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EFFECTS OF HEAVY THINNINGS ON THE INCREMENT AND STABILITY OF A NORWAY SPRUCE STAND AND ITS TREES BETWEEN THE AGES OF 32 AND 50

UTJECAJ JAKIH PRORJEDA NA PRIRAST I STABILNOST STABALA I SASTOJINE SMREKE U STAROSTI OD 32. DO 50. GODINE

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Summary

The paper studies effects of two heavy thinnings on the increment and slenderness of various categories of trees and stability of the stand as a whole. The research was conducted on a permanent experimental plot in an Norway spruce *(Picea abies* /L./ Karst.) monoculture in Serbia. This monoculture was established with 5,000 seedlings per hectare on the site of mountain beech forest and the effects of heavy thinnings were investigated in the 33-40 and 41-50 age periods.

To determine the thinning effects we compared current diameter increments (i_{dt}) and current height increments (i_{ht}) of dominant trees (D_{100} and D_{400}) obtained by a detailed analysis of trees and of mean stand dominant trees (D_{100} and D_{400}). At the stand level, we compared the current diameter (i_d), basal area (I_G) and volume (I_V) increments of all trees and of the same collective of aspirants in two periods after the thinnings, between the ages of 33 and 40, and between the ages of 41 and 50.

The first thinning was carried out at the age of 32 when the dominant trees were 15 *m* tall and the next at the age of 40 when the dominant trees were above 20 *m* in height. They were both low (q_d <0.85) and heavy selective thinnings (34-36% of the volume). A more significant increase in the diameter increment was recorded after the second thinning between the ages of 41 and 50. It amounted to 29.1% in aspirants and 36-42% in dominant trees (D_{100} and D_{400}) compared to the period after the first thinning, i.e., between the ages of 33 and 40. The thinnings further contributed to the establishment of more favorable relations in diameter and height increments of the trees in the studied culture and thus improved their stability.

KEY WORDS: *Picea abies* /L./ Karst., monoculture, permanent experiment plot, heavy thinning, slenderness

INTRODUCTION
UVOD

In Serbia excluding Kosovo conifer cultures have been established on an area of 124,800 ha, where 95% are pine and spruce cultures. Norway spruce (*Picea abies* /L./ Karst.) cultures cover an area of 32,400 ha (26.0%), (Banković *et al.*, 2009). A large number of conifer cultures in Serbia typically had spontaneous development in the first decades after the

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establishment. In the later period they were extensively tended. The first thinnings were usually carried out at the age when economically viable assortments were most likely to obtain. Such a trend has also been characteristic of conifer cultures throughout Europe because late crown thinnings provide higher and more valuable cutting yields (Valsta, 1992; Slodičák *et al.*, 2005).

An objective assessment of this tending approach to spruce cultures is most rationally achieved on permanent experimental plots where thinnings have been carried out and periodic measurements and assessments have been conducted using standard procedures (Zeide 2001; Pretzsch 2005). The effects of thinning verified on permanent experimental plots determine the silvicultural treatment of the forest stands in a wider area. They are particularly significant if experimental plots are located in areas where there are adverse exogenous impacts (ice-breaks and snow-breaks). Thinning approaches to spruce cultures in Serbia have been studied by a number of authors. These studies were mostly based on the analysis of the structure of untended stands or on the research results of initial state on experimental plots (Marković and Petrović, 1960; Vučković *et al.*, 1990; Dražić, 1994; Bjelanović and Vukin, 2010). Short-term thinning effects determined on the basis of periodic measurements of the elements of growth conducted on permanent experimental plots in Serbia can be found in Stojanović and Krstić (1984) and Bobinac (2004).

Based on the available research results obtained on permanent experimental plots in other study areas in the surrounding regions of Serbia, we can conclude that they have used similar approaches to thinning in spruce cultures. In Bosnia and Herzegovina, there are no data of long-term investigations on the effects of thinning on permanent experimental plots. On the newly established permanent experimental plots in the said country, moderate to light thinning from below was studied on the basis of the analysis of the structure of untended stands (initial measurements of the elements of growth) and the effects of thinning on the stand development may be expected in the future (Govedar, 2007; Govedar *et al.*, 2013; Bodružić *et al.*, 2015). In Croatia, results from a number of permanent experimental plots have been published and provided data only on short-term effects of thinnings from below of light to moderate intensity (Orlić *et al.*, 1991; 1997; Orlić, 1999). Regarding the impact of thinning from below of light to moderate intensity and spontaneous development on the development of spruce cultures, there are some interesting results of long-term monitoring of stand development on a permanent experimental plot, between the ages of 113 and 161 (Dubravac *et al.*, 2006).

The approach to thinning in spruce plantations both in Serbia and in neighboring countries, as well as in the whole of Europe, has been under a heavy influence coming from Germany after the publication of the results of several decade long research on the implementation of crown thinning and thinning from below with varying intensity on permanent experimental plots (Assmann, 1970). The most important conclusions of these long-term studies have shown that spruce stands in which thinnings from below of light to moderate intensity were conducted had greater current volume increments per hectare in their early to middle age compared to untended stands. Furthermore, higher increments resulted in the higher overall productivity of these stands in comparison to unthinned stands (control plots). On the other hand, the stands which had crown thinning operations carried out in the second half of the rotation had smaller volume increments compared to the stands with light to moderate thinnings from below. They had lower productivity than unthinned stands and stands with light thinning from below. Recent studies have shown that late crown thinnings produce higher and more valuable cutting yields, but their total productivity is lower (Slodičák *et al.*, 2005). These were some of the main reasons for the absence of crown thinning operations in spruce stands. Due to biological characteristics of spruce, primarily its brittle tip and shallow root system, spruce stands are more susceptible to breakages and windfalls. Such negative phenomena are more pronounced in the cultures established outside of its ecological potential and they are intensified in untended and extensively cultivated stands after each canopy opening over a short period of time. That was another reason for the absence of crown thinning operations in spruce stands (Nilsson et al. 2010; Wallentin and Nilsson, 2014). The absence of thinning at an early age increases the tree slenderness but improves the stem clearness. Thus, it follows that spruce cultures require intensive thinning, *i.e.* it should be implemented as early as possible, in shorter intervals and the intensity of interventions should be moderate (Mraček and Perez 1986; Cameron, 2002). However, this method of spruce culture management entails higher felling costs and thinner assortments of small economic value. Recent results of several decade long research on permanent experimental plots in spruce stands in which crown selective thinnings were carried out at early ages show that this approach has intensified the growth of trees after the thinning, especially of final crop trees which have been the primary tending objects. This approach further contributed to the rapid increase in their size and thus to the shortening of the production cycle. It also reduced their slenderness and thus increased the stability of the remaining trees after thinning (Slodičák and Novák, 2003; 2010; Nilsson et al., 2010; Štefančik, 2012). Furthermore, the results of long-term research on the effects of thinning in spruce cultures generally indicate that stands respond positively to thinning, regardless of their age at the time of commercial thinning (Makinen and Isomaki, 2004a, 2004b). However, not only do delayed thinnings of heavy intensity produce weak reactions of the remaining trees and consequently significantly smaller volume increments per hectare, but they also increase the instability of stands several years after thinning (Nilsson et al., 2010).

The paper studies two thinnings carried out on a permanent experimental plot in a spruce monoculture. They were characterized as selective thinnings and based on the overall structure of the felled trees they were heavy to very heavy thinnings from below. The research has made it possible to assess the effects of thinning on the increment and slenderness of different categories of trees and stability of the stand in two stand age periods - from 33 to 40 and from 41 to 50 years of age.

