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Structural Features of Old Growth Forest from South Eastern Carpathians, Romania

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ABSTRACT

Background and Purpose: Romania's forests are of globally significant value due to their natural characteristics, as similar forests in some other parts of the world have been lost forever. These types of forests, so-called "virgin" and "quasi-virgin (old growth)" forests, are also identified in the Buzau Mountains, which are part of the Eastern Carpathians in Romania (Curvature Region).

Materials and Methods: To study and understand the structure and dynamics of primeval forest, four permanent one-hectare research plots were installed in the Penteleu Mountains, part of the Buzau Mountains. All trees with a diameter at breast height (DBH) greater than 80 mm were measured and their main dendrometric characteristics (DBH, height and social position) registered. The forest structure was analysed by fitting different theoretical distribution functions (beta, gamma, gamma 3P, gamma 3P mixt, loglogistic 3p, lognormal 3P and Weibull 3p). The structural homogeneity of the permanent research plots was tested using the Camino index (H) and Gini index (G).

Results: For the smaller DBH categories, Norway spruce was relatively shorter in height, but with increasing DBH, the heights of Norway spruce exceeded those of European beech. Stand volume varied between 615 and 1133 m^3 per hectare. The area of maximum stability where we encountered the lowest tree height variability was recorded between the 60 cm and 100 cm diameter categories. The Lorenz curve and the Gini index indicated that the studied stands have high structural biodiversity.

Conclusions: The results showed that the studied forests have an optimal structural diversity, assuring them a higher stability and multifunctionality. Thus, these forests are models for managed forests.

Keywords: forest structure, quasi-virgin forests, old growth forests, DBH, optimal diversity, multifunctionality

INTRODUCTION

Romania's primary forests are of globally significant value due to their natural characteristics, as similar forests in some other parts of the world have been lost forever [1, 2]. Quasi-virgin forests are those that have been managed in the past but that over time have been left to develop naturally, gaining specific features such as mixed tree ages, the presence of development phases, and strong relationships between dendrometric elements (i.e., diameter at breast height - DBH, height, and volume) [3, 4]. The study of these forests is of high value, as they are considered an important source of scientific information that can be used in the management of uneven-aged forests [5]. Quasi-virgin forests have numerous ecological, scientific, economic, social, and cultural characteristics, and they provide shelter for numerous species of flora and fauna [6] that have disappeared from managed forests.

Despite their importance, many quasi-virgin forests are partially or completely unprotected, and their surface area is decreasing. Given their importance, there is an urgent concern to protect all of these types of forests, in Romania as well as on a global scale [2, 7]. Recently, interest in sustainable forest management concerning biodiversity and the protection of nature has increased enormously [8].

Numerous scientists have highlighted the importance of these types of ecosystems in different locations around the world [2]. In Europe, interest in natural forest stands began to appear with the publication of G. Gayer's Silviculture Treaty

(1878), in which he proposed respecting natural laws in forest development. After World War II, Leibundgut carried out multiple studies in natural forest stands [9-11], promoting the importance of these special ecosystems at the International Union of Forest Research Organizations (IUFRO). In 1971, IUFRO established a research group focused on studying natural forest stands and, taking into account the remarkable results and work done by Leibundgut, appointed him chairman of this scientific group [12]. In the period from 1995-1999, research was carried out within the secular forest stands situated in the boreal area of the Scandinavian Peninsula and in the northern European region of Russia, which exhibited the dangers of forest loss due to excessive logging [13]. Other studies of this kind were carried out in the Perućica Forest Reserve in the territory of Bosnia and Herzegovina; that work concluded that these natural forests are clearly superior in terms of biodiversity and structure compared to managed forests [14]. In 2000, a research area of 10 hectares was installed in the Uholka-Shyrokyi Luh Reserve (total area of the reserve is 15,974 ha, of which approx. 9,000 ha are considered virgin beech forests) located in the Transcarpathian region of Ukraine [15]. The naturalness, uniqueness, and the high level of biodiversity of these forests have attracted the attention of politicians and led to changes in the legislative framework in order to better protect them [12]. In Croatia, laws adopted for the protection and maintenance of natural forests date back to the 18th century [16]. In Romania, quasi-virgin forests have been protected by modifying the legal framework [17]. The aim of this paper is to emphasize the structural characteristics and very high structural diversity of quasi-virgin forests located in the Curvature Carpathians region (Romania) and to highlight the knowledge of their special structural features. The results of research on primary forests are extremely valuable for developing sustainable forest management practices.

