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STRUCTURAL FEATURES OF VIRGIN BEECH FORESTS IN SEMENIC MOUNTAINS. THE DYNAMIC STRUCTURE OF VIRGIN BEECH FOREST P20 SEMENIC BETWEEN 2005–2013

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The objective of this paper is to develop the knowledge of special structural features of virgin beech forests as a continuation of research activities initiated in 2005, in virgin beech forests from Semenic Mountains. All trees with diameter at breast height (DBH) higher than 80 mm were measured, the main biometrics characteristics (DBH, height, social class and quality class) being registered and the structure was analyzed by fitting different theoretical distribution functions (Beta, Gamma, Weibull). Also, due to the fact that biodiversity is a component of great importance for the functionality of virgin forests, the structural homogeneity was tested using Camino index (H) and Gini index(G). The results showed that the experimental distributions of diameters have a slight reverse J shape, being adjusted using Gamma theoretical distribution. The tree height distribution has an increasing allure with two maximum points, being in the best way characterized by Beta theoretical distribution. The correlative relationship between DBH and height is statistically significant (R^2= 0.854) and a high heterogeneity was emphasized (H= 1.73; G=0.88). These knowledge have a high contribution for understanding the natural mechanisms of these types of forests structure.

Key words: virgin beech forests, Camino index, Gini index, Lorenz curve.

INTRODUCTION

The presence of virgin forests in our country is of big importance for the whole Europe due to the fact that they preserve the natural heritage values lost in other countries. Their protection and preservation is an example to follow for current national and international forestry.

Although, after human intervention, the area occupied by virgin forests has diminished considerably, "Romania has about two-thirds of virgin /quasi-virgin forests in Europe-except for Russia" [5, 11].

The first major studies in this domain, of real scientific interest, have been made by the illustrious forest researcher Mihail Prodan in 1940[10], in Ostra Forest District, his efforts representing the first biometric research of this type in our country, achieved through application of specific statistical and mathematical models.

Other important studies were also carried in Penteleu Mountains, by one of the founders of the Romanian dendrometric school, Ion Popescu Zeletin [9] in virgin stands of fir, spruce and beech.

The main objective of this paper is to develop the knowledge on special structural features of virgin beech forests as a continuation of research initiated in 2005 by Forest Research and Management Institute's researchers [14, 15], in virgin beech forests from Semenic Mountains.

The specific objectives refer to the analysis and the evolution of these virgin beech stands during 2005–2013 period [16–18].

MATERIALS AND METHODS

P20 Semenic research plot was placed in 2005 in "Izvoarele Nerei" Nature Reserve, located at the upper limit of "Semenic-Cheile Carasului" National Park (Fig.1), and it is an uneven-aged stand, with trees which have ages from lowest to 363 years, in different stages of development (Photo 1).

"Izvoarele Nerei" Nature Reserve, where virgin beech forests were identified and selected in this study, was not anthropically influenced and meets the criteria to be classified as primary forest (OM3397/2012 regarding criteria and indicators for identification of virgin and quasi-virgin forests).

Photo 1. Virgin beech from Semenic Mountains with different development stages: initial and decay in front and optimal in the back.

