

COMPARATIVE ANALYSIS OF THE STANDS' STRUCTURE OF VIRGIN AND MANAGED BEECH FORESTS FROM THE SEMENIC MOUNTAINS

Oliver MERCE, Daniel-Ond TURCU, Cătălin-Ionel CIONTU

National Institute for Research and Development in Forestry "Marin Dracea",
8 Padurea Verde Alley, Timisoara, Romania

Corresponding author email: oliver_merce@yahoo.com

Abstract

This paper presents the results of a comparative analysis of the structural characteristics of virgin and managed beech forests in the Semenic Mountains. The research was conducted in eight sample areas, each measuring 2,500 m², with two areas in each forest category (virgin and managed) at two altitudes (1200 m and 1350 m). The structural characteristics were compared using the following parameters: diameter distribution, height distribution, maximum dimensions of living trees (with emphasis on thick trees), Gini index, Shannon index, slenderness coefficient, and regeneration. The density of the stands and their productive characteristics were also studied, using the number of trees, basal area, and volume as attributes. The greatest differences were found in terms of tree diameters, slenderness coefficients, and regeneration, which may lead to the conclusion that silvicultural interventions carried out in managed forests over time have significantly affected their structure.

Key words: beech forest, virgin forest, managed forest, structural diversity.

INTRODUCTION

In Europe, beech is the predominant native species providing multiple ecosystem services, with its range extending from hilly to mountainous regions (Kulla et al., 2023). At the European level, beech occupies approximately 15 million hectares (Brunet et al., 2010), while its share in the total volume of wood is approximately 12% (Forest Europe, 2020). According to the potential vegetation in Europe, beech forests could cover a much larger area than the current one, with an estimated coverage of approximately 92 million hectares (Bohn et al., 2004). Similar to Europe, beech is also the most widespread species in Romania, occupying about 31% of the country's forest area. It has a very wide altitudinal range, forming the upper limit of the forest in the Semenic Mountains (Stănescu et al., 1997).

Intensive exploitation of European forests has led to their homogenization and simplification in terms of composition and structure, leaving only remnants of virgin forest ecosystems in the temperate zone (Kisin et al., 2025). It is estimated that approximately 0.3 million hectares of intact forests (0.4% of the total forest area) are found in strict forest reserves and other protected areas in the European temperate zone (Parviainen, 2005).

Forest management affects their characteristics and natural processes, and numerous studies have shown that managed forests differ from natural ones. The differences between managed and unmanaged forests depend heavily on the intensity of silvicultural interventions, whether we are talking about tending operations or treatment method. Their magnitude and type can have a different effect on biodiversity as well as on forest structure (Baran et al., 2020).

An essential part of modern forestry consists of "copying" the dynamics and natural structure of forests as found in primary forests, without giving up their production function (Stiers et al., 2018), this is all the more important given that, in recent years, due to the tense economic situation, forest districts have been forced to reduce the costs of tending operations and to make full use of the forest's self-regulating processes (Commarmot et al., 2005).

In order to mimic the natural dynamics and structure of managed forests as closely as possible, primary forests must be studied as reference systems and their structural characteristics must be quantified (Stiers et al., 2018).

To quantify these differences, a series of structural attributes are used, such as diameter at 1.3 m, tree height, number of trees/ha, basal area, and stand volume, etc., based on which

conclusions can be drawn about the structure of the entire stand.

Virgin and quasi-virgin forests have the following structural characteristics:

- they have a large biomass volume;
- they contain large, old specimens that can reach the maximum development potential of the species;
- they have significant volumes of dead wood in various stages of decomposition;
- they present a heterogeneous structure, with a mosaic distribution of components (Radu et al., 2004).

In order to achieve such characteristics in managed forests, these characteristics must first be measurable and reproducible (Stiers et al., 2018). Only then we can talk about close to nature forestry, a concept that has been widely accepted and gained popularity in practice, becoming the main or only approach to forest management in an increasing number of countries (Schütz et al., 2016).