MATERIALS AND METHODS
MATERIJALI I METODE

The experiment – *Pokusni objekt*

The research was conducted in a spruce culture on Velika Brezovica of the Kučaj mountain range in north-eastern Serbia (MU Bogovina I, compartment 87a) at 870 m above sea level with southern and southwestern aspects and an inclination of 5°. According to the Base Geological Map (1968) and its description (1970), the culture was established on the soil developed on proluviums, a material made mainly from crystalline schist and Paleozoic sediments, sandstone, argilo schist, lydite and, less frequently, Mesozoic limestone. On the study area, at 900 m above sea level, the mean annual air temperature is 7.5°C and the mean annual rainfall amounts to 840 mm. According to Thornthwaite climate classification, the study area has a continental humid climate, type B_2. Spruce is not a part of the natural composition of the forest communities in the study area, which is dominated by mountain beech forest. The culture was established by afforestation of pasture on the site which is not suitable for spruce due to periodic ice-breaks or snow-breaks. It was established by dense planting (2×1 m), and according to available data from the management records it hadn`t been thinned before the age of 32. At the end of 1994 (culture aged 32 years), a permanent experimental plot (15×30 m) was established in a densely closed part of the stand where the diameter of 176 trees was measured and the first thinning conducted (Bobinac, 2004). The second tree diameter measurement and the second thinning were carried out on the permanent experimental plot at the age of 40, and the third measurement was conducted at the end of 2012 when the culture was 50 years old. A total of 48 trees had the diameter measured on this occasion.

Treatment – *Tretman*

Investigated culture is characterized by high productivity, which causes that the production of sawmill roundwood can be set as a management goal together with the attainment of the stand stability in short rotations.

Two heavy selective thinnings were carried out using the procedure described by Schädelin (1934). At the age of 32, the initial number of 556 candidates per hectare for tending were selected in the upper storey, and it was approximated from yield tables of Schwapach for the stand age of 80 years and site class I (Nikolić i Bankovic, 2009). Based on this number of candidates, the first selective thinning was done at the stand age of 32 (Bobinac, 2004). At the age of 40, of the 556 candidates, 311 future trees per hectare (55.9%) were selected, 67 trees (12.1%) were felled and 178 trees (32.0%) were declared indifferent. This method of tree selection was applied because of frequent snow and ice breaks in the study area which break tree tips and crowns, thus preventing the achievement of long-term goals of stand tending.

The selected candidates and future trees had one of the strongest rivals in the category of dominant trees cut down. Dying, damaged and tapering trees were also cut down.

Measurement and data analysis of growth elements – *Izmjera i analiza podataka elemenata rasta*

All trees on the permanent experimental plot had two cross diameters measured with an accuracy of 1 mm. In order to construct height curves at the stated ages of the culture, we measured the heights of the selected candidates, at the age of 32, or aspirants, at the age of 40. Minimum five heights in each diameter degree of 5 cm were measured with Blume-Leis and Vertex III hypsometers, at the age of 32 and 40, respectively. Some trees had their lengths measured during the thinning with a diameter tape made of steel, in order to check measurements given by hypsometers. Height curves were smoothed using Michailoff`s function, $h=ae^{-b/d}+1.30$. Tree volume was determined from spruce volume tables by Baur (1890) with the following analytical form: $v=0{,}00007 \cdot d_{1,3}^{2{,}05363} \cdot h^{0{,}70952}$ (1971). The measurements of diameters at breast height and heights are presented for the culture ages of 32, 40 and 50. The volume of the trees that were damaged or died between two thinnings was determined based on their diameters and heights at the beginning of the study period.

For the numerical characterization of the thinnings, the ratio of the quadratic mean diameter of the trees marked for felling to the mean diameter of the trees that remained after the thinning, *i.e.* q_d ratio was used (Pretzsch, 2005). The degree of slenderness ($h/d_{1,3}$ ratio) according to the classification used by (Slodičák and Novak, 2006) was used as an indicator of the stability of the stand and the trees. For the distribution of the degree of slenderness at the stand level in the 32^{nd}, 40^{th} and 50^{th} year of age we used the tree heights from the height curve.

For the reconstruction of the growth of dominant trees in height and diameter in the study culture, two dominant trees at the age of 40 were analyzed. The trees belonged to D_{100} and D_{400} category of dominant trees and the model of height growth was developed. The height growth model was constructed using the Chapman-Richards function (Pienaar and Turnbull, 1973). The model of dominant tree height growth was in line with the increase in the mean stand height of dominant trees in the period between the ages of 41 and 50 taken from the height curve.

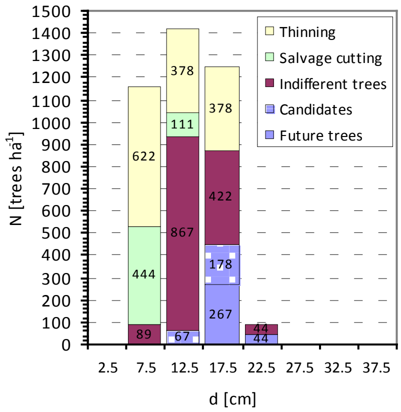
To define the effects of thinning on the growth of trees, we compared the current diameter (i_{dt}) and height (i_{ht}) increments obtained by a detailed analysis of dominant trees (D_{100} and D_{400}) in the periods between the age of 25 and 32 and between the age of 33 and 40. At the stand level, we compared the current diameter (i_{dt}) and height (i_{ht}) increments of dominant trees (D_{100} and D_{400}) in the periods between the age of 33 and 40 and between the age of 41 and 50. We further compared the current diameter, basal area, and volume increments of all trees and of aspirant trees in the periods between the age of 33 and 40 and 41 and 50.

Statistical data analysis comprised measurement of standard numerical parameters of diameter structure: arithmetic mean (d_a), standard deviation (s_d), coefficient of variation (C_v), variation width (v_w), minimum (d_{min}), maximum (d_{max}), coefficient of skewness (α_3) and kurtosis (α_4). The Kolmogorov-Smirnov nonparametric test (|D| statistics) was used for the mutual comparison of the structures of the slenderness degree ($h/d_{1,3}$ ratio). The t-test was used to test the differences between the current increments in different periods.

RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA

Stand structure elements – *Elementi strukture sastojine*

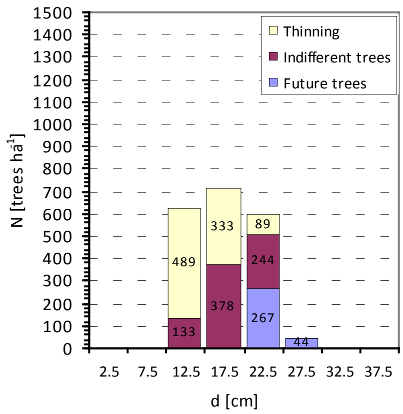
The most important data about the elements of stand structure at the ages of 32, 40 and 50 are shown in Tables 1 and 2. At the age of 32, there were 3,911 trees per hectare, with a basal area of 57.39 $m^2 \cdot ha^{-1}$ and the volume of 384,17 $m^3 \cdot ha^{-1}$, while the average periodic increment at the age of 32 amounted to 12 $m^3 \cdot ha^{-1} \cdot year^{-1}$. Trees were distributed in diameter degrees from 7.5 to 22.5 cm, with the maximum distribution in the diameter degree of 12.5 *cm* (Graph 1). The quadratic mean diameter was 13.7 *cm*, Lorey`s mean



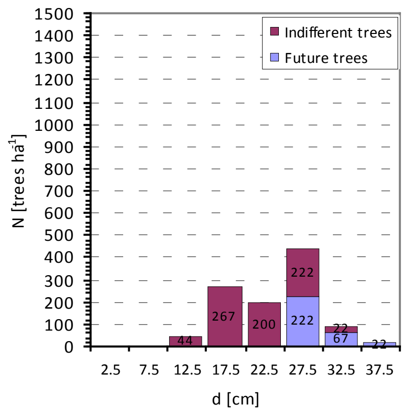
Graph 1. Diameter distribution at the age of 32.
Grafikon 1. Debljinska struktura stabala u 32. godini.