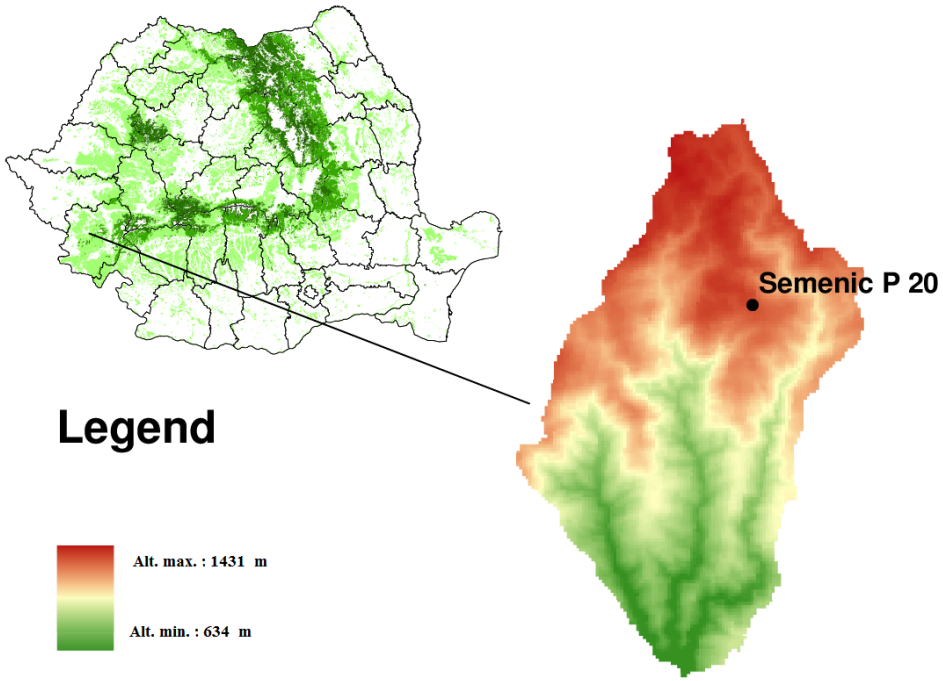

Figura 1 P20 Semenic research plot localization in "Semenic – Cheile Cara□ului" National Park– (Tomescu, 2013, EEA, 2000, NASA, 2003).The permanent research plot, placed in 2005, has circular form and a surface of 1 ha (56,41 m radius). Plot delimitation and ground measurements were made using FieldMap equipment, including an IMPULSE dendrometer and an electronic compass.

The permanent research plot, placed in 2005, has circular form and a surface of 1 ha (56.41 m radius). Plot delimitation and ground measurements were made using FieldMap equipment, including an IMPULSE dendrometer and an electronic compass.

In 2013, all trees were re-inventoried by measuring the diameter at breast height (DBH) and height (H), and assessing the social and quality class.

Based on the information recorded in field, the main dendrometric features of stand inventory were determined and stand structure was analyzed.

Virgin forest structural biodiversity is also an important specific component in terms of ecosystem functionality and stability, being "the result of long and complex evolutionary processes that have taken place over geologic eras" (Giurgiu, 2013). The structural homogeneity was tested using Camino and Gini indexes.

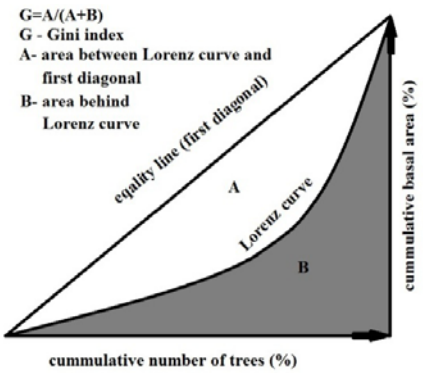

Figure 2. The calculation of the Gini coefficient.

Camino Index (H) was determined using the relationship (Roibu, 2010) :

$$H = \frac{\sum_{i=1}^{n-1} SN\%}{\sum_{i=1}^{n-1} SN\% - SG\%} \quad (1)$$

where SN% represents the number of trees in category i; SG% – cumulative basal area of trees in category i and n – the maximum diameter category for which SN% = 1.

Gini coefficient quantifies the diameters deviation from perfect equality, as a measure of diameter heterogeneity [12]. It is computed using Lorenz curve (Fig. 2), a graphical representation of the heterogeneity degree of stand. Gini coefficient represents the ratio of the area that lies between the line of equality (first diagonal) and the Lorenz curve (marked A Fig. 2) over the total area under the line of equality (marked A and B in Fig. 2).

Gini coefficient proved to be the best estimator of stand structure based on DBH [12]. The values of this coefficient varies between 0 (no diversity) and 1 (maximum diversity).

The height curve was computed using the following equation [3]:

$$h = 1{,}3 + \frac{d^2}{a_0 + a_1 d + a_2 d^2} \quad (2)$$

where d represents the DBH and a_0, a_1, a_2 – regression coefficients determined based on experimental data.
Tree volume was determined using the equation [13*]:

$$\log v = a_0 + a_1 \log d + a_2 \log^2 d + a_3 \log h + a_4 \log^2 h \quad (3)$$

where a_0, a_1, a_2, a_3 and a_4 are coefficients determined for each specie [3,4].

Goodness of fit of empirical DBH distribution was tested with three theoretical distributions: beta, Weibull and gamma. To estimate the goodness of fit of actual DBH distributions with theoretical distributions, $\chi 2$ criterion, Kolmogorov Smirnov (KS) and Anderson Darling (AD) tests were used. Statistical analysis were performed using Excel Software and EasyF*it.*

RESULTS AND DISCUSSION

The stand structure in relation to DBH. To obtain the experimental distribution curves, all trees were grouped in 4 cm DBH categories. In order to analyze the dynamics of DBH distribution in the period 2005–2013, both experimental distribution curves (at the beginning and end of the study period) were represented and compared (Fig. 3).

The comparative analysis shows a reduction of number of trees in low DBH categories and a slight enlargement of DBH amplitude. It can be noticed that, in 2013, the number of trees in 4 and 8 cm DBH categories decreased compared to 2005, but trees with a diameter greater than 92 cm were present, showing a stability of the growing trend, due to the expansion of diameters amplitude of variation (Fig. 3). The average diameter calculate din 2013 was 33.36 cm compared to 31.52 cm in 2005.

The experimental frequency corresponding to DBH = 50 cm remained relatively the same, highlighting the fact that in the last 10 years there were no significant structural changes and the stand follows the natural laws known stages of development(Giurgiu, 1979).

