ROMANIAN ACADEMY

Institute of Biology Bucharest

TRANSILVANIA UNIVERSITY OF BRASOV

Interdisciplinary Doctoral School

PhD THESIS

SUMMARY

The structure and auxology of some virgin forests in Semenic Mountains, Retezat Mountains, Fagăraș Mountains and Penteleu Mountains

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ABBREVIATIONS LIST

ASAS – The Academy of Agricultural and Forestry Sciences

INCDS Marin Drăcea – "Marin Drăcea" National Institute for Research and Development in Forestry

OS – Forest district

PRP – permanent research plot

ua – management unit

UP – production unit

INTRODUCTION

In the past the Romanian actual territory was 80% covered by forests counting 18-19 million hectares (2000 years BC) (Giurgiu 2013). Although human activity led to a significant decrease in the virgin forests area, our country still owns about two thirds of Europe's total virgin / quasi-virgin forests - except Russia (Reininger, 1997, Giurgiu, 2013, Chivulescu et al. , 2014). These unique structures have a significant importance in forests management and through their research, the dynamics and ecosystem processes that take place within them can be better understood (Wirth et al., 2009; Visnjic et al., 2013, Petritan et al. 2015).

The main reason for existing of this large area of virgin forests in Romania is represented by the efforts of the Romanian scientists (Petre Antonescu, Alexandru Borza, Emil Pop și I. Popescu Zeletin) and foresters that made great efforts during harsh periods for keeping them intact (Giurgiu, 2012, 2013)

By kipping the natural values of forest ecosystems, Romanian virgin forest can be an example for the national and international silviculture (Chivulescu et al., 2014). These days, few of European forests can be considered virgin and most of them are located in Eastern Europe (Parviainen, 2005).

Virgin forests have tremendous research potential and it is a privilege to our country to own these ecosystems. Among the effects caused by the disappearing of these natural areas, are climate changes and irreversible losing of different material and spiritual values. Now, society tries to reconstruct and maintain those values by imitating the nature, the main aims being to conserve the last virgin forests and learn from them in order to create a similar ecosystem.

1. RESEARCH AIM AND OBJECTIVES

The research from this paper has a significant importance and a great interest for present and future silvicultural concerns. **The aim** of the research is to know the functionality laws of virgin forest ecosystems in order to develop and improve their management system.

Main objective of research is to understand virgin forest functionality mechanisms, from structural and auxologic point of view, to offer ecological solutions and structural models for a sustainable management.

Specific research objectives are:

1. Analysis of virgin tree structure and their dynamics;
2. Knowledge of auxological laws specific to researched virgin trees and their relation to environmental conditions;
3. Delimitation and analysis of development phases specific to virgin forests;
4. Determination of the dead wood volume and its degradation level.

2. RESEARCH MATERIAL AND METHOD

2.1. Research location

Permanent research plots (PRP) are located in representative areas for Romanian virgin forests (Fig. 1) situated in different zones (Semenic Mountains, Retezat Mountains, Făgăraș Mountains and Penteleu Mountains) with diversified stational and vegetation stand characteristics. Those ecosystems have never been influenced by humans activities and have the structural characteristics of virgin forests.

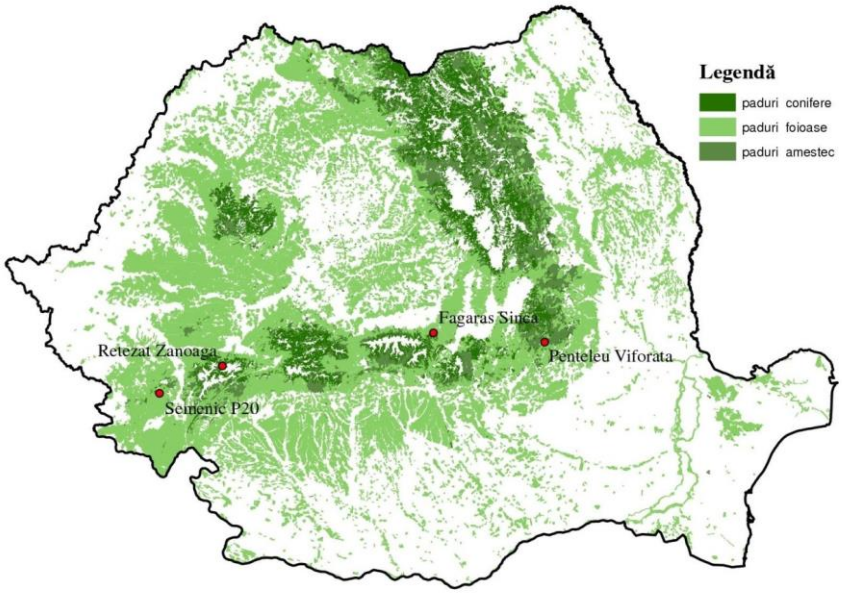

Fig. 1. Research plots location on Romania's forest cover map (EEA, 2000).

2.2. Research methodology

In selected stands was placed 1 hectare research plots where was inventoried all the trees with breast height higher than 80 mm.

