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GROWTH ELEMENTS OF THE TREES AND THE STAND OF *Gymnocladus dioicus* (L.) K. Koch AT FRUŠKA GORA (SERBIA)

ELEMENTI RASTA STABALA I SASTOJINE *Gymnocladus dioicus* (L.) K. Koch NA FRUŠKOJ GORI (SRBIJA)

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SUMMARY

The species *Gymnocladus dioicus* (L.) K. Koch has been present in the territory of Serbia for over 150 years, and is most commonly cultivated in the form of decorative single trees or in small groups. The largest heterogeneous group of trees is situated at Fruška Gora on the site of pedunculate oak and hornbeam. The growth elements of trees and the group (stand) are presented in this paper. The spacing between the trees in the stand was 3 × 3 *m*. The growth elements of the trees and the stand are shown for 75, 80 and 85 years of culture ages, for all trees and collectives of trees that were developed under the influence of different growing space. The productivity of the stand is high. At the age of 85 years, 502 trees per hectare were determined with quadratic mean diameter (d_g) of 39.6 *cm*, dominant diameter (D_{100}) 51.5 *cm*, Lorey's mean height (h_L) 33.0 *m*, dominant height (H_{100}) 35.0 *m*, basal area 61.74 $m^2 \cdot ha^{-1}$ and volume of 918.23 $m^3 \cdot ha^{-1}$.

KEY WORDS: *Gymnocladus dioicus* (L.) K. Koch, introduction, culture, growth elements, growing conditions, Serbia

INTRODUCTION
UVOD

The genus *Gymnocladus* (*Fabaceae=Leguminosae*) consists of five species (Roskov *et al.*, 2005). One species (*G. dioicus* (L.) K. Koch) is endemic in the eastern part of north America, and four species (*G. angustifolius* (Gagnep.) J.E. Vidal, *G. chinensis* Baill., *G. assamicus* Kanjilal ex P.C. Kanjilal i *G. burmanicus* Parkinson) are endemic in eastern Asia (Lee, 1976). In Europe, *G. dioicus* is a widespread tree species in parks and avenues (2018). The Kentucky coffeetree is native to North America with a range that includes southern Ontario, then east to central New York, southwestward to Oklahoma, and north to southern Minnesota (Harlow *et al.*, 1996). The trees grow up to about 30 *m* in height and up to about 1.2 *m* in diameter (Werthner *et al.*, 1935). According to Petrović (1951), in the area of Lake Michigan and Huron it grows up to 33 *m* in height and up to 100 *cm* in diameter and in old growth forests it branches close to the ground. In nature, it builds communities with many tree species and some of the most important associates of the Kentucky coffeetree are *Juglans nigra* L., *Celtis occidentalis* L., *Ulmus americana* L., *Quercus rubra* L., *Acer saccharum* Marsh. (McClain and Jackson, 1980). The root system is deep, widespreading, the tree is considered to be wind-firm (Van Dersal, 1938). The species has the ability to withstand very low temperatures up to –34 °*C* (Elias, 1980). The wood has a wide use and the seeds were used as a coffee substitute so the tree got its name ”coffeetree” (Alden, 1995). Although

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the Kentucky coffeetree natural range is wide, it is nowhere abundant and it can be found at the edges of woods and along streams (Werthner *et al.*, 1935). It is typically distributed as widely separated single trees or small groups that are presumably clonal and is the result of root suckering (McClain and Jackson, 1980). On natural sites of Kentucky coffeetree, there are no special means of dispersal of the fruit, so the natural distribution of the fruit is scanty. Even a strong wind cannot carry the pods far and it is not known that the rodents are storing them for food (Werthner *et al.*, 1935). It is hypothesized that the Kentucky coffeetree is an ecological anachronism, sinking to extinction in the wild because nothing animate appears to be its primary or secondary dispersal agent in natural and semi-natural habitats in North America (Zaya and Howe, 2009). The leaves and the fruit are poisonous (Pammel, 1911), so the species is generally resistant to herbivory (Janzen, 1976). Thanks to the Native American ethno-botanical practices, the current range of the species is, to a certain extent, shaped by human influence which is suggested by the strong correlation between current stands of Kentucky coffeetree and former Native American settlements (VanNatta, 2009). The problem of poor natural regeneration of this dioecious species is even more difficult having in mind that there are populations with sexual structure that consists only of single-sex individuals (Environment Canada, 2014).

In the territory of Serbia, the species *G. dioicus* has been present for over 150 years, and it was most commonly cultivated in the form of decorative single trees or small groups of trees in the parks and estates of former noblemen in Vojvodina and one site was registered in Topčider in the territory of Belgrade (Petrović, 1951; Bobinac *et al.*, 2017). The largest, heterogeneous group of trees is at Fruška Gora on the site of pedunculate oak and hornbeam. The data about the growth elements of this group of trees (culture) are presented at the age of 17 years (Petrović, 1951) and at the age of 75 years (Bobinac and Stojadinović, 2007; Bobinac *et al.*, 2008). According to these authors, Kentucki coffeetree has potentially high productive possibilities and can be considered as a fast growing tree species which makes it economically interesting on this site. The justification of cultivation of the species is confirmed by anatomical research which pointed out that *G. dioicus* has good wood properties, and is especially recommended for recultivation of degraded sites (Vilotić *et al.*, 2011; Jokanović *et al.*, 2015). The research and observations in the cultures in Serbia have pointed out the limited ability of subspontaneous expansion of *G. dioicus* as well as some biological traits that could be useful in the control of subspontaneous expansion in the cultures (Bobinac *et al.*, 2017; Bobinac *et al.*, 2018).