Fitting of experimental DBH distribution. The experimental DBH distribution was adjusted using the theoretical frequency functions: Weibull, Beta, Gamma. The most suitable proved to be Gamma function followed by Beta and Weibull functions (Fig. 4).

The goodness of fit was tested using $\chi 2$, Kolmogorov Smirnov (KS) and Anderson-Darling (AD) tests. $\chi 2$ and KS tests showed that the experimental DBH distribution in P20 Semenic virgin stand doesn't follow the Gamma, Beta and Weibull theoretical distributions. Only AD test showed no significant differences between experimental and theoretical distributions (Table 1).

[*] The experimental calculation made by us demonstrate the fact that the mathematical model used is correct, despite claims from literature (xxx)

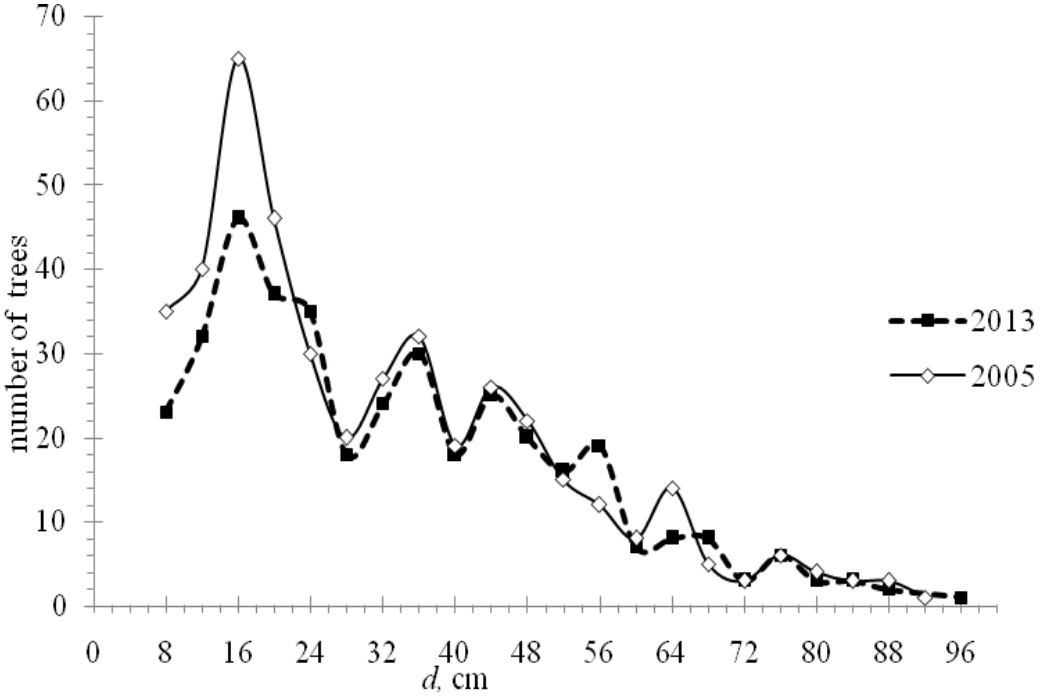

Figure 3. Experimental DBH distributions (2005 and 2013 inventories) in P20 Semenic research plot.

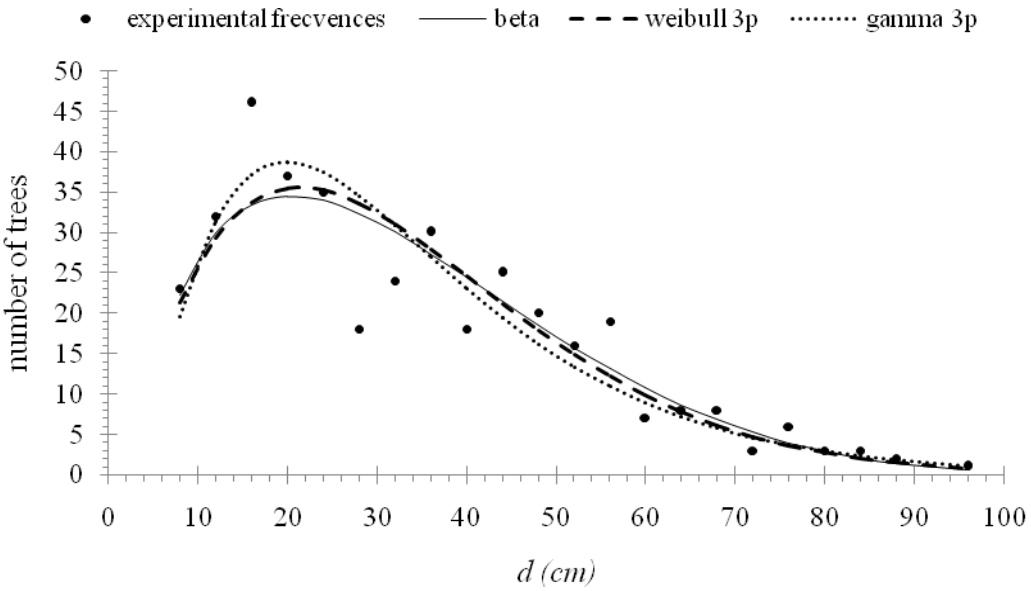

Figure 4. Fitted experimental DBH distribution using Beta, Gamma and Weibull theoretical functions in P20 Semenic research plot (2013 data).

