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The state and structure of beech primaeval forests in the "Zacharovanyi Krai" National Nature Park

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Abstract. The relevance of the study is determined by the need to preserve natural values, which are considered the heritage of all mankind, namely the primaeval forests and old-growth beech forests of the UNESCO World Natural Heritage. The aim of the research was to study the state and structure of the beech primaeval forest in the national nature park "Zacharovanyi Krai". For the study, a permanent sample plot of 1 ha (100×100 m) was laid down in the prevailing forest type – moist pure beech forest. This plot is located in the optimal forest-growing conditions for European beech (*Fagus sylvatica* L.) within the Vyhorlat-Hutyn volcanic ridge of the Ukrainian

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Carpathians. It was found that the beech forest stand on the plot is pure in composition and complex in form, characterised by different development phases (age groups by diameter): the first layer stand belongs to the mature age group (senile), the second layer – to the middle-aged group, and the third – to the pole (virginal). It was determined that 95% of the primaeval forest stock is the stock of the first layer, while the share of commercial trees of the first layer is 89% (66% of the total volume of stem wood of trees on the permanent sample plot). The main types of damage in the site are caused by abiotic factors. As a result of such damage, 43 $m^3 \cdot ha^{-1}$ of deadwood was recorded, characterised by all 5 stages of decomposition. Under the canopy of the stand, 10,375 $pcs \cdot ha^{-1}$ of undergrowth was recorded, of which the share of beech is 88%. Beech undergrowth is weakly differentiated by age groups: it was recorded only in the group of 7-year-olds and older and well-differentiated by height groups. By age group, undergrowth belongs to the juvenile-immature age state. The herbaceous cover is typical for nemoral forests. The presence of stationary research plots in the National Nature Park "Zakharovanyy Kray" makes it possible to constantly monitor the trends of natural development of the ecosystem – the beech primaeval forest

Keywords: Ukrainian Carpathians; stand; undergrowth; deadwood; ecosystem

Introduction

Beech primaeval forests hold multifaceted scientific, natural, ecological, and social significance. However, the increase in human activity and climate change threatens these natural complexes, making research relevant. Understanding the current state of beech primaeval forests enables the development of effective measures for their protection and management, contributing to the preservation of these unique ecosystems for future generations.

According to V.I. Parpan *et al.* (2017), primaeval forests are forest ecosystems (communities) that have arisen and developed naturally under the influence of only natural forces and phenomena and have undergone a complete cycle of development without significant human interference. Their species, age and spatial structure are determined only by factors of the natural environment.

Considering the characteristic cenotic peculiarities of primaeval forests, S. Stoyko (2018) defines them as follows: a primaeval forest is an ecosystem formed during phylocenogenesis, in which all age groups are wrepresented – from juvenile to the disintegration group of the cenosis, the relationships between the autotrophic and heterotrophic blocks and the pedosphere, and therefore it functions as a self-regulating ecosystem.

As of 2020, 97 thousand hectares of primaeval forests, quasi-virgin forests, and natural forests have been identified in Ukraine (Shparyk *et al.*, 2021). According to A. Smaliychuk (2019), at the beginning of 2018, over 94 thousand hectares of primary natural forests were identified in the Ukrainian Carpathians, of which about 53% are classified as primaeval forests. The researcher noted that about half of the identified natural forests in the region have protected status, and the same share belongs to the Emerald Network.

In terms of administrative regions, the largest area of natural forests is found in the Zakarpattia Region, accounting for 71% of their total area (Smaliychuk & Gräbener, 2018). Beech natural forests predominate by main tree species (58%), which in the prevailing forest types (moist pure beech forest – 18%, moist

pure sub-beech forest – 18%), mainly form pure beech stands.

Intensification of primaeval forest research began two decades ago, which is obviously associated with the inclusion of Carpathian beech primaeval forests in the list of UNESCO World Natural Heritage sites. At the same time, beech primaeval forests were studied mainly on the territory of the Carpathian Biosphere Reserve (Trotsiuk *et al.*, 2012; Kabal *et al.*, 2021), in the national nature parks of the Carpathian region and in other protected areas, which led to the proposal to expand the national nature parks. I.F. Shyshkanynets *et al.* (2023) noted that within the territory of the potential expansion of the national nature park "Zacharovanyi Krai", 2,178.5 ha of primaeval forests, 1,197.0 ha of natural forests, 881.2 ha of old-growth forests, and 275.0 ha of primaeval forests were identified. The corresponding sites require effective conservation within the framework of a multifunctional object of the natural reserve fund – the national natural park.

It is also worth noting that research on the territory of the Carpathian Biosphere Reserve is conducted with the support of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and has a systematic character. The corresponding studies are conducted on a 10-hectare plot using a specially developed methodology by B. Commarmot *et al.* (2013). In the rest of the Carpathian region, research on beech primaeval forests mostly does not have a systematic character.

The aim of this work is to study the primaeval beech (*Fagus sylvatica* L.) forest in the territory of the NNP "Zacharovanyi Krai", which is a UNESCO World Natural Heritage site. To achieve this aim, the following main research objectives have been set: to investigate the state, structure, and development dynamics of the beech primaeval forest in the most widespread forest type – moist pure beech forest.

Materials and Methods

In the National Nature Park (NNP) "Zacharovanyi Krai" (Ukraine, Zakarpattia Region), research on primaeval forests began in 2013: a permanent sample plot (PSP) of 1 hectare (100×100 m) was established, and information about it is provided in the publication by I.F. Shyshkanynets *et al.* (2019). In addition, studies of myxomycetes of beech primaeval forests have been conducted (Dudka & Kryvomaz, 2013).

