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STRUCTURE MODELS FOR BEECH-CONIFERS STANDS WITH PROTECTIVE FUNCTIONS

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Abstract: *To manage forest stands in order to achieve management goals it is necessary to develop functional structural models. This study aimed at developing structural models for mixed stands considering natural forest types and site conditions. These models have been defined by the species' structural parameters such as: target diameter, number of trees and volume per diameter, basal area and volume per hectare. The target diameter determines the structure and the size of the growing stock and it has been determined as the diameter of the largest healthy, actively growing tree per hectare. The analysis of radial growth of very thick trees has led to lower target diameters and lower growing stock than recommended by the Romanian technical norms for forest management. For modeling the real structures, the intensity of the silvicultural interventions was determined. The effect of silvicultural interventions should be observed periodically, through successive inventories, to know the dynamics of the structure and the size of the real growing stock. Since the aim is to achieve a functional structure of the stands, the developed model is a flexible one. Depending on the dynamics of the stand structure, the parameters of the model may vary, but stands should retain their vitality, productivity, regeneration capacity and protective function.*

Key words: *structural model, target diameter, stand structure, selection system, management measures, silver fir.*

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1. Introduction

Concerns about setting up optimal stand structures in relation to the assigned functions have always been a research focus. The importance of establishing optimal structures also arises from the fact that many stands have structures that do not perform their functions effectively due to:

- Composition-wise the proportion of species is far different from those corresponding to natural-type ecosystems (defined by the composition of the forest type);
- Low densities;
- Transformation cuttings that led to dimensional class structures, very different from those specific to the uneven-type structures.

Research done in Romania highlighted the effectiveness of uneven-type structures in exercising the assigned protection functions that mountain forests must possess as well as have laid the groundwork for the application of selection cutting [1, 4, 6, 14-16, 20]. Subsequently, this treatment was introduced into the practice of forest planning through technical instructions [19].

Although initially the problem of selection was placed within the forests with hydrological and anti-erosion functions, the effectiveness of the selection structures was also emphasized in the case of the forests of social interest located near big urban and tourist areas [17-18].

The experience of applying selection in other countries [3] and its experimentation in Romania led to the development of type distributions that represent the main structural parameters on functional subgroups for pure spruce, fir and beech stands [7]. These distributions are based on Liocourt and Meyer's relationships [12, 18]. In relevant literature [2, 5], these functions are known as patterns that convey tree diameters decrease in uneven-aged stands.

In the last decade due to climate change, the coniferous plants located on the edge of their area have become much more sensitive, suffering premature drying. There is a growing emphasis on the need to promote mixed stands, as being capable to respond to climate challenges. Future structures, as stable as possible to the action of climatic factors are also necessary in the case of beech wood mixtures. Such structures are to ensure the permanence of the forest in order to continuously exercise the functions it performs.

Through these researches, such models have been attempted for the Silver fir-European-beech stands and for the mixed European beech-Norway spruce-silver fir from the Postavarul Massif. This is the goal we have set ourselves. In this respect, the following objectives were considered:

- Understanding the structural particularities of the mixed beech-conifers and their spreading in the area;
- Determining biometric features of stands;
- Defining structure conditions that the stands must fulfil in order to exercise their assigned protection functions;
- Elaborating models to guide current stand structures.

2. Material and Methods

2.1. Material

Research was carried out in the production unit IV Braşov from the Postavărul Massif, Oriental Curvature Carpathian Group. Within the production unit, observations and measurements were made in mixed beech-conifers stands in order to determine the real characteristics of the structure of the stands. A representative tree was selected from the surveyed stands where a one-hectare sample area (100m x 100m) was placed and the biometric features of the trees were measured (Figure 1).

Fig. 1. Research location

For each tree we measured: breast height diameter - dbh (cm), total height (m), pruning height, crown diameter. The coordinates of each tree were determined, wood cores were extracted from very thick trees, and tree quality, vitality and health were assessed. An Excel database has been elaborated to develop structural models.

