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Spatial structure, biodiversity indicators and carbon stocks of the old-growth natural forests in the protected areas of the Ukrainian Carpathians

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Abstract: Intensive management in European forests in the 20th century resulted in the substitution of the old-growth natural forests with plantations on vast territories. The spatial structure and tree species composition of the planted forests are simplified making the forests vulnerable to diseases and disturbances. The old-growth natural forests that remained in some places can be used as etalon forests for the reconstructed forests in similar environmental conditions. We studied spatial structure, biodiversity indicators, and carbon stocks of the old-growth natural forests in the Ukrainian Carpathians for setting forest management targets for the forest plantations in the region.

Keywords: old-growth natural forest; carbon stocks; biodiversity indexes; spatial distribution indexes; etalon forest

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1. Introduction

Current forests of the Ukrainian Carpathian are at different stages of vegetation succession from pioneer to stable phytocenosises, which were formed over a long time. The concept of forest management in the Ukrainian Carpathian, especially in a postwar period (150-1980-s), was based on clearcut loggings and artificial reforestation (planting or sowing). This led to appearance of the large-scale areas of even-aged and single-species stands. However, in the areas with poor road infrastructure and in the protected areas, old-growth natural forests and primeval type forests remain. These stands nowadays are of a particular interest, because they have complex spatial and vertical structures, multiple tree species composition and uneven age structure, having high biodiversity, and adaptation capacity. In the Ukrainian Carpathian, beech, norway spruce, and fir primeval forests (quasi-primeval forests) are located, which cover an area up to 95 thousand ha [1, 2]. The area of Ukrainian primeval forests under the protection of UNESCO is almost 24 thousand ha and almost 35 thousand ha belongs to its buffer zone (http://cbr.nature.org.ua/whc/whc.htm) [3].

In the Gorgany region, at the altitude of 800-1500 meters above sea level, considerable areas of the beech-fir-norway spruce, fir-norway spruce, and Norway spruce old-growth natural forests and primeval forests are located. They are growing mostly on the damp forest site types. At the top belt of spruce forests, relict moist cedar-norway spruce forests of fairly infertile site type grow. On the protected areas of National Natural Park "Skole Beskyds", at the altitude of 700-1200 meters above sea level, forests of primeval type remain as well. They mostly include moist norway spruce-fir-beech fairly fertile and fertile site types with the addition of fir, Norway spruce, and sycamore tree species. The main site type species are beech, Norway spruce, and fir. As the admixture are sycamore,

mountain elm, and mountain-ash. The protected zone of the National Park, based on the inventory data, is about 5 thousand ha.

The aim of the study is estimation of carbon stock in the natural old-growth forests of protected areas of the Ukrainian Carpathians, their spatial structure and biodiversity indexes, and to select the stands with the highest productivity and complex structure as a target standard for performing forest management in artificial and wood production forests

2. Materials and Methods

For estimating the spatial structure of stands the remote sensing data (RS) and the results of ground measurements on the sample plots were used. The usage of high-resolution RS data allows to analyse the spatial structure of stands on a large territory based on the measurements on the sample plots [4]. Landsat images were used for covering the whole study area. When the choosing the RS data, we considered data accessibility, enough number of images of high quality with minimal cloud cover which are taken for a short period. For the verification of classes, high-resolution QuickBird images were used. The methodology of image interpretation is described in [4,5].

For the choosing places for field measurements, we applied a uniform raster network in altitudinal and horizontal dimensions for the territory of Nature Reserve "Gorgany" and National Natural Park "Skole Beskids". Further, using results of forest inventory, we chose the plots (inventory compartments), where the average age of stands was 120 years and more. That type of disposition of sample plots (testing plots) guarantees the unbiassed character and contingency of territory coverage.

The sample plot was taken as the basic unit for carbon stock estimation, taking into account sylvicultural and inventory indexes, i.e., species composition, average age, productivity, relative stocking. The carbon stock in the phytomass of stands was calculated using the method "bottom-up" approach that is based on the direct calculation of carbon stock of individual phytomass components and wood density for every tree species with the usage of conversional coefficients [6-8]. The calculation using the conversional coefficients method was realized in the developed database of statistical inventory of the sample plots applying statistical regressions (dependence of phytomass on tree species, average age, productivity class, relative stocking, etc.) [6-11].

The spatial and age structures, and stands growing stock were estimated for the round sample plots of area of 500 m². The centers of the sample plots were determined using a GPS receiver. The vertical structure of the stands (the structure of tree levels or the vertical horizons) represents a percentage of occupation of each layer by vegetation. The vertical stand structure was estimated using three indicators: diversity of tree positions (positioning), value diversity (variability of the indicator), tree species diversity (composition). The diversity of species was estimated using the Shannon index and trees differentiation index (T). The formulas of the species diversity are presented in Table 1.