It is worth noting that on July 7, 2017, two areas (clusters) of the NNP (Irshavka – 93.94 ha and Velykyi Dil – 1,164.16 ha) were included in the list of UNESCO World Natural Heritage sites (Hamor, 2023). The Irshavka cluster consists of primaeval forests of the Pidhirnianske forestry, while the Velyky Dil cluster consists of primaeval forests of the Pidhirnianske forestry (18%), old-growth forests of the Ilnytske forestry (59%), and primaeval forests of the state enterprise (SE) "Dovzhanske Forestry-Hunting Management" (FHM) (23%) (Shyshkanynets *et al.*, 2019). At the same time, the corresponding plots in the SE "Dovzhanske FHM" are agreed upon for inclusion in the NNP. The PSP is located in the Irshavka cluster.

In 2023, trees with a diameter ⩾6 cm were numbered on the PSP and the boundaries of the plot were restored in situ. Tree inventory was carried out using a measuring fork: diameters were measured in 2-centimeter increments at breast height (1.3 m), classified by species. At the same time, technical suitability categories, Kraft classes, and sanitary conditions were assessed (Grom, 2007; Methodical recommendations..., 2011; Sanitary Forests..., 2016). Tree heights and crown lengths were measured using a height measurer Vertex IV (Sweden) on 36 trees: from the middle, upper, and lower levels (12 trees in each layer).

The sanitary condition index was calculated using formula (1):

$$I_c = \frac{1}{N}\sum_{J=1}^{6} K_j \cdot n_j, \quad (1)$$

where I_c is the sanitary condition index; $K_1 \ldots K_6$ are the tree condition categories; $n_1 \ldots n_2$ are the number of trees in each condition category; N is the total number of trees considered. If $I_c \leqslant 1.5$, the stand is considered healthy; 1.6-2.5 – weakened; 2.4-3.5 – severely weakened; 3.6-4.5 – drying out; ⩾4.6 – dried up.

The Kraft class index was calculated using formula (2):

$$I_K = \sum_{J=1}^{N} K_j \cdot n_j / \sum_{j=1}^{N} n_j, \quad (2)$$

where $I_к$ is the Kraft class index; $K_1 \ldots K_5$ are the Kraft class categories; $n_1 \ldots n_2$ are the number of trees in each category; N is the total number of trees considered.

To assess defoliation, the atlas of the loss of the assimilation apparatus in forest trees (Borecki & Keczynski, 1992) was used. Based on the defoliation of trees, the average value of the feature was determined for the tree species and stand, and the stand was classified according to damage to one of four degrees: undamaged (0) – defoliation ⩽10%; slightly damaged (1) – 11-25%; moderately damaged (2) – 26-60%; severely damaged (3) – 61-90%; dead (4) – 91-100%.

To determine the stability of the beech forest stand, the stability coefficients (ratio of crown length to tree height) and slenderness (ratio of tree height to its diameter) were also determined (Cherniavskyi, 2006). Additionally, a transect measuring 10×100 m was laid out in situ in the middle of the PSP (along the slope), within which trees were assessed according to the IUFRO (International Union of Forest Research Organizations) classes.

When calculating the Cox clumping index, the transect was first divided into subplots of a fixed size (10×10 m). The index was determined by the formula (3) as the ratio of the variance of the number of trees in the subplots to the average number of trees (Kaganjak & Rehush, 2014):

$$I_c = \frac{\delta^2}{n}, \quad (3)$$

where I_c is the Cox index; δ^2 is the variance; n is the average number of trees per subplot, pcs. The Cox index can take the following values: $I_c < 1.0$ indicates a uniform distribution of trees; $I_c > 10$ indicates a clumped distribution of trees; $I_c \approx 1.0$ is characteristic of a random distribution of trees.

The accounting of self-seeding and undergrowth was carried out within the transect. For this purpose, 20 plots of 2×2 m were laid out, evenly spaced from each other (2 within a square of 10×10). Within the plots, natural regeneration was assessed by species, height groups, age, and condition. Age was determined by the number of increments (whorls) in the individual, and condition by the presence of damage. Individuals without signs of damage and with good annual increments were classified as healthy; those with slight annual increments (<5 mm), occasional dry branches, minor mechanical damage to the trunk (bark damage less than 1/4 of the trunk perimeter), and the presence of galls were classified as slightly weakened; individuals with 1/3 of the tree dried (broken) were classified as moderately weakened; those with up to 3/4 of the tree dried (broken), and a trunk tilt greater more than 45° were classified as severely weakened.

The description of the herb cover was carried out by species, assessing the abundance of the species according to the H.M. Vysotsky scale (Methodical recommendations..., 2011). The study was conducted in accordance with the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973). As for deadwood, it was counted during the general inventory of trees on the PSP, classifying it as

standing deadwood or damaged, and assessing it according to the five stages of decomposition (Commarmot *et al.*, 2013). Additionally, within the transect, wood residues or branches with a diameter of ⩾7 cm that were not included in the previous inventory were counted

Results and Discussion

On the territory of the NNP "Zacharovanyi Krai", 300.5 hectares of beech primaeval forests have been identified (Order of the Ministry of Ecology and Natural Resources of Ukraine No. 161, 2018).

The predominant forest type for the growth of primaeval forests is moist pure beech forest (D_3-B) – 264.9 ha (D – trophotope, characterising the most fertile soils (habitat conditions); 3 – hygrotope, characterising moist soils; B – beech forest, the predominant (indigenous) species for these habitat conditions) and fresh pure beech forest (D_2-B) – 35.6 ha (2 – hygrotope, characterising fresh soils).

The PSP is located in the predominant forest type (D_3-B), which makes it possible to monitor the dynamics of development of the beech primaeval forests growing in these conditions. A more detailed silvicultural-taxation characteristic of the beech forest stand (primaeval forest), where the PSP is located, is given in Table 1.