Table 1. Stand structure elements at the ages of 32, 40 and 50.
Tablica 1. Elementi strukture sastojine u 32., 40. i 50. godini.

Age *Starost*	Total *Ukupno*	Future trees *Stabla budućnosti*	Trees marked for felling *Doznačena stabla*	Mortality *Mortalitet*	Final state *Konačno stanje*
			N *[trees·ha⁻¹]*		
age 32 *32. god.*	3,911	311	1,378	555	1,978
age 40 *40. god.*	1,978	311	911	–	1,067
age 50 *50. god.*	1,067	311	–	–	
			G $[m^2 \cdot ha^{-1}]$		
age 32 *32. god.*	57.39	8.71	17.48	3.78	36.13
age 40 *40. god.*	50.25	13.20	17.62	–	32.62
age 50 *50. god.*	52.87	22.32	–	–	
			V $[m^3 \cdot ha^{-1}]$		
age 32 *32. god.*	384.17	62.34	115.13	21.97	247.07
age 40 *40. god.*	424.75	118.90	142.28	–	282.47
age 50 *50. god.*	539.72	238.04	–	–	



Graph 2. Diameter distribution at the age of 40.
Grafikon 2. Debljinska struktura



Graph 3. Diameter distribution at the age of 50.
Grafikon 3. Debljinska struktura stabala u 50. godini.

height (h_L) 14.0 *m*, and degree of slenderness ($h/d_{1,3}$) 102. At the age of 32, the variability of diameter structure amounted to 29.3% , with weak positive skewness (α_3 = 0.212) and platykurtic kurtosis (α_4= 2.076). The mean diameter of the collective of 311 aspirant trees per hectare at the age of 32 was 1.38·dg, while the mean height amounted to 1.08·h_L. Aspirant trees had characteristically small diameter variation (*kv%*=10.1%) and the degree of slenderness of 80.

At the age of 40, there were 1,978 trees per hectare, with a basal area of 50.25 $m^2·ha^{-1}$ and the volume of 424.75 $m^3·ha^{-1}$. The trees were distributed in diameter degrees from 12.5 to 27.5 *cm*, with the greatest number of trees in the diameter degree of 17.5 *cm* (Graph 2). The quadratic mean diameter was 18.0 *cm*, Lorey`s mean height (h_L) was 19.1 *m*, while the degree of slenderness amounted to 106. At the age of 40, the variability of diameter structure amounted to 25.3%, with weak right skewness (α_3 = 0.116) and platykurtic kurtosis (α_4 = 2.203).

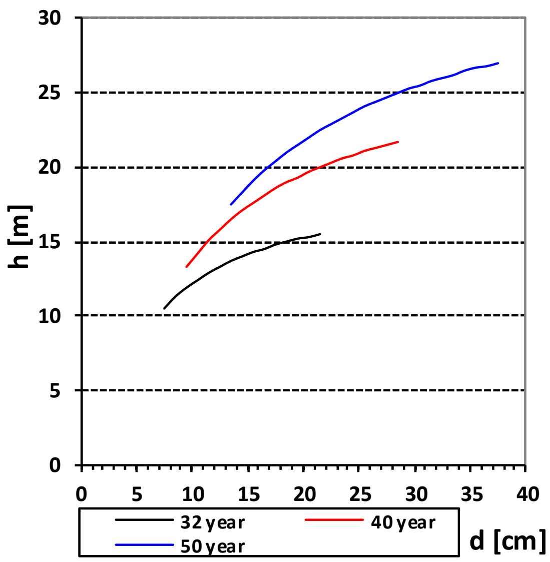
At the age of 50, there were 1,067 trees per hectare, with a basal area of 52.87 $m^2·ha^{-1}$ and the volume of 539.72 $m^3·ha^{-1}$. The trees were distributed in diameter degrees from 12.5 to 37.5 *cm*, with the greatest number of trees in the diameter degree of 27.5 *cm* (Graph 3). The quadratic mean diameter was 25.1 cm, Lorey`s mean height (h_L) was 24.3 *m*, while

Table 2. Numerical parameters of tree structure on the experimental plot at the ages of 32, 40 and 50.
Tablica 2. Brojčani pokazatelji strukture stabala na pokusnoj plohi u 32., 40. i 50. godini.

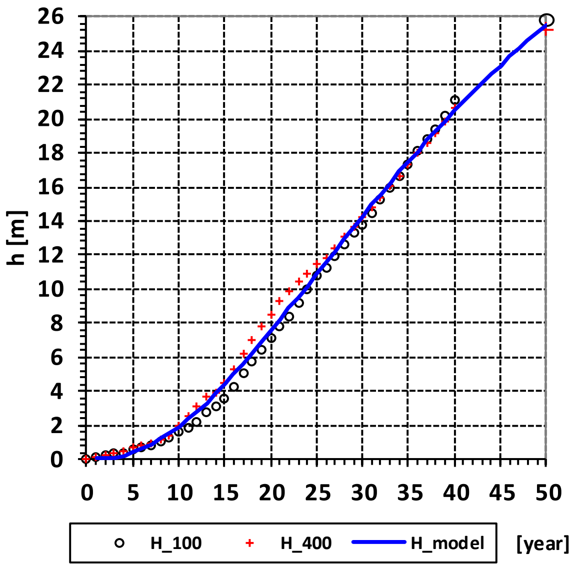
Structure parameters *Parametri strukture*	age 32 *32. god.*					age 40 *40. god.*				age 50 *50. god.*	
	Total *Ukupno*	Future trees *Stabla budućnosti*	Trees marked for felling *Doznačena stabla*	Mortality *Mortalitet*	Final state *Konačno stanje*	Total *Ukupno*	Future trees *Stabla budućnosti*	Trees marked for felling *Doznačena stabla*	Final state *Konačno stanje*	Total *Ukupno*	Future trees *Stabla budućnosti*
n	176	14	62	25	89	89	14	41	48	48	14
d_s	13.1	18.8	12.1	9.2	14.9	17.4	23.1	15.2	19.3	24.4	30.0
s_d	3.84	1.89	4.00	1.11	3.09	4.41	2.33	3.84	3.99	5.89	3.42
k_v%	29.3	10.1	33.2	12.0	20.7	25.3	10.1	25.2	20.6	24.1	11.4
d_{min}	6.6	16.3	7.0	6.6	9.7	10.1	20.2	10.1	11.5	11.6	26.6
d_{max}	24.0	24.0	20.0	10.6	24.0	29.3	29.3	23.9	29.3	39.0	39.0
vš	17.4	7.7	13.0	4.0	14.3	19.2	9.1	13.8	17.8	27.4	12.4
α_3	0.212	1.427	0.316	-1.081	0.283	0.116	1.295	0.326	–0.026	–0.093	1.354
α_4	2.076	5.299	1.623	3.564	2.585	2.203	4.623	1.960	2.384	2.445	4.183
d_g	13.7	18.9	12.7	9.3	15.3	18.0	23.2	15.7	19.7	25.1	30.2
$d_{g20\%}$	18.6	21.5	18.0	10.4	19.5	23.5	26.7	20.7	24.3	31.8	35.4
h_L	14.0	15.1	13.7	11.8	14.3	19.1	20.5	18.1	19.6	24.3	25.4
h_L/d_g	102	80	108	127	94	106	88	115	99	97	84
q_d			0.83					0.80			

Table 3. Parameters of the height curve model and the elements of the model assessment.
Tablica 3. Parametri modela visinskih krivulja i elementi ocjene modela.