The main objective of the research in this article is to compare the structural characteristics of virgin and managed beech forests in the Semenik Mountains in order to determine (I) the impact of past forestry operations on the structural diversity of beech stands, even though such operations have not been carried out in

recent decades (stands in sample areas at 1200 m altitude) and (II) the impact of past and present forestry operations on the structural diversity of beech stands (stands in sample areas at 1350 m altitude).

MATERIALS AND METHODS

The research was conducted in sample areas located in both virgin and managed forests. Data was collected only for living trees in eight circular sample plots, each measuring 2500 m². In order to limit the differences caused by site variability, we chose stands at the same altitude for both forest types, with sample plots located at 1200 m and 1350 m altitude, respectively (two in each forest category at each altitude level).

The sample plots are located in the Semenik Massif (Figure 1), in the Caraș-Severin County, four of them being located within the Izvoarele Nerei Nature Reserve (Forest District Nera, parcels: 113, 123 and 12, 14, 115 in management unit (UP II and III, respectively), with stands aged 180 years (xxx, 2015) and another four in two managed stands nearby, within Văliug Forest District (parcels 39B - management unit (UP XII), and 17A and 21A - management unit (UP II), 100-year-old stands (xxx., 2021).

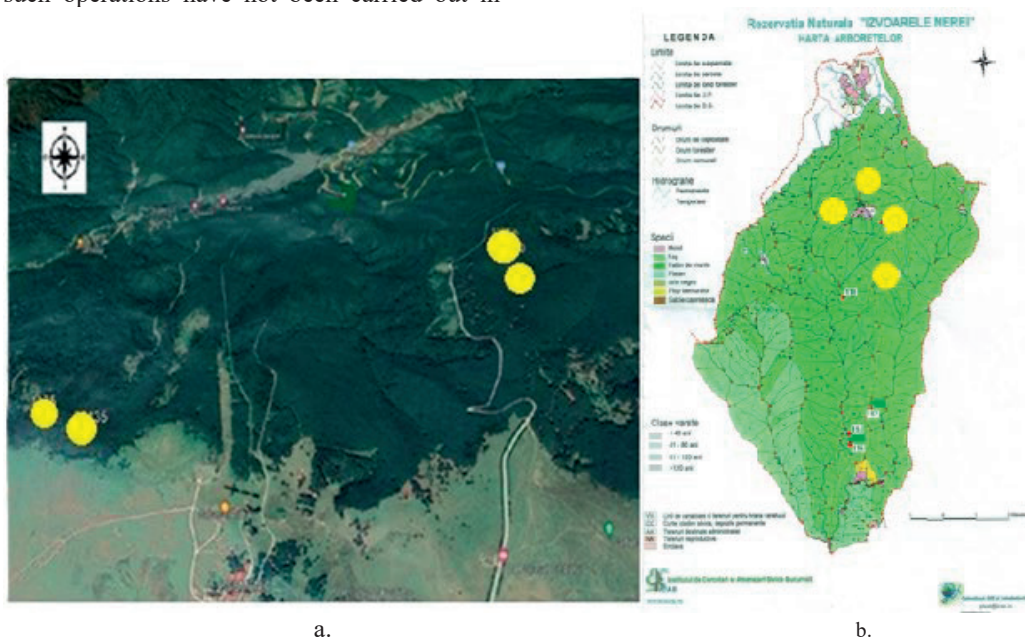


Figure 1. Location of sample plots within the managed forest (a) (<https://earth.google.com/web>) and within the Izvoarele Nerei Nature Reserve (b) (Tomescu et al., 2004)

In order to observe the influence of forestry operations on the structure of the stands, two types of sample areas were selected within the managed forest: those at an altitude of 1200 m were located in the stands where human intervention had been minimal in recent decades, while those at an altitude of 1350 m were chosen in stands where various types of forestry work had been carried out, with varying intensities, some more recently.