Table 1. Silvicultural-taxation characteristics of beech forest stand (primaeval forest) based on forest management materials (2011, 2021 years)

Forestry	Sq./ Species	Area, ha	Stand composition	Age, years	H_{avg}, m	D_{avg}, cm	Yield class	Forest type	Density	Stock, $m^3 \cdot ha^{-1}$	Exposure	HASL, m
Pidhirnianske	2011											
	1/3	28.3	7Fa.sy.(210)3Fa.sy.(100)	210 100	35 28	56 32	1	D_3-B	0.55	360	N, 25°	800
	2021											
	1/3	28.3	7Fa.sy.(221)3Fa.sy.(111)+Fa.sy.40	221 111 40	35 22	52 24	1	D_3-B	0.65	430	N, 25°	800

Note: Fa.sy. – European beech; stand composition – the proportion of the species (genus) in the total stock expressed in tenths of a unit; HASL – height above sea level; $H_{avg.}$ – the average height of the stand; $D_{avg.}$ – the average diameter of the stand

Source: developed by the authors

It is worth noting that over a 10-year period, the stand stock per hectare has increased significantly (by 19%): apparently, the data from the 2013 studies were taken into account by the taxator (Table 2). According to the results of the 2013 studies (Table 2), it was found that the beech stand on the PSP is pure in composition and complex form: the middle and lower layers are pronounced. At the same time, the share of stem wood of trees growing in the first layer is dominant, accounting for 92.7% (404 $m^3 \cdot ha^{-1}$).

Table 2. Silvicultural-taxation characteristics of beech primaeval forest on the PSP, 2013

Stand composition	Distribution by levels	Species	N, pcs·ha^{-1}	H_{avg}, m	D_{avg}, cm	G, m^2·ha^{-1}	M, m^3·ha^{-1}
10 Fa.sy.+Ac. ps.	First	Fa.sy.	124	35.1	52.5	26.85	401
	Second	Fa.sy.	57	21.5	22.6	2.28	23
	Third	Fa.sy.	267	9.7	10	2.11	9
	First	Ac.ps.	1	37.5	52.0	0.21	3
Total living			449			31.45	436
Dead lying		Fa.sy.	15		42.5	2.13	27
Dead standing		Fa.sy.	25		44.2	3.84	49
Total dead			40			5.97	76

Note: Fa.sy. – European beech, Ac.ps. – sycamore, N – number of trees per 1 hectare; $H_{avg.}$ – the average height of the stand; $D_{avg.}$ – the average diameter of the stand; G – absolute density expressed in square meters per 1 hectare; M – wood stock expressed in cubic meters per 1 hectare

Source: developed by the authors

As a result of repeated surveys in 2023 at the PSP, it was found that the total number of trees and the sum of cross-sectional areas decreased by 6 and 3%, respectively (Table 3). At the same time, the stock increased by 10%, which is apparently explained by an increase in the average height of the first layer stand: heights were measured in different trees. It is also worth noting that in a complex beech stand, not all tree tops are well visible, which complicates the process of measuring heights in the same trees.

Table 3. Silvicultural-taxation characteristics of beech primaeval forest on the PSP, 2023

Stand composition	Distribution by levels	N, pcs·ha^{-1}		H_{avg}, m	D_{avg}, cm	G, m^2·ha^{-1}	M, m^3·ha^{-1}	P (relative)	Class of heights
		total	Fa.sy.						
10 Fa.sy.+Ac.ps.	First	137	136	37.7	48.0	27.3	454.6	0.61	1a (c)
	Second	79	79	18.8	18.0	2.1	18.7	0.06	2
	Third	207	207	9.8	8.0	1.2	6.9	0.05	2
The entire stand		423	422	-	-	30.6	480.2	0.72	-
100 largest trees		*99*	*98*	*37.8*	*54.0*	*24.4*	*408.4*	*0.55*	*1a*
Standing dead trees (natural mortality)		*5*	*5*	*7.0*	*10.0*	*0.1*	*0.3*	*0.00*	*5a*
Standing dead parts of the stem with lying parts of crowns (natural mortality)		*7*	*7*	*33.0*	*62.0*	*2.3*	*34.0*	*0.05*	*2*
Dead parts of stems (assortments) and dead lying parts of trees (assortments)		-	-	-	-	-	*8.98*	-	-

Note: Fa.sy. – European beech, Ac.ps. – sycamore; N – number of trees per 1 hectare; $H_{avg.}$ – the average height of the stand; $D_{avg.}$ – the average diameter of the stand; G – absolute density expressed in square meters per 1 hectare; M – wood stock expressed in cubic meters per 1 hectare; P – relative density; 1a (c), 2, 5a – indicators characterising stands by height and diameter

Source: developed by the authors

The share of stem wood of trees growing in the first layer has not changed significantly compared to 2013 and is 95% (454.6 $m^3 \cdot ha^{-1}$). 90% of the stock of the main layer (408.4 $m^3 \cdot ha^{-1}$) is the stock of the *100 largest trees*. At the same time, the trees of the first layer belong to the 1a height class. The share of stem wood of trees of the second and third layers is insignificant (5%), and the trees belong to the 2nd height class, which is evident: they grow under the canopy of the main layer.

On the PSP, the largest number of trees was counted in the lowest thickness steps of the third layer (Fig. 1, Table 3). At the same time, according to their technical suitability, the trees belong to the firewood category. There are commercial trees in the second layer, but their share is insignificant (Table 3). It is worth noting that trees with a diameter of ⩾22 cm were classified as commercial (taking into account the presence of assortments of the quality class D, in the diameter group 20-24 cm, for the beech species). The largest number of commercial trees was counted in the first layer, which is 89% of the total number of trees in the layer. At the same time, the stock of commercial trees on the PSP is 317 $m^3 \cdot ha^{-1}$, or 66% of the total volume of stem wood of trees on the PSP. Moreover, the share of commercial wood of the first layer complies with standards. As for the share of commercial wood in the second layer: it is significantly smaller, which is characteristic of the corresponding stands. This is explained by the following: trees with a diameter of ⩾22 cm were classified as commercial, while trees with a diameter of ⩾6 cm were considered for the inventory.