Age *[year]* *Starost [god.]*	Model *Model*	Model parameters *Parametri modela*		Model assessment *Ocjena modela*	
		a	b	R^2	s_e
32		17.91353	4.9856	0.9603	0.3865
40	$h=a \cdot e^{-b/d}+1,3$	26.57067	7.55829	0.9009	1.0334
50		33.37437	9.756627	0.9123	0.8104



Graph 4. Height curves at the ages of 32, 40 and 50.
Grafikon 4. Visinske krivulje u 32., 40. i 50. godini.



Graph 5. Height growth of dominant trees (D_{100} and D_{400}) and the height growth model.
Grafikon 5. Visinski rast dominantnih stabala (D_{100} i D_{400}) i model visinskog rasta.

the degree of slenderness amounted to 97. The trees were characterized by a relatively small variation in diameter ($k_{v\%}$=24.1), and their distribution per diameter degrees was characterized by weak skewness (α_3=-0.092) and mild platykurtic kurtosis (α_4 = 2.445).

Height curves of the investigated culture at the ages of 32, 40 and 50 are shown in Graph 4. The assessment of the height curve model, expressed through the coefficient of determination (R^2) and the standard error of regression (s_e), shows a satisfactory agreement between the empirically measured heights and the obtained models (Table 3).

At the age of 40, we can notice a more intense shift of height curves towards greater heights compared to the age of 32. At the age of 50, they shifted to the right, towards greater diameters compared to the age of 40. In the period between the ages of 33 and 40, the mean stand height (h_L) of the aspirant collective increased by 5.4 *m* (from 15.1 *m* to 20.5 *m*) and in the period between the 41st and 50th year of age by 4.9 *m* (from 20.5 *m* to 25.4 *m*) .

The growth of individual trees – *Rast pojedinačnih stabala*

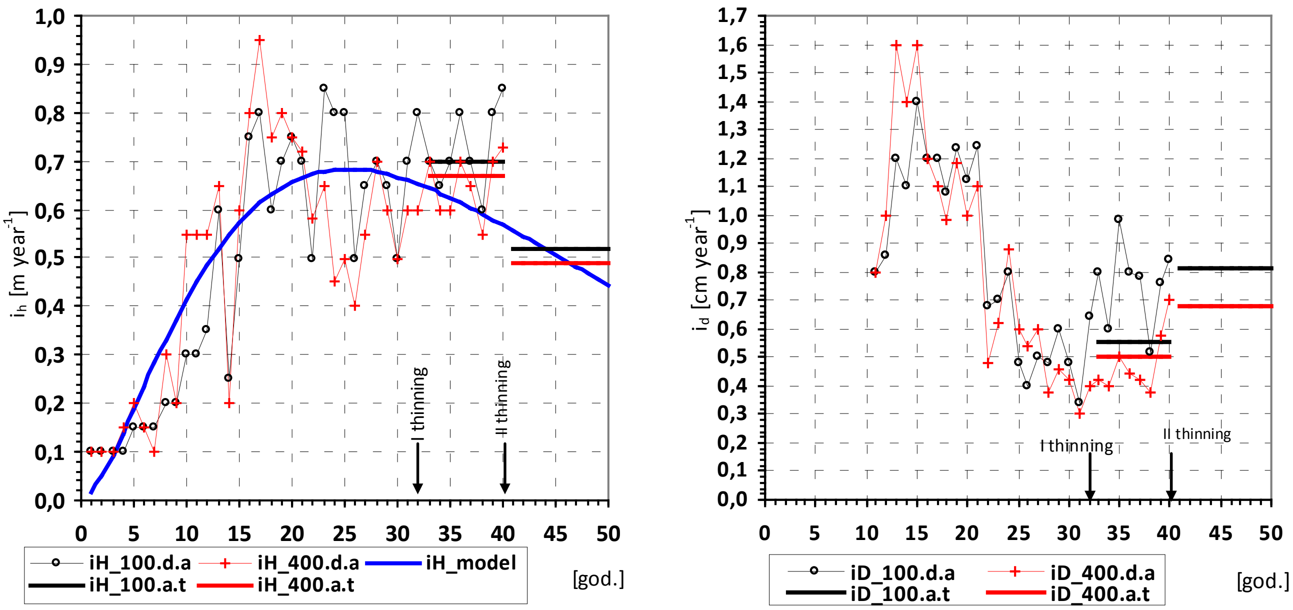
The height growth determined by the detailed analysis of dominant trees (D_{100} and D_{400}) before the age of 40 and the model of height growth before the age of 50 are depicted in Graph 5. The model of the height growth of dominant trees before the age of 50 shows satisfactory agreement with the empirical sizes obtained on the basis of the detailed analysis in the period before the age of 40 and the measurement of growth elements conducted at the age of 50 (Table 4).

The height growth of the studied dominant trees was characterized by a gradual rise before the age of 10 and the current height increment culmination at the age of 17 at a height of about 6 *m*. After the culmination, the current height increment retained high annual values to the observed age of 40. The height growth model points to the culmination of the current height increment at the age of 25, at a height of 11 *m* (Graph 6 left).

The current diameter increment of dominant trees, obtained from the detailed tree analysis, had a culmination at the age of 15. It retained high values to the age of 21, which was then followed by a significant decline, so that at the age of 31 it had the smallest values (Graph 6 right). The average value of the diameter increment of dominant trees in the period between the ages of 25 and 32 amounted to 4.9 $mm \cdot year^{-1}$ in the representative of the 100 thickest trees and

Table 4. Parameters of the height growth model of dominant trees (D_{100} and D_{400}).
Tablica 4. Parametri modela visinskog rasta dominantnih stabala (D_{100} i D_{400}).

Model *Model*	*a*	*b*	*c*	R^2	s_e
$y = a \cdot (1-e^{-b \cdot x})^c$	38.64201	0.03859	2.63996	0.9966	0.42158



Graph 6. Height (left) and diameter (right) increments of dominant trees (D_{100} and D_{400}) in the first 40 years (from the detailed tree analysis) and in 33–40 and 41–50 year periods. (from the measurement of all trees).
Grafikon 6. Visinski (lijevo) i debljinski (desno) prirast dominantnih stabala (D_{100} i D_{400}) u prvih 40 godina (iz detaljne analize stabla) i u razdoblju od 33.–40. i 41.–50. godine (iz izmjere svih stabala)

4.6 $mm \cdot year^{-1}$ in the representative of the 400 thickest trees per hectare.

Since height and diameter increments of dominant trees retain high values in the period after the culmination, up to the age of 21, the period between the age of 15 (17) and 21 can be taken as the optimum time for thinning in the investigated stand. According to the model, the current height increment had a culmination at the age of 25 (when the dominant trees reached a height of 11 *m*), so if we apply this biological criterion, the first commercial thinning should be carried out not later than the age of 25 (Graph 6).

Thinning characteristics – Karakteristike prorjeda

Thinning in the study culture was primarily aimed at fostering the development of high-quality trees (candidates and aspirants) that belonged to the category of dominant trees. The first thinning was carried out at the age of 32 (when the aspirants reached an average height of 15.1 m) and the second thinning at the age of 40 (when the aspirants reached an average height of 20.5 m).

In the thinning that was conducted in the 32nd year of age, 1,378 trees were cut per hectare (35.2%). Their volume amounted to 115.1 $m^3 \cdot ha^{-1}$. In the period from the age of 32 to the age of 40, 555 trees per hectare were cut down due to mortality and snow-breaks (14.2%). Their volume was 22.0 $m^3 \cdot ha^{-1}$. It follows that out of the initial number of trees, a total of 1,933 trees per hectare were cut down (49.4%) in the 32nd year of age. Their total volume was 137.1 $m^3 \cdot ha^{-1}$ (35.9%). The trees harvested at the age of 32 had diameters at breast height from 7.0 to 20.0 cm and the mean diameter of 12.7 cm ($0.93 \cdot d_g$), while the subsequently harvested trees had diameters of 6.6-10.6 cm and the mean diameter of 9.3 cm ($0.68 \cdot d_g$) (Tables 1 and 2, Graph 1).