The aim of this paper is to point out the growth elements of trees and the stand of *G. dioicus* at Fruška Gora (Serbia) and consider their values depending on different growing space in the culture.

MATERIALS AND METHODS
MATERIJALI I METODE

Research object – *Objekt istraživanja*

The culture of *G. dioicus* is situated in the western part of National park "Fruška Gora" (in the territory of forest administration Erdevik, φ=45°07'N, λ=19°21'E), in a wide stream valley 120 *m* above sea level. The culture was raised on a pedunculate oak-hornbeam site (*Carpino betuli-Quercetum roboris /Anić 59/ Rauš 1971.*) (Tomić, 2013).

Regarding the geographical position, this area is under the influence of humid continental climate. Based on the data from the weather station Sremska Mitrovica (φ=45°06'N, λ=19°33' E, elevation=82 *m* above sea level), the mean annual air temperature is 11.3 °*C*. The absolute maximal temperature of 43.6 °*C* was measured in July and the absolute minimal temperature of –29.5 °*C* was measured in January. The mean annual rainfall is 614.2 *mm* with 60% falling during the growing season (data from the Republic Hydrometeorological Service of Serbia for the closest weather station for the period 1981–2010).

The culture is established in the spring of 1932 with seedlings 2.5 *m* tall, with 3 × 3 *m* spacing (1111 trees per hectare) in a triangular pattern. The seedlings were produced in Ilok (Croatia) in the nursery of the landowner Odeskalski who owned the culture at the time. At the end of 1948 (17 years after the establishment) 70 trees were measured (833 trees per hectare) with a quadratic mean diameter (d_g) of 12.4 *cm*, Lorey's mean height (h_L) 10.5 *m*, basal area 10.11 $m^2 \cdot ha^{-1}$ and estimated volume of 68.30 $m^3 \cdot ha^{-1}$ (Petrović, 1951).

The establishment of *G. dioicus* culture at Fruška Gora is the result of individual collectoral activity, directed to the expansion of the floristic diversity of the area with the main purpose of using it as hunting grounds for big game.

Because of its botanical peculiarity for the territory of Serbia, the culture was put under special protection in the National park in 1978 in the category Natural monument (1981). Later, the change in attitude towards allochthonous species that took place in the National park caused the cancelation of the protection (2004) and the culture was left to spontaneous development as it was the case before protection.

The researched *G. dioicus* culture is in the surrounding of other tree species of similar age and is partially formed in the irregular geometric shape. The crowns of the trees on the edge of the stand were under the influence of approximately double the growing space compared to the space between the rows in the stand (3 *m*).

In order to define the total area covered by the stand, and the growing space of the trees in it, every tree was set in the local coordinate system of the stand. In this local coordinate system, the border of the experimental plot was defined by

Figure 1. The appearance of 75 years old *G. dioicus* culture at Fruška Gora (Photo: N. Stanković).

Slika 1. Izgled kulture *G. dioicus* na Fruškoj gori u starosti 75 godina (Foto: N. Stanković).

the middle of the distance between the trees on the edge of the stand that belong to it and the neighbouring trees outside the stand. Based on the coordinates of every individual tree in the space defined in the previously mentioned way, the so called "Voronoi" polygons were constructed (Okabe *et al.*, 2000) which were used to present the growing space of the trees in the stand above ground. "Voronoi" polygons were defined using the deldir package in R environment (Turner, 2016). Using the mentioned procedure, the total area of the stand was defined (0.0976 *ha*) and that is the growing space of the preserved homogenous group of trees at the age of 75 years with the initial growing space of 3 × 3 *m* (Figure 1).

The use of "Voronoi" polygons enabled the segregation of different collectives of trees that were under the different influence of neighbouring trees, i.e. the segregation of the collective of inner trees (A) and the edge trees (B) with their respective growing space (Figures 2 and 3).

Measurement and data analysis of growth elements – *Premjer i analiza podataka o elementima rasta*

At the age of 75 years, all the living trees that could have been linked to the trees from 1932, i.e. 1948 in the culture were permanently marked and periodically measured in the coming period. At the ages of 75, 80 and 85 years, two cross diameters with precision of 1 *mm* were measured as well as the tree heights using the Vertex III hypsometer with precision of 0.1 *m*. The thin trees that were present in the stand as a result of subspontaneous expansion caused by the decomposition of the stand were not included in this research.