Table 1

Experimental values of specific goodness-of-fitness

Distribution	**Kolmogorov Smirmov Test (KS)**		**Anderson Darling Test (AD)**		**χ^2 Criterion (χ^2)**	
	experimental values	**theoretical values**	**experimental values**	**theoretical values**	**experimental values**	**theoretical values**
Beta	0.08	0.06	1.95	2.50	37.16	14.06
Gamma	0.07	0.06	2.49	2.50	35.18	14.06
Weibull	0.08	0.06	2.20	2.50	26.62	14.06

Stand tree height structure. The mean height corresponding to a DBH of 50 cm increased from 28.43 m in 2005 to 31.93 m in 2013. Therefore the amplitude of variation in stand height grew, which explains the increase in stand vertical variability. Height (h_{50}), corresponding to the diameter d_{50}, increased from 28.43 m in 2005 to 31.93 m in 2013. More over the amplitude variation in stand height it is growing, which explains the increase in vertical variability stand. Data obtained from 2013 measurements were compared with those recorded in 2005 [14,15], and showed that the stand follows a normal trend, with a shift from lower height classes to a higher ones (Fig. 5).

Regarding the distribution curve of the number of trees in relation to height, an increasing allure with two peaks, which is specific to beech stands, one between 6 and 16 m corresponding to dominated thin trees, and a second one corresponding to dominant trees with heights between 28 and 36 m, was observed. There is also a uniform distribution of trees in medium height classes, which shows a relative stability of competitive relations in the middle ceiling.

The diameter – height relationship, together with the correlation intensity between diameter and height is of utmost importance in the analysis and characterization of the stand structure [1,2,9,10].

The coefficient of determination between diameter and height for virgin stand P20 Semenic is R^2=0.854 (Fig. 6) and the correlation coefficient (r) is 0.84. The intensity of diameter – height correlation is generally higher in uneven-aged stands compared to the one registered in even aged stands (r = 0.85–0.90), as well as the slope of the curve (Giurgiu, 1979).

The investigated stand is an second index class site, regarding site productivity.

In order to analyze the high variability and evolution, the coefficient of variation of heights in each DBH category was computed (Fig. 7). The total coefficient of variation of heights varies between 44.57% in 2005 and 40.62% in the 2013.

In 2005, the lowest variability as well as the greater stability is found in trees DBH ranging from 30 cm to 70 cm (Fig. 7). In 2013, this stability is maintained even at DBH reaching values of 80 cm. The maximum stability for both measurements was noticed for DBH = 50 cm, reference diameter for the indicative height (h_{50}) specific to uneven-aged natural stands.