MATERIALS AND METHODS

Four permanent research plots (Plots A, B, C and D) were established in the Penteleu Mountains in the Curvature Carpathians Region, Romania (Figure 1).

The forest stands where the permanent research plots were located have not been influenced by human activity for a very long time, according to the criteria for identifying quasi-virgin forests [17, 18]. The permanent research plots were established during the period 2015-2018 and have dimensions of 100×100 m (1 ha). The perimeter of each plot was delineated using a Global Positioning System (GPS). All trees in each permanent research plot with a DBH>8 cm were inventoried by measuring the DBH and height (H) and establishing the tree's social position in the canopy. Tree height was measured using an ultrasonic hypsometer (Vertex IV) and DBH using a measuring tape. Based on the field inventory of the forest stands, their structural characteristics were processed and analysed. First the DBH distribution was analysed, then the structural biodiversity of the studied forest stands. It has been established that in the absence of human intervention, natural dynamics lead to very diverse forest stand structures [19, 20]. One of the important aspects of diversity in forests is tree size variability. Gini [21] and Camino [22] are two relevant indices of forest structure based on dispersion estimates of tree size [20]. The structural homogeneity of the studied forest plots was tested using the Camino and Gini indexes, and a graphic representation was made using the Lorenz curve [23]. The Gini coefficient has proven to perform better as an indicator of forest structure than Shannon's diversity index, Simpson or other indices [24]. Therefore, the Gini coefficient is recognised as the best estimator of stand structure based on DBH [25, 26].

The volume of each tree was determined using the following formula:

$$\log v = b_0 + b_1 \log d + b_2 \log^2 d + b_3 \log h + b_4 \log^2 h \qquad [27]$$

where b_0, b_1, b_2, b_3 and b_4 are nationally (Romanian) specific coefficients for each species. The experimental DBH distribution was fitted using different theoretical distribution functions (beta, gamma, gamma 3P, gamma 3P mixt, loglogistic 3p, lognormal 3P and Weibull 3p). To estimate the goodness of fit of the theoretical distributions to the measured DBH values, the $\chi2$ criterion, Kolmogorov Smirnov (KS) [28] and Anderson Darling (AD) [29] statistical tests were used. Analyses were performed using Microsoft Excel Software, Mathwave - EasyFit Distributions, IBM SPSS Statistics, and packages fitdistrplus [30] and mixdist [31] of the software R.

RESULTS AND DISCUSSION

All the permanent research plots exhibited uneven-aged structure, a large number of trees and a high volume per hectare (Table 1).

Fitting of Experimental DBH Distribution Related to Number of Trees

To identify the best theoretical function to fit the distribution of the collected field data, beta, gamma, gamma

TABLE 1. General characteristics of permanent research plots.

Research Plot	Altitude (m)	Area (ha)	Shape	Stand structure	No. of trees per ha	Volume ($m^{-3}\cdot ha^{-1}$)
Plot A	1130	1	square	uneven - aged	612	1133.34
Plot B	1100	1	square	uneven - aged	749	785.44
Plot C	1250	1	square	uneven - aged	522	910.25
Plot D	1250	1	square	uneven - aged	486	615.13

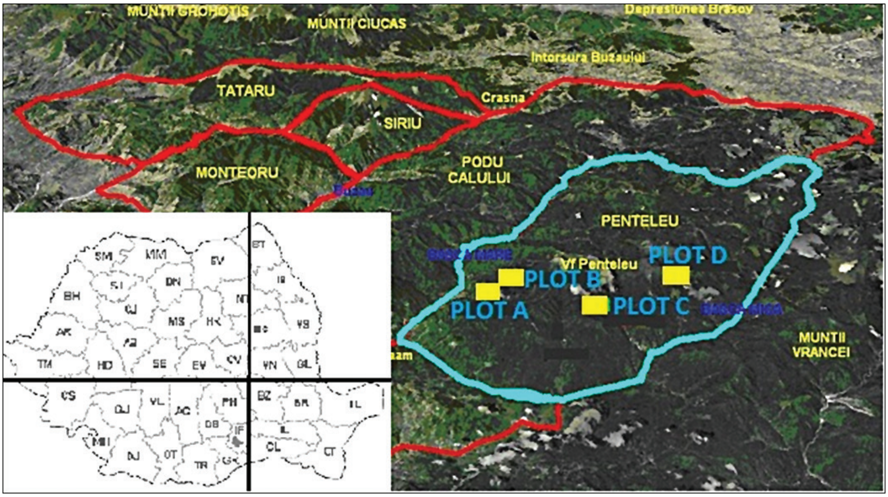

FIGURE 1. Research plots location (www. fetch.ro).