Following the analysis of existing forest management plans, it was found that in the forest management units where the sample areas were located at an altitude of 1200 m, only accidental felling was carried out in 2012 (26 m³ – intensity 0.5%), while in the parcels selected for the sample plots located at an altitude of 1350 m, they were carried out: thinnings (8 ha – 41% of the parcel) and principal cuttings (1293 m³ – intensity 11.7%) in 1993, other cuttings (563 m³ – intensity 5.3%), thinning (25 m³ – intensity 0.25%), accidental cuttings (78 m³ – intensity 0.8%) and conversion cuttings to selection system (1316 m³ – intensity 13.2%) in 2002 and thinnings (12 m³ – intensity 0.16%) and accidental cuttings (21 m³ – intensity 0.28%) in 2012.

The diameters at 1.3 m were measured with a forestry caliper, and all trees with a diameter greater than or equal to 6 cm were inventoried. Heights were measured with a Vertex device. The degree of regeneration of the stands was also investigated by inventorying all seedlings taller than 10 cm and with a dbh < 6 cm. In each of the eight sample plots, the regeneration layer was inventoried in 13 sample areas arranged according to the following scheme: one in the center of the 2500 m² sample area, and another 3 sample areas at respectively equal distances (9 m) in the cardinal directions – N, E, S, W. Each regeneration sample plot consists of 3 concentric circles, as follows: RC1 - a 5 m² circle in which all seedlings with a height between 10 and 39 cm were inventoried, RC2 - a 10 m² circle in which seedlings with heights between 40 and 130 cm were inventoried, and RC3 - a 20 m² circle in which all seedlings with a height greater than 130 cm and a dbh < 6 cm were inventoried.

The diversity of diameters was calculated using the Gini index. The Gini coefficient is defined as the area between the line of perfect equality (diagonal) and the Lorenz curve, expressed as

the proportion of the area under the diagonal (Weiner & Solbrig, 1984), and its general formula is: $G = 1 - \sum_{i=1}^k [(ba_{i-1} + ba_i)(ni - ni_{i-1})]$ where ba_i (ba_{i-1}) is the cumulative fraction of the basal area (per cent) of the trees from all diameter classes thinner than or equal to the i th ($i - 1$) diameter class (for $i = 1$, $ba_{i-1} = 0$), ni (ni_{i-1}) is the cumulative fraction of the number of trees (per cent) from all diameter classes thinner than or equal to the i th ($i - 1$) diameter class (for $i = 1$, $ni_{i-1} = 0$) and k represents the number of diameter classes (Duduman, 2011). The values of this coefficient vary between 0 (lack of diversity) and 1 (maximum diversity). In order to highlight the distribution of diameters as accurately as possible, we used a mixed model of Gaussian functions.

Also, using the Shannon index (H), the diversity of diameters and heights was computed, where 0 means no diversity and higher values of the Shannon index indicate a higher degree of diversity. The calculation formula for this index is $H = -\sum_{i=1}^S p_i * \ln p_i$ where $p_i = ni/N$, and p_i is the proportion of species representation, ni is the number of individuals of a species, and N is the total number of individuals in the analyzed perimeter.

The slenderness coefficient (z) was determined, which is expressed by the ratio between tree height h (m) and base diameter d (cm) (Grudnicki, 2004).

The following double logarithmic regression equation was used to calculate the volume of living wood:

$$\log V = a_0 + a_1 * \log(D) + a_2 * \log^2(D) + a_3 * \log(H) + a_4 * \log^2(H),$$

where: D – diameter (cm) at 1.3 m, H – total height (m), a_0 , a_1 , a_2 , a_3 , a_4 – regression coefficients for different species established by Giurgiu and Draghiciu (2004).

RESULTS AND DISCUSSIONS

Density and productivity of the stands

In the virgin forest, the number of living trees per hectare is quite similar at both altitudes. Compared to the managed forest, this number is much lower, with a large number of trees per hectare present in the sample plots of managed forest at an altitude of 1200 m (Table 1). This number can be attributed to the (almost total) lack of forestry interventions, to the age (the

trees are much younger than those in the virgin forest, being in the middle forest development phase, the trees not being at the limit of their physiological longevity), but also to the lack of abiotic disturbances.

In the sample areas of the managed forest at an altitude of 1350 m, the number of trees/ha was closer to that in the virgin forest, with forestry interventions of varying degrees of intensity being carried out in these stands.