2.2. Structural Models

In order to establish the structural models of the future, the objectives established through the forest facilities, respectively the functions of the stands in the area, were taken into account, as they determine the future structures and the management measures to be applied, according to the relationship:

- Multiple protection targets;
- Protective functions assigned to the stands;
- Structures to be carried out (structural models);
- Management measures.

Structures of the future were drawn from the relations established between the characteristics of the trees, namely: diameter, height, quality, crown dimensions.

The elaborated models were defined by: the structure in the vertical plane; the structure viewed from the perspective of tree design and the degree of proximity of their crowns; the structure by species, respectively the composition of the stands, the proportion of the species being important in the case of mixed stands.

For the definition of structural models, the multiple objectives were pursued such as forest management, mainly recreational purposes, as well as the static conditions specific to the forest formations, in which the silver fir (BR), Norway spruce (MO) and European beech (FA) are the main base or mixed. Along with these species, he is also participating conifers species (DR) Norway spruce (MO), European larch (LA) and other hardwood species (DT): Norway maple (PA), sycamore (PAM) and ash (FR). The following target compositions were adopted (in tenths): 4 BR 4 FA 1 DT 1 DR for the silver fir-European beech stands; 4 MO 2 BR 3 FA 1 DT, 3 MO 3 BR 3 FA 1 DT, 2 MO 4 BR 3 FA 1 DT, 5 MO 2 BR 2 FA 1 DT, 6 MO 2 BR 1FA 1 DT for mixed European beech-Norway spruce-silver fir.

Within each formation the main parameters that a model should contain were analyzed, namely:

- Structure by species (target composition);
- A normal fund size different according to the stand production class;
- The target diameter adopted for each species in relation to the static conditions (Table 1);
- Distribution of the number of trees by diameters.

The results show the parameters for silver fir-European beech forest formation.

Table 1

Target diameters [cm]

Species	Relative yield class				
	I	II	III	IV	V
Norway spruce (MO)	72	68	60	56	52
Silver-fir (BR)	84	80	72	64	52
European-beech (FA)	68	64	56	52	48

3. Results

3.1. Real Stand Structures Characterization

The stands surveyed have different structures that differ in relation to the management measures that have been applied, but also due to the development of the stands in time. An example illustrating the structure of the stands in the production unit under investigation is the structure of the stand in the compartment 543 shown in Figure 2.

3.2. Defining Structural Models

Structural models give the parameters of the structures to be achieved through forest management. The structure of the production fund in relation to the thickness of the trees is analyzed by their distribution by categories and classes of diameters. The structure of the stands is normal when the number of trees decreases in diameters following a geometric progression.

Structural models were defined by the following parameters: the size of the production fund, expressed by volume per hectare, V (m^3); a basal area per hectare, G (m^2); a limit diameter, Dl (cm); number of trees per hectare, N; the number of trees expressed (percentage) by classes of diameters; volume (percentage) by diameter class.

These parameters differ in relation with the composition of the stands and the static conditions. Taking into account observations made, the target diameters for spruce, fir and beech species can be adopted as in Table 1.

Tracing the volume curve was necessary for modelling (Figure 3). It is of practical importance for the determination of the volume of trees for the area surveyed, only by diameter.