3P, gamma 3P mixt, loglogistic 3p, lognormal 3P and Weibull 3p functions were tested (Figure 2). In the case of research plot C, a bimodal experimental distribution was observed. For this particular situation where the forest stand could not be fitted with the studied theoretical functions, a combination of two gamma functions was used. The bimodal distribution is more accentuated in research plot C than in the other plots and is related to the plot's history [32, 33] and events like fire [34], wind disturbance or other biotic and abiotic factors.

The KS test and χ^2 criterion for goodness of fit for plot A showed no differences between the experimental and theoretical distributions for the lognormal 3P function. The AD test showed no differences between the experimental and theoretical distributions for the Weibull 3P, gamma 3P and lognormal 3P functions. In the case of plot B, all of the goodness of fit tests indicated that the experimental DBH distribution followed the theoretical distributions except for the gamma distribution, where the statistical tests showed significant differences between the experimental and theoretical distributions. In the case of plot D, the relationship between DBH distribution and number of trees was analysed using the lognormal 3P, gamma 3P and beta functions. None of these theoretical functions adjusted the experimental DBH distribution (Table 2). Using the χ^2 criterion, in the case of plot C, the theoretical frequencies resulting from the mixed gamma 3P function were significantly different from the experimental distribution (p>0.05) (Table 3). The experimental DBH distribution has a descending form, with the highest numbers of trees in small DBH categories and a shape similar to a reverse "J" [35], which is specific to the structure of quasi-virgin forests. All research plots exhibited high variation in DBH, over 90 cm, an aspect specific to uneven-aged stands [36, 37].

Structural Biodiversity Analysis of Studied Forest Stands

To test the biodiversity of the studied stands, the Gini (G) and Camino (H) indexes were calculated, and for graphical analysis, a Lorenz curve was generated (Figure 3). The Lorenz

TABLE 2. Main indicators of theoretical distributions.

Research plot	Distribution	Kolmogorov Smirnov Test		Anderson Darling Test		χ2 Criterion	
		Experimental values	Theoretical values	Experimental values	Theoretical values	Experimental values	Theoretical values
Plot A	Weibull 3p	0.06	0.054	2.47*	2.50	25.76	16.92
	Lognormal 3p	0.05*	0.054	2.05*	2.50	13.21*	16.92
	Gamma 3p	0.06	0.054	2.33*	2.50	25.17	16.92
Plot B	LogLogistic 3p	0.04*	0.049	1.99*	2.50	8.02*	16.92
	Lognormal 3p	0.03*	0.049	1.38*	2.50	10.71*	16.92
	Gamma	0.15	0.049	22.46	2.50	130.91	16.92
Plot D	Lognormal 3p	0.07	0.057	5.22	2.50	38.47	16.92
	Beta	0.09	0.057	5.74	2.50	48.39	16.92
	Gamma 3p	0.09	0.057	5.57	2.50	49.42	16.92