Table 1. Main criterions for the forest species diversity estimation.

Index	Formula	Significance
Shannon index, E_H	$H' = -\sum_{j=1}^{n} \frac{n_i}{N} ln\left(\frac{n_i}{N}\right)$, $E_H = \frac{H}{H_{max}}$, $M_i = \frac{1}{n}\sum_{j=1}^{n} m_{ji}$	E_H = 0,00 – absent; 0,25 – low; 0,50 – middle; 0,75 – high; 1.00 – very high
Trees differentiation index, T_i	$T_i = \frac{1}{n}\sum_{j=1}^{n} t_{ji}$, $T_i = \frac{\sigma}{X}$	T_i = 0,05 – very low; 0,06 – 0,15 – low; 0,15 – 0,30 middle; 0,31 – 0,60 – high; more than 0,61 – very high

The value diversity (T) was calculated as the ratio of the standard deviation of indicator (σ) by its average (X) . Using this value, it is possible to determine the variability of the indicators. The type of trees disposition was estimated applying the value of Clark-Evans index R [12] and its modifications by Donelli [12], angle index of Gadow [13-14]. The formulas of the estimation of the type of trees disposition are presented in Table 2.

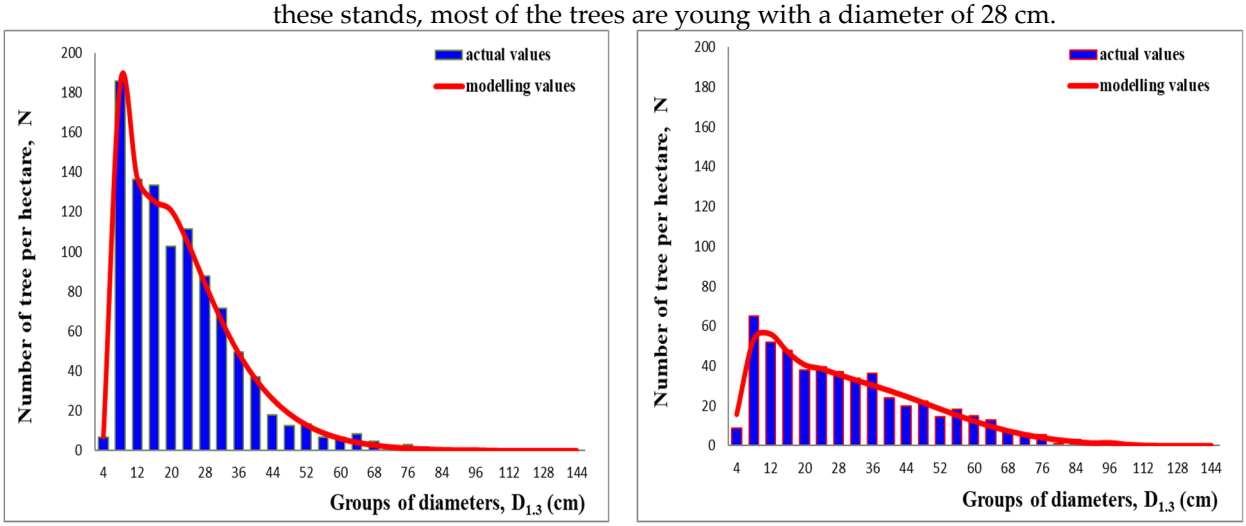
Table 2. Main criterions for the disposition of trees estimation.

Index	Formula	Significance
Clark-Evans, *R*	$R = \frac{r_A}{r_E} = \frac{\frac{1}{N}\sum_{1}^{N} r_i}{0{,}5 \cdot \sqrt{\frac{S}{N}}}$	if R<1 – the disposition is group; R>1 – uniform disposition, R=1 – random disposition
Donelli, R_D	$R = \frac{\frac{1}{N}\sum_{1}^{N} r_i}{0{,}5 \cdot \sqrt{\frac{S}{N}} + + 0{,}0514 \cdot \frac{P}{N} + 0{,}041\frac{P}{\sqrt{N^3}}}$	if R<1 – the disposition is group; R>1 – uniform disposition; R=1 – random disposition
Angle index of Gadow, *W*	$W_i = \frac{1}{n}\sum_{j=1}^{n} v_{ji}$	W_i = 0,00 – strictly uniform; 0,25 – uniform disposition; 0,50 – group disposition; 1,00 – random disposition

The structural variety of the stand can be the indicator for the estimation of ecological diversity and the stability of the ecosystem.

3. Results and Discussion

Mixed forests of the National Nature Park "Skole Beskids" and the Nature Reserve "Gorgany" grow on altitude of 700-1400 meters above sea level. The differentiation of the trees by groups of diameters in the studied stands follow bimodal distribution (Fig. 1). This type of distribution is inherent to the natural forest stands with vertical diversion. In these stands, most of the trees are young with a diameter of 28 cm.