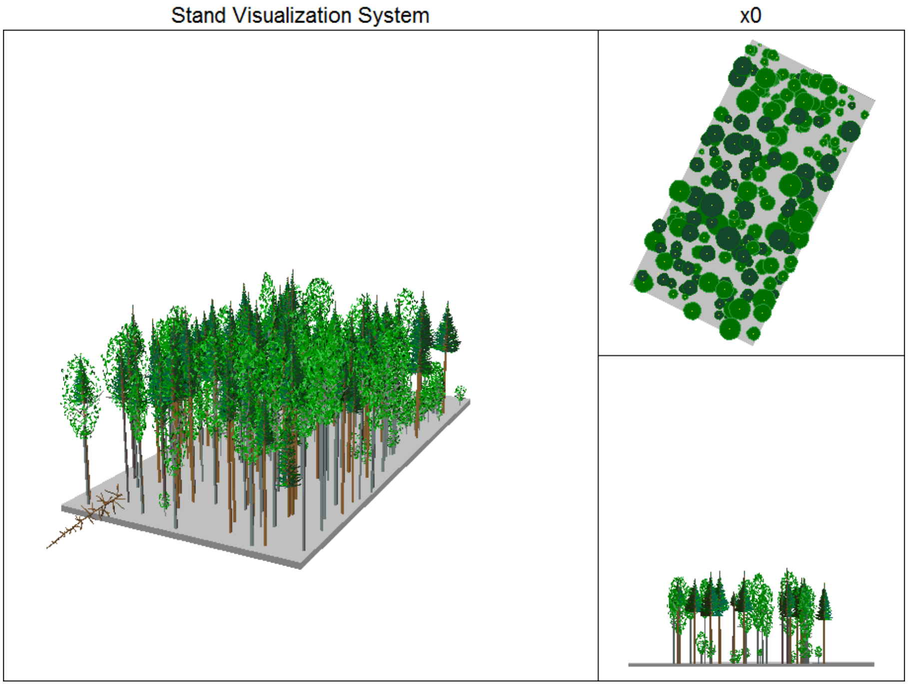

Fig. 2. Vertical profile (compartment 543)

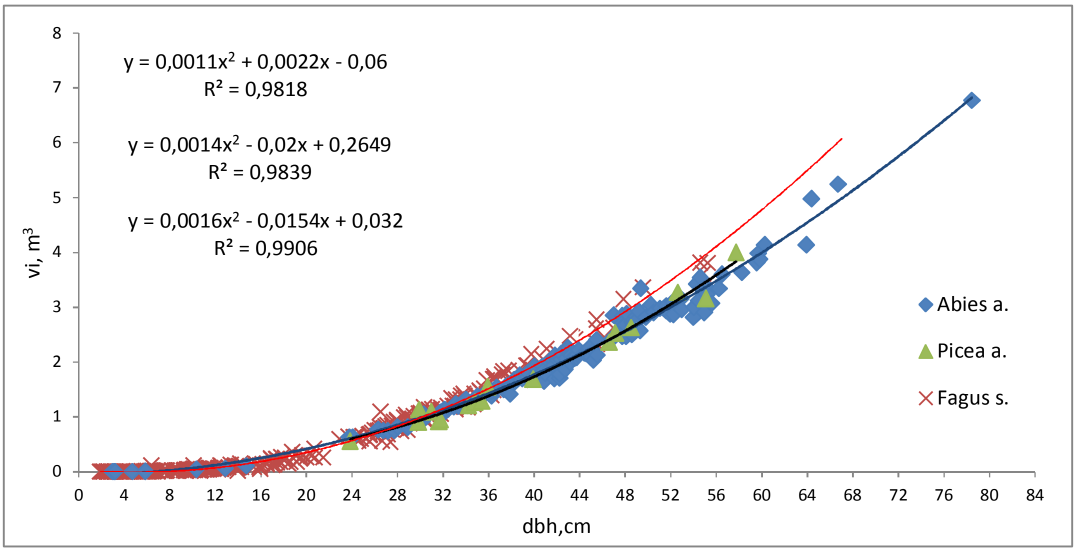

Fig. 3. Relationship between tree volume and their diameter

3.3. Characteristics of Structural Models

For defining the structural models, the following conditions were considered: altitude: 700 – 950 m; formation: silver fir-European beech; composition: 4BR 4FA 1DR 1DT.

The size of the normal growth stock ranges from 210 to 540 m^3 (Table 2).

The structure of the normal production fund shows the decrease of trees by diameter class (Figure 4).

The normal distribution of trees by diameters (Table 3) was determined for the target diameters set out in Table 1.