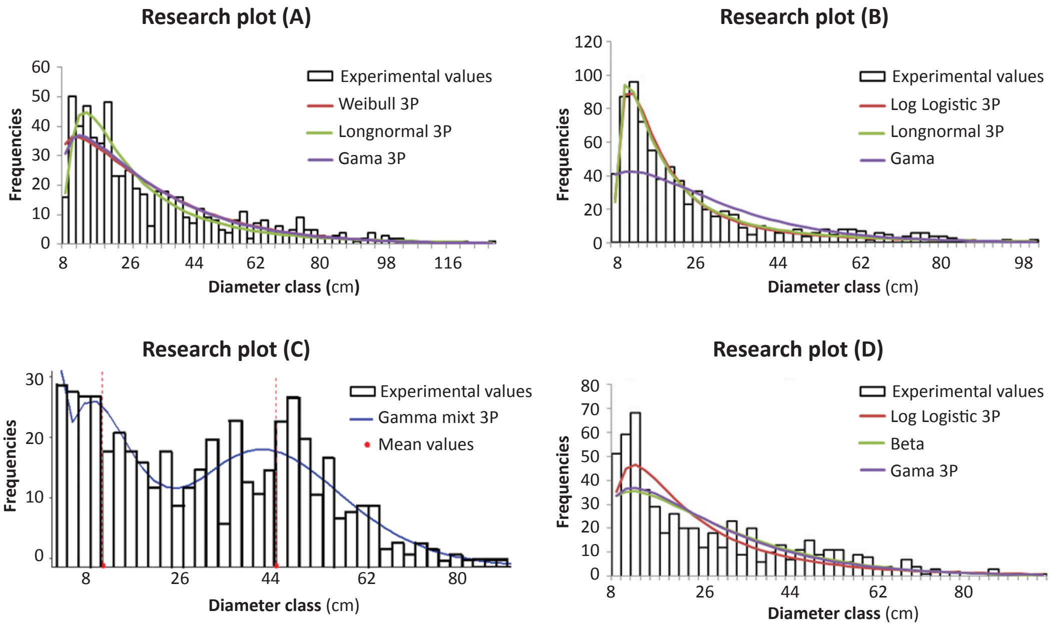

FIGURE 2. Fitting experimental (observed) DBH distributions with theoretical functions.

curve and the Gini indexes indicate that the studied stands have high structural biodiversity, which is specific to this type of forest ecosystem. The Gini index of the plots ranged from 0.69-0.71 which is very close to the index's maximum value of 1 [24]. The Camino index of the plots ranged between 1.62 and 1.71. The Gini and Camino coefficients calculated for the

TABLE 3. The results of the statistical test χ2 used to fit experimental distribution with Gamma mixt function in research plot C.

Research plot	Function	f	χ2	p
Plot C	Gamma	42	48.567	0.2254

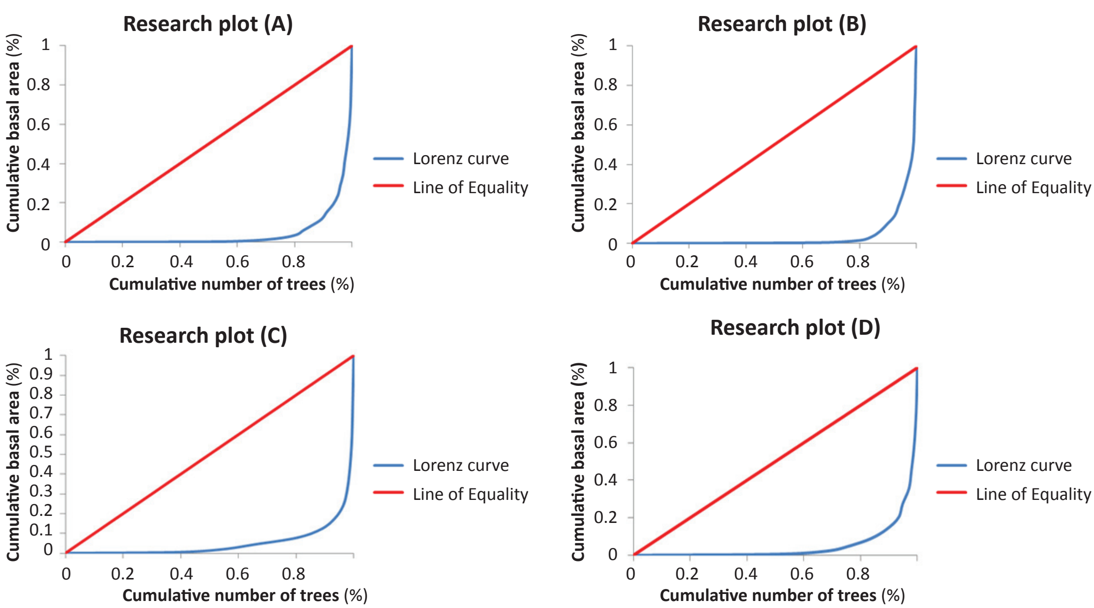

FIGURE 3. Lorenz Curve for each permanent research plot.

forest stands in the present research are close to the values obtained for other uneven-aged forests, which emphasizes that the studied stands are characterized as uneven-aged stands [38-40].

CONCLUSIONS

Based on the results presented in this research, it can be concluded that due to their structural complexity, quasi-virgin forests represent a very good scientific base for studying the natural structure and dynamics of a forest, and can be considered as "real laboratories in situ". The presence of large-DBH trees and fast development phase alternations are signs of strong dynamics as well as a great capacity to regenerate after natural competition processes.

The protection of quasi-virgin forests should be a precondition for successful scientific research in natural science. To develop improved forest management practices, it is very important to understand the structural principles and development of natural forests. The legislative system in Romania for protection of natural areas where we still encounter natural ecosystems that are not influenced by humans must generally be improved, and very valuable quasi-virgin forest areas must be included among other natural conservation areas.

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