On the area of 0.0976 *ha* at the age of 75 years, there were 54 trees in total, and at the age of 85 years (in 2017) 49 trees were still in the culture. These trees were the available sample that was used for the presentation of the growth elements of the trees and the stand per hectare.

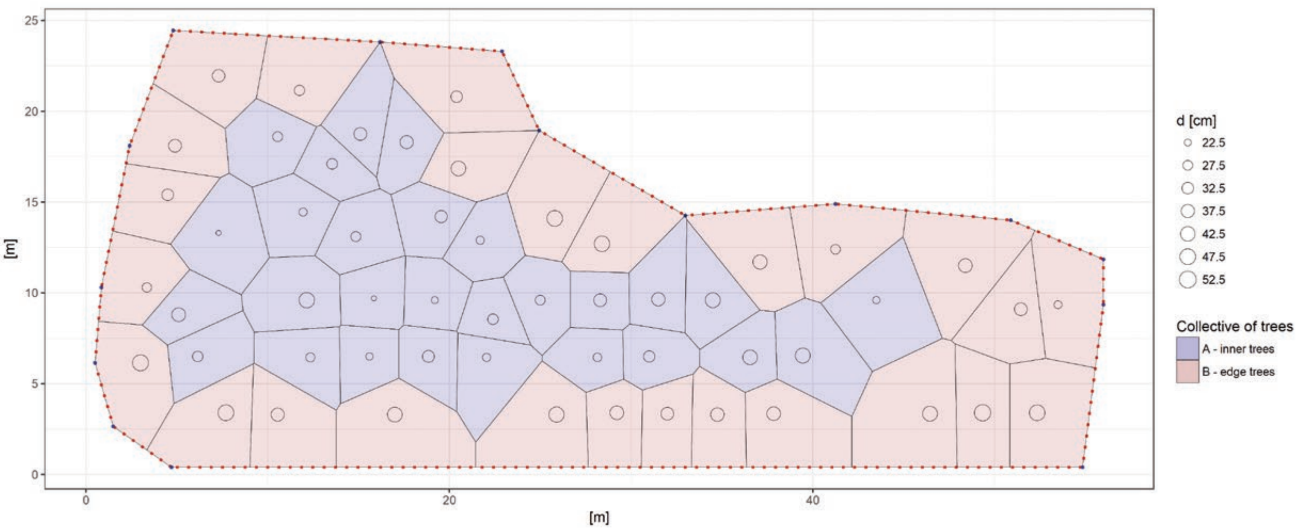


Figure 2. The spatial distribution of the trees in the culture and their available area defined by "Voronoi" polygons.

Slika 2. Prostorni raspored stabala u kulturi i njihova stajališna površina definirana "Voronoi" poligonima.

Figure 3. The habit of 85 years old *G. dioicus* trees on the edge of the culture at Fruška Gora (Photo: M. Bobinac).

Slika 3. Habitus rubnih stabala *G. dioicus* u kulturi na Fruškoj Gori, u starosti 85 godina (Foto: M. Bobinac).

For the construction of the height curves, the Richards function (Richards, 1959) was used. It served well for the obtaining the heights of the standing trees that couldn't have been measured since they were damaged or had irregular crowns.

The volume was determined using the volumetric tables of total volume down to 3 *cm* for narrow-leaved ash (Pantić, 1997).

The mean and dominant quadratic diameters (d_g i D_{100}) and the Lorey's mean and dominant height (h_L i H_{100}) were calculated. For the presentation of the diameter and height distribution of the trees, the following numerical parameters were used: arithmetic mean (x_s), standard deviation (s_d), coefficient of variation (c_v%), minimum (x_{min}), maximum (x_{max}), range (r), skewness (skew) and kurtosis (kurt).

The current diameter (i_d), height (i_h), basal area (i_g) and volume (i_v) increment of the mean tree were shown for the same, i.e. comparable collective of trees in the observed five year periods.

The differences between the current increments of different collectives of trees in the stand were tested using the t-test.

RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA

Stand structure elements – *Elementi strukture sastojine*

At the stand age of 75 years, 533 trees per hectare were registered with basal area of 55.92 $m^2 \cdot ha^{-1}$ and the volume of 791.42 $m^3 \cdot ha^{-1}$. The quadratic mean diameter (d_g) was 35.9 *cm* and the diameter of dominant trees (D_{100}) was 46.6 *cm*. The Lorey's mean height was 31.2 *m* and the dominant height (H_{100}) 32.7 *m*. Due to mortality and windthrow, the number of trees was reduced, so at the age of 80 years, 512 trees per hectare remained in the culture. At the age of 85 years, 502 trees per hectare remained in the stand, so in the observed 10-year period the number of trees was reduced by 9.2%. The current basal area and volume increment of the remained collective of trees in the period of 76-80 years of stand age was 1.04 $m^2 \cdot ha^{-1} \cdot year^{-1}$ and 18.80 $m^3 \cdot ha^{-1} \cdot year^{-1}$, while in the period of 81-85 years of stand age, it was 0.97 $m^2 \cdot ha^{-1} \cdot year^{-1}$ and 18.27 $m^3 \cdot ha^{-1} \cdot year^{-1}$.