Table 2

Normal growing stock

Relative yield class	Silver fir-European beech stands (4BR 4FA 1DR 1DT), $m^3 \cdot ha^{-1}$				
	Total	BR	FA	DR(MO,LA)	DT(PA,PAM,FR)
I	540	230	210	60	40
II	440	180	170	50	40
III	360	150	140	40	30
IV	280	110	115	25	30
V	210	80	85	20	25

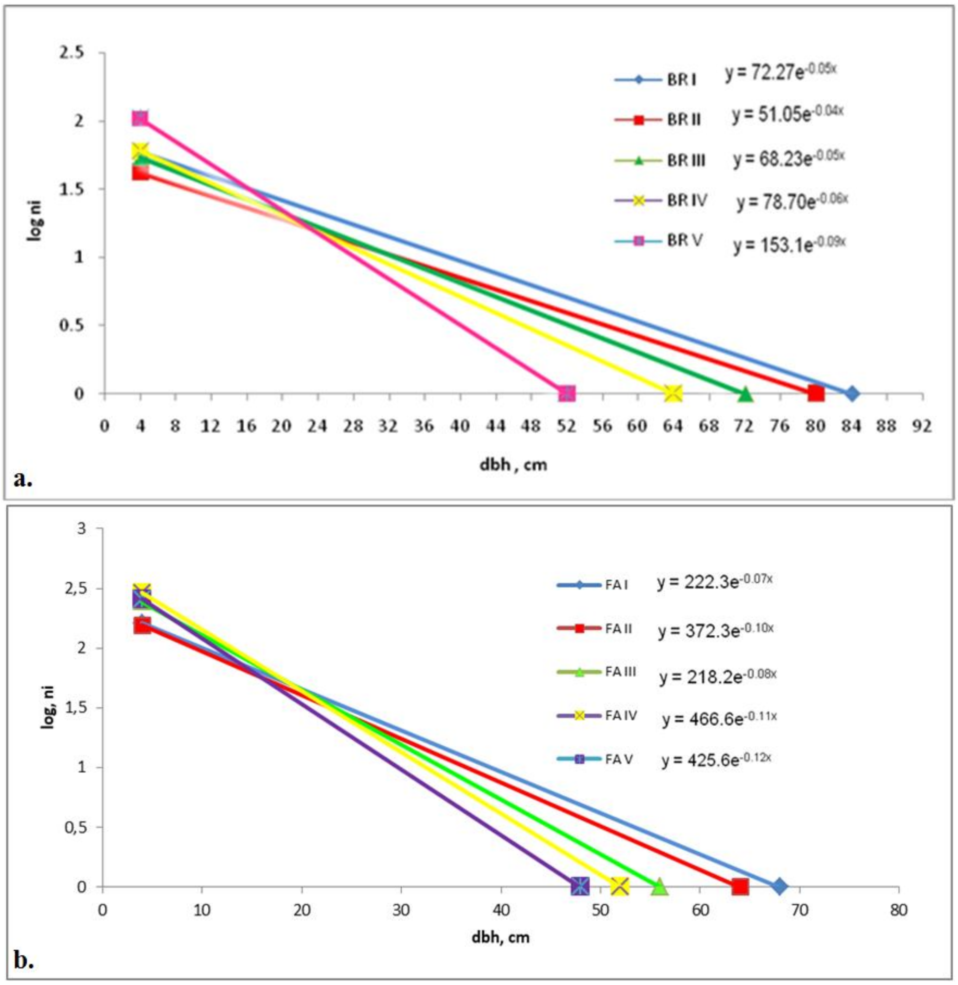

Fig. 4. Logarithmic representation of the number of trees for established target diameter for: a) silver-fir (BR) and b) European-beech (FA)

Table 3

Structural parameters for normal growing stock (per hectare)

Species	N/ha	Vn [$m^3 \cdot ha^{-1}$]	Gn [$m^2 \cdot ha^{-1}$]	q	Dl [cm]	N to Dl
4 BR	315	230	18	1.22	84	1
	264	180	14.2	1.22	80	1
	276	150	11.4	1.27	72	1
	263	110	8.51	1.32	64	1
	341	80	6.3	1.47	52	1
4 FA	602	210	16.6	1.37	68	1
	553	170	13.7	1.39	64	1
	724	140	12.3	1.51	56	1
	777	115	10.8	1.6	52	1
	659	85	8.23	1.64	48	1
1 Mo (LA)	32	60	5.56	1.03	84	1
	28	50	4.3	1	80	1
	26	40	3.34	1.04	72	1
	23	25	2.25	1.05	64	1
	25	20	1.5	1.09	52	1
1 DT (PAM, PA, FR)	25	40	2.91	1.04	68	1
	35	40	2.77	1.1	64	1
	40	30	2.13	1.15	56	1
	61	30	2.3	1.22	52	1
	67	25	2.02	1.27	48	1

(N = tree number; Vn = normal volume; Gn = normal basal area; 1/q = ration; Dl = target diameter; N to Dl = tree number from the target diameter class).