To determine **radial growth**, from all the trees were taken samples with Pressler drill. Also, for the dendrological analysis were taken samples from 40 trees to cover entire ontogenetic duration. In Penteleu – Viforâta permanent research plot were taken samples, which cover entire tree lifetime, from all the trees. For measuring tree rings was used CooRecorder 7.4 software. To check the quality analysis of tree rings data was used COFECHA software (Holmes, 1983; Cook et al., 1997) and for the standardization of growth series was used ASTRANwin software (Cook and Krusic, 2006). For the graphic representation of dendrochronological series, Rstudio software dplR and detrendeR packages were used (Bunn, 2008, Campelo, 2012) for a common period of at least 5 samples.

Analysis and characterization of **stand structure** was made using specific methods (Giurgiu, 1979) for the main distributions (related to diameter, height, quality class, cenotic position). For

adjusting the experimental distributions was used theoretical functions like: Beta, Gamma, Exponential, Weibull and Normal.

Stand **structural biodiversity** of virgin forests represent a specific component of great importance regarding stand functionality and stability, being "the result of long and complex evolutive process which have taken place over the geological ages" (Giurgiu, 2013).

Tree **volume** was calculated using the regression equation based on the height curve and tree diameter (Giurgiu, 2004).

The **stand growth volume** was determined by the method based on a single forest inventory and increment core samples from standing trees (Giurgiu, 1979, Leahu, 1994, Badea 2008, Chivulescu et al, 2016).

For testing **structural homogeneity** was used Camini and Gini indexes and for graphic representation was used Lorenz curve.

To estimate **dry biomass and carbon stock** from dead wood different methods were used depending on the dead wood category (standing or lying).

As a result of evolutive process, virgin forests have a dynamic structure (Leibundgut, 1959). **Development phases** characterization was made using specific methods (Cenușă, 1996). Those methods are based by characterization of main delimitation and identification of development phases (Mayer, 1976; Cenușă, 1996; Roibu, 2010).

3. RESULTS

3.1. Analysis of virgin forest stands structure

3.1.1. Virgin forest stands structure in relation to tree DBH

In the past, stand distribution in relation with diameter was used for structural description of virgin forests (Roibu, 2010), this type of characterization of stand is based on quantitative and qualitative analysis of forest ecosystems (Leca, 2014).

Uneven aged stands are distinguishing from even aged ones by a large number of trees of small diameters. Those ecosystems have a dynamic equilibrium between regeneration process and mortality, obtaining in that way a continuous dense stand.

The most appropriate theoretical function for characterization the stands was Beta, Gamma and Weibull (Fig. 2).

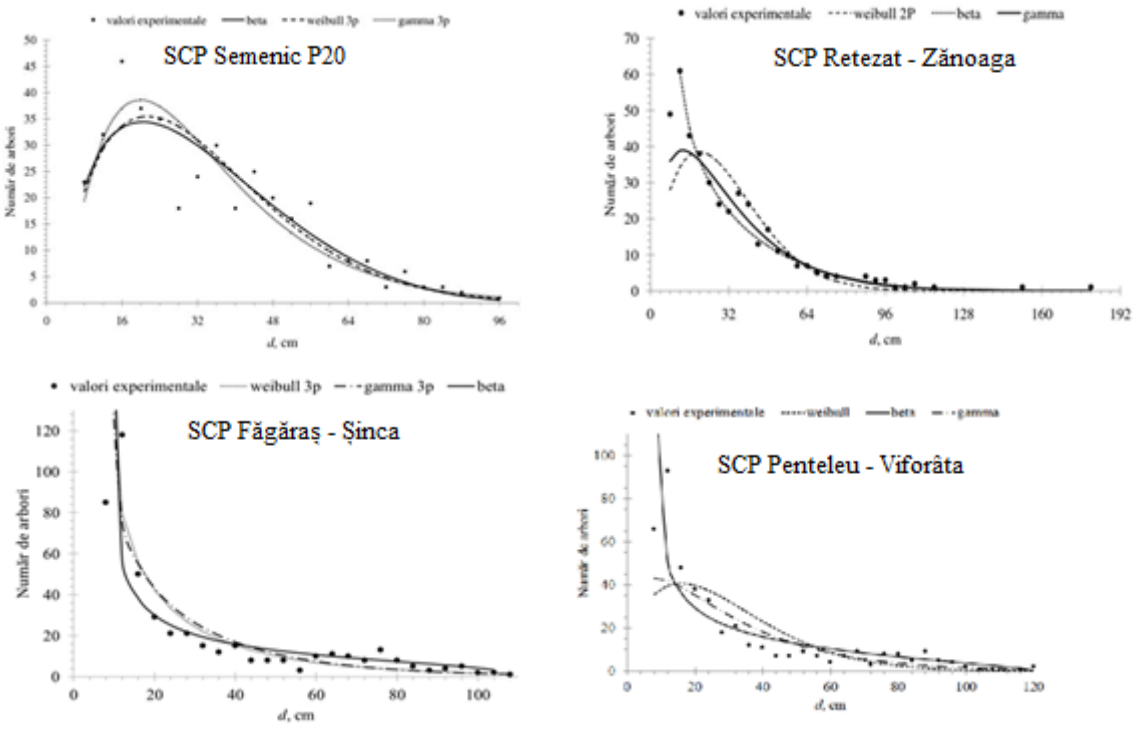

Fig. 2 Fitting experimental DBH distributions using Beta, Gamma and Weibull functions.

The existing differences between the structures of the virgin forest stands are due to the existence of their specific development phases and the environmental conditions that have influenced the respective stands over time, confirming thus, its structural complexity (Chivulescu et al., 2016).