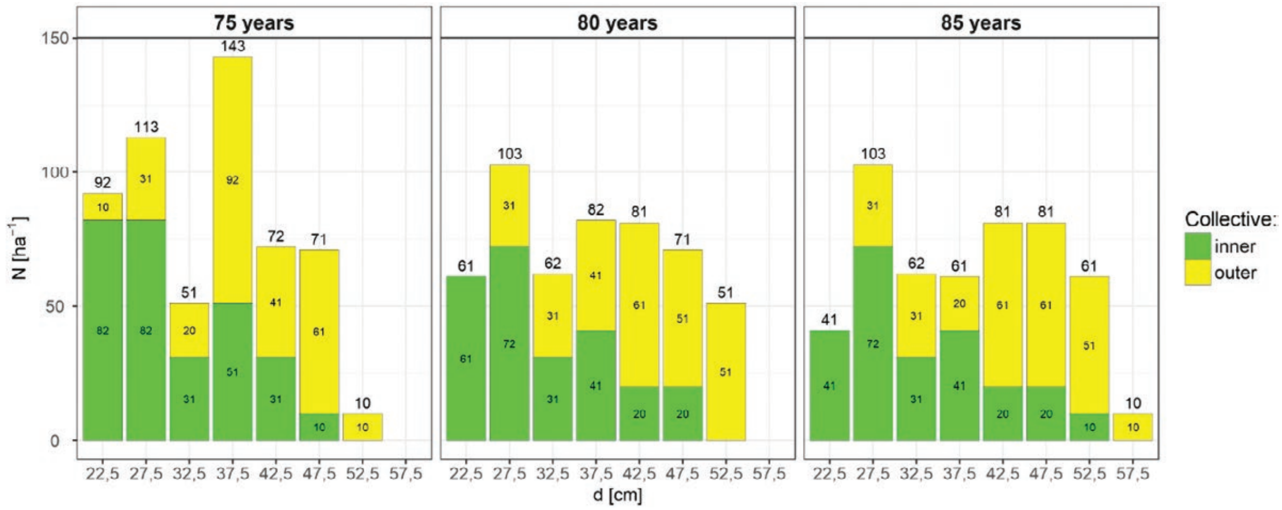
Table 1. The growth elements of trees and the stand.

Tablica 1. Elementi rasta stabala i sastojine.

Stand age *Starost sastojine*	d_g	D_{100}	h_L	H_{100}	h_L/d_g	H_{100}/D_{100}	N	G	I_G	V	I_V
[years] *[godina]*	[*cm*]		[*m*]				[*ha*$^{-1}$]	[*m*^{2}·*ha*$^{-1}$]	[*m*^{2}·*ha*$^{-1}$·*year*$^{-1}$]	[*m*^{3}·*ha*$^{-1}$]	[*m*^{3}·*ha*$^{-1}$·*year*$^{-1}$]
75	35.9	46.6	31.2	32.7	87	70	553	55.92	–	791,42	–
80	37.8	49.2	32.1	34.0	85	69	512	57.34	1.04	832,64	18,80
85	39.6	51.5	33.0	35.0	83	68	502	61.74	0.97	918,23	18.27

Legend: d_g – quadratic mean diameter; D_{100} – quadratic dominant diameter based on the basal area of 100 thickest trees per hectare; h_L – Lorey's mean height; H_{100} – dominant height; N – number of trees per hectare; G – basal area per hectare; V – volume per hectare; I_G – annual basal area increment per hectare; Iv – annual volume increment per hectare; h_L/ d_g – slenderness index of the mean tree; H_{100}/ D_{100} – slenderness index of the dominant tree.

Legenda: *d_g – srednji promjer po temeljnici; D_{100} – srednji promjer po površini presjeka 100 najdebljih stabala po hektaru; h_L – srednja visina po Loraju; H_{100} – dominantna visina; N – broj stabala po hektaru; G – temeljnica po hektaru; V – volumen po hektaru; I_G – tečajni prirast temeljnice po hektaru; Iv – tečajni prirast volumena po hektaru; h_L / d_g – stupanj vitkosti srednjeg stabla; H_{100} / D_{100} – stupanj vitkosti dominantnog stabla.*



Graph 1. The diameter distribution of the trees in the stand.
Grafikon 1. Debljinska struktura stabala u sastojini.

Table 2. The descriptive statistics of the diameter distribution of the trees in the stand.
Tablica 2. Deskriptivna statistika debljinske strukture stabala u sastojini.

Age *Starost* [years] *[godina]*	n [trees] *[stabala]*	d_a [cm]	d_{min} [cm]	d_{max} [cm]	s_d [cm]	c_v [%]	skew	kurt
75	54	34.9	20.7	50.3	8.480	24.3	0.040	–1.179
80	50	36.6	21.3	52.9	9.230	25.2	0.048	–1.187
85	49	38.4	21.6	55.3	9.760	25.4	0.026	–1.180

Legend: n – number of measured trees; d_a – arithmetic mean diameter; d_{min} – minimal diameter; d_{max} – maximal diameter; s_d – standard deviation; c_v – coefficient of variation; skew – distribution skewness; kurt – distribution kurtosis.

***Legenda:** n – broj mjerenih stabala; d_a – aritmetički srednji promjer; d_{min} – minimalni promjer; d_{max} – maksimalni promjer; s_d – standardna devijacija; c_v – koeficijent varijacije; skew – asimetrija debljinske srukture; kurt – spljoštenost debljinske strukture.*

Table 3. The descriptive statistics of the height distribution of the trees in the stand.
Tablica 3. Deskriptivna statistika visinske strukture stabala u sastojini.

Age *Starost* [years] *[godina]*	n [trees] *[stabala]*	h_a [m]	h_{min} [m]	h_{max} [m]	s_d [m]	c_v [%]	skew	kurt
75	54	29.7	17.9	35.5	4.510	15.2	–1.021	0.189
80	50	30.5	18.3	36.5	4.810	15.8	–0.995	0.028
85	49	31.3	18.8	37.3	4.970	15.9	–1.041	0.117

Legend: n – number of measured trees; h_a – arithmetic mean height; h_{min} – minimal height; h_{max} – maximal height; s_d – standard deviation; c_v – coefficient of variation; skew – distribution skewness; kurt – distribution kurtosis.

***Legenda:** n – broj mjerenih stabala; h_a – aritmetički srednja visina; h_{min} – minimalna visina; h_{max} – maksimalna visina; s_d – standardna devijacija; c_v – koeficijent varijacije; skew – asimetrija visinske strukture; kurt – spljoštenost visinske strukture.*

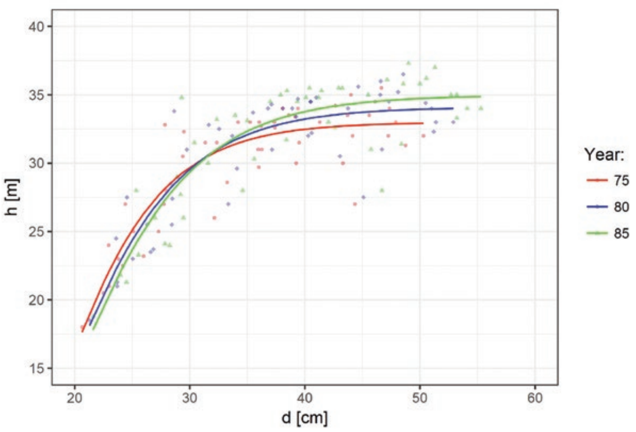
At the stand age of 85 years, the basal area was 61.74 $m^2 \cdot ha^{-1}$ and the volume 918.23 $m^3 \cdot ha^{-1}$. The slenderness index (h/dbh ratio) at the age of 75 years was 87 and was gradually reduced until the age of 85 years when it reached 83. The slenderness index of the dominant trees at the age of 75 years was 70 and was gradually reduced until the age of 85 years, when it reached 68 (Table 1).

The diameter distribution of the stand at the ages of 75, 80 and 85 years showed bimodality, with the range of diameter classes from 22.5 *cm* to 52.5 *cm*, and 57.5 *cm*, respectively (Graph 1).

The diameter distribution of trees is approximately symmetrical and platykurtic while the variability of diameter at breast height is 24.3-25.4% (Table 2).

The height distribution of trees is characterized by left asymmetry and mesocurtic distribution while the height variability of the trees is 15.2-15.9% (Table 3).

The positions of height curves constructed for the stand ages of 75, 80 and 85 years are pointing to the usual dynamics of height curves moving with age in regular stands. The small value of height increment and the superiority of diameter growth compared to height growth in thinner trees caused the small moving of height curves towards greater heights compared to the age of 75 years (Graph 2).



Graph 2. The height curves at stand ages of 75, 80 and 85 years.
Grafikon 2. Visinske krivulje u starosti sastojine 75, 80 i 85 godina.

The elements of estimation of the height curve smoothing show a good fit compared to measured values with the coefficient of determination 0.76-0.79 (Table 4).

The growth elements and the current increment of growth elements of trees in different growing conditions in the stand – *Elementi rasta i tečajni prirast elemenata rasta stabala u različitim uvjetima za rast u sastojini*.

The average value of available growing space at the age of 75 years, defined by ''Voronoi" polygons, in collective of inner trees (A) is 14.6 $m^2 \cdot tree^{-1}$ and is significantly smaller than in the collective of edge trees (B) where it is 21.84 $m^2 \cdot tree^{-1}$ ($p < 0.0001$).

During the spontaneous development of the stand, the collective A was characterized by the reduction of the number of trees (mortality and windthrows) compared to the age of 75 years. Compared to the collective B, collective A had higher the number of trees by 19-33%, but lower the mean diameter by 24-29%, the dominant diameter by 10-16%, the mean height by 7-10% and the dominant height by 1-2% in the observed stand ages. These ratios in the values of diameter and height of mean and dominant trees in different collectives of trees are pointing out the differences between them, that are expressed in the value of the slenderness index as well. In the collective A, the slenderness index of the mean trees is 16-21% higher compared to the collective B. The dominant trees in the collective A have 7-13% higher slenderness index compared to the collective B.

Table 4. The parameters and elements of the model estimation for the dependence of heights from their breast height diameters.
Tablica 4. Parametri i elementi ocjene modela ovisnosti visina stabala od njihovih prsnih promjera.

Age [years] *Starost [godina]*	Model: h = $a \cdot (1-e^{-b \cdot DBH})^c$			Elements of the model estimation *Elementi ocjene modela*		
	a	b	c	n	r^2	s_e
75	31.68559	0.191191814	33.9723176	50	0.7891	1.9636
80	32.79534	0.171076281	25.1987287	48	0.7776	2.1427
85	33.66993	0.160764572	22.6041835	47	0.7637	2.2751

Legend: *a*, *b*, *c* – model parameters; n – number of measured trees; r^2 – coefficient of determination; s_e – standard error of regression.
***Legenda:** a, b, c – parametri modela; n – broj mjerenih stabala; r^2 – koeficijent determinacije; s_e – standardna greška regresije.*

Table 5. The growth elements of trees and the stand in the collectives that grew in different growing space.
Tablica 5. Elementi rasta stabala i sastojine kod kolektiva u različitim uvjetima za rast.

Collective of trees with their total area *Kolektiv stabala sa pripadajućom površinom*	Age *Starost* [years] *[godina]*	d_g [cm]	D_{100} [cm]	h_L [m]	H_{100} [m]	h_L / d_g	H_{100} / D_{100}	N [ha^{-1}]	G [$m^2 \cdot ha^{-1}$]	V [$m^3 \cdot ha^{-1}$]
A (P = 0.0409 *ha*)	75	31.9	43.4	30.0	32.3	94	74	685	54.82	765,56
	80	32.6	43.8	30.7	33.5	94	76	587	48.89	700,43
	85	34.1	45.7	31.6	34.2	93	75	563	51.30	753,69
B (P = 0.0568 *ha*)	75	39.7	47.7	32.0	33.0	81	69	458	56.70	810,03
	80	42.0	50.4	32.9	33.9	78	67	458	63.41	927,82
	85	43.9	52.9	33.7	34.8	77	66	458	69.21	1036,7

In previously mentioned relations, the collective B with 33.3% smaller number of trees at the age of 75 years has higher basal area and volume per hectare compared to the collective A for around 3% and 6%, respectively. At the age of 80 years, the smaller number of trees for 22% in collective B has higher basal area and volume per hectare for 30-32%, and at the stand age of 85 years, the 19% smaller number of trees in collective B has higher basal area and volume per hectare for 35-37% compared to the collective A (Table 5).

In observed ages, the variability of diameters at breast height in collective A (24.7-25.6%) is higher compared to the collective B (18.9-19.5%). The diameter distribution of the trees in the collective A is characterized by right asymmetry and platykurtic distribution while in the collective B the left asymmetry and platykurtic distribution were registered (Table 6).

In observed ages, the variability of heights of trees in collective A (18.3-19.8%) is higher compared to the collective B (9.8-10.4%). The height distribution of trees in collective A is characterized by left asymmetry and platykurtic distribution, while in collective B a strong left asymmetry and leptocurtic distribution was registered (Table 7).

The current diameter and height increment in the collective B is higher by 90% and 32%, compared to the collective A, respectively. The differences are significant ($p < 0.05$). The current basal area and volume increment in the collective B is 2.19-2.34 times higher compared to the collective A and the differences are highly significant ($p < 0.001$) (Table 8).

Table 6. The descriptive statistics of the diameter distribution of the trees in the collectives that grew in different growing space.
Tablica 6. Deskriptivna statistika debljinske strukture stabala kod kolektiva u različitim uvjetima za rast.

Collective of trees *Kolektiv stabala*	Age *Starost* [years] *[godina]*	n *[trees]* *[stabala]*	d_a *[cm]*	d_{min} *[cm]*	d_{max} *[cm]*	s_d *[cm]*	c_v [%]	skew	kurt
A	75	28	31.0	20.7	46.1	7.660	24.70	0.525	–0.864
	80	24	31.6	21.3	48.1	7.920	25.00	0.597	–0.709
	85	23	33.1	21.6	50.6	8.470	25.60	0.570	–0.710
B	75	26	39.0	23.8	50.3	7.380	18.90	–0.385	–0.701
	80	26	41.3	26.6	52.9	7.940	19.20	–0.362	–0.857
	85	26	43.1	27.7	55.3	8.410	19.50	–0.354	–0.912

Table 7. The descriptive statistics of the height distribution of the trees in the collectives that grew in different growing space.
Tablica 7. Deskriptivna statistika visinske strukture stabala kod kolektiva u različitim uvjetima za rast.

Collective of trees *Kolektiv stabala*	Age *Starost* [years] *[godina]*	n [trees] *[stabala]*	h_a	h_{min}	h_{max} *[m]*	s_d	c_v [%]	skew	kurt
A	75	28	28.2	17.9	34.5	5.15	18.30	–0.57	–0.83
	80	24	28.7	18.3	35.6	5.62	19.60	–0.45	–1.10
	85	23	29.5	18.8	36.2	5.83	19.80	–0.52	–1.07
B	75	26	31.2	23.0	35.5	3.07	9.80	–1.20	1.10
	80	26	32.1	23.5	36.5	3.25	10.10	–1.20	0.96
	85	26	32.9	24.0	37.3	3.43	10.40	–1.18	0.79

Table 8. The annual (mean periodic) increments of the diameter, height, basal area and volume of trees that grew in different growing space.
Tablica 8. Tečajni prirast prečnika, visine, temeljnice i volumena stabala u različitim uslovima za rast.

Collective of trees *Kolektiv stabala*	Age *Starost* [years] *[godina]*	n [trees] *[stabala]*	i_d $[cm \cdot tree^{-1} \cdot y^{-1}]$	i_{hL} $[m \cdot tree^{-1} \cdot y^{-1}]$	i_g $[cm^2 \cdot tree^{-1} \cdot y^{-1}]$	i_v $[dm^3 \cdot tree^{-1} \cdot y^{-1}]$
A	76-85	23	0.21	0.13	11.7	22.6
B	76-85	26	0.40	0.17	27.3	49.5
t-test[1]			–5.07	–2.66	–4.81	–4.70
p value			<0.0001	0.0106	<0.0001	<0.0001

[1] The results of the t-test comparison of collectives of trees in different growing conditions in the stand.

Legend: i_d – annual diameter increment; i_{hL} – annual height increment; i_g – annual basal area increment; i_v – annual volume increment.

Legenda: *i_d – tečajni prirast promjera; i_{hL} – tečajni prirast visine; i_g – tečajni prirast temeljnice; i_v – tečajni prirast volumena.*

DISCUSSION AND CONCLUSIONS
RASPRAVA I ZAKLJUČCI

The species *Gymnocladus dioicus* (L.) K. Koch has been present in the territory of Serbia for over 150 years and it is one of the earliest introduced species (Bobinac *et al.*, 2017). Usually, the tree was used decoratively, in the form of single trees or in small groups in parks and estates of the former nobleman in Vojvodina. The species regenerates well from seed and root suckers, but it doesn't show invasiveness (Bobinac *et al.*, 2017). That is the reason why the species is mostly present only in locations where it was introduced until the first half of the 20th century having in mind that in the later period, only single trees and small groups were planted. In the current reviews of exotic species in Serbia (Perović and Cvjetićanin, 2005) *G. dioicus* is not identified as the species that is important for a broader use in silviculture.

The largest and the best preserved heterogeneous group (culture) of trees of *G. dioicus* in Serbia is at Fruška Gora on the site of pedunculate oak and hornbeam. In the researched culture at Fruška Gora, the growth elements of the trees of *G. dioicus* (in the first place, the dominant height of 35 *m* and Lorey's mean height of 33 *m*) at the age of 85 years from the establishment are pointing out the productive potential of the pedunculate oak site for the silvicultural cultivation of *G. dioicus*. According to Halaj *et al.* (1987) and Jović *et al.* (1989-90), pedunculate oak reaches above mentioned heights on best sites. In the researched stand, the highest recorded height of *G. dioicus* tree at the age of 85 years was 37 *m*.

The growth elements are pointing out the high productivity of the culture in the observed ages. At the age of 85 years from the establishment, 502 trees per hectare were registered with quadratic mean diameter (d_g) of 39.6 *cm*, dominant diameter (D_{100}) 51.5 *cm*, Lorey's mean height (h_L) 33.0 *m*, dominant height (H_{100}) 35.0 *m*, basal area 61.74 $m^2 \cdot ha^{-1}$ and volume 918.23 $m^3 \cdot ha^{-1}$. The current volume increment was 18.80 $m^3 \cdot ha^{-1}$ in the age period 76-80 years and 18.27 $m^3 \cdot ha^{-1}$ in the age period 81-85 years (Table 1).

The variability of height distribution of the trees in the stand is significantly smaller compared to the variability of the diameter distribution and that is the characteristic of stands consist of trees with the same age (Andrašev, 2008). The conducted analysis showed that the structural characteristics and the growth elements of the stand are defined by the growing space of the trees so the two different collectives of trees were separated in the stand.

The collective of inner trees (A) is falling behind in diameter and height growth, compared to the collective of edge trees (B), that is shown by the achieved mean and dominant diameters and heights (Table 5), as well as the significant differences between the current diameter, height, basal area and volume increments (Table 8). In the collective A, in the observed 10-year period, the processes of a strong differentiation between the trees occurred. That is presented by higher values of coefficients of variation of diameter and height distribution compared to the collective B (Tables 6 and 7). That resulted in the reduction of the number of trees, due to mortality, wind breakage and windthrow compared to the initial state at the age of 75 years.

The above shown relations in the structure and the value of increment of different collectives of trees in the stand are pointing out the strong reaction of edge trees, i.e. the trees that grew in more favourable conditions at the same age. This implies the need for application of tending measures in order to maintain the optimal levels of increment. The trees in the stand are characterized by straight stem, well cleaned from branches. The slenderness index, as an indicator of the stem form (Pretzsch, 2009), is 93 in the collective A and 21% higher compared to the collective of edge trees (B) where it amounts 77. Besides the high productivity of dendromass, the mentioned indicators are pointing out that this species can be directed to the production of technical assortments of good quality. The species has quality wood, but is prone to rough branching (Petrović, 1951) so it would be important to investigate the optimal value of the growing space for the trees in the process of establishing cultures and project-

Figure 4. The wind break of *G. dioicus* tree caused by the presence of the butt rot fungi (*Ganoderma sp.*) in the stand at Fruška Gora at the age of 80 years (Photo: M. Bobinac).

Slika 4. Vjetrolom stabla *G. dioicus* uzrokovanog prisutnošću truležnice (*Ganoderma sp.*) u sastojini na Fruškoj Gori, u dobi 80 godina (Foto: M. Bobinac).

Figure 5. The "ideal" tree phenotype of *G. dioicus* in the stand at Fruška Gora at the age of 85 years (Photo: M. Bobinac).

Slika 5. "Idealni" fenotip stabla *G. dioicus* u sastojini na Fruškoj Gori, u starosti 85 godina (Foto: M. Bobinac).

ing the tending measures, as well in the case of establishing the cultures with secondary tree species.

The absence of tending measures in the researched culture, due to mentioned conservation approach and the lack of knowledge about growth characteristics of this rare species in Serbia contributed to the decrease of the species perspective and sustainability. From the total number of trees per hectare at the age of 75 years, 34% trees were registered in the understory and 80% of the trees had significantly reduced crowns (Bobinac *et al.*, 2008). In the period of 75-85 years of the stand age, at the butt of the trees, the wood decaying fungi carpophores were registered and the windbreakages are present as well (Figure 4).

Because of the absence of the tending measures in this unique culture of *G. dioicus* in Serbia, the knowledge about characteristics of growth of trees in "optimal" growing space conditions has been denied. Having in mind all the restrictions that limited the generalization of the conclusions based on this small sample in the stand, it can still be concluded that the dominant trees with well developed crown are representing the achieved phenotype that is interesting for the production of technical assortments (Figure 5).

Besides the decorative role and resilience to disease and pests (Carter, 1966); with poisonous leaves that made it generally resistant to herbivores (Janzen, 1976); with relative resistance to damage caused by ice and wind (Carter, 1966) and limited ability for subsponatneous expansion (Bobinac *et al.*, 2017; 2018), *G. dioicus* has a range of positive characteristics that are pointing to the possibility of a wider use of this species in forestry.

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SAŽETAK

Istraživanje je provedeno u kulturi alohtone vrste *Gymnocladus dioicus* (L.) K. Koch na Fruškoj gori, osnovanoj 1932. godine s razmakom sadnje 3 × 3 m, na staništu lužnjaka i običnog graba (*Carpino betuli-Quercetum roboris /Anić 59/ Rauš 1971.*), na nadmorskoj visini 120 m.

Elementi rasta stabala i sastojine u dobi od 75, 80 i 85 godina ukazuju na visoku proizvodnost kulture. U 85 godina od sadnje zabilježeno je 502 stabla po hektaru s prosječnim promjerom od 39,6 cm (d_g), dominantnim promjerom (D_{100}) 51,5 cm, srednjom visinom 33,0 m, dominantnom visinom (H_{100}) 35,0 m, s temeljnicom 61,74 $m^2 \cdot ha^{-1}$ i volumenom od 918,23 $m^3 \cdot ha^{-1}$. Tečajni prirast volumena bio je u razdoblju od 76 do 80. godine 18,80 $m^3 \cdot ha^{-1}$, a u razdoblju 81-85. godine 18,27 $m^3 \cdot ha^{-1}$ (Tablica 1). Provedena analiza pokazala je da strukturna svojstva i veličine elemenata rasta sastojine definira prostor za rast stabala u kulturi. Skupina unutarnjih stabala u kulturi (A) zaostaje u debljinskom i visinskom rastu u odnosu na skupinu rubnih stabala (B), što pokazuju postignuti srednji i dominantni promjeri i visine (Tablica 5), kao i značajne razlike između tečajnog prirasta promjera, visine, temeljnice i volumena (Tablica 8).

Uz sva ograničenja za generalizaciju zaključaka, zbog malog uzorka stabala u kulturi, može se ipak zaključiti da stabla dominantnog položaja i pravilno razvijenih kruna predstavljaju realizirani fenotip zanimljiv za proizvodnju tehničkih sortimenata (slika 5).

KLJUČNE RIJEČI: *Gymnocladus dioicus* (L.) K. Koch, introdukcija, kultura, elementi rasta, uvjeti za rast, Srbija