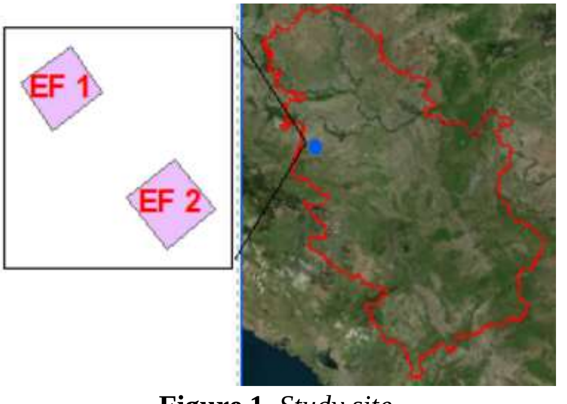


Figure 1. *Study site*

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

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

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

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

3. RESULTS AND DISCUSSION

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

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

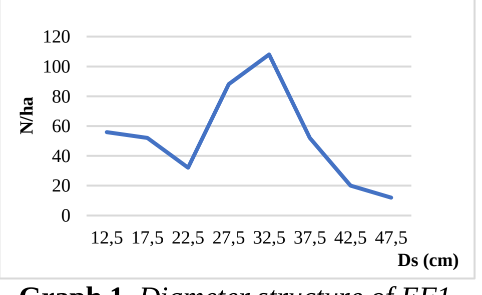
Table 1. *Basic stand parameters of the experimental fields prior to the implementation of silvicultural treatments*

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

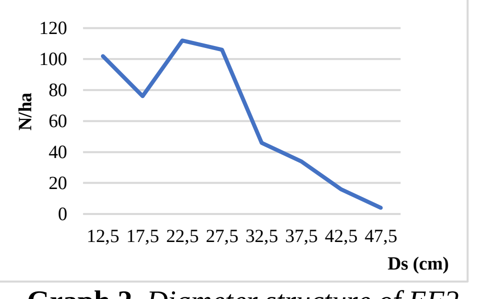
Tree species	Experimental Field I						Experimental Field II					
	N/ha	G m^2/ha	hg (m)	dg (cm)	Iv (m^3/ha)	V (m^3/ha)	N/ha	G m^2/ha	hg (m)	dg (cm)	Iv (m^3/ha)	V (m^3/ha)
Black ash	32	0.60	15.00	15.50	0.12	4.58	14	0.20	11.00	13.30	0.03	1.19
Small-leaved lime	94	5.59	23.50	27.50	1.31	53.2						
Wild cherry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

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

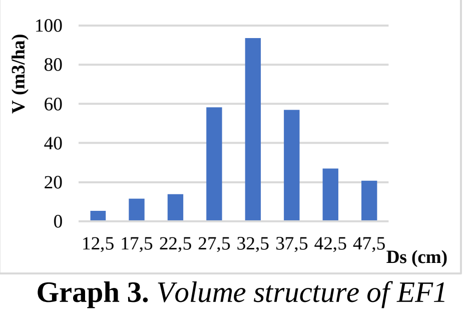
Graphs 1–4 illustrate the diameter and volume structure of the investigated stands.



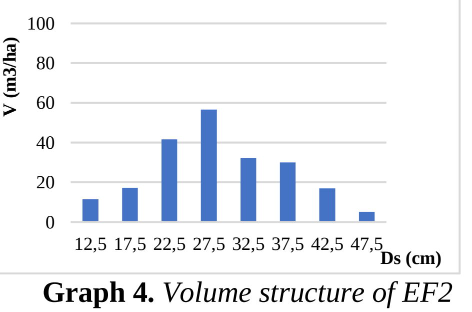
Graph 1. *Diameter structure of EF1 prior to the implementation of silvicultural treatment*



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



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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

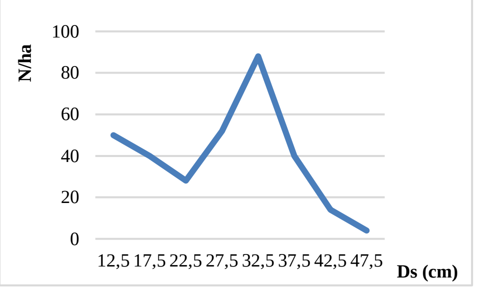
On EF II, the marking intensity amounted to 57.7% of the total volume and 237% of the ten-year volume increment. The number of trees remaining after felling was 138 per hectare. Of these, 134 were Hungarian oak, while the remaining four were Turkey oak trees. Rowan tree and wild service tree individuals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

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

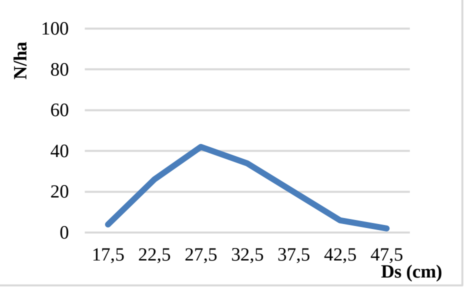
Tree species	Experimental field I		Experimental field II	
	Dg max (m)	Hg max (m)	Dg max (m)	Hg max (m)
Hungarian oak	39,80	25,20	39,50	19,30

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

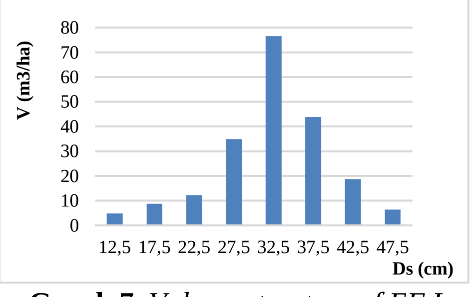
Graphs 5–8 present the diameter and volume structure of the studied stands after the implementation of silvicultural treatments.



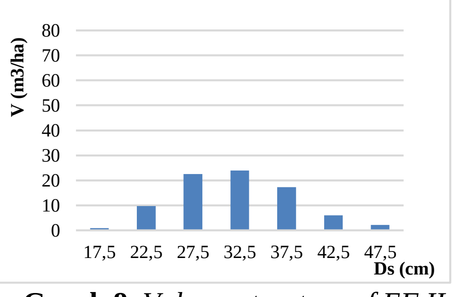
Graph 5. *Diameter structure of EF I after the implementation of the silvicultural treatment*



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



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



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

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

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

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

4. CONCLUSIONS

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

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

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

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

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Summary

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

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

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

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

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

UPOREDNI PRIKAZ RAZLIČITIH GAZDINSKIH TRETMANA U SASTOJINAMA SLADUNA ISTE STAROSTI

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

Rezime

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

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

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