3.1.2. Relationship between DBH and heights of trees

The relation between the diameter and the height is an important element of the stand characterization. This was studied along with the intensity of the correlation and the shape of the height curve by the Romanian scientists in the field of forest biometrics such as M. Prodan, I. Popescu-Zeletin and V. Giurgiu.

In order to characterize the structure of the studied stands, through this correlative relation between diameter and height, the main characteristics of the trees (d and h) were measured and the next mathematical expression was used to plot the heights curve:

$$h = 1{,}3 + \frac{d^2}{a_0 + a_1 d + a_2 d^2 + a_3 d^3}$$ (Giurgiu, 1999)

where: d represent diameter of the tree, cm
h – height of the tree, m
a_0, a_1, a_2, a_3 – regression coefficients determined based on the field measurements.

For studied stands the height curve indicates a normal trend, biologically justified which highlights the relation between trees diameters and heights (Fig. 3).

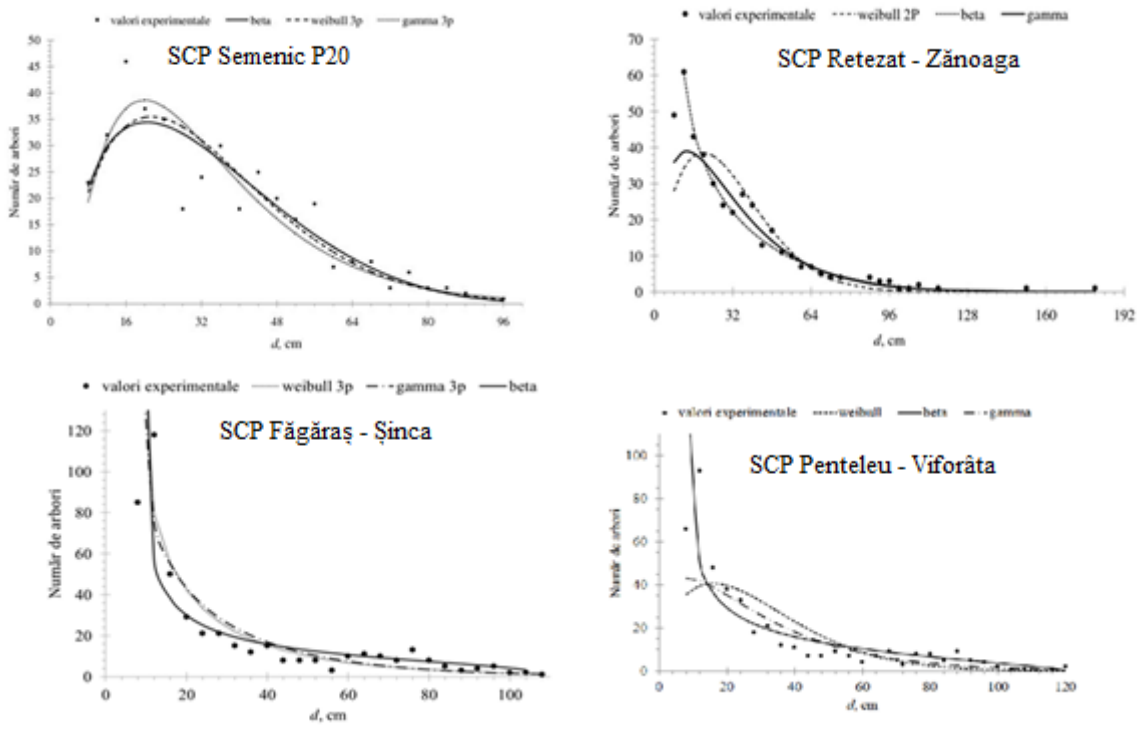

Fig. 3 Height distribution in relationship to DBH.

The strong correlation between trees diameters and heights it is indicated by the correlation coefficient (r) values (0,84-0,92) showing the complexity of these type of ecosystems (Table 1).

Table 1

Correlation between DBH and heights in the studied virgin stands

Permanent research plot PRP	Specie	Correlation coefficient r
Semenic P20	Fag	0,84
Retezat- Zănoaga	Fag	0,84
	Molid	0,84
Făgăraș-Șinca	Fag	0,92
	Brad	0,92
Penteleu-Viforâta	Fag	0,90
	Brad	0,90

3.1.3. Forest stand structure in relation to tree volume

Compared to even-aged stands, the uneven-aged stands including the virgin forest stands have a higher volume per hectare due to the presence of big and very big trees (Fig. 4). The proportion of their participation and consequently their timber volume are dependent by the size and the presence of the development terminal phases of these virgin stands.