4. Discussion

4.1. Relationship between Biometric Features

The investigated stands are part of forest formations beech-fir and mixtures of beech-conifers [21-22] of different yield classes [9].

In the area researched are stands whose structures tend to uneven structures, where the process of transforming structures began 6 decades ago. In other stands, there is a tendency for trees to be overlapped, with two or three generations being distinguishable, the structures being that of irregular shelter wood cuttings. There are also stands in which the structures resemble the regular ones or stands in which, trees are arranged in close proportions by diameters class, without clearly delimiting the respective structures as regular or uneven, but only as irregular structures. An example is the structure of the stand in the compartment 543 (Figure 5).

The basal area has a higher share in large diameters, although the number of trees in these categories is lower compared to thin and medium trees in categories below the average diameter of the stands. The field observations and the results of the determinations show that in all cases, the lower average diameter is grouped with a lower basal area compared to the other categories (Figure

5). In some cases, the presence of a maximum of this surface in the central, categories shows that respective structures belong to those specific to the regular forest. The transformation of these structures involves the reduction of the basal area in the central categories and, implicitly, of the number of trees in these categories, in order to further create conditions for the seedbed and for the development of young trees.

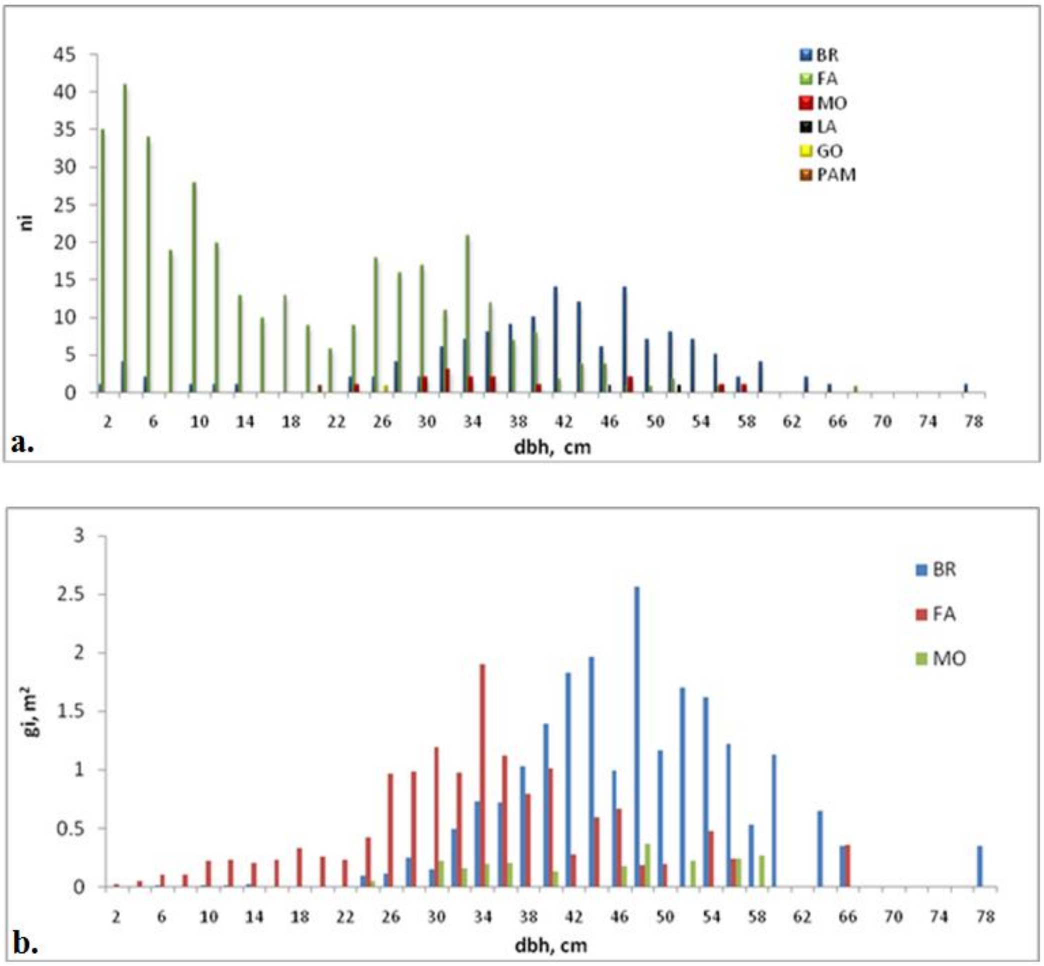

Fig. 5. Tree distribution by diameter class in compartment 543: a) number trees (BR - *Abies alba*; FA - *Fagus sylvatica*; MO - *Picea abies*; LA - *Larix decidua*; GO - *Quercus petraea*; PAM - *Acer pseudoplatanus*) and b) basal area

4.2. Target Diameter, Basic Element for Defining the Structural Model

The target diameter determines the structure and size of the growing stock. It marks the upper limit of the diameters categories and is established in relation to the categories of land quality and productivity assessment characterizing the forest resorts in the stands subject to modelling.

To establish target diameters, research has been done to determine the health of the very thick trees, their quality and the variation of their radial growth. Particularly useful in this respect were the samples extracted with the increment borer.

