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BIOMASS AND PRIMARY PRODUCTION OF EUROPEAN BEECH (*FAGUS SYLVATICA* L.) STANDS IN UKRAINIAN CARPATHIANS

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INTRODUCTION

Forests of Ukrainian Carpathians are among the important environment stabilizing factors in mountainous ecosystems of the region. They serve as a main mean for sustaining environmental stability. Forest plant communities of the studied region feature important climate regulative, water flow regulative, water protective, soil protective, sanitary and hygienic, and other ecosystem services[1,2]. The mentioned sphere of forestry-related research elaborates ideas of V.I. Vernadskyi and H.M. Vysotskyi. Well-known scientists have worked in this sphere, namely P.S. Pasternak[3], S.A. Hensiruk[4,5,6], S.M. Stoiko[7,8], V.S. Oliinyk[9], Ya.A. Saban[10], K.K. Smahliuk[11], I.F. Kalutskyi[12] and many others[13,14].

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V.I. Parpan[15] claims that research of biosphere functions of forests in the Carpathians shall rest upon the main principles of the modern paradigm of mountain silvics, silviculture, and sustainable forestry.

An integral part of the environmental component of mountain forestry should be a monitoring system capable of ensuring operational control over the state of the environment. This will make it possible to develop long-term forecasting models of changes in the state of forests, taking into account trends in their development and global climate change[16].

Carpathian forests as a type of vegetation, in particular European beech stands, play a major regional role in the accumulation of solar energy in the biotic energy cycle of the biosphere and in the processes of oxygen production and sequestration of carbon emitted from various sources. Due to their vertical structure and significant territorial distribution, the forest plant communities of the region have important buffering properties, i.e. they act as a kind of boundary strip between the atmosphere and the lithosphere. Therefore, they have a critical role among other types of vegetation in the transformation of precipitation, heat fluxes and the main geochemical cycles of natural ecosystems. Such properties determine the most active environment-forming and protective functions of forests and help maintain a stable natural balance both in forested areas and in neighboring landscapes[17].

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Currently, more than 260 million tons of carbon, or about a third of the amount for the whole Ukraine, have been accumulated in the forests of the Ukrainian Carpathians. At the same time, Carpathian forests have the highest density of sequestered carbon per unit area of forested plots compared to other regions[18]. The values of this index range from 11 to 40 kg $C \cdot (m^2)^{-1}$.

The share of forest cover in Ukrainian Carpathians is significantly higher than in other regions of the country (Fig. 1). Over 20 % of forest areas of Ukraine are covered with forest vegetation, and forests, which cover an area of 2085.6 thousand hectares, are the main factor in maintaining the ecological balance of the region and, among others, play an important hydrological role.

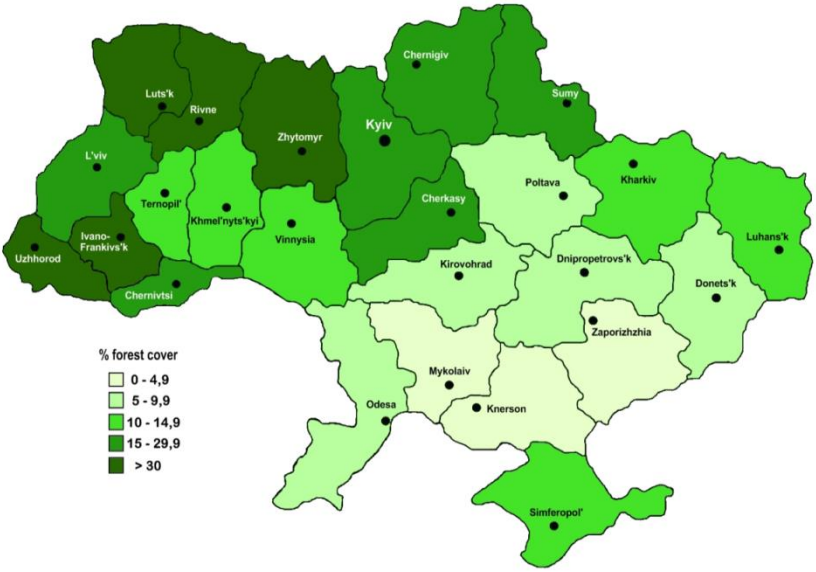

Fig. 1. Percent of cover in Ukraine by oblasts (administrative regions)[19]

This feature of forest plant communities is formed as a result of moisture regulation by the system "forest stand – soil" (water-regulative

[18] Василишин Р.Д. Ліси Українських Карпат: особливості росту, біологічна та енергетична продуктивність. Монографія. Київ : ТОВ «ЦП «Компринт», 2016. 418 с.