The thinning that was conducted at the age of 40 included 911 trees per hectare (46.1%) with the volume of 142.3 $m^3 \cdot ha^{-1}$ (33.7%). The trees harvested at the age of 40 had diameters at breast height from 10.1 to 23.9 cm and the mean diameter of 15.7 cm ($0.88 \cdot d_g$) (Tables 1 and 2, Graph 2).

The two thinnings and the subsequently felled thin trees on the experimental plot in the period from the age of 33 to 40 included 2,844 trees per hectare (72.7%) with the volume of 279.4 $m^3 \cdot ha^{-1}$. Based on the ratio between the quadratic mean diameter of the trees harvested in the thinning and the remaining trees at the ages of 32 and 40, the thinnings were low (q_d=0.84-0.80) and based on the percentage decrease in basal area (35-37%) and volume (34-36%), they were heavy thinnings (Tables 1 and 2).

Table 5. Current annual diameter and height increments determined by a detailed analysis of the representatives of dominant (D_{100} and D_{400}) trees in the stand.
Tablica 5. Tečajni godišnji debljinski i visinski prirast detaljno analiziranih predstavnika dominantnih (D_{100} i D_{400}) stabala u sastojini.

Tree category *Kategorija stabala*	Representative tree *Odabrano stablo*	n	age 25–32 *25–32 god.*	age 33–40 *33–40 god.*	age 41–50 *41–50 god.*	t-test	Ratio
				i_d [cm·year^{-1}]			
Detailed Analysis* *Detaljno analizirana stabla*	D_{100}	1	0.49	0.76	-	4.439^{***}	1.55
	D_{400}	1	0.46	0.48	-	0.321^{ns}	1.04
				i_h [m·year^{1}]			
	D_{100}	1	0.66	0.72	-	1.23^{ns}	1.09
	D_{400}	1	0.56	0.65	-	2.49^{*}	1.18

* The current annual diameter and height increments were determined as the averages of the annual increments in the detailed tree analysis in the above-stated periods.
* *Tečajni godišnji debljinski i visinski prirasti dobiveni su kao prosjeci godišnjih prirasta detaljno analiziranih stabala u navedenim razdobljima.*

Table 6. Current diameter and height increments of the 100 and 400 thickest trees in the stand (D_{100} and D_{400}).
Tablica 6. Tečajni debljinski i visinski prirast 100 i 400 najdebljih stabala u sastojini (D_{100} i D_{400}).

Tree category *Kategorija stabala*	Representative tree *Odabrano stablo*	n	age 25–32 *25–32 god.*	age 33–40 *33–40 god.*	age 41–50 *41–50 god.*	t-test	Ratio *Omjer*
				i_d [cm·year^{-1}]			
All trees** *Sva stabla*	D_{100}	5	–	0.54	0.76	2.343*	1.42
	D_{400}	18	–	0.50	0.68	3.524**	1.36
				i_h [m·year^{1}]			
	D_{100}	5	–	0.70	0.52	6.33***	0.74
	D_{400}	18	–	0.67	0.49	15.67***	0.73

** The current annual diameter and height increments were determined as the averages of the annual increments in the detailed tree analysis in the above-stated periods.
** *Tečajni debljinski i visinski prirast je prosjek periodičnog prirasta 100, odnosno 400 najdebljih stabla po hektaru u navedenim razdobljima.*

Table 7. Current diameter, basal area and volume increments of all trees and of the future trees in the period after the thinnings at the ages of 32 and 40.
Tablica 7. Tečajni prirast promjera, temeljnice i volumena svih stabala i stabala budućnosti u razdoblju poslije prorjede u 32. i 40. godini.

Tree category *Kategorija stabala*	age 33–40 *33.–40. god.*				age 41–50 *41.–50. god.*			
	N	i_d	I_G	I_V	N	i_d	I_G	I_V
	[trees ha^{-1}]	[cm·year.$^{-1}$]	[m^2·ha^{-1}·year.$^{-1}$]	[m^3·ha^{-1}·year.$^{-1}$]	[trees ha^{-1}]	[cm·year.$^{-1}$]	[m^2·ha^{-1}·year.$^{-1}$]	[m^3·ha^{-1}·year.$^{-1}$]
All trees *Sva stabla*	1,978	0.31	1.76	22.21	1,067	0.51	2.02	25.73
Future trees *Stabla budućnosti*	311 (15.7%)	0.54 (174.2%)	0.56 (31.8%)	7.07 (31.8%)	311 (29.1%)	0.69 (135.3%)	0.91 (45.0%)	11.91 (46.3%)

In the thinning at the age of 32, out of the total 115.1 m^3·ha^{-1}of the trees marked for felling, almost 100 m^3·ha^{-1} were in the diameter range of 10 to 20 cm. However, in the thinning performed at the age of 40, out of the total 142.3 m^3·ha^{-1} of the trees marked for felling, over 110 m^3·ha^{-1} were found in the diameter range of 10 to 20 cm and about 30 m^3·ha^{-1} was in the diameter range of 20 to 25 cm.

The effects of thinning on trees and stand increment – *Utjecaj prorjeda na prirast stabala i sastojine*

In the period after the first thinning, between the ages of 33 and 40, the current annual diameter increment determined by a detailed analysis of the representative of the 100 thickest trees in the stand was higher by an average of 55% compared to the period before the thinning, between the ages of 25 and 32. The differences were highly statistically significant ($p<0.001$). In the period after the thinning, the current annual height increment of the representative tree was higher by an average of 9% compared to the study period before the thinning, but the differences were not statistically significant. The current annual diameter increment determined by a detailed analysis of the representative of the 400 thickest trees was, in the period between the ages of 33 and 40, higher by an average of 4% compared to the period before the thinning, but the differences were not statistically significant. After the thinning, the current annual height increment of the representative tree was higher by an average of 18% compared to the period before the thinning, and the differences were statistically significant (Table 5, Graph 6).

At the stand level, the diameter increment of the 100 and 400 thickest trees in the stand in the period between the ages of 41 and 50 was higher by 36 to 42% than the diameter increment in the period between the ages of 33 and 40. The statistical significance was weak ($p < 0.05$) to high ($p < 0.001$). The current annual height increment of the representatives was lower in the period between the ages of 41 and 50, by an average of 26-27%, than in the period between the ages of 33 and 40 and the differences were highly statistically significant (Table 6, Graph 6).

The current diameter increment of the aspirants in the specified periods (41-50 and 33-40 years of age) was within the range of the diameter increment of dominant (D_{100} and D_{400}) trees in the stand (Table 7). The diameter increment of the aspirants was 29.1% higher between the ages of 41 and 50 than between the ages of 33 and 40. In the 400 and 100 thickest trees in the stand, the current diameter increment was 36% or 42% higher in the period between the ages of 41 and 50, compared to the period between the ages of 33 and 40. When calculating the current diameter increment for the collective of all trees, calculation is different because there is a different number of trees in each period, so the current diameter increment in the period between the ages of 41 and 50 was 68% higher compared to the previous period when the number of trees on the experimental plot was almost twice bigger (Table 7).