Analyzing the radial growths on the extracted cores it can be concluded that the trees have undergone several periods in their development (Table 4).

Table 4

Mean radial increment (ir) over periods of tree development

Species	Age	Dbh, cm	Mean radial increment, ir (mm), over period ...			
			until 1908	1909 – 1942	1943 – 2002	2002 – 2017
BR	150	80.9	2.4	4.4	2.2	1.4

Growth reduction at 1.4 mm at this age was also followed by drying, especially after the 2012 drought, which indicates that after a period of growth regress, drying phenomena may occur in the area, at this level.

The target diameter is proposed in the Romanian current Technical norms on silvicultural systems (2000) depending on the tree species and stand functions (Table 5).

The normal growing stock is proposed in the Romanian current Technical norms (2000) depending on the tree species and site conditions (relative yield classes) (Table 6).

Through these researches, the target diameter is computed based on the vigour and tree quality (Table 1), and normal growing stock is much smaller (Table 2).

Table 5

Target (limit) diameter in selection forests in Romania [23]

Stand function	Species	Target (limit) diameter in yield class ... [cm]				
Stands performing special protection functions (functional group I)						
Stands with water protection functions	Silver fir – Norway spruce	76	72	64	60	56
	European beech	68	64	60	56	52
Stands with soil protection functions Stands withclimate protection functions. scientific reserves and nature monuments	Silver fir – Norway spruce	68	64	60	56	52
	European beech	64	60	56	52	48
Stands with social, hunting and leisure functions	Silver fir – Norway spruce	100	90	80	70	60
	European beech	84	76	68	60	52
Stands performing special wood production functions (functional group II)						
–	Silver fir – Norway spruce	92	84	76	68	60
	European beech	84	76	68	60	52

Table 6
Indicative values of normal growing stock in selection forests in Romania [$m^3 \cdot ha^{-1}$]

Species	Relative yield class				
	I	II	III	IV	V
Norway spruce	847	697	548	405	268
Silver fir	729	609	494	385	285
European beech	598	478	372	279	197

4.3. Management Measures for Tending Stands to Optimal Structures

In uneven stands the main feature of the structure is the continuous decrease of the number of trees by diameters. Guiding the stands to the optimal structures defined by the model in relation to the functions assigned to the stands is a long-term process and depends on many factors. Of these, the actual structure of the stands is very important, then the size of the real growing stock, ie the existing volume [8-11] compared to the normal volume established by the model.