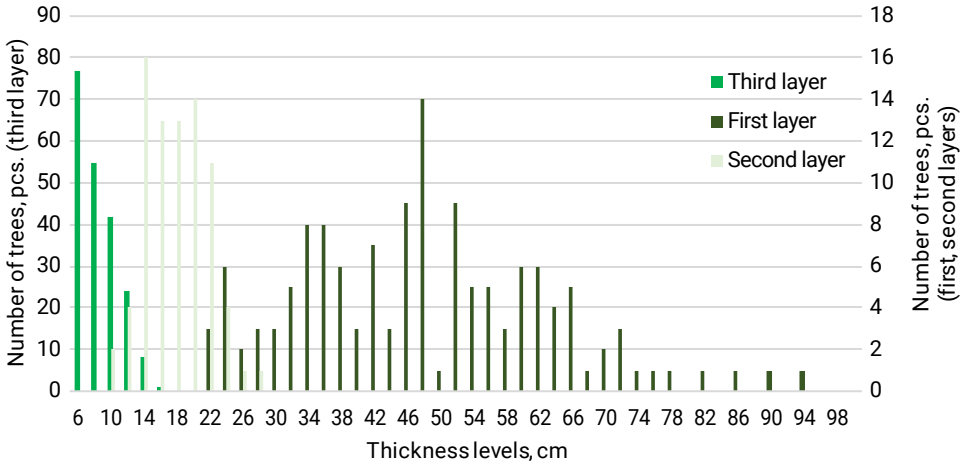

Figure 1. Distribution of the number of trees within the layers

Source: developed by the authors

Regarding deadwood: on the permanent sample plot, the volume of natural losses amounts to 34.3 $m^3 \cdot ha^{-1}$. At the same time, the site is dominated by *standing deadwood or damaged (to the point of growth cessation) stem parts with lying crown parts*, the volume of which is 34 $m^3 \cdot ha^{-1}$ (Table 4). These are mainly trees that have reached the age of physiological maturity and have been damaged by abiotic and biotic factors (windbreak, tinder fungus, etc.). They are characterised by stages 1-4 of deadwood decomposition. The volume of dead

stem parts and dead lying parts of trees that are not included in the above list is 9 $m^3 \cdot ha^{-1}$. They are mainly characterised by stages 3-5 of decomposition.

According to the degree of degradation of the photosynthetic apparatus, the beech stand on the PSP belongs to the "slightly damaged" stage (Table 4). At the same time, the loss of leaf mass in the trees of the main layer is somewhat higher than in the trees of the subordinate layer, which is obvious, based on the physiological condition (age) of the stand.

Table 4. Indicators of beech stand condition on a permanent sample plot, 2023

Distribution by layers	Distribution of trees by category of technical suitability				Defoliation index	Kraft class index	Sanitary condition index	Resilience	Slenderness
	commercial, pcs/%	semi-commercial, pcs/%	firewood, pcs/%	standing deadwood, pcs/%					
First	89 61.8	29 20.1	19 13.2	7 4.9	22.6	2.6	1.8	0.57	0.79
Second	1 1.3	13 16.3	65 81.3	1 1.3	14.4	-	2.0	0.67	1.04
Third	-	-	207 98.1	4 1.9	16.5	-	2.1	0.65	1.24
Total	90	42	291	12	-	-	-	0.60	0.97

Source: developed by the authors

The distribution of trees by Kraft classes was carried out for the trees of the first layer. It was found that the Kraft class index is 2.6. The share of trees assigned to the II Kraft class is predominant and comprises 38.0%. The share of trees assigned to the III and IV Kraft classes is smaller and comprises 23.4 and 25.6%, respectively. At the same time, the share of trees assigned to IV^a and IV^b comprised 11.7 and 13.9%, respectively. The smallest share is that of trees assigned to the I Kraft class – 12.4%. The absence of trees assigned to the 5^{th} Kraft class (0.7% of trees are assigned to V^a) is explained by the fact that the stand is complex: the remaining trees on the PSP form underlying layers.

According to sanitary conditions, the beech stand is weakened: the sanitary condition index fluctuates within 1.8-2.1, depending on the layer (Table 4). The most damage is observed in the first layer (Table 5). At the same time, the most common damages are cracks – 13.2% (frost cracks – 6.3%), mechanical damage (7.6%) and side-dryness (6.9%). In the second layer, the predominant type is mechanical damage (3.8%). For the third layer, stem (7.1%), windthrow (5.7%) and canker (4.7%). It is worth noting that canker is found only on trees of the third tier. After calculating the stability coefficients, it has been established that the beech primaeval forest on the PSP is resistant to environmental factors: the crown length is 0.57 for trees of the first layer and 0.67 and 0.65 for trees of the second and third layers, respectively (Table 5, Fig. 2).

Table 5. Distribution of trees by type of damage on the PSP, 2023

Distribution by layers	Share of trees by type of damage (%)													
	cracks (including frost cracks)	mechanical damage	side-dryness	ribbed root	hollows	fibre tilt	stem tilt	tinder fungus	growths	windthrow (breakage of top, stem)	stem curvature	cankers	other damages	total
First	13.2	7.6	6.9	5.6	4.2	4.2	4.2	4.2	4.2	3.5	2.8		8.2	68.8
Second		3.75	2.5				2.5			1.25	1.25		2.5	13.75
Third		3.3	1.9		0.5		7.1			5.7	0.9	4.7	1.5	25.6