In the period between the ages of 33 and 40, the remaining trees (1978 trees per hectare) achieved a total volume increment of 177.68 $m^3 \cdot ha^{-1}$, or an average of 22.21 $m^3 \cdot ha^{-1} \cdot year^{-1}$, which is 29% higher than the attained cutting yield at the age of 32. In the period between the ages of 41 and 50, the remaining trees (1,067 trees per hectare) achieved a total volume increment of 257.3 $m^3 \cdot ha^{--1}$, or an average of 25.73 $m^3 \cdot ha^{-1} \cdot year^{-1}$, which is 81% higher than the realized cutting yield at the age of 40. In the period between the ages of 33 and 40, 311 aspirant trees per hectare (15.7% of the total number of trees) had a share of about 32% in the current increment of basal area and volume, while in the period between the ages of 41 and 50, these 311 aspirant trees per hectare (29.1% of the total number of trees) had a share of 45 to 46% (Table 7). In the period between the ages of 41 and 50, almost half the total number of trees achieved a 15.8% higher volume increment per hectare than in the period from 33 to 40, and the same collective of aspirant trees (311 trees per hectare) achieved a 68.5% higher current volume increment (Table 7).

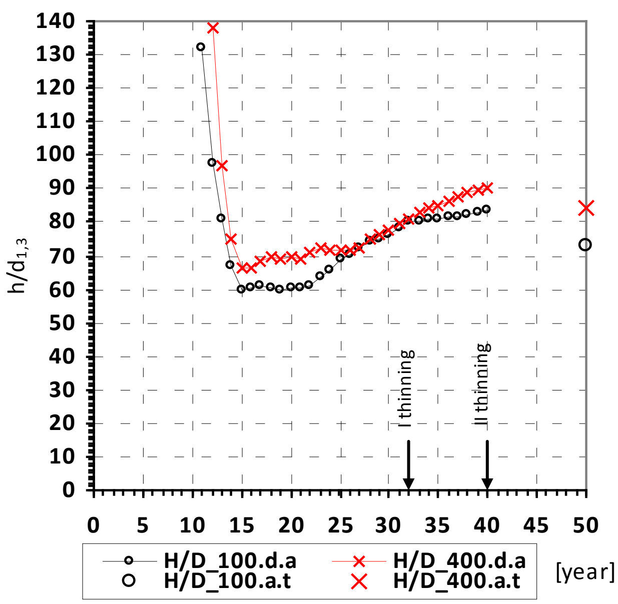
The total stand volume increment recorded on the experimental plot at the age of 40 amounted to 561.85 $m^3 \cdot ha^{-1}$, and the average annual increment was 14.05 $m^3 \cdot ha^{-1} \cdot year^{-1}$. The share of the previous increment in the stand before the age of 40 amounted to 137. $m^3 \cdot ha^{-1}$ or 24.4% of the total volume increment. The total volume increment measured at the age of 50 amounted to 819.1 $m^3 \cdot ha^{-1}$, the average annual increment was 16.38 $m^3 \cdot ha^{-1} \cdot year^{-1}$, and the share of the previous increment amounted to 279.4 $m^3 \cdot ha^{-1}$ or 34.1% of the total recorded volume increment.

The effect of thinning on slenderness of trees and stability of stand – *Utjecaj prorjeda na stupanj vitkosti stabala i stabilnost sastojine*

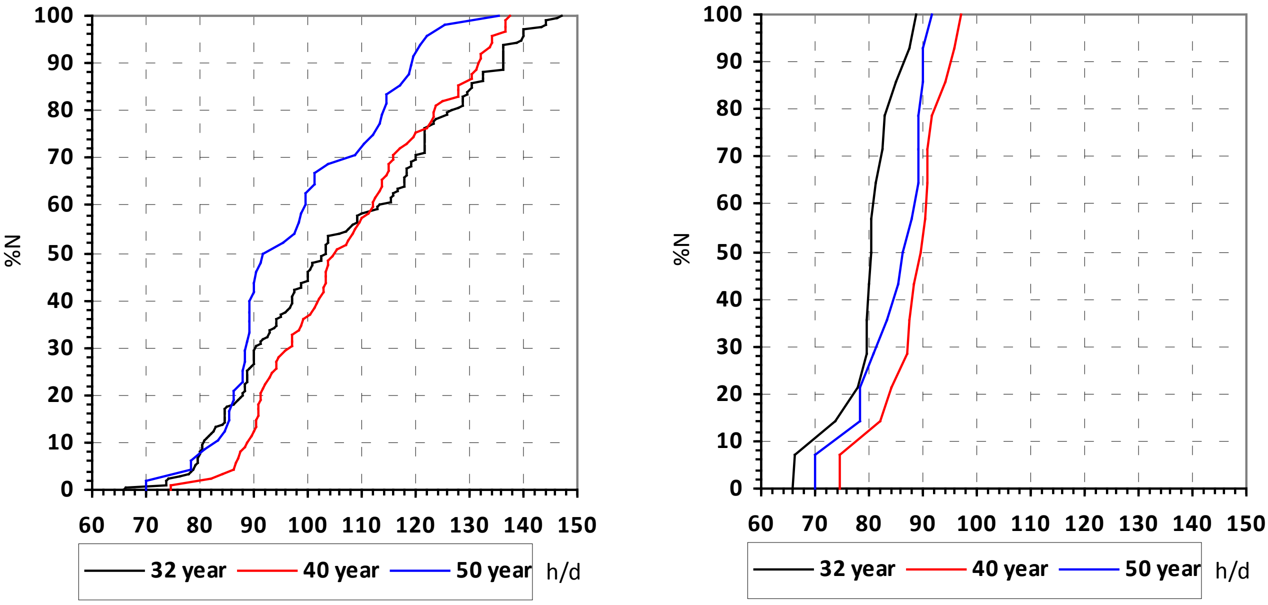
The degree of slenderness of dominant trees, obtained on the basis of the detailed analysis of dominant trees (D_{100} and D_{400}), had minimum values in the period between the ages of 15 and 26 and amounted to 60-70. After this period, the degree of slenderness showed an increase and reached the value of approximately 80 at the age of 32 in both trees. At the age of 40, the degree of slenderness of the tree representing the 100 thickest trees was 80, and 90 of the tree representing the 400 thickest trees. At the age of 50, the average degree of slenderness of dominant trees, obtained based on the measurement of growth elements, corresponded to the degree of slenderness obtained by a detailed analysis of trees at the age of 40 (Graph 7).

The cumulative curves of slenderness for the total number of trees show that at the age of 32 less than 8% of trees had the degree of slenderness below 80, only 2% at the age of 40, and 8% of trees at the age of 50. Furthermore, 53% of trees had the degree of slenderness above 100 at the age of 32, 63% at the age of 40 and 36% at the age of 50 (Graph 8 left).

At the age of 32, 50% of the aspirant trees had the degree of slenderness below 80, less than 15% at the age of 40, and less than 30% at the age of 50. However, all aspirant trees had the degree of slenderness below 90 at the age of 32, 50%



Graph 7. Development of the slenderness (h/d) of dominant trees
Grafikon 7. Razvoj stupnja vitkosti (h/d) dominantnih stabala.



Graph 8. Sum curves of slenderness distribution (h/d) at the ages of 32, 40 and 50 for all trees (left) and for the future trees (right).
Grafikon 8. Sumarne krivulje distribucija stupnja vitkosti (h/d) u 32., 40. i 50 za sva stabla (lijevo) i stabla budućnosti (desno).

Table 8. Results of KS-test for all trees and for the future trees at different ages.
Tablica 8. Rezultati KS-testa za sva stabla i stabala budućnosti u različitim godinama

Tree category *Kategorija stabla*	Age *Starost*	All trees *Sva stabla* age 32 *32. god.*	All trees *Sva stabla* age 40 *40. god.*	All trees *Sva stabla* age 50 *50. god.*
Future trees *Stabla budućnosti*	age 32 *32. god.*	–	0.1831*	0.233*
	age 40 *40. god.*	0.6429**	–	0.3251**
	age 50 *50. god.*	0.5^{ns}	0.4286^{ns}	–

of the aspirant trees at the age of 40 and 90% at the age of 50 (Graph 8 right).