Knowing that uneven structures best meet the requirements imposed by the protection functions, stands that have such structures are much easier to be guided to structures established by the model. For uneven-aged stands, in Romanian forest management planning, annual allowable cut is calculated with check method, by current volume increment ($m^3 \cdot ha^{-1} \cdot year^{-1}$). In contrast, it is more difficult to optimize even-aged stands, which require a long-lasting transformation process to selection forests.

The cuttings of transformation to selection forests aims to bring the real structure, as close as possible, to the normal one [13].

In the studied stands, the actual structures are very varied as a result of applied cuttings. Trees of medium (28 – 36) and thick (40 – 48) diameter class are particularly well represented. Very thin (4 – 12) and thin (16 – 24) trees, as well as very thick (> 52cm) trees, are generally less represented and in varied proportions depending on the species. There are also stands where trees are very young, either beech or fir, and in others, there are thicker trees in fir than beech stands. However, silvicultural system can create favourable conditions for the installation of young trees, as well as conditions for the development of already existing young trees, in order to pass into higher classes of diameters, by covering the stands with moderate intensities.

The Romanian current Technical norms (2000) recommend that wood volume to extract during a 10-year cutting cycle should be maximum 17% of real growing stock.

In order to guide the stands, whose structure was presented in Figures 2 and 5, towards the model structure, in the decade of application of the forest management planning, it is expected to cover it at a 16% pace, and subsequently 69,6 m^3 will be extracted (Table 7).

Harvested trees were selected according to two important criteria:

- according to their state of health, with priority being given to the extraction of the trees with broken tops, the poorly conformed, the sick, the bent and those not viable in the future;

- according to the normal number of trees by diameter, aiming at extracting the trees from the excedentary categories as they prevent the seed tree from installing and developing.

Following interventions should take into account these criteria so, as the number of real trees approaches the normal one, favourable conditions for the continuous regeneration of the stands are created (Figure 6).

Table 7

Initial volume and extraction volume by species

Species	Real growing stock, Fr			Normal growing stock, Fn			Trees for harvesting					
							by state			healthy		
	N	G [m^2]	V [m^3]	N	G [m^2]	V [m^3]	N	G [m^2]	V [m^3]	N	G [m^2]	V [m^3]
BR	143	21.19	290.1	317	14.2	180	20	2.15	21.8	7	1.11	34
FA	363	14.24	186.9	522	13.7	170	58	1.38	12.7	–	–	–
DT	2	0.06	1.5	29	1.1	50	–	–	–	–	–	–
DR	17	2.18	30.5	35	4.3	40	1	0.07	1.1	–	–	–
Total	525	37.67	509	903	33.3	440	79	3.6	35.6	7	1.11	34

5. Conclusions

The Postavarul Massifs stands perform multiple functions and in order for these functions to be performed in optimum conditions it is necessary for the respective stands to meet certain structural conditions. As a result of the applied management measures, the stands in the researched area show different structures in relation to their share of the component species and a great variation of tree thicknesses. Given the multiple protection functions assigned to the area stands (hydrological, anti-erosion and social), the most favourable structures in terms of exercising these functions are the uneven type.

Mixed stand structures are very diverse, exhibit large variations of stand density, sometimes with abundant young trees, as well as a wide-ranging dimensional structure. The elaboration of the structural models requires a thorough knowledge of the actual structures of the stands, their growth and development laws, as well as the relations between the trees.

The models elaborated are applicable to conifers-beech stands, situated at altitudes between 700 and 950 m, with recreational main functions. They defined by the following structural parameters: normal volume, differentiated in relation to the tree productivity class from 210 m^3 (5^{th} yield class) to 540 m^3 (1^{st} yield class); target diameters by species ranging from 48 to 68 cm in beech and 52 – 84 cm in fir) basal area of the trees between 18,1 and 43,1 m^2 and the number of trees is variable on the diameter class (on average by production classes, 60% thin trees, 23% medium-sized trees, 10% thick trees, 7% very thick trees).