For the virgin forests, the results are similar to other virgin beech forests in Central and Eastern Europe in terms of the number of trees per hectare. Therefore, in the Havešova Reserve, the average number of living trees per hectare is 290 (Drössler & von Lüpke 2007), in the Puka Reserve, 325 living trees per hectare were inventoried (Meyer et al., 2003), and in the Rožok Reserve, 270 living trees/ha were inventoried (Kucbel et al. 2012).

Regarding the volume and basal area, the values calculated for the Semenik forest stands are high (Table 1), higher than those in the beech forests in Serbia, where the basal area in managed forests is 27.37 m²ha⁻¹ and the volume is 429.53 m³ha⁻¹ (Matović et al., 2018). In the Havešova Reserve, the basal area is 35 m²ha⁻¹ and the volume was 716 m³ha⁻¹ (Drössler & Lüpke

2007), in the Puka Reserve, the basal area is 45.6 m²ha⁻¹ and the volume was 780.7 m³ha⁻¹ (Meyer et al. 2003), and in the Rožok Reserve, the basal area is 39.5 m² ha⁻¹ and the volume was 744 m³ha⁻¹ (Kucbel et al. 2012).

Table 1. Number of trees, basal area, and volume per hectare by forest category

Forest category	Altitude (m)	Number of trees (Nha ⁻¹)	Basal area (m ² ha ⁻¹)	Volume (m ³ ha ⁻¹)
virgin	1200	294	53,77	962,77
	1350	318	43,12	682,49
managed	1200	1082	52,95	739,90
	1350	516	50,10	631,15

Diameters of the trees

In terms of tree diameters, based on the Shannon index, greater diversity and higher average and maximum values and standard deviations are observed in the virgin forest compared to the managed forest. However, the average tree diameter in the managed forest at 1350 m is close to that in the virgin forest at 1350 m altitude due to the thinning of the forest stands through forestry operations (Table 2).

Table 2. Statistical indicators of tree diameters

Forest category	Altitude (m)	Average (cm)	Standard deviation (cm)	Minimum (cm)	Maximum (cm)	Shannon index (H)
virgin	1200	41.5	24.9	7.6	90.8	2.97
	1350	35.7	21.1	7.1	93.1	2.82
managed	1200	23.7	7.7	7.1	59.4	2.03
	1350	32.6	13.2	6.5	70.1	2.54

The Gini index proved to be the best estimator of tree structure based on tree diameter (Silaghi, 2013).

The average value of the Gini index for the stands in the virgin forest at 1200 m is 0.541, and for the virgin forest at 1350 m it is 0.555.

The Gini index calculated for tree diameters in the managed forest at 1200 m is 0.341, and for

the managed forest at 1350 m it is 0.415 (Figure 2). These values indicate a higher inequality in the distribution of tree diameters in the virgin forest and a greater diversity of size classes.

In the managed forest, the values indicate a more uniform distribution of diameters, trees having similar sizes, which is typical for a managed forest.