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properties). The positive consequences of this process result in an increase of groundwater resources (water protective role) and reduction of slope water flows, as well as a uniform return of moisture to the channel network (flow regulative role).

European beech stands in the region, which cover an area of almost 680 thou. hectares, are a key factor not only in the formation of biodiversity of forest ecosystems in Ukrainian Carpathians, but also perform important ecosystem functions, including energy accumulative, carbon sequestrative and oxygen productive. The evaluation of the mentioned functions is based on quantitative indices of biomass of studied stands, taking into account the intensity of bioproduction process on the basis of primary production.

1. Silvicultural and biometric characteristics of European beech stands in Ukrainian Carpathians

Silvicultural and biometric characteristics of European beech stands are presented on the basis of the industrial relational database "Stand level biometric characteristics of forests", which is operated by Industrial Association "Ukrderzhlisproekt". The database contains a detailed biometric characteristics of stands composed by dominant forest-forming tree species according to the current state forest account[20]. According to the mentioned information resource, the forests of Ukrainian Carpathians cover an area of over 2 million hectares with standing stock of about 580 million m^3 (Table 1).

Table 1

Distribution of area and growing stock of stands of the main forest-forming tree species in Ukrainian Carpathians

Tree species	Area, thou. ha	Growing stock, Mio m^3
Norway spruce	591,6	199,3
Silver fir	129,7	36,0
European beech	674,8	217,0
Other tree species	616,2	125,2
Total	2012,3	577,5

[20] Довідник лісового фонду України [укладений спеціалістами виробничо-технологічного відділу ВО «Укрдержліспроект» за матеріалами державного обліку лісів станом на 01.01.2011 р.]. Ірпінь: ВО «Укрдержліспроект», 2012. 130 с.

European beech (*Fagus sylvatica* L.) – one of the most widespread tree species in the flora of Ukrainian Carpathians. It forms pure and mixed (with oak, hornbeam, spruce, fir, and birch) stands in the altitude range from 300 to 1300 m above sea level. This is a shade-tolerant species that can be depressed during a long time, and therefore often in mixed forests, beech grows in the second layer under the canopy of dark conifers. European beech is common in the plains and mountains of the country. Mountain beech forests are a unique phenomenon. First of all, science considers them as an environmental and climate-regulating factor. Their destruction can lead to negative, even catastrophic, irreversible global changes.

Quantitative parameters of distribution of the mentioned tree species within the administrative regions in Ukrainian Carpathians is presented in Table 2.

Table 2

Distribution of quantitative characteristics of European beech stands by administrative regions

Administrative region	Number of stands	Area, thou. ha	Growing stock, Mio m^3
Zakarpattia	57361	387,3	129,1
Ivano-Frankivsk	23592	111,3	33,8
Lviv	22195	115,5	35,0
Chernivtsi	8499	60,6	19,1
Total	111647	674,8	217,0

Nearly 57 % of beech forests with a growing stock of 129.1 Mio m^3 are located in Zakarpattia region, another 30 % – in Ivano-Frankivsk and Lviv regions. In general, European beech stands in Ukrainian Carpathians cover 33.5 % of the forested area in the region.

Analysis of the site index class distribution of area covered by beech stands shows that in the Carpathians highly productive stands of I-I^a site index classes are the most widespread and occupy 71.4 % of the total area of beech forests. Almost 20 % of the area is covered by stands of II site index class, while the share of low-productive stands (site index IV and lower) does not exceed 1 %.

Regarding the relative stocking of European beech stands, it should be noted that medium-stocked stands are dominant. The share of stands with a relative stocking of 0.6 and 0.7 is 50.6 % of the area of beech forests in the Carpathian region, while highly-stocked (0.9 and higher) and low-stocked (0.4 and lower) account for 10.5 % and 3.2 % respectively. At the same time, the largest representation of highly-stocked European beech stands is in Zakarpattia region (6.8 %).

The age structure of the studied beech stands is shown in Table 3.

The data presented in Table 3 shows that the age structure is dominated by mid-aged stands, the share of which is 56 %. Almost 20 % are mature and overmature stands.