Source: developed by the authors

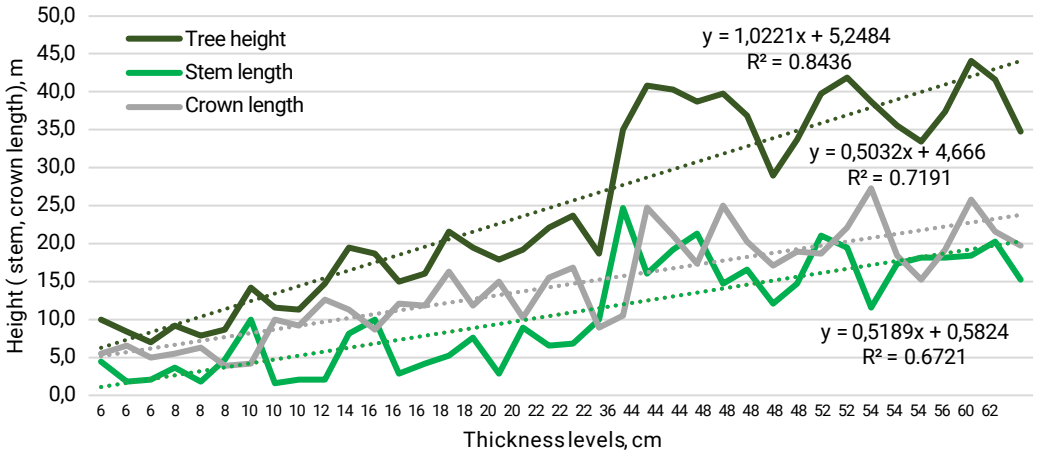

Figure 2. Tree heights, lengths of stems and crowns within layers on the PSP

Source: developed by the authors

The slenderness coefficient for the first layer is optimal (0.79), for the second layer – limiting (1.04), and for the third – minimal (1.24). The corresponding coefficients confirm that the stand is developing naturally (Cherniavskyi *et al.*, 2006). It is also worth noting that there is a strong correlation between tree diameter and height, and significant correlations between diameter and crown and stem lengths (Fig. 2).

A more detailed study of the beech primaeval forest was conducted on a PSP transect (Table 6). The silvicultural-taxation indicators of the stand on the transect reflect (proportionally) the corresponding indicators of the stand on the PSP, but are slightly lower. Specifically, along the transect, 35 trees were recorded, which constitutes 8.3% of the total number of trees on the PSP; the stock volume

is 26.5 $m^3 \cdot ha^{-1}$, accounting for 5.5% of the stock on the PSP. Moreover, the distribution of trees along the transect is uniform.

Regarding the comprehensive stability of the beech stand (IUFRO classes): along the transect, there are predominantly middle-layer trees that are well-developed (with good vitality), of average increment (mostly co-dominant), valuable, with good stems and long crowns (Table 7).

Table 6. Silvicultural-taxation characteristics of beech primaeval forest on the transect, type of tree placement

Stand composition	Distribution by levels	N, pcs·ha^{-1}	H_{avg}, m	D_{avg}, cm	G, $m^2 \cdot ha^{-1}$	M, $m^3 \cdot ha^{-1}$	Cox index	Type of tree placement
10Fa.sy.	First	7	37.7	50.0	1.4	23.9	0.65	uniform
	Second	8	18.8	18.0	0.2	2.0		
	Third	20	9.8	8.0	0.1	0.6		
The total stand		35	-	-	1.7	26.5		

Note: Fa.sy. –European beech; N – number of trees per 1 hectare; $H_{avg.}$ – the average height of the stand; $D_{avg.}$ – the average diameter of the stand; G – absolute density expressed in square meters per 1 hectare; M – wood stock expressed in cubic meters per 1 hectare

Source: developed by the authors

Table 7. Distribution of beech trees by IUFRO classes along the transect

Layer	Vitality	Position	Silvicultural value	Merchantability	Crown length
2.3	1.8	2.4	4.7	5.5	4.3

Source: developed by the authors

After counting the undergrowth, it was found that beech undergrowth is mainly found under the canopy of the mother stand, which is poorly differentiated by age groups: it belongs to the 7-year-old group and older (88.0%). The undergrowth is well differentiated by height groups: its largest number is in the 26-50 cm height group – 33.7% and the lowest is in the height group up to 25 cm – 4.8% (Table 8). In other height groups, the number of undergrowth ranges from 10.8 to 21.7%. The share of sycamore (*Acer pseudoplatanus* L.) undergrowth is insignificant and is 11.0%.

Regarding the condition of the undergrowth, the proportion of individuals categorised as healthy and insignificantly weakened predominates, comprising 44.6% and 45.8% respectively. The shares of individuals categorised as moderately and severely weakened are insignificant, each accounting for 4.8%.

Table 8. Distribution of the number of undergrowth within the transect

Species	Number of undergrowth by age and height groups (cm), pcs.·ha^{-1}/%										
	1-year-old	2-3 y.o	4-7 y.o.	over 7 y.o.	Total	⩽25	26-50	51-100	101-150	151-250	⩾250	Total
Fa.sy.				9,125 88.0	**9,125** **88.0**	250 2.4	2,750 26.5	1,625 15.7	1,250 12.1	2,250 21.7	1,000 9.6	**9,125** **88.0**
Ac.ps.	125 1.2			1,000 9.6	**1,125** **10.8**	250 2.4	750 7.2				125 1.2	**1,125** **10.8**
Co.av.				125 1.2	**125** **1.2**			125 1.2				**125** **1.2**
Total	125 1.2			10,250 98.8	**10,375** **100.0**	500 4.8	3,500 33.7	1,750 16.9	1,250 12.1	2,250 21.7	1,125 10.8	**10,375** **100.0**

Note: Fa.sy. – European beech; Ac.ps. – sycamore; Co.av. – common hazel

Source: developed by the authors

In addition to the above species, spruce (*Picea abies* L.) undergrowth is also found within the PSP. His species appeared in the area due to the arrival of seeds from an adjacent area where a derivative spruce plantation is growing. The undergrowth on the PSP is almost absent: *Sorbus aucuparia* L. and *Corylus avellana* L. are occasionally found. The herbaceous cover is typical for the corresponding forest stand: *Galium odoratum* (L.) Scop. – 2, *Rubus hirtus* Waldst. et Kit. – 1, *Gymnocarpium dryopteris* L.) Newm. – p, *Athyrium filix-femina* (L.) Roth – p, *Dryopteris filix-mas* (L.) Schott – p, *Dentaria glandulosa* Waldst.et Kit. – n, *Oxalis acetosella* L. – u. In the place where surface water comes to the surface, the herbaceous cover is more diverse (about 0.05 ha), in addition to the above species, there are: *Impatiens noli-tangere* L. – 3, *Urtica dioica* L. – 2, *Symphytum cordatum* Waldst. et Kit. ex Willd. – p, *Chrysosplenium alternifolium* L. – p, *Lamium maculatum* L. – n, *Myosotis sylvatica* Ehrh. ex Hoffm. – u. Summer aspect: 15.06-17.08. *Fagetum asperulosum*. The area features an outcrop of rocky formations on the surface. Type of growing conditions: D^{4C}_{3} (wet fairly fertile forest site conditions subtype of the moist fairly site condition).