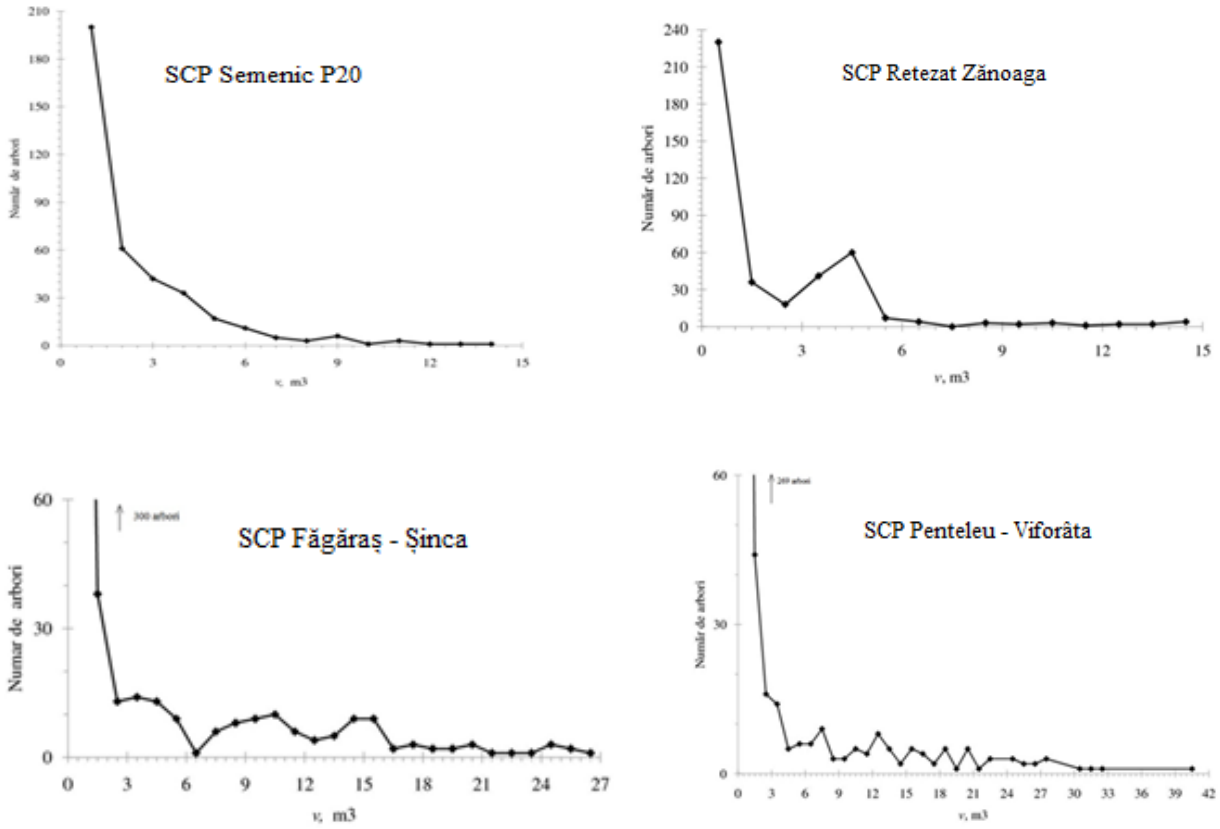

Fig. 4. Distribution of trees in relation to volume classes in the studied virgin forest stands.

3.2. Auxologic analysis of the studied virgin forest stands

3.2.1. Forest stand structure in relation to diameter increment

In order to characterize the structure of the virgin forest stands in relation to the diameter increment of the trees within the research plot, a stratification of the values by classes of increments in diameter was performed. Thus, similarly with the diameter distribution which has an exponentially decreasing form, most of the diameter increment values are in the lower categories (Fig. 5) (Chivulescu et al., 2016).

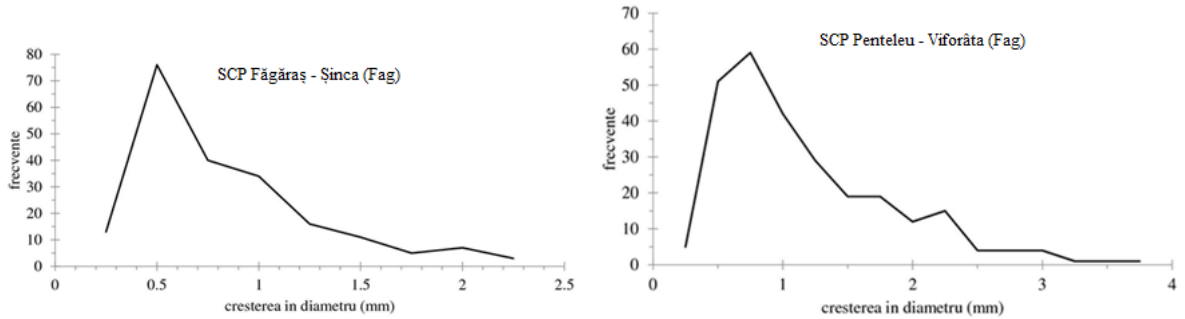

Fig. 5 Number of trees distribution in relation to diameter increment.

3.2.2. Radial growth variation in relation to DBH

In analysis of radial growth variation, a high variability was observed due to the trees competitional relations as well as some biotic and abiotic factors (Leca, 2014). Though the radial growth variation coefficient values have a descending trend related to diameter growth (Fig 6). This is explained by the decreased inter- and intra- specific competitional relations (Giurgiu, 1979; Leca, 2014).