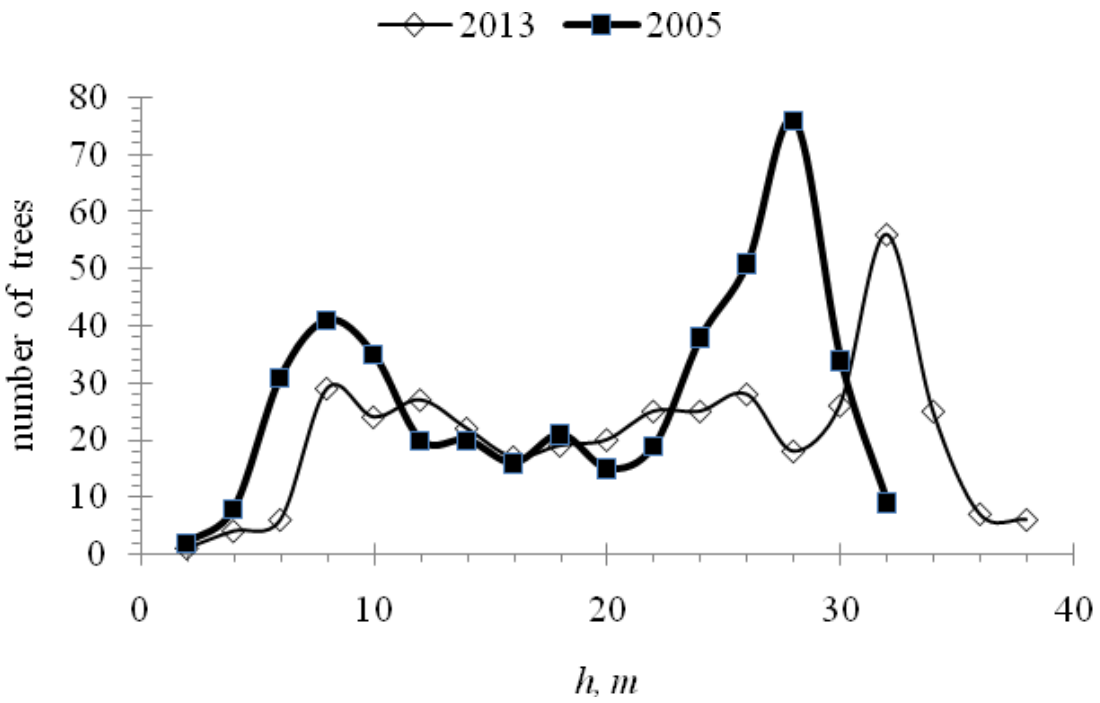

Figure 5. Distribution of trees by heights classes in P20 Semenic research plot.

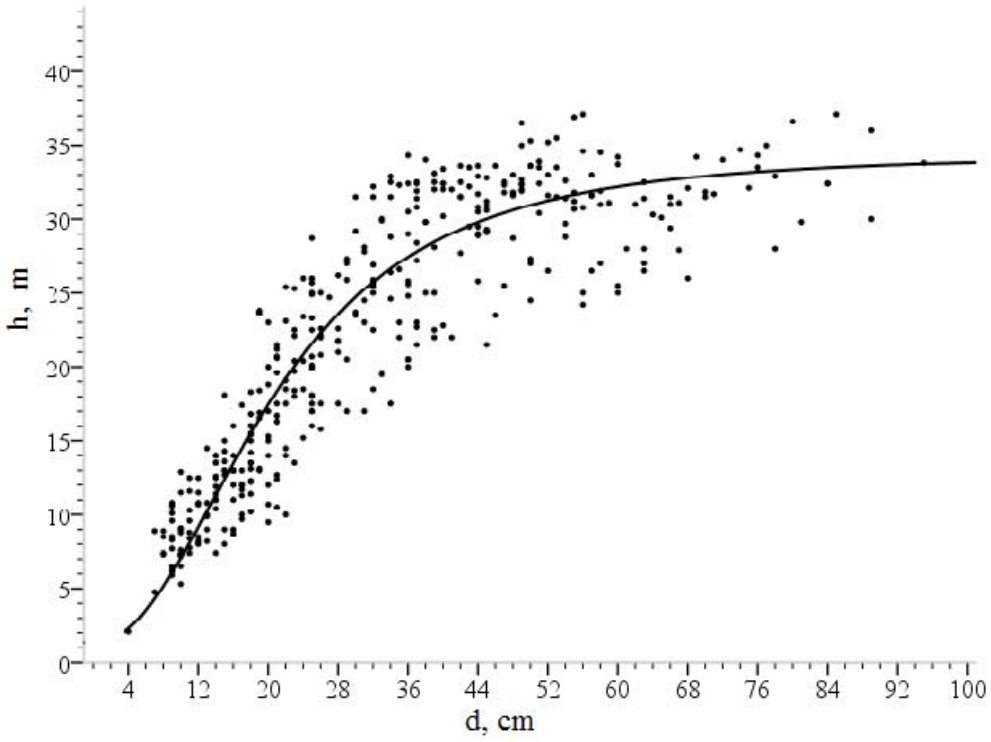

Figure 6. Correlation between diameter and height P20 Semenic research plot (2013).