The study of primaeval forests in the Ukrainian Carpathians, particularly in Zakarpattia, began in the 1930s by the Czech researcher A. Zlatnik in 1938 (Stoyko, 2013). The further history of primaeval forest research within the Ukrainian Carpathians is covered in the studies of U. Brändli & J. Dowhanytsch (2003), F. Hamor & P. Veen (2008). According to forest management zoning ning (Holubets, 2003), the research on the PSP concerns the Volcanic Carpathians (Vyhorlat-Hutyn ridge) and intermountain depressions. The vast majority of research on beech primaeval forests in the Ukrainian Carpathians relates to the Mountain Carpathian forestry district. Thus, P.M. Ustymenko & D.V. Dubyna (2014) established that about 3,000.0 hectares of beech forests on the territory of the Synevyr National Nature Park have the characteristics of primaeval forests. The researchers conducted geobotanical descriptions on the corresponding sites. The research of M.V. Sayats (2009) is dedicated to the beech primaeval forests of the Uzhansky National Natural Park, whose territory is an integral part of the "Eastern Carpathians" international biosphere reserve. It is worth noting that virgin forests are preserved in the

Uzhanskyi National Nature Park, and reserves of beech and beech-spruce forests were created in 1908-1913 (Stoyko, 2018). Repeated studies by Z. Hruby (1997) of the cenotic and age structure of this primaeval forest, on the experimental plots of A. Zlatnik showed that the stock has not changed significantly (Sayats, 2009).

More long-term studies by Yu. Shparyk *et al.* (2018), and V. Trotsiuk *et al*. (2012), which cover the issues of the state and structure of beech primaeval forests, were conducted on the territory of the Carpathian Biosphere Reserve. The authors considered how the diversity of climatic conditions, soil types and relief influence the formation and development of these unique ecosystems. Studying these influences helps to better understand the processes taking place in beech primaeval forests and contributes to their effective management and preservation.

The authors of this study note that even though the above studies were conducted in different institutions and forestry (forest-growing) districts, they were carried out in homogeneous growing conditions (forest type D_3-B) and in the alti altitude range, which is optimal for the growth of beech forests. The stands are homogeneous in terms of the composition of the stand, however, there is a difference in the wood stock: in the Carpathian Biosphere Reserve, the stock is higher, which is evidently due to the greater participation of species in the stand composition and the phase (interval of beech tree diameters on the permanent sample plot) of the beech primaeval forest's development (Yanovska, 2015). In particular, the first layer stand belongs to the overmature (post-senile) age group. In the NNP, the interval of diameters of beech trees on the site is smaller, and the stands are also characterised by different phases of development (age groups by diameters): the stand of the first layer belongs to the mature age group (senile), the second layer to the middle-aged group, and the third layer to the pole (virginal) group.

An important structural feature of primaeval forests is also that the first layer of the primaeval forest is the main biogeocenotic horizon, which holds the majority of the forest's wood stock: in the NNP, the corresponding share was 92.7% in 2013 and 95% in 2023. On the PSP in the Carpathian Biosphere Reserve, the corresponding share is identical (about 93%).

The hypothesis that the primaeval forest is a stable ecological system is confirmed by the stability and slenderness coefficients of the stand. At the same time, the prevailing types of damage on the site are cracks, mechanical damage, and side dryness – damage caused mainly by abiotic factors. However, their share is not significant, which is reflected in the commercial structure of the stand: in the first layer, the share of commercial trees is 89% or 66% of the total volume of stem wood of trees on the PSP.

The resilience of this ecosystem to the influence of abiotic factors is confirmed by research on the territory of the Carpathian Biosphere Reserve. Thus, according to Yu.S. Shparyk *et al.* (2018), a windfall in 2007, from which more than 25% of trees were lost in individual thickness steps, did not destroy the primaeval forest – within three years after the disaster, the fullness of the stand was restored, and the decrease in wood stock did not exceed 10%. M.V. Kabal *et al.* (2021) note that at the research station, where more than 80% of the trees were felled by a catastrophic storm after 12 years sufficient natural renewal and the formation of a young forest were found – which indicates a tendency to recover. As a result of the functioning of the ecosystem, it is characterised by different stages of development, including decay: on the plot, were recorded about 43 $m^3 \cdot ha^{-1}$ of deadwood, characterised by five stages of decomposition. *Dry standing or damaged (to the point of stopping growth) parts of the stems with lying parts of the crown* (34 $m^3 \cdot ha^{-1}$) predominate. Long-

term studies have established that the amount of dead wood can vary significantly, depending on natural factors, including the aforementioned windfalls.