(**a**) (**b**)

Figure 1. Differentiation of trees by groups of diameters: (**a**) Nature Reserve "Gorgany"; (**b**) – National Natural Park "Skole Beskids".

The diameter distributions between the two studied objects is quite different. The greater number of trees per 1 ha grow in Nature Reserve "Gorgany" (approx. 1 thousand trees per hectare), but at National Nature Park "Skole Beskids" it is close to 500 trees per

hectare. The main biometrical indexes of the studied stands by diameter and height are presented in Table 3.

Table 3. The main biometrical indexes of the stands.

Name	Average diameter, cm	Variation indexes					Skewness, A	Kurtosis, E	Mode, Mo	Median, Me
		minimal value	maximal value	variability, σ^2	standard deviation, σ	coefficient of variation, V				
by diameter										
NR "Gorgany"	22,3	6,0	104,4	186,4	13,7	61,2	1,42	2,93	9,2	19,6
NNP "Skole Beskids"	30,0	6,0	105,0	354,8	18,9	62,8	0,77	-0,08	9,3	26,5
by height										
NR "Gorgany"	10,8	4,3	39,2	18,5	4,3	40,0	0,42	-0,69	9,3	10,2
NNP "Skole Beskids"	19,0	4,2	41,8	102,2	10,1	53,2	0,22	-1,1	9,9	18,0

The variation of diameters and heights of trees on the nature reserve territories are quite high and make more than 40 %. The mode is in the range of 10 cm for diameter and 10 m for height. The median has considerable deviations for the diameter and the height. These results of biometrical estimation of diameter and height affirm that these stands are heterogeneous, which means that they have complex structures.

The distribution of number of tree by the vertical levels has some regularity and differs for the sample plots. For the stands in National Nature Park "Skole Beskids" the upper level prevails (up to 60 %), respectively the lowest layer is around 30 %, and the middle level is up to 20 %. For the stands of the core zone of the Nature Reserve "Gorgany" the regularity of the structure by the vertical levels, it is differing and, on average, it is the same for all levels – around 33 %. It is dominating the lowest level almost 40 % here.

The other interesting characteristics of the stands is the vertical distribution of the tree species. For the stands in Nature Reserve "Gorgany", the prevailing species in all vertical levels is Norway spruce (Picea abies L.). Its average contribution to the species composition is around 70 %, the fir is up to 25 % and the beech is up to 5 %. At the lowest level, it is considerable increasing the share of fir (up to 30 %). Swiss pine (Pinus cembra L.) is rare. This tree species is growing in the high and middle levels, its share in the the species composition is around 1 %.

For the stands in the National Nature Reserve "Skole Beskids", the prevailing species in the vertical levels is beech (Fagus sylvatica, L.) (around 60 %). The contribution of Norway spruce is 20 % and fir up to 15 %. On this territory, a the share of fir (almost 20 %) in the lowest level and the share of mountain ash (Sorbus aucuparia L.) up to 2 % are observed. On the altitude of more than 1 thousand m, the beech (Fagus sylvatica L.) prevails, up to 45 %, the share of fir and Norway spruce is 25 %, the hare of sycamore is up to 15 %.

The variability of the features of the diameter and height on the nature reserve areas is high, over 40 %. The mode of these indexes is in the range of 10 cm by diameter and 10 m by height. The median has a considerable error for the diameter, and for the height. These results of biometrical estimation by the diameter and the height affirm, that our stands are heterogeneous.

The main criteria of the disposition of the position of trees, the species diversity, and differentiation for the stands on the nature reserve areas are presented in Table 4.

Table 4. The main criteria of the stands estimation.

Name	Indexes of horizontal structure			Indexes of species diversity and differentiation		
	Clark-Evans, *R*	Donelli, R_D	Angle index of Gadow, *W*	Shannon index, E_H	Trees differentiation index, T_i	
					diameter	height
NR "Gorgany"	1,06	1,05	0,87	0,44	0,61	0,40
NNP "Skole Beskids"	1,07	0,98	0,78	0,63	0,63	0,53

As you can see from the results of the calculations in Table 3, the natural stands in the nature reserves have mainly random and group disposition. It means, that these stands have the group-random disposition of trees on the area. This type of disposition is inherent to the natural stands with the long-time absence of anthropogenic loading and loggings. The Shannon index shows that the species diversity for the Nature Reserve "Gorgany" is average, but for the National Nature Park "Skole Beskids" it is high. Trees differentiation index by diameter is very high, but for the height, it is high. It is proving the heterogeneity of stands. The distribution of the growing stock by the vertical layers differs considerably from the distribution by the number of trees. For the nature reserve areas, the groving stock of the upper level is about 80-90 % of the total growing stock. It means that the dominant share of the stock is in the upper leyer. The growing stock distribution by tree species in different stand layers presented in Figure 2.