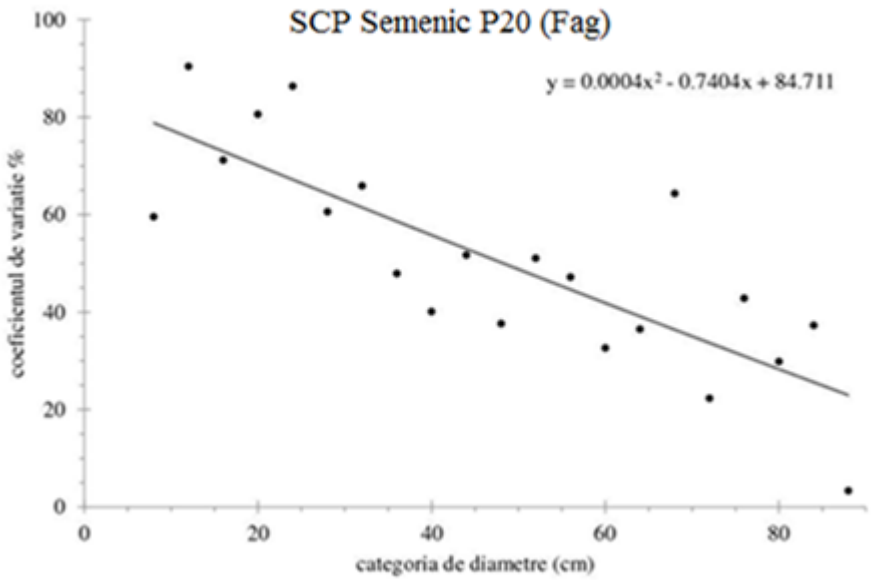

Fig. 6. Radial growth variation coefficient distribution in relation to the diameter

3.2.3. Dendrochronological series

For the development of the dendrochronological series, radial growth samples were taken for the entire ontogenetic period of the trees, using the Pressler drill, and after the preliminary processing 725 samples were analyzed (182 for the fir, 447 for the beech and 96 for the spruce).

In addition, 8 dendrochronological series (2 for fir, 4 for beech and 2 for spruce) were elaborated within the four permanent virgin research plots located in different geographical and climatic areas of the Southern Carpathians (Semenic Mountains, Retezat Mountains, Făgăraş Mountains and Buzău Mountains).

The graphical representation of these dendrochronological series was made using the *dplR* and *detrendeR* packages of the *RStudio* software for a common period of at least 5 samples. To maximize the signal-to-noise ratio a standardization using the spline function was made (Figure 7).

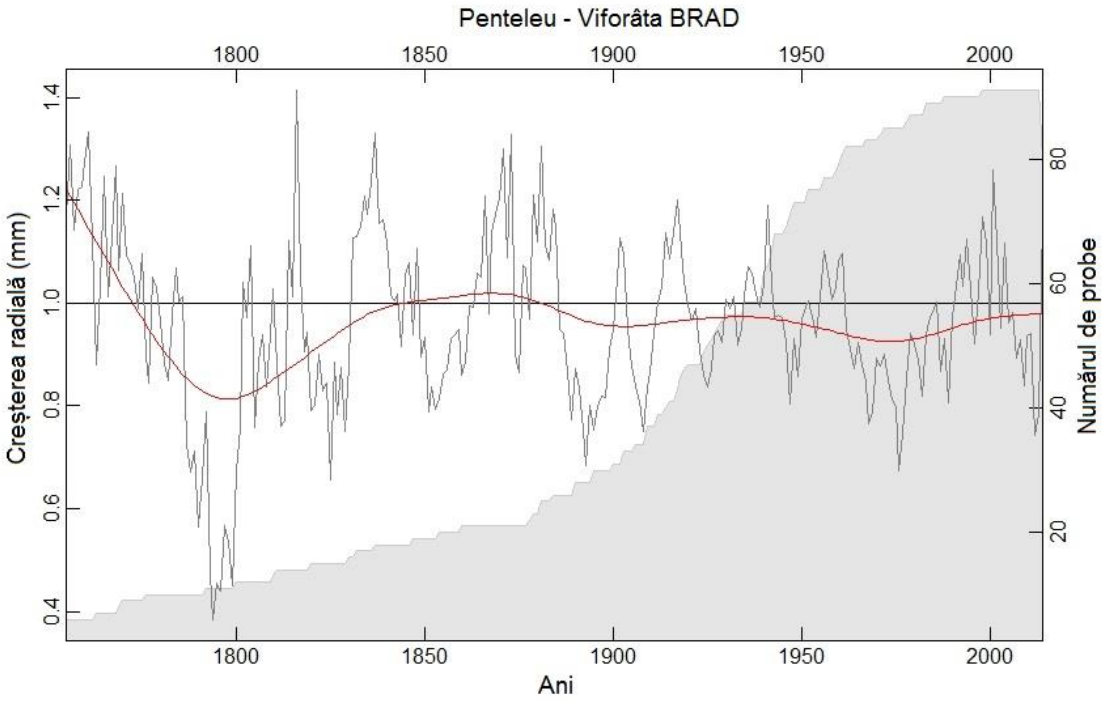

Fig. 7 Penteleu – Viforâta SILVER FIR (vifoBR) dendrochronological standardized series by spline model (red).

3.3. Description of development stages identified in the studied virgin forest stands

Forest is a complex ecological system with a dynamic structure being the result of many organic and anorganic processes, with a sinuous evolution in time and space (Leibundgut, 1959; Cenuşă, 1996; Roibu, 2013). Based on this, some authors consider that virgin forests have a specific dynamic, determined mainly by the succession of several stages of evolution (Cenuşă, 1996). For the

characterization of the studied virgin stands, specific methodological procedures based on the definition "a development phase represents an obviously different structural development stage within a certain forestry association" were used to identify, delineate and describe the development phases (Cenuşă, 1996).