An important component of the primaeval forest is also its "potential" (undergrowth) – a sufficient number of tree species that can potentially fully replace the maternal stand. During the study, 10,375 pcs·ha^{-1} of undergrowth were recorded, of which beech accounts for 88.0% (Table 7). Beech undergrowth is weakly differentiated by age groups: only in the group of 7-year-olds and older was recorded and well-differentiated by height groups. The absence of undergrowth in younger age groups is explained by the biology of the tree species: fruiting intervals (average yields are observed every 1(4)-6 years) and canopy closure (due to insufficient light, a significant amount of self-seeding dies in the first year of life). However, this amount of undergrowth is optimal for these conditions and the natural development of the ecosystem (phase of development). According to Yu.S. Shparyk & I.M. Yanovska (2017), about 26,000 pcs·ha^{-1} of undergrowth were recorded in a monodominant beech primaeval forest under the conditions of a moist pure beech forest. The larger amount of undergrowth is explained, obviously, by the age of the maternal stand (belongs to the post-senile age group) and the participation of other species in the composition of the maternal stand. In particular, the researchers recorded a significant number of other species in the undergrowth. V. Lavnyy *et al.* (2021) note that natural regeneration of tree species is well formed in the "gaps" of the forest canopy in beech primaeval forests. At the same time, its quantity increases with the increasing size of the gaps in the canopy.

Under the canopy of the monodominant beech primaeval forest, the herbaceous cover is typical for nemoral forests. Moreover, the same vegetation is also found at the research station in the Carpathian Biosphere Reserve.

Conclusions

The state, structure, and dynamics of development of a beech primaeval forest in the conditions of a moist pure beech forest were studied. It was established that the stand of the first layer belongs to the mature age group (senile), the second layer to the middle-aged group, and the third to the pole stage (virginal). It was determined that 95% o of the primaeval forest's stock is from the first layer, while the share of commercial trees of the first layer is 89% (66% of the total volume of stem wood of trees on the PSP). The main types of damage on the site are damage caused by abiotic factors. As a result of the corresponding damage, about 43 m^3·ha^{-1} of deadwood was recorded, which has all 5 stages of decomposition.

Under the canopy of the maternal stand, 10,375 pcs·ha^{-1} of undergrowth were recorded, of which beech accounts for 88.0%. Beech undergrowth is weakly differentiated by age groups: only in the group of 7-year-olds and older was recorded and well-differentiated by height groups. By age group, the undergrowth belongs to the juvenile-immature age state.

The beech primaeval forest in the corresponding growing conditions develops naturally, under the influence of only natural forces and phenomena, without significant human intervention, and its species, age, and spatial structure are determined by environmental factors.

Further research on the state and structure of beech primaeval forests may include a more detailed study of the dynamics of changes in the composition and functioning of the ecosystem over time, as well as an analysis of the impact of various factors, including anthropogenic and climatic, on its stability and self-renewal ability. Additional research may also focus on assessing the vulnerability of these ecosystems

to environmental changes and developing adaptation strategies to the future challenges they face. Furthermore, it is possible to conduct research aimed at understanding the relationships between beech primaeval forests and other types of ecosystems in the park in order to ensure a comprehensive approach to their conservation and management.

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Conflict of Interest

None.

References

[1] Borecki, T., & Keczynski, A. (1992). *Atlas of the loss of the assimilation apparatus in forest trees*. Warszawa: Agencia Reklamowa ATUT.

[2] Brändli, U.-B., Dowhanytsch, J., & Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft (Eds.). (2003). *Urwälder im Zentrum Europas. Ein Naturführer durch das Karpaten-Biosphärenreservat in der Ukraine*. Bern: Haupt.

[3] Cherniavskyi, M.V., *et al.* (2006). *Close-to-nature forestry in the Ukrainian Carpathians*. Lviv: Piramida.

[4] Commarmot, B., Brändli, U.-B., Hamor, F., & Lavnyy, V. (Eds.). (2013). *Inventory of the largest primeval beech forest in Europe*. Rakhiv: Carpathian Biosphere Reserve.

[5] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[6] Convention on the Trade in Endangered Species of Wild Fauna and Flora. (1973, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_129#Text.

[7] Dudka, O.I., & Kryvomaz, T.I. (2013). Myxomycetes in the virgin beech and old-aged spruce forests of National Nature Park "Zacharovany Kraj" (Ukrainian Carpathians). *Studia Biologica*, 7(2), 107-118. doi: 10.30970/sbi.0702.286.

[8] Grom, M.M. (2007). *Forest assessment*. Lviv: NFU.

[9] Hamor, F. (2023). *Ecodiamonds of Europe. History of beech Primeval Forests Nomination to the UNESCO World Heritage List*. Lviv: Prostir-M.

[10] Hamor, F., & Veen, P. (Eds.). (2008). *Virgin forests of Transcarpathia. Inventory and management*. Rakhiv: Carpathian Biosphere Reserve.

[11] Holubets, M. (2003). Geobotanical division of the Ukrainian Carpathians – a basis of rational natural use. *Proceedings of the Shevchenko Scientific Society*. *Ecological Collection: Ecological Problems of the Carpathian Region*, 7, 283-292.

[12] Kabal, M.V., Gleb, R.Yu., Sukharyuk, D.D., Polyanchuk, I.Y., & Anger, R.Ya. (2021). Windfall successions in primeval beech forests of the Uholka-Shyrokyi Luh massif of the Carpathian Biosphere Reserve. *Nature of the Carpathians: Annual Scientific Journal of CBR and the Institute of Ecology of the Carpathians NAS of Ukraine*, 1(6), 27-33.

[13] Kaganjak, Ju., & Rehush, N. (2014). Spatial stand structure of beech forests in Transkarpathia. *Proceedings of the Forestry Academy of Sciences of Ukraine*, 12, 135-139.

[14] Lavnyy, V., Mazepa, V., Shyshkanynets, I., & Zayats, M. (2021). Peculiarities of natural regeneration in beech stands of the Ukrainian Carpathians. *Proceedings of the Forestry Academy of Sciences of Ukraine*, 22, 41-51. doi: 10.15421/412103.

[15] *Methodical recommendations on forest monitoring of Ukraine of the I level*. (2011). Kharkiv: UkrNDILHA.

[16] Order of the Ministry of Ecology and Natural Resources of Ukraine No. 161 "On Approval of the Methodology for Determining the Belonging of Forest Areas to Virgin, Quasi-Virgin and Natural Forests". (2018, May). Retrieved from https://zakon.rada.gov.ua/laws/show/z0707-18#Text.