Table 3

Distribution of quantitative characteristics of beech stands by administrative regions and age classes (numerator – area, ha; denominator – growing stock, thou. m^3)

Age class	Administrative region				Total
	Zakarpattia	Ivano-Frankivsk	Lviv	Chernivtsi	
I	7162,0 123,7	1181,6 13,3	1674,2 26,1	1619,7 15,9	11637,5 179,0
II	15509,2 1042,2	2871,2 106,9	2747,0 108,2	2347,9 99,5	23475,3 1356,8
III	32901,4 5757,5	3052,3 494,9	3006,6 294,3	1253,2 125,9	40213,5 6672,6
IV	26413,2 6424,7	3206,9 798,6	3457,6 572,3	1587,9 276,2	34665,6 8071,8
V	25211,4 7100,8	6313,1 1674,4	6097,8 1354,1	3479,4 898,6	41101,7 11027,9
VI	51741,4 18043,2	17604,5 5221,2	13243,8 3829,2	5174,3 1586,9	87764,0 28680,5
VII	36061,6 13468,0	16851,4 5173,0	18747,1 5866,6	7009,4 2300,8	78669,5 26808,4
VIII	34030,1 13661,6	17043,0 5675,1	19707,1 6734,5	8820,0 3136,4	79600,2 29207,6
IX	24459,1 10160,3	12004,3 4142,4	13454,6 4564,7	9866,8 3669,6	59784,8 22537,0
X	21005,5 8799,8	9516,6 3285,2	9630,8 3361,6	6062,6 2236,1	46215,5 17682,7
XI	16879,2 6965,7	7179,7 2414,8	8794,8 3069,6	7019,2 2479,8	39872,9 14929,9
XII	10893,2 4420,3	4042,7 1351,4	5851,4 2076,4	3044,0 1069,5	23831,3 8917,6
XIII	7413,4 2880,7	3397,0 1153,8	3340,1 1175,9	1322,8 470,5	15473,3 5680,9
XIV and older	77659,9 30272,8	7013,0 2291,1	5767,1 2002,5	2005,8 726,3	92445,8 35292,7
Total	387340,6 129121,2	111277,3 33796,3	115520,0 35035,8	60613,0 19092,0	674750,9 217045,3

Forest typological structure has a significant influence on the efficiency of performance of ecological functions by European beech stands. European beech in the Carpathian region is widespread in fresh, moist and damp types of moisture conditions within fairly rich and rich forest growth conditions. European beech acts as forest-forming tree species in fairly rich and rich site types, where it occupies 40.4 and 59.5 % of the area covered with forest vegetation (Table 4).

Table 4

Distribution of area of European beech stands by administrative regions and types of forest growth conditions, ha

Administrative region / Site fertility types	Total	Including by moisture site types			
		fresh	moist	damp	wet
fairly infertile site types					
Zakarpattia	16,8	–	16,8	–	–
Ivano-Frankivsk	187,6	134,2	53,4	–	–
Lviv	119,0	22,5	95,3	–	1,2
Chernivtsi	97,1	63,5	33,6	–	–
fairly fertile site types					
Zakarpattia	153521,2	32277,6	121238,9	3,0	1,7
Ivano-Frankivsk	69802,8	4615,3	65104,5	83,0	–
Lviv	32686,9	4676,8	27997,0	13,1	–
Chernivtsi	16773,3	2968,1	13780,4	24,8	–
fertile site types					
Zakarpattia	233802,6	59800,0	173993,2	4,9	4,5
Ivano-Frankivsk	41286,9	8788,2	32489,6	9,1	–
Lviv	82714,1	25030,2	57679,8	4,1	–
Chernivtsi	43742,6	19879,8	23844,2	6,3	12,3
total within the region					
Fairly infertile site types	420,5	220,2	199,1	–	1,2
Fairly fertile site types	272784,2	44537,8	228120,8	123,9	1,7
Fertile site types	401546,2	113498,2	288006,8	24,4	16,8

At the same time, beech stands occupy the biggest area in moist (76.5 %) forest growth conditions. The share of other types of conditions (fresh, damp) is about 20 % of the total area of beech stands. The following forest types are the most widely represented in the region: fresh and moist fairly fertile oak-hornbeam-beech forests, moist fairly

fertile hornbeam-beech forests, fresh and moist fairly fertile hornbeam-pine-beech forests, fresh and moist fertile hornbeam-beech forests, fresh and moist fertile oak-hornbeam-beech forests, fresh and moist fertile fir-beech forests, moist fertile hornbeam-fir-beech forests. The most productive beech stands grow in the conditions of fresh fertile oak-hornbeam-beech forests and moist fertile fir-beech forests.