Within these researches there were identified and described the development phases for SCP Retezat - Zănoaga and SCP Penteleu - Viforâta (Fig.8, Fig.9)

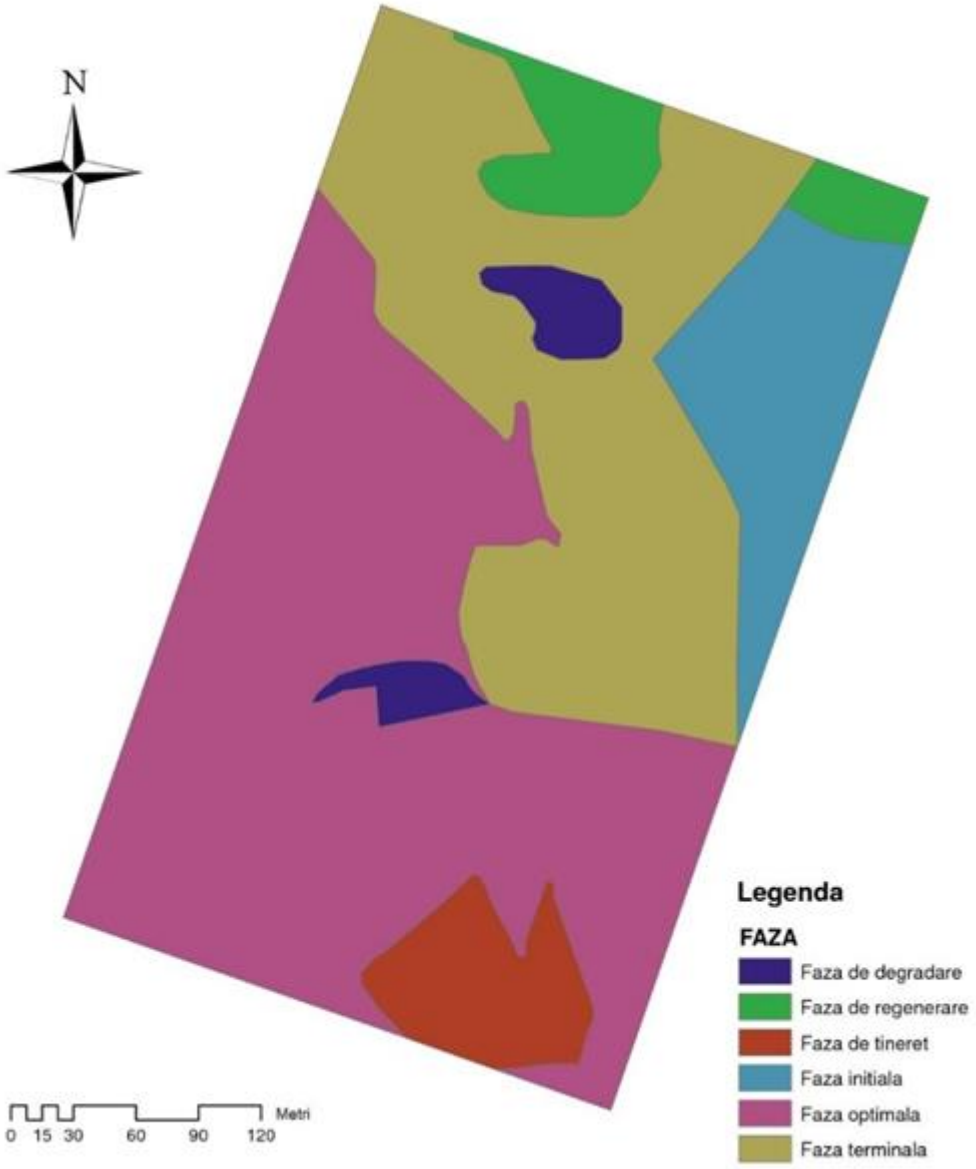

Fig. 8. Development stages identified and delimited in permanent research plot Retezat – Zănoaga.