According to the non-parametric Kolmogorov-Smirnov test, the cumulative curves of slenderness for all trees show significant differences between the three measurements of growth elements, which is ascribed to the reactions of trees to the conducted thinning and to the reduction in the number of trees due to thinning. However, with the same number of aspirant trees, significant differences were found only in the period between the ages of 32 and 40, *i.e.* after the first thinning (Table 8).

DISCUSSION AND CONCLUSIONS
RASPRAVA I ZAKLJUČCI

A comparison of the growth elements of the investigated culture with the elements of growth in other young to middle-aged spruce cultures in Serbia (Stojanović and Banković,1981; Stojanović and Krstić, 1984; Vučković *et al.*, 1990; Tomanić, 1990; Dražić, 1994; Koprivica and Ratknić, 1996; Koprivica *et al.*, 1998; Krstić, 1998; Ratknić, 1994; Ratknić and Vučković, 1999; Ratknić *et al.*, 2001) shows that the investigated culture is in the category of the best cultures in Serbia. Another conclusion we can make from the comparison of the elements of growth of the investigated culture and the spruce cultures in other areas is that the investigated culture has high productivity (Assmann,1970; Maunaga, 1999; Pretzsch, 2005; Orlić, 1987; 1994; 1999; Orlić *et al.*, 1997, Oršanić, 1995; Slodičak and Novak, 2003) or good site quality (Halaj *et al.*, 1987, Maunaga, 2001).

The first thinning at the age of 32 and the height of dominant trees of 15 m was low (q_d <0.85) and heavy (36% of the volume) selective thinning. The age at which the thinning was carried out does not significantly deviate from the age at which the first "commercial" thinnings are performed in Europe (Slodičák and Novak, 2003). However, the flows of the current diameter increment determined by the detailed analysis of dominant trees (D_{100} and D_{400}) show that the thinning at the age of 32 was performed late, while the height growth (increment) model shows that the culmination was reached at the age of 25 (when the dominant trees reached the height of 11 m), which means that the first commercial thinning should not be performed later than the age of 25. The adoption of this biological criterion for the determination of the optimum timing for thinning would, according to (Vučković, 1991; Kotar, 2005), produce the best effects of thinning on the increment and stability of trees and stands. Following the recommendations of Assmann (1970), it has been stated that when applying selective thinning after Schädelin (1934), tending candidates should be selected from the dominant trees that are 8 to 12 m tall.

The initial large number of trees with high volume per hectare and heavy thinning at the ages of 32 and 40 have caused high values of the cutting yield, 115.13 $m^3 \cdot ha^{-1}$ and 142.28 $m^3 \cdot ha^{-1}$, which are in the category of the highest cutting yields achieved on individual experimental plots of young stands (Stojanović and Krstić, 1984; Vučković *et al*., 1990; Orlić 1999; Orlić *et al*., 1991). The applied thinnings had the highest intensity broadly recommended in the literature for spruce cultures of similar age (Halaj *et al*., 1986; Maunaga, 2001).

In the period between the ages of 33 and 40, total of 555 trees per hectare were cut down due to mortality and snowbreaks (14.2%). Their volume was 22.0 $m^3 \cdot ha^{-1}$. Thus it follows that out of the initial number of trees, a total of 1,933 trees was cut down (49.4%) in the 32nd year of age. Their total volume was 137.1 $m^3 \cdot ha^{-1}$ (35.9%). The research of Valinger and Petersson (1996) carried out on permanent experimental plots established in 24-45-year-old spruce cultures suggests that the greatest relative number of trees damaged by snow and wind was recorded on control plots and in the early period after extremely heavy thinnings (over 40% of basal area). According to these results, the increased risk of damage caused by snow and wind is greatly affected by the unfavourable position of the culture and high culture density, which is consistent with our research.

In the period between the ages of 33 and 40, the reaction in the diameter increment of the remaining trees was weak. Compared to the results of Stojanović and Krstić (1984), the current diameter increment of the remaining trees after the thinning, between the ages of 33 and 40 (0.31 $cm \cdot year^{-1}$, Table 7), was similar to the value of the diameter increment on the control area with a 30% higher number of trees per hectare in the two five-year age periods between the stand ages of 32 and 42 (0.31 to 0.34 $cm \cdot year^{-1}$). The current diameter increment of the future trees in the investigated culture (0.54 $cm \cdot year^{-1}$, Table 7) was within the range of the increment of remaining trees on the experimental plots with the thinnings of light to moderate intensity stated by Stojanović and Krstić (1984). The size of the diameter increment of the aspirant trees in the researched culture between the ages of 33 and 40 was significantly lower than the sizes stated by Štefančík (2012) for the thinning procedures first implemented at the stand age of 20. In the period after thinning was performed in the investigated culture, between the ages of 33 and 40, the current volume increment was 22.15 $m^3 \cdot ha^{-1} \cdot year^{-1}$ and it was similar to the increment found by Orlić (1999) in 41-year-old spruce cultures with about 40% smaller number of trees after a thinning at the age of 32. Compared to the sizes of the current increment of basal area and volume stated by Stojanović and Krstić (1984), which were achieved at a similar age and with the application of light to moderate thinning from below, the increments in the investigated culture were 35% smaller. Compared to data provided by Slodičák and Novak (2003), who conducted light selective thinnings at a similar age on a series of experimental areas in spruce stands of approximately the same age, basal area increments per hectare in the investigated culture were higher by 13-166%.

The second thinning at the age of 40 and at the height of dominant trees over 20 *m* was low (q_d <0.85) heavy (34% of the volume) selective thinning. The heavy thinning at the age of 40 with the thinning volume of 142.28 $m^3 \cdot ha^{-1}$ caused a greater diameter increment, *i.e*. better reaction in the diameter increment of the remaining trees, compared to the thinning at the age of 32. The future trees had a 28% higher diameter increment in the age period between 41 and 50 years compared to the age period between 33 and 40.

The difference in the diameter increment size between the two study periods in the investigated stand is in line with other authors` results that spruce stands on favourable sites and with the number of trees that is not too large for the given age react positively to thinning even if they are performed later in life (Makinen and Isomaki, 2004a; 2004b; Preuhsler and Schmidt, 1989). According to the results (Preushler and Schmidt, 1989), late moderate to heavy thinnings from below in densely closed spruce stands, aged 48 and 58 years, exhibit a slower reaction in the volume increment in the early period after the cutting (5-7 years) compared to the following five-year period, which is consistent with our research. According to the results of Stojanović and Krstić (1984) that refer to the stand age between 32 and 42, larger diameter (11%) and volume (20%) increments in the second five-year period than in the first were identified only on the heavily thinned experimental plots. On the experimental plots with light to moderate first thinning and light second thinning, the mentioned autors recorded smaller diameter, basal area and volume increments in the second than in the first observed (five-year) period. The higher increment in the later age period, between the ages of 50 and 70 years, is related to a small number of trees per hectare in spruce monocultures. Slodičák and Novak (2003) noted increment increase in the later period, after heavy thinning from below, while Štefančík (2012) stresses that heavy thinning, particularly selective thinning, increases the diameter increment of target trees. In the case of heavy and very heavy thinning from below, larger increase in diameter increment was also observed after the second compared to the period after the first thinning (Nilsson *et al*., 2010).