[17] Parpan, V.I., Chernyavskyy, M.V., & Parpan, T.V. (2017). virgin forests and natural forests and their definitions. *Scientific Bulletin of UNFU*, 27(6), 11-15. doi: 10.15421/40270601.

[18] Sanitary Forests Regulations in Ukraine. (2016, October). Retrieved from https://zakon.rada.gov.ua/laws/show/555-95-%D0%BF#Text.

[19] Sayats, M.V. (2009). Virgin beech forests of Uzhansky national nature park and their protection. *Scientific Bulletin of UNFU*, 19.12, 66-73.

[20] Shparyk, Y., Losyuk, V., & Plyha, A. (2021). The state and structure of virgin forests in the Ukrainian Carpathians according to the monitoring. *Proceedings of the Forestry Academy of Sciences of Ukraine*, 22, 77-88. doi:10.15421/412106.

[21] Shparyk, Yu.S., Viter, R.M., & Shparyk, V.Yu. (2018). Influence of natural factors on the dynamics of the beech (Fagus sylvatica L.) virgin forest of the Ukrainian Carpathians. *Scientific Bulletin of UNFU*, 28(7), 13-16. doi:10.15421/40280702.

[22] Shparyk, Yu.S., & Yanovska, I.M. (2017). Natural regeneration of beech (*Fagus Sylvatica* L.) virgin forests in wet mehatrophic soil conditions. *Scientific Bulletin of UNFU*, 27(4), 21-24. doi:10.15421/40270403.

[23] Shyshkanynets, I.F., Cherniavskyi, M.V., Fennich, V.S., & Lutak, V.V. (2019). Primary and old-grown forests of Zacharovany Kraj National Nature Park protected as UNESCO world nature heritage. In *State and prospects of in modern conditions: Materials of IV- of the all Ukrainian research and practice conference* (pp. 119-123). Uzhhorod: UzhNU.

[24] Shyshkanynets, I.F., Felbaba-Klushina, L.M., Potish, L.A., & Chernyavskyi M.V. (2023). Justification for expanding of Zacharovanyi Krai National Nature Park area. *Nature of the Carpathians: Annual Scientific Journal of CBR and the Institute of Ecology of the Carpathians NAS of Ukraine,* 1(8), 91-106.

[25] Smaliychuk, A. & Gräbener, U. (Eds.). (2018). *Natural forests of Ukrainian Carpathians*. Lviv: Carty i Atlasy.

[26] Smaliychuk, A. (2019). Old-growth and virgin forests of Ukrainian Carpathians: Geospatial pattern and prospects of conservation. *Visnyk of the Lviv University. Series Geography*, 53, 301-314. doi: 10.30970/vgg.2019.53.10680.

[27] Stoyko, S. (2013). Beech primeval forests of the Carpathians as the object of World Heritage List. *Proceedings of the Forestry Academy of Sciences of Ukraine*, 11, 17-24.

[28] Stoyko, S. (2018). Ecology, coenotic heterogeneity of the forest beech formation in Ukraine and the protection of pristine ecosystems. *Proceedings of the Forestry Academy of Sciences of Ukraine*, 17, 149-157. doi:10.15421/411830.

[29] Trotsiuk, V., Hobi, M.L., & Commarmot, B. (2012). Age structure and disturbance dynamics of the relic virgin beech forest Uholka (Ukrainian Carpathians). *Forest Ecology and Management*, 265, 181-190. doi: 10.1016/j.foreco.2011.10.042.

[30] Ustymenko, P.M., & Dubyna, D.V. (2014). Primeval beech forests in the territory of the National Nature Park "Synevir": Forest science and sozological aspect. *Forestry & Forest Melioration,* 125, 79-86.

[31] Yanovska, I.M. (2015). Some stages of development of virgin beech forests and their dynamics. *Scientific Bulletin of UNFU*, 25(8), 82-87. doi: 10.15421/40250813.

Стан і структура букових пралісів у національному природному парку «Зачарований край»

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Анотація. Актуальність дослідження визначається необхідністю збереження природних цінностей, які вважаються надбанням усього людства, – пралісів і старовікових букових лісів Всесвітньої природної спадщини ЮНЕСКО. Метою роботи було дослідити стан та структуру букового пралісу національного природного парку «Зачарований край». Для дослідження закладено постійну пробну площу розміром 1 га (100×100 м) в переважаючому типі лісу – вологій чистій бучині. Дана ділянка розташована в оптимальних для бука лісового (*Fagus sylvatica* L.) лісорослинних умовах, у межах Вигорлат-Гутинської вулканічної гряди Українських Карпат. Встановлено, що буковий лісостан на ділянці є чистим за складом та складним за формою, якому притаманні різні фази розвитку (вікові групи за діаметрами): деревостан першого ярусу належить до стиглої вікової групи (сенільної), другого ярусу – до середньовікової, а третього – до жердняку (віргінільної). Визначено, що 95 % запасу пралісу – це запас першого ярусу, при цьому частка ділових дерев першого ярусу становить 89 %

(66 % від загального об'єму стовбурної деревини дерев на постійній пробній площі). Основними видами пошкоджень на ділянці є пошкодження спричинені абіотичними чинниками. У результаті відповідних пошкоджень, обліковано 43м^3·га$^{-1}$ мертвої деревини, якій притаманні всі 5 стадій розкладу. Під наметом деревостану обліковано 10375 шт·га$^{-1}$ підросту, частка бука у складі якого становить 88 %. Підріст бука слабо диференційований за віковими групами: обліковано лише у групі 7-річного віку і старше та добре диференційований за висотними групами. За віковою групою підріст належить до ювенільно-іматурного вікового стану. Трав'яне вкриття є типовим для неморальних лісів. Наявність стаціонарних ділянок досліджень у національному природному парку «Зачарований край» дає можливість постійно відстежувати тенденції природного розвитку екосистеми – букового пралісу

Ключові слова: Українські Карпати; деревостан; підріст; мертва деревина; екосистема