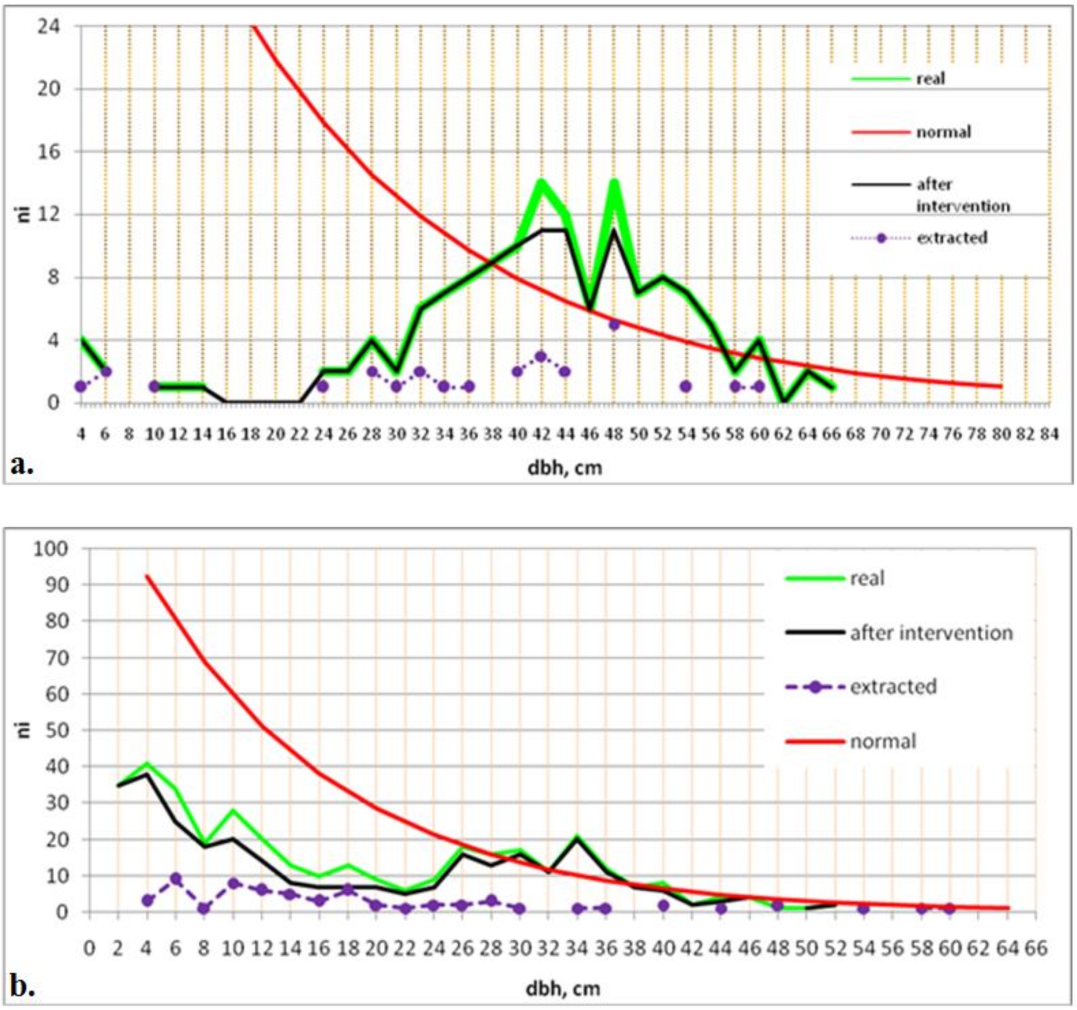

Fig. 6. Number of trees per diameter – real, before and after intervention for: a) fir (BR) and b) beech (FA)

In the target diameter class, thickest, with active increases, healthiest trees are included, that can develop in specific stationary conditions. A valuable indicator in setting the target diameter is the dynamic of the diameter and current volume increment. In order to guide the actual structures of the stands towards the structures envisaged by the models, the intensity of the interventions is variable, in relation to the actual structure of the stands. To maintain the structure of a viable, functional position there are recommended moderate intensities of 16% (17%) from and a permanent control of the number of trees categories based on diameters, through principally inventories. Applying into the practice of forest management, structural models require experience in knowledge of stand structure and proficiency in applying silvicultural system.

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