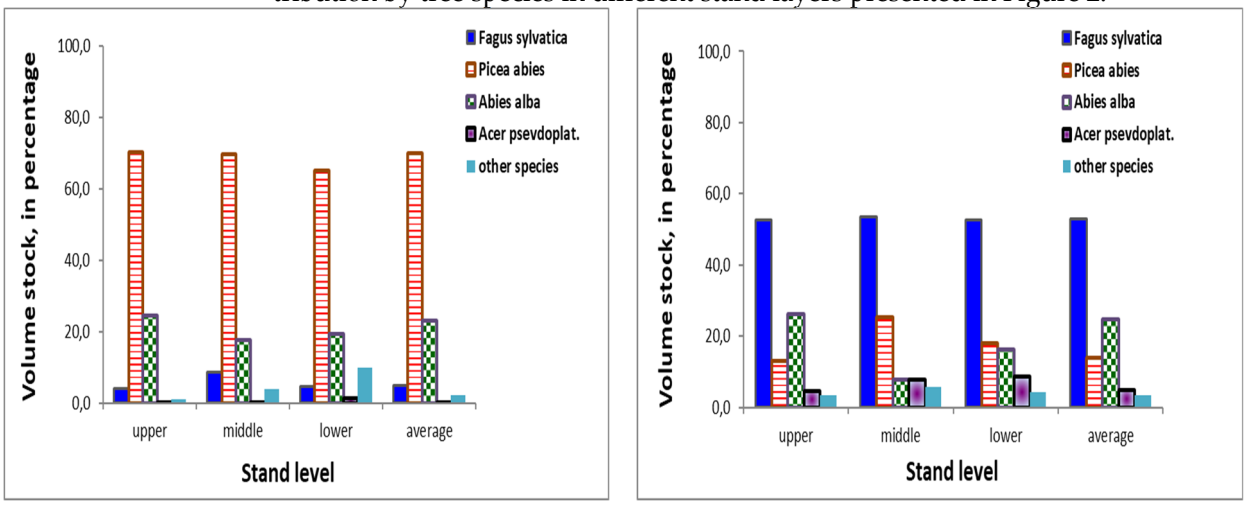


Figure 2. Distribution of the growing stock by the stand layers and tree species: (**a**) Nature Reserve "Gorgany"; (**b**) – National Nature Park "Skole Beskids".

For the Nature Reserve "Gorgany", where Norway spruce prevails in stand composition, the growing stock of this tree species is about 70 % in all stand layers. For the stands in National Nature Park "Skole Beskides", where beech prevails in stand composition, the growing stock of this tree spesies is about 55 % in all stand layers. The main part of the phytomass structure of the stands in Nature Reserve "Gorgany" take the stands of Norway spruce – 74 %, fir – around 17 %, and beech – 5 %. The other tree species, birch, sycamore, Norway maple, and mountain ash contribute up to 1 % of the growing stock. The carbon density of phytomass on the land covered by forests is 211 tC/ha in Nature Reserve "Gorgany".

In National Nature Park "Skole Beskides", the main share of phytomass make beech trees – 62 %, Norway spruce – 16 %, and fir – 13 %. The least share of phytomass (up to 5 %) make sycamore, Norway maple, birch, Scots elm, and other tree species. The carbon density of phytomass in these stands is 266 tC/ha.

The carbon density of phytmass is the highest in the upper stand leyer, 170-250 tC/ha. The phytomass carbon density over the tree layers in the nature reserve forest stands is 220-280 tC/ha. The phytomass carbon density depends on the spatial structure of the stand and its species composition. The maximal values of phytomass carbon density (up to 500 tC/ha) are in National Nature Park "Skole Beskids" in the stands composed of 5-7 units of beech, 4-5 units of fir, and 1-2 units of Norway spruce with the group-random type of spatial distribution and the distribution the number of trees in vertical layers of 40 % in the upper layer, 15 % in the middle layer and 45 % in the lower layer. For the stands in Nature Reserve "Gorgany", the optimal species composition depends on altitude. Below the 900 meters above sea level, the optimal stand composition is 5-6 units of fir, 2-3 units of beech, and 1-2 units of Norway spruce. For the stands over 900 meters above sea level, the optimal composition is 8-9 units of Norway spruce and 1-2 units of fir and admixture of Swiss pine.

4. Conclusions

Based on the analysis of horizontal and vertical structures, indexes of spatial distribution and species diversity we can claim that the studied forest stands are of complex structure, mixed by the tree species composition, with prevailing random and group types of tree disposition. The results of our study could be used for setting targets for forest management in artificial forest stands in similar growing conditions.

Conflicts of Interest: The authors declare no conflict of interest.

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