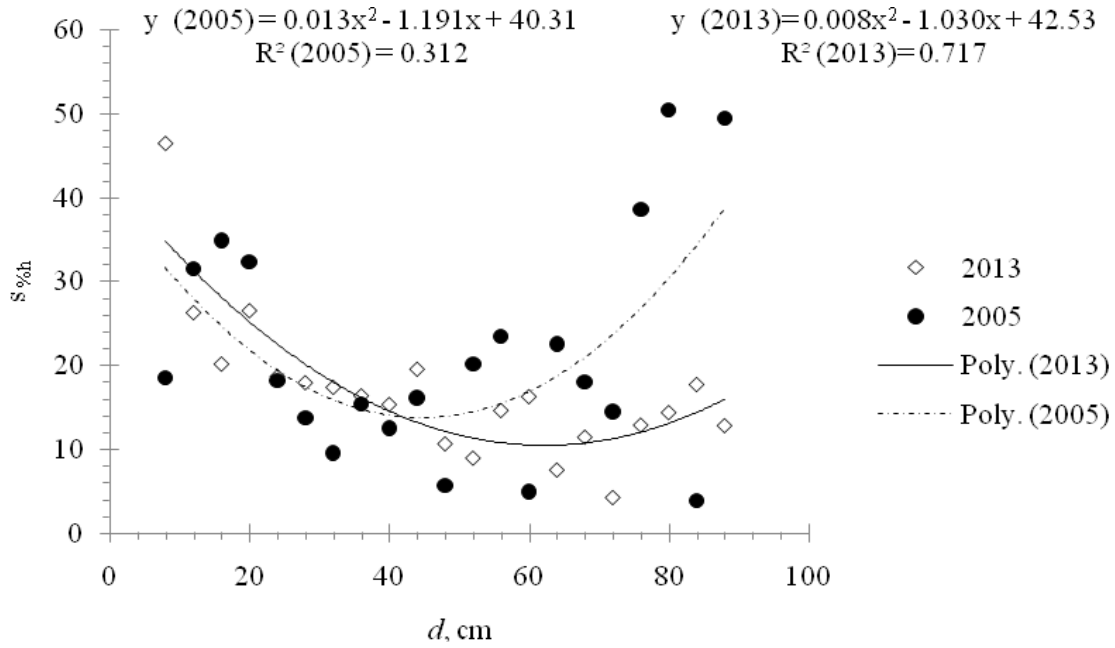

Figure 7. Changes in the coefficient of variation $s_{\%h}$ of heights in each DBH category in P20 Semenic research plot.

The distribution of trees in relation to quality classes

All the trees included in the P20 Semenic research plot, 47% are included in first quality class, 34% in second and 9% in third and fourth (Fig. 8).

Despite claims from literature, that in old-growth forests the quality classes are lower [6], in studied research plot majority of the trees are situated in superior quality classes.

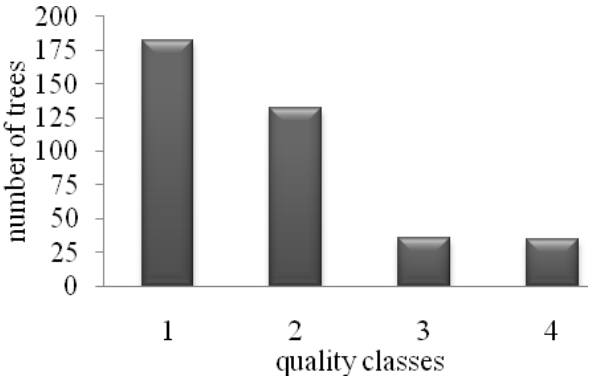

Figure 8. Distribution of trees according to the quality grade of virgin stand P20 Semenic.

The distribution of trees in relation to their social position

Regarding the vertical positioning of trees, is observed that most of the trees were employed in competition at the highest floor (220 trees). In the lower middle floors the competition is reduced, the stability of tree height distribution being higher (Fig. 9).

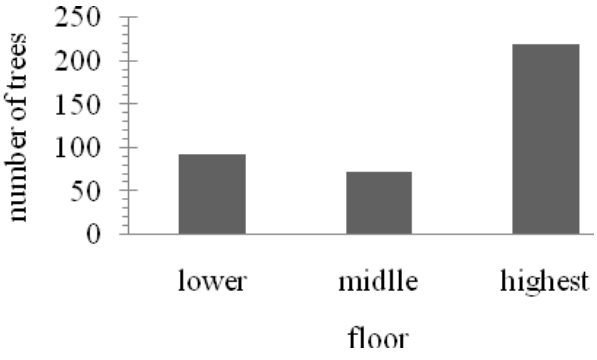

Figure 9. Vertical structure of trees in P20 Semenic research plot (2013).

Stand structure in relation to trees basal area and volume

Compared to 2005, the average basal area increased from 0.1156 m^2 to 0.1069 m^2 in 2013. Analyzing the distribution of the number of trees in relation to the basal area (Fig. 10), a decreasing trend can be observed.

The total volume increased from 610.24 m^3/ha in 2004 to 677.64 m^3/ha volume in 2013 (the problems of growth will be detailed in a further article). The distribution of trees by volume categories shows a decreasing trend (Fig. 11).

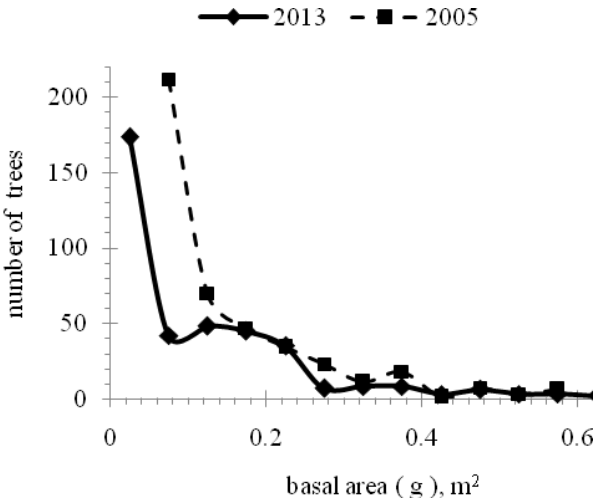

Figure 10. Distribution of trees on the basal areas categories of virgin stand shall P20 Semenic.

The beech has a height volume increment when is placed in the light, even in old age.