The mean age of beech stands in the Carpathians is 78 years, which is almost two age classes older than the corresponding values of spruce and fir stands (Table 5). However, in terms of mean growing stock of stands per 1 ha, they are slightly inferior to spruce stands.

The data in Table 5 shows that the studied stands within the administrative regions have close mean values of relative stocking, which varies in the range of 0.66-0.69. Insignificant variation of relative stocking testifies that the specified stands are formed under the influence of typical intensive forest management activities.

Table 5

Mean biometric indices of beech stands within administrative regions

Administrative region	Mean biometric indices				
	age, years	diameter, cm	height, m	relative stocking	growing stock, $m^3 \cdot ha^{-1}$
Zakarpattia	81	27,9	22,2	0,69	333
Ivano-Frankivsk	75	28,2	22,3	0,66	304
Lviv	73	30,1	23,3	0,66	303
Chernivtsi	76	29,2	23,1	0,69	315
Average for the region	78	28,5	22,5	0,68	322

In general, European beech in Ukrainian Carpathians forms pure and mixed stands of natural and artificial origin. These are mostly highly productive, medium-stocked stands, which often grow in moist, fairly fertile and fertile conditions.

The analysis of silvicultural and biometric structure of beech forests of Ukrainian Carpathians shows the presence of certain regional features of forest formations in the study region, which is significantly linked with the application of regional forest management approaches.

2. Potential of biomass of mountain beech forests

The dominant component in the structure of the total biomass of mountain beech forests is their live biomass, which serves as a quantitative weight characteristic of a stand. It is not measured at practical mensurational assessment directly in the forest, but is rather calculated using mathematical models based on experimental data collected on temporary sample plots.

For modeling and assessing live biomass of mountain beech forests in Ukrainian Carpathians, data from 269 temporary sample plots (TSPs) were used, where over 600 sample trees were biometrically assessed, 183 of which included estimation of live biomass for tree crown components.

Statistical characteristics of empirical data collected on temporary sample plots that characterize the studied beech stands is presented in Table 6.

Table 6

Statistical characteristics of biometric indices of beech stands on temporary sample plots

Index	Value		Statistics			
	min	**max**	$\overline{X}$	σ	***A***	***E***
Age, years	7	230	79,4	45,8	0,6	-0,4
Diameter, cm	1,5	52,0	24,1	11,8	0,2	-0,6
Height, m	2,6	39,8	22,4	7,6	-0,4	-0,4
Basal area, $m^2 \cdot ha^{-1}$	0,7	64,4	27,1	7,9	-0,3	0,4
Relative stocking	0,31	1,23	0,76	0,2	-0,3	0,7
Growing stock, $m^3 \cdot ha^{-1}$	2,0	857,0	313,5	154,7	0,4	0,1

In this research, the ratio between the mass of individual live biomass fractions (Ph_{fr}) and growing stock of stands, i.e. conversion factors, was used as a basis for modeling live biomass stocks of beech stands in Ukrainian Carpathians. Then, using growing stock of stands, which is determined independently, for example, at the time of mensurational assessment of forests, live biomass of an individual stand is calculated as the product of its growing stock and the corresponding conversion factors.

A generalized view of the mathematical expression used in the research to model the quantitative parameters of live biomass components of beech forests in Ukrainian Carpathians is as follows:

$$R_v = {Ph_{fr}}/{M} = a_0 \cdot A^{a_1} \cdot B^{a_2} \cdot P^{a_3} \cdot exp(a_4 \cdot A + a_5 \cdot P), \quad (2.1)$$

where R_v – relation of mass of separate live biomass fractions of a stand (stem, wood of crown branches, foliage, roots) to its growing stock; Ph_{fr} – mass of separate live biomass fractions; M – growing stock of a stand; A – mean age of a stand, years; B – site index class code; P – relative stocking of a stand; $a_1, a_2, \ldots a_5$ – regression coefficients.

Characteristics of the parameters of equations of ratio coefficients R_v of live biomass fractions in beech stands are presented in Table 7.