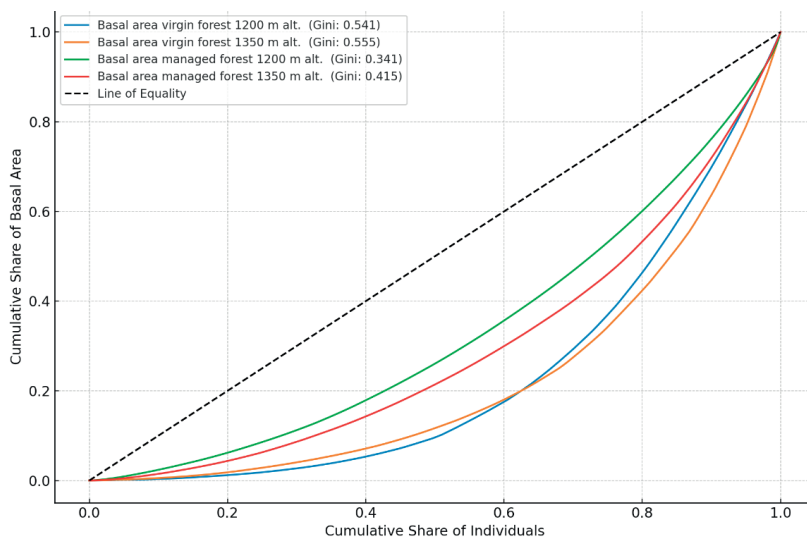


Figure 2. Lorenz curves for tree diameters with Gini Index

In the managed beech forests in Serbia, the Gini index ranged between 0.49 and 0.57, while in virgin forests the values varied between 0.45 and 0.52 (Matović et al., 2018). In managed beech forests in Bohemia, the Gini index values averaged 0.22 (Bilek et al., 2011), below those found in the beech forests of Semenik. In contrast, for virgin forests, the values were higher in Bohemia, ranging between 0.67 and 0.75 (Bilek et al., 2011).

The distribution of trees by diameter categories was modeled as the sum of two normal

distributions using a mixed model of Gaussian functions. In the case of virgin forest, they were observed two major groups of trees, one concentrated around 28 cm (medium-sized, younger trees) and another concentrated around 68 cm (corresponding to older, larger trees) for the forest at an altitude of 1200 m, and a group of trees concentrated around 26 cm (younger trees) and another at 64 cm (corresponding to older, larger trees) for the forest at an altitude of 1350 m (Figure 3).

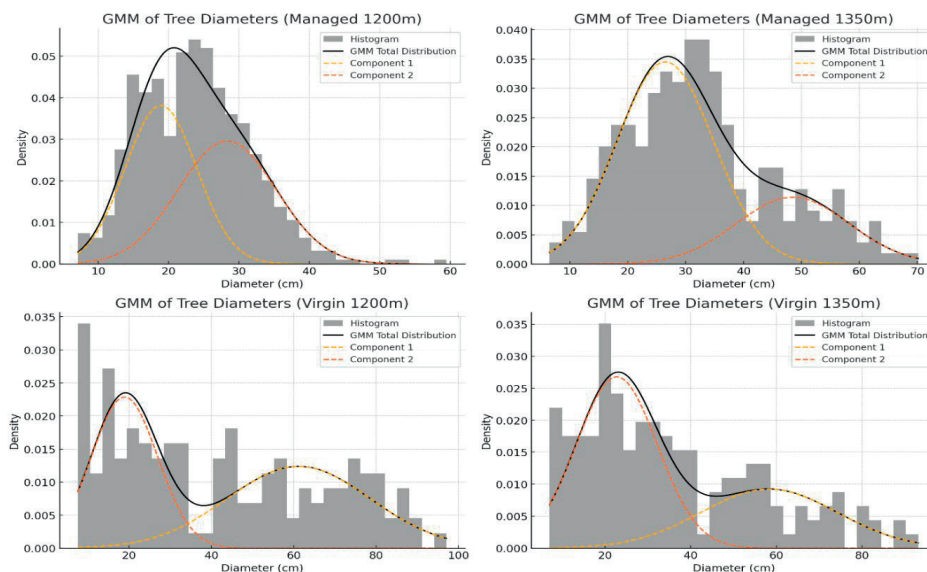


Figure 3. Gaussian Mixture Model Distribution for diameters

Density of thick trees per hectare

We defined the large trees as those with a diameter greater than or equal to 60 cm (Turcu et al., 2015). These are essential components in terms of maintaining biomass accumulation, carbon storage, structural heterogeneity, biodiversity, and forest integrity. They also regulate biotic filtration processes, dominating the structure, dynamics, and functions of many forests in temperate zones (Lutz et al., 2013 and Fichtner et al., 2015). Such trees are also called "habitat trees" because they provide or can provide ecological niches due to their size (Bütler et al., 2013).

Most thick trees are found in the virgin forest at 1200 m, followed by those in the virgin forest at 1350 m altitude. No such trees were found in the managed forest at 1200 m. This fact can be attributed to the lower age but also to the increased density of the stands. In the managed forests at 1350 m, due to the lower consistency of the forest as a result of silvicultural interventions, such trees are found in the diameter category $d \geq 60$ -80 cm (Table 3).