Analyzing the distribution of trees by volume categories, it can be seen that most of the trees are found in the volume classes 0.5 to 1.5. The volume curve (Fig. 12), obtained using the equation[1]: $v = b_0 + b_1 d^2 + b_2 e^{-b_3 d^2}$, indicates that the volume of trees is very strongly correlated with the DBH, the correlation coefficient being very high (r = 0.937).

Also, it is confirmed that the equation used to determine the volume curve it is applicable to beech stands (it was used before in spruce and fir stands).

Analysis of structural biodiversity

To test heterogeneity of the investigated virgin stand, Camino (H) and Gini (G) indexes were calculated and graphically represented by constructing the Lorenz curve (Fig. 13).

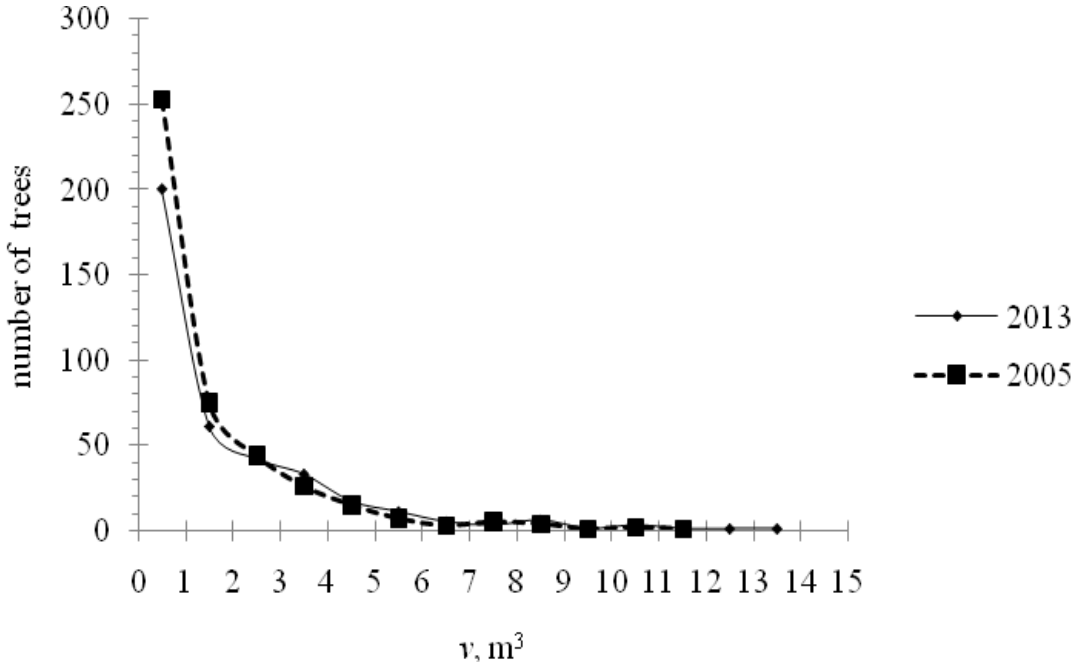

Figure 11. Distribution of trees by volume categories in P20 Semenic research plot.