Table 7

Parameters of equations of conversion factors' dynamics

Live biomass fractions	Parameters of equation						R^2
	a_0	a_1	a_2	a_3	a_4	a_5	
Stem over bark	0,6709	0,1232	-0,0413	0,3894	-0,0021	-0,3827	0,91
Bark	0,0642	-0,1711	0,3248	-0,0670	0,0022	-0,4586	0,87
Branches	0,2897	-0,4746	0,9142	0,3390	0,0066	-0,9940	0,82
Foliage	0,0860	-1,4142	0,4447	-2,1296	0,0108	2,3949	0,81
Roots	0,3696	-0,5612	0,5132	-0,790	0,0054	0,3560	0,45
Undergrowth, understorey	0,0012	1,5658	0,6301	-0,3590	-0,0068	0,2567	0,65
Green forest floor	0,4529	0,4664	0,5579	0,0064	-0,0023	-1,0993	0,56

It should be noted that during the research of live biomass of beech stands such components as root systems, understorey vegetation and green forest floor were not assessed. Therefore, to estimate these components their multiple regression equations from scientific literature sources were used[21]. At the same time, the equations of live biomass dynamics of understorey vegetation (undergrowth, understorey, green forest floor) reflect not its relation to growing stock, but rather a direct assessment of live biomass.

Thus, the in the frame of this research regression equations that relate fractions of live biomass of forest stands with their biometric indices. Application of multidimensional dependencies allows to obtain

[21] Швиденко А.З., Щепащенко Д.Г., Нильсон С., Булуй Ю.И. Таблицы и модели хода роста и продуктивности насаждений основных лесообразующих пород Северной Евразии. Москва : ОАО «Московская типография № 6», 2008. 887 с.

maximum information from research data and to some extent take into account the regional features of forest ecosystems.

The combination of the presented models with the data from the relational database "Stand level biometric characteristics of forests" allows to obtain quantitative values of live biomass stocks in European beech stands of the research region (Table 8).

Table 8

Regional distribution of live biomass of beech stands in Ukrainian Carpathians

Administrative region	Live biomass by components, Mio tons							
	wood and bark of stem	wood and bark of branches	foliage	roots	undergrowth, understorey	green forest floor	total	live biomass density, kg·(m^2)$^{-1}$
Zakarpattia	70,0	26,9	1,2	28,4	1,1	1,3	128,9	35,9
Ivano-Frankivsk	20,8	5,7	0,4	8,5	0,3	0,4	36,1	30,2
Lviv	21,8	6,7	0,4	8,9	0,4	0,5	38,7	30,8
Chernivtsi	10,3	3,2	0,2	4,0	0,2	0,2	18,1	32,3
Total	122,9	42,5	2,2	49,8	2,0	2,4	221,8	31,8

When analyzing the quantitative parameters of live biomass presented in Table 8, it becomes possible to conclude that its density in beech stands is higher than 30 kg·(m^2)$^{-1}$, which is almost 70 % higher than the figure for hardwood stands of Ukraine (18.9 kg·(m^2)$^{-1}$) [22]. The variance of live biomass density of beech stands in Carpathian mountains has a clear regional character. Thus, in Zakarpattia the mentioned index equals 35.9 kg·(m^2)$^{-1}$, in Bukovyna – 32.3 kg·(m^2)$^{-1}$, and in Lviv and Prykarpattia – 30.8 and 30.2 kg·(m^2)$^{-1}$, respectively. The distribution of the total live biomass of beech stands by age groups is presented in Table 9.

[22] Швиденко А.З., Лакида П.І., Щепащенко Д.Г., Василишин Р.Д., Марчук Ю.М. Вуглець, клімат та землеуправління в Україні: лісовий сектор. Монографія. Корсунь-Шевченківський : ФОП Гавришенко В. М., 2014. 283 с.

Table 9

Distribution of live biomass of beech stands in Ukrainian Carpathians by age groups

Species group, dominant species	Live biomass by age groups, Mio tons					
	young	mid-aged	maturing	mature	overmature	total
Hardwood broadleaves	17,2	147,7	46,4	43,5	25,3	280,1
Including European beech	8,0	114,0	38,4	37,4	24,0	221,8

The age structure of stocks of live organic matter in bone-dry state (Table 9) is characterized by the dominance of mid-aged stands, which account for more than a half of live biomass of beech forests in the region (51.4 %), while the share of young, maturing, mature, and overmature stands is 3.6; 17.3; 16.9 and 10.8 %, respectively.

The basis for forecasting live biomass stocks