In the old beech forests in Central Europe, inventories have found approximately 30 living trees per hectare with a diameter greater than 70 cm, and the number of living trees with a diameter greater than 80 cm varies between 10 and 17 trees/ha (Nilsson et al., 2003).

Table 3. Distribution of the number of thick trees/ha by diameter categories

Forest category	Altitude (m)	$d \geq 60$ -80 cm	$d \geq 80$ -100 cm
virgin	1200	58	26
	1350	28	16
managed	1200	0	0
	1350	18	0

Heights of the trees

The distribution of trees by height categories within the virgin forest at an altitude of 1200 m is wide and relatively symmetrical, but with a slight tendency towards higher values. Several size classes are present, reflecting a layered structure typical of virgin forests. The forest has an extremely heterogeneous structure: very small and very tall trees coexist.

The absence of forestry interventions has favored the coexistence of young, mature, and old trees. In the case of the virgin forest at an altitude of 1350 m, the distribution suggests a high vertical diversity, but with a lower concentration in a dominant class. The possible influence of more severe climatic conditions (higher altitude) may have led to a lower increase in tree height. Here, too, we find a stable natural structure, with trees of varying sizes and high vertical diversity (Figure 4).

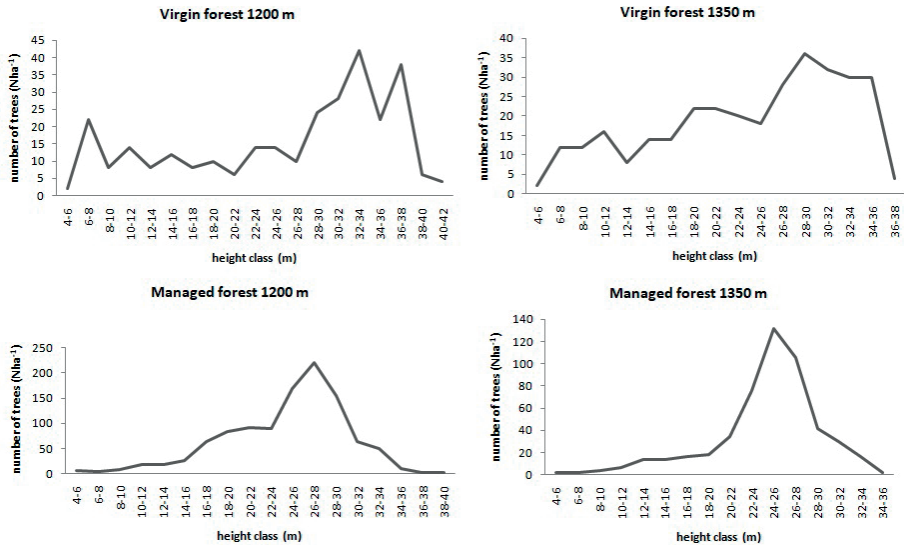


Figure 4. Distribution of the number of inventoried trees/ha, by height categories in the sample plots at 1200 m and 1350 m altitude in virgin forest and managed

Within the managed forest at an altitude of 1200 m, it can be observed that the distribution of trees by height category is positively asymmetrical, with a well-defined peak in the 26-28 m height class. Most trees are of average height, which indicates a dominant cohort, i.e., a forest that is relatively uniform in age, with a homogeneous structure and less vertical structural diversity than in virgin forest. In the managed forest at an altitude of 1350 m, it can be observed that the distribution of trees by height categories is similar to that at 1200 m, positively asymmetric, but with a slight shift

towards lower height values, possibly due to the increased altitude. The forestry interventions applied have led to a fairly uniform structure (Figure 4).

In Table 4, the Shannon index values indicate greater diversity, and we can also observe higher average and maximum values and standard deviations in the virgin forest compared to the managed forest. The exception is the average and maximum values in the managed forest at an altitude of 1200 m, where they are higher compared to the virgin forest at an altitude of 1350 m.