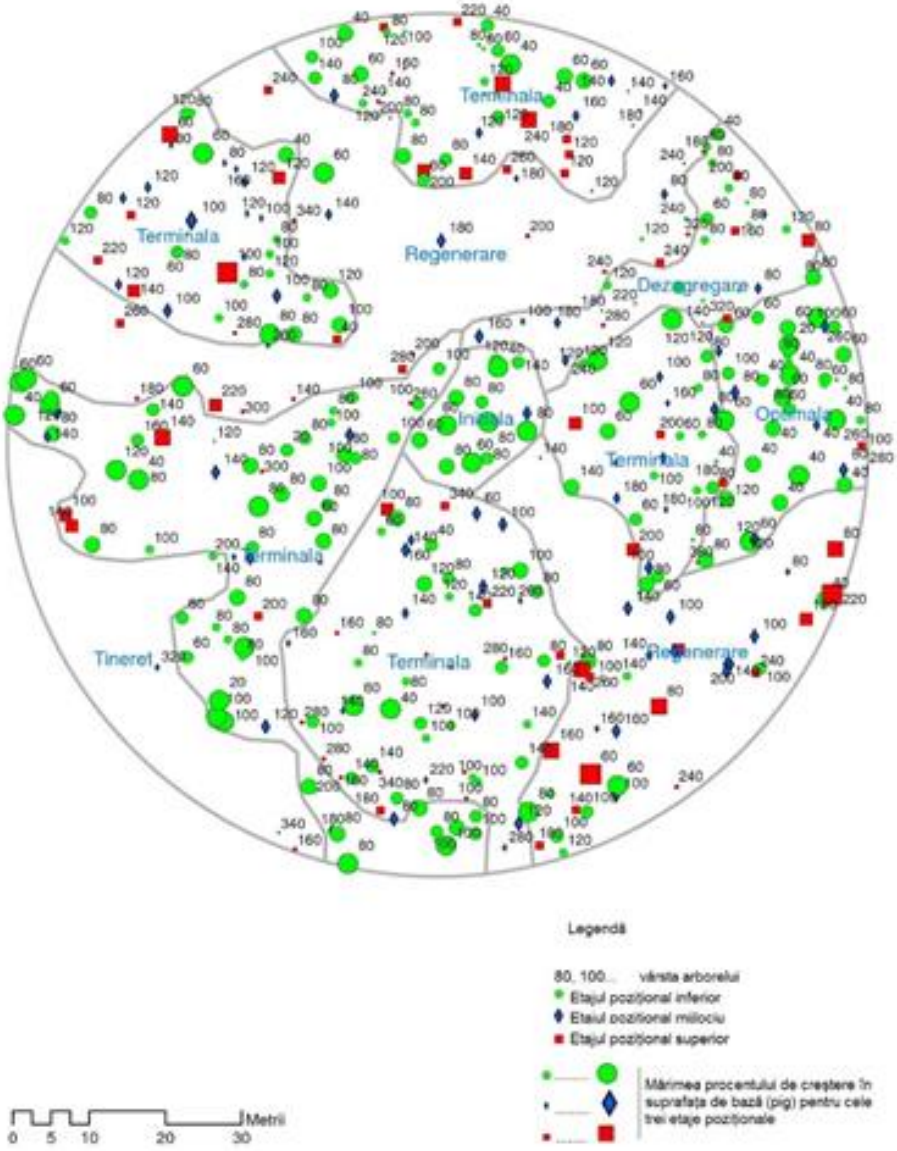

Fig. 9. Development stages identified and delimited in permanent research plot Penteleu - Viforâta.

3.4. Structural biodiversity, dead wood and its above ground biomass and carbon stock aspects in the studied virgin forest stands

In the research plots the quantity of dead wood is consistent with an average volume of 104,461 m^3/ ha. Because the research plots are located in various parts of the country with different development phases and composition this average value is representative for virgin stands beeing similar to the ones from others researches (Colak, 2010).

3.4.1. Structural biodiversity analysis. Lorenz curve, Camino and Gini structural biodiversity indexes

In order to test the heterogeneity of the studied virgin stands (Table 2), Camino (H) and Gini (G) indices were calculated, and the graphical representation was made using the Lorenz curve (Figure 10).

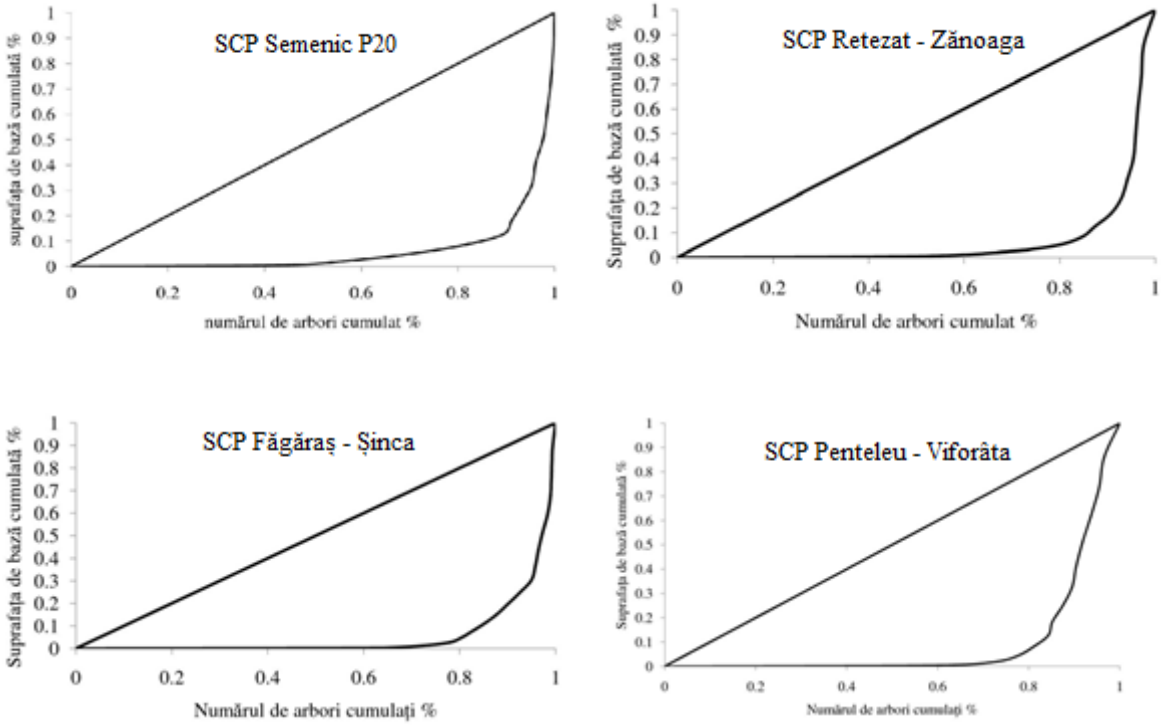

Fig. 10 Lorenz curve.