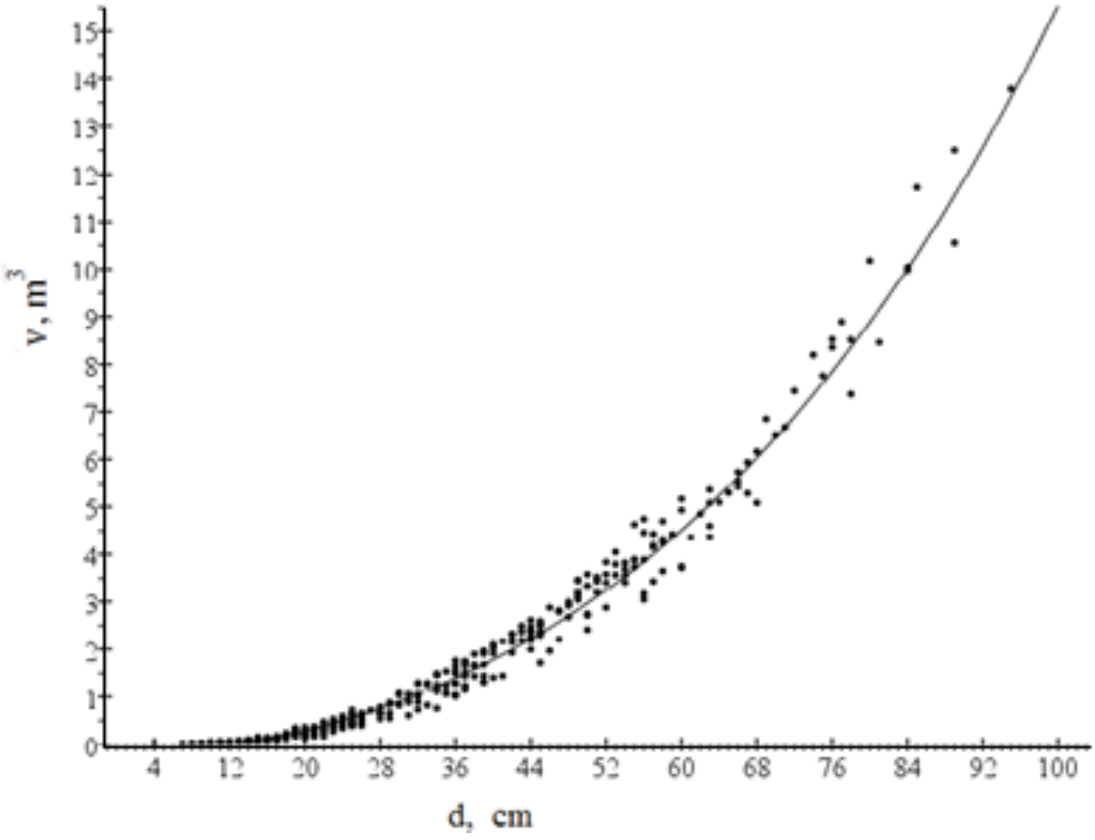

Figure 12. Tree volume curve in P20 Semenic research plot (2013).

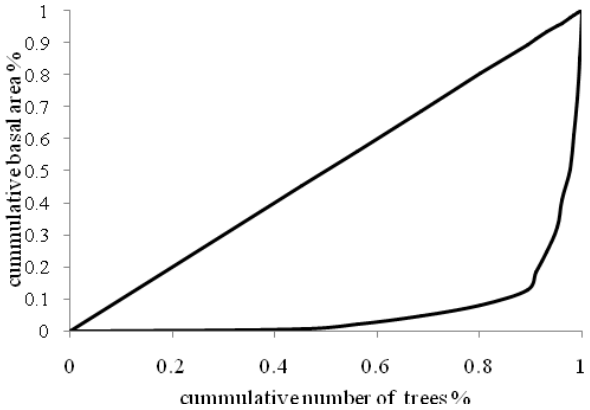

Figure 13. Lorenz curve of P20 Semenic research plot (2013).

Lorenz curve and Gini index, demonstrate the fact that virgin beech forest studied has a height structural biodiversity, specific to these forest ecosystems (Gini index, 0.88 is very closed to maximum value).

For un even age stands, Camino index value (H) should be around 2 [7]. In P20 Semenic research plot, the Camino index has a value of 1.73, being confirmed that the studied stand has the characteristics of a virgin uneven-aged stand (Photo 2).

Therefore, it is confirmed that the investigated stand is characterized by high heterogeneity specific to virgin natural stands.

Conclusions

Based on the results presented in the previous section, it can be concluded that in the year 2013 the number of trees in lower DBH categories decreased compared to 2005, and the amplitude of variation has expanded both at lower and higher categories. The mean DBH increased from 31.52 cm in 2005 to 33.36cm in 2013. The frequency corresponding to DBH = 50 cm remained relatively the same, which highlights the fact that in the past 10 years there were no significant structural changes. Experimental distributions can be adjusted using theoretical functions, applied only in relation to Anderson-Darling test, in which AD experimental value is lower than the theoretical AD, so between the experimental and Gamma, Weibull and Beta theoretical distributions there aren't significant differences.

The height (h_{50}), corresponding to the diameter d_{50}, increased from 2005 to 31.93 m 28.43 m to 2013.

Tree middle heights categories have a uniform distribution, which shows a relative stability of competitive relations in the middle ceiling. Also, the coefficient of determination between diameter and height in P20 Semenic research plot is R^2=0.854 and the correlation coefficient has a value of 0.84.

Photo 2. Virgin beech stand from Semenic Mountains in optimal development stage.

Height coefficient of variation $s_{\%h}$ in relation to the diameter in P20 Semenic virgin stand has a maximum stability, for both measurements, at 50 cm DBH category, which represents the reference diameter for indicative height (h_{50}) specific to virgin natural stands.

In P20 Semenic research plot, the majority of trees are in first and second quality classes.

The vast majority of trees in the research plot are engaged in competition at the higher ceiling. In the lower and middle floors the competition is weaker.

The distribution of trees in relation to the basal area in the research plot is of a descending type. Also, in terms of volume, it can be affirmed that the total volume rose to 67.40 m^3/ha from 2005.

The Lorenz curve analysis shows high heterogeneity, area between the equality line and the Lorenz curve being quite high. The Gini index (G) it has the value 0.88, and the Camino index (H) has the value 1.73, values that are around the multi-index for natural stands. Therefore, the investigated stand is characterized by a high heterogeneity specific to virgin natural stands.

In conclusion virgin forests are of profound continuity of biodiversity due to the stability that gives to ecosystem.

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