Table 4. Statistical indicators of tree heights

Forest category	Altitude (m)	Average (m)	Standard deviation (m)	Minimum (m)	Maximum (m)	Shannon index (H)
virgin	1200	26.03	10.16	5.2	40.6	2.71
	1350	23.94	8.37	5.1	36.9	2.63
managed	1200	24.45	5.55	4.3	38.6	2.36
	1350	22.35	5.00	3.7	32.8	2.19

The relationship between heights and diameters

The mathematical modeling of these distributions was done using logarithmic equations

(Figure 5). In the case of the virgin forest at an altitude of 1200 m, R² has a value of 0.8602 and 0.8721 for the virgin forest at an altitude of 1350 m.

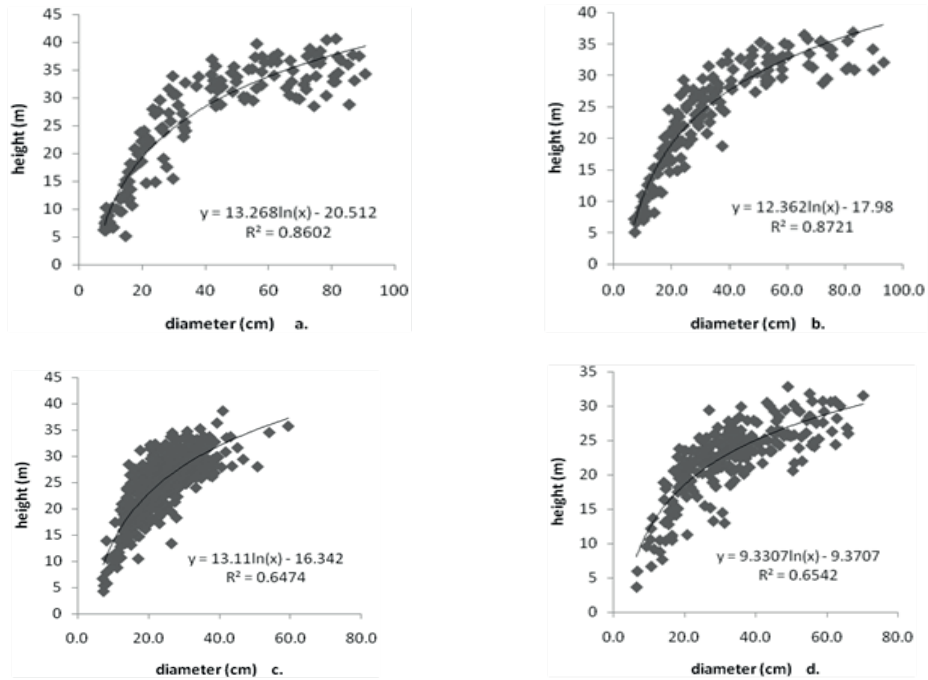


Figure 5. The relationship between heights and diameters in virgin forest (a. - at 1200 m altitude, b. - at 1350 m altitude) and in managed forest (c. - at 1200 m altitude, d. - at 1350 m altitude)

These values indicate a significant correlation between diameter and height, although there is considerable variability, characteristic of a mature ecosystem.

For the managed forest at an altitude of 1200 m, R^2 has a value of 0.6474, and for the forest at 1350 m, the value is 0.6542. A rapid increase in height can be observed at small diameters, which tends to stabilize at larger diameters, which is typical for managed forests (Figure 5)

The slenderness coefficient

This coefficient varies considerably depending on the species, the structure of the stands, their density, age, etc. In dense stands, trees are tall and have small diameters, therefore this coefficient can reach high values (above 1 or even higher).

The density is considered satisfactory when this coefficient has values between 0.6 and 0.9 in pre-logging forests (Florescu and Nicolescu, 1996).

In the virgin forest at an altitude of 1200 m, the minimum and maximum values of the slenderness coefficient were 0.34 and 1.22, respectively, while in the virgin forest at an altitude of 1350 m, the minimum and maximum values of the slenderness coefficient were 0.34 and 1.30, respectively.

For the managed forest, the minimum and maximum values are: 0.39 and 1.34, respectively, for the forest at an altitude of 1350 m, and 0.51 and 1.96, respectively, for the forest at an altitude of 1200 m. Most trees have slenderness coefficients lower than 0.9, with the exception of those in the managed forest at an altitude of 1200 m, where 77% of trees have slenderness coefficients higher than 0.9 (Table 5).