The graphical representation indicates a great structural diversity for all the investigated permanent plots, specific to these types of forest ecosystems, the area between the line of equality and the Lorenz curve being quite large, an aspect highlighted by the values of the Gini (G) index, which is very close to value 1, the maximum value for the biodiversity.

Table 2

Values of Gini (G) and Camino (C) indexes for Semenic P20, Retezat-Zănoaga, Făgăraș-Șinca and Penteleu-Viforâta permanent research plots

Permanent research plot (PRP)	Gini index (G)	Camino index (H)
Semenic P20	0,88	1,73
Retezat-Zănoaga	0,88	1,71
Făgăraș-Șinca	0,70	1,66
Penteleu-Viforâta	0,84	1,74

3.4.2. Estimation of dead wood and its above ground biomass and carbon stock

The presence of the dead wood is very important in the absorption of carbon emissions from the atmosphere (Weggler, 2012) and for a sustainable forest management it is necessary to estimate the carbon stock of the dead wood. Thus, for each permanent research plot, the carbon stock of the dead wood was estimated in terms of volume, density, above ground biomass and the carbon fraction of the dead wood (Table 3).

Table 3

Main indicators used for determination of dead wood carbon stock in the permanent research plots

Permanent research plot (PRP)	Volume (m^3/ha)	Above ground biomass (t/ha)	Carbon stock (t/ha)
Semenic P20	48,94	17,40	8,17
Retezat - Zănoaga	97,14	30,51	14,34
Făgăraș - Șinca	148,40	26,63	12,52
Penteleu - Viforâta	123,35	24,08	11,32

Regarding the amount of carbon stored by the dead wood, this is an estimate, and in future research it could be more accurately determined based on direct measurements.

4. CONCLUSIONS

The opportunity for Romania to maintain a considerable area of virgin forests was one of the main drivers of the researches carried out during the elaboration of this PhD thesis. In this respect the thesis provides real progress in the scientific knowledge of structuring and functioning processes of these forests in order to identify new solutions for their management, in the context of the permanent increasing of the climate change process. Based on the results of these research, the following conclusions can be drawn:

- ***Concerning the analysis of the virgin forests structure***

  - The information obtained from the permanent research plots located in the selected virgin forests stands proved to be representative and statistically ensured for the undertaken researches, leading to a scientific substantiation of the specific laws of structuring and functioning of the natural forest. This confirms the exponentially negative distribution of the number of trees in relation to their diameters, according to which most of the trees are in the lower diameter category.
  - The most appropriate theoretical functions for describing the distribution curves in relation to the volume are the Weibull 2P and Weibull 3P, highlighting the large number of trees present in the lower volume categories and a decreased number in the highest ones.

- ***Knowing the specific auxological processes of the selected virgin forests and their relation to environmental conditions.***

  - The auxological analysis of these forests stands revealed that the diameter growth distribution curve has a descending line, with high frequencies in the small categories of radial increases, which confirms the presence of large groups of small trees in these stands located in the lower forest floor, with low values of growth and in the initial phase.
  - The high variability of the radial growth in relation to the tree diameter at the level of the whole forest stand proves once again the great age and dimensions diversity of the trees that are present in different development phases which are superior to even aged forest stands.
  - The value of the elaborated dendrochronological series, given by their length (for more than 227 years), their diversity (for the main species in our country) and the modern methods used in data processing and interpretation contributes directly to the development of knowledge of these forests as a whole.

- The spatial identification of the various stages of development on different areas within the stands and defining the features of the virgin forests, allowed for the spatial representation and the detailed description of each of these phases. This made it possible to capture their functioning mechanisms and structuring of the studied virgin stands.

- ***Structural biodiversity and biomass of research virgin stands***
  - The researched virgin stands are characterized by a higher degree of heterogeneity, from a structural point of view, compared to other virgin forests as well as to the managed forests, proven by the resilience of these primary ecosystems, characterized by an advanced degree of integrity, self-regulation, stability and self-preservation.
  - The average amount of carbon stored in the dead wood in different stages of decomposition (11.6 t / ha) is however below the average known in the literature (17.0 t / ha). This is explained by the fact that in the studied plots, the dead wood originating from the resinous species is predominant while higher carbon beech dead wood is less represented.

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The present PhD thesis contributes through the results obtained, to the development of the knowledge on structuring and auxological laws regarding the virgin stands in our country. The research on structure and growth of virgin forests in the Romanian Carpathians remains open for the future development of extensive and complex inter- and transdisciplinary approaches of a fundamental character leading to the in-depth knowledge of the natural processes specific to these highly complex biological systems.

List of publications:

- **Chivulescu, Ș.,** Leca, Ș.. Silaghi, D., Cristea, V., 2018. Structural biodiversity and dead wood in virgin forests from Eastern Carpathians. Agriculture and Forestry, 64 (1): 177-188
- **Chivulescu, S**., Leca, S., Silaghi, D., Badea, O. ,2016. Growth of virgin forests in the southern Carpathians. Agriculture and Forestry, 62 (3): 39-48. DOI:10.17707/AgricultForest.62.3.03
- **Chivulescu S.**, Badea O., Tomescu R., Silaghi D., Leca S**.**, Turcu D., 2014, *Structural features of virgin beech forests in Semenic mountains. The dynamic structure of virgin beech forest P20 Semenic between 2005-2013.,* Proc. Rom. Acad., Series B, 2014 16(2), p. 115-124.
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