On several series of experimental plots in several decades of research (over 100 years) in spruce stands, it has been found that if the stands are young and if we apply light to moderate thinning from below in a short period of time, they will achieve higher increments of basal area (and volume) per hectare than control plots. Further, similar values (below 5% decrease) of the basal area increment per hectare are also attainable with heavier thinnings performed later in life (Assmann, 1970). Quantification of the `qualitative` research of spruce cultures was conducted by Pretzsch (2005), who created practical models of the current increment of basal area (and volume) depending on the intensity of thinning and site class. However, a large number of authors point to a pronounced variability in the size of the current increment of basal area and volume per hectare depending not only on the applied thinning techniques and intensity, but also on the age and site class. These values can be 25% lower or 40% higher compared to control plots or the surface areas with light thinnings from below (Pretzsch, 2005; Wallentin, 2007).

The first selective thinning of heavy intensity in the studied culture was conducted at the age when economically viable assortments were most likely to achieve. According to the flows of diameter and height increments of dominant trees, it was a late thinning and it resulted in the weak revitalization of tree diameter increments in the period between the ages of 33 and 40. However, dominant trees, especially the 400 thickest trees per hectare, were in the phase of more pronounced height growth during the thinning, which increased the degree of slenderness and consequently reduced the stability of the stand. According to Abetz and Klädtke (2002), the optimum degree of slenderness in spruce cultures is 80-90, and above that size trees are highly prone to wet snow and wind breakages, so it can be concluded that at the age of 32 only the tending trees fulfilled the criterion (h_L/d_g=80) and the stand as a whole was highly prone to wet snow and wind breakages (h_L/d_g =102). Under the influence of the second selective thinning of heavy intensity, at the age of 40, the future trees had a 29% larger diameter increment in the period between the ages of 41 and 50 compared to the period between the ages of 33 and 40, which together with the decreasing trend of height increment caused a smaller degree of slenderness and greater stability of the stand and individual trees. All things considered, it follows that the heavy thinnings carried out at the ages of 32 and 40 contributed to the establishment of favorable relations in the diameter and height growth of trees in the investigated culture and thereby improved their structural stability.

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Sažetak

Istraživanja su obavljena u kulturi smreke (*Picea abies* /L./ Karst.), koja je osnovana sa 5.000 sadnica po hektaru na staništu planinske šume bukve na nadmorskoj visini 870 *m*. Na osnovi usporedbe elemenata rasta istraživane kulture s elementima rasta u drugim mladim do srednjedobnim kulturama smreke, istraživana kultura je u kategoriji visokoproizvodnih kultura u Srbiji i šire u Europi.

Na trajnoj pokusnoj plohi, u dobro sklopljenom dijelu istraživane smrekove kulture u starosti 32 godine, izmjereno je 3.911 stabala po hektaru, s volumenom od 384,17 $m^3 \cdot ha^{-1}$, a ukupno evidentiran prirast drvne zalihe sastojine do 40. godine iznosio je 561,85 $m^3 \cdot ha^{-1}$, a do 50. godine 819,1 $m^3 \cdot ha^{-1}$. Na osnovi dvije prorjede, u 32. i 40. godini i naknadno posječenih tanjih stabala u razdoblju od 33. do 40. god., na pokusnoj plohi ukupno je posječeno 2.844 stabla po hektaru (72,7%) volumena 279,4 $m^3 \cdot ha^{-1}$ (tablica 1). Numerički pokazatelji strukture stabala na pokusnoj plohi u 32., 40. i 50. godini prikazani su u tablici 2, a debljinska struktura na grafikonima 2, 3 i 4.

Za definiranje utjecaja prorjeda na prirast stabala uspoređen je tečajni debljinski (i_{dt}) i visinski (i_{ht}) prirast u razdoblju od 25. do 32. godine i 33.-40. godine kod detaljno analiziranih dominantnih stabala (D_{100} i D_{400}), a na sastojinskoj razini uspoređen je tečajni debljinski (i_{dt}) i visinski (i_{ht}) prirast u razdoblju od 33. do 40. godine i 41.do 50. godine kod dominantnih stabala (D_{100} i D_{400}). Testiranje razlika između tečajnih prirasta u različitim razdobljima obavljeno je uz pomoć t-testa. Na razini sastojine uspoređen je i tečajni prirast promjera, temeljnice i volumena svih stabala i stabala budućnosti (311 kom.$\cdot ha^{-1}$) u razdoblju od 33.-40. godine i u razdoblju od 41.-50. godine. Neparametrijski Kolmogorov-Smirnov test korišten je za međusobnu usporedbu struktura stupnja vitkosti (odnos $h/d_{1,3}$). Istraživanja su omogućila da se definira utjecaj prorjeda na prirast i stupanj vitkosti različitih kategorija stabla i sastojine u dva starosna razdoblja sastojine, 33.-40. i 41.-50. godine.

Prva prorjeda u 32. godini, pri visini dominantnih stabala 15 m, imala je karakter selektivne prorjede, bila je niska (q_d<0,85) i jaka (jačina prorjede je 36% volumena). Prorjeda je obavljena u starosti sastojine koja značajnije ne odstupa od razdoblja kada se izvode prve „komercijalne“ prorjede u Europi. Međutim, tokovi tečajnog debljinskog prirasta detaljno analiziranih dominantnih stabala (D_{100} i D_{400}) pokazali su da je prekasno izvršiti prorjedu u 32. godini, a model rasta (prirasta) visina je pokazao kulminaciju u 25. godini (kada su dominantna stabla postigla visinu 11 m), pa bi se 25. godina mogla označiti i kao godina u kojoj je najkasnije trebalo izvršiti prvu komercijalnu prorjedu (grafikon 7). Zatečeni velik broj stabala, s velikom drvnom zalihom po hektaru, u 32. godini i jaka prorjeda uvjetovali su visoki iznos prorjednog etata, od 115,13 $m^3 \cdot ha^{-1}$, što je u kategoriji najviših iznosa volumena koji se okvirno preporučuju u literaturi za sličnu starost smrekovih kultura. U razdoblju od 33.-40 godine debljinski prirast je iznosio kod preostalih stabala 0,31 cm$\cdot$god^{-1}, a kod stabala budućnosti 0,54 cm$\cdot$god.$^{-1}$ (tablica 7). Dominantna stabla, posebno 400 najdebljih stabala po hektaru, nalazila su se u fazi velikog visinskog prirasta u vrijeme i poslije prorjede u 32. godini (tablica 5 i 6), što je za posljedicu imalo povećanje stupnja vitkosti stabala, odnosno povećanje nestabilnosti sastojine (grafikon 8).

Druga prorjeda u 40. godini, pri visini dominantnih stabala preko 20 m, imala je karakter selektivne prorjede, bila je niska (q_d<0,85) i jaka (jačina prorjede je 34% volumena). Jaka prorjeda u 40. godini, s prorjednim etatom 142,28 $m^3 \cdot ha^{-1}$, uvjetovala je veći debljinski prirast, odnosno bolju reakciju debljinskog prirasta na preostalim stablima, u odnosu na prorjedu u 32. godini. Stabla budućnosti imali su za 29%, a dominantna stabala (D_{100} i D_{400}) za 36-42%**,** veći debljinski prirast u starosnom razdoblju od 41.-50. godine, u odnosu na starosno razdoblje 33.-40. godine, što je uz opadajući trend visinskog prirasta uvjetovalo i manji stupanj vitkosti, odnosno veću stabilnost stabala i sastojine (grafikon 8).

Na osnovi navedenog, proizlazi da su provedene jake prorjede doprinijele uspostavljanju povoljnih odnosa u debljinskom i visinskom rastu stabala u istraživanoj kulturi i time poboljšale njihovu stabilnost.

KLJUČNE RIJEČI: *Picea abies* /L./ Karst., monokultura, trajna pokusna ploha, jake prorjede, stupanj vitkosti