This aspect can be attributed to the thin trees that make up a large proportion of the managed forests. According to Korpel et al., 1991, for beech forests, the slenderness coefficient is considered to have a critical value if it is between 1.8 and 2.2.

Table 5. Distribution of trees by slenderness coefficient categories

Forest category	Altitude (m)	$z < 0.6$ (%)	$z = 0.6-0.9$ (%)	$z > 0.9$ (%)
virgin	1200	32	42	26
	1350	46	39	39
managed	1200	22	1	77
	1350	49	27	24

In the managed beech forests in Serbia, the slenderness coefficient ranged between 0.34 and 2.22, while in virgin forests the values ranged between 0.30 and 1.65 (Matović et al., 2018). In the virgin beech forests of Central Bohemia, the range of this coefficient was higher: from 0.28 to 1.89 (Bilek et al., 2011).

The regeneration

Following the inventory of the seedlings layer, the vast majority of it belongs to beech, the only exceptions being in the sample plots at an altitude of 1200 m in the managed forest, where there are three fir seedlings and two mountain ash seedlings in the 10-39 cm height category and one fir seedling in the 40-129 cm height category. Comparing the regeneration in the

managed forest with the regeneration in the virgin forest, it can be seen that in the managed forest it is practically non-existent. Thus, of the total number of beech seedlings inventoried, 83% are found in the virgin forest in the 10-39 cm height category and only 2% in the managed forest at an altitude of 1350 m, 10% are found in the virgin forest in the 40-129 cm height category and 4% in the virgin forest in the >130 cm height category. In the managed forest at an altitude of 1200 m, regeneration is less represented compared to that in the managed forest at an altitude of 1350 m (these stands had silvicultural interventions in the past - regeneration cuttings, which favors the establishment of seedlings and, implicitly, of a new generation of trees (Table 6).

Table 6. Distribution of beech seedlings per hectare in managed and virgin forests within sample plots at an altitude of 1200 m

Forest category	Altitude (m)	Height category (number of seedlings/ha, %)		
		10-39 cm	40-129 cm	>130 cm
virgin	1200	47769 (67%)	7192 (10%)	2308 (3%)
	1350	11462 (16%)	346 (0%)	538 (1%)
managed	1200	77(0%)	115(0%)	0 (0%)
	1350	1385 (2%)	77 (0%)	0 (0%)

CONCLUSIONS

After the comparative analysis of the structure of the two forest categories (virgin and managed), the following conclusions can be drawn:

1. Past forestry operations in beech stands, followed by their exemption from silvicultural interventions, had the greatest impact on the structural diversity of managed forests. The greatest differences were found between the stands in the managed forest at an altitude of 1200 m and the virgin forests regardless of altitude, but also in comparison with the managed forest at an altitude of 1350 m. These differences were noted both in terms of the size of the largest trees (especially diameters) and in the distribution of diameters and heights, the relationship between these two components, and the values of the slenderness coefficient. These differences are also reflected in the values of the Gini index or the Shannon diversity index (with one exception, this index having the lowest value in the case of tree distribution by height categories for the managed forest at an altitude of 1350 m).

2. Although over time there have been a series of forestry interventions in the managed forest at an altitude of 1350 m, some of them more recent, its structural diversity is higher compared to the managed forest at an altitude of 1200 m and, in some respects, it is close to the structural diversity of the virgin forest at an altitude of 1350 m. These indicators may be a sign of adequate forest management (close to nature), which will enable the long-term conservation of these beech forests and ensure their ecological stability.

3. Even though the managed forest has been affected by human intervention over time, the Gini index and Shannon index show that these beech forests in Semenik still retain a fairly high structural diversity, which is very important,

especially as there is a low diversity of tree species.

4. Monitoring tree diameters in managed forests can provide a good picture of their structural diversity, and maintaining trees in large diameter classes increases the structural diversity of these forests.

5. The results of this study allow for limited conclusions to be drawn, as the stands are of different ages (180 years for the virgin forest and 100 years for the managed forest), and further detailed analysis is needed to provide a better comparison between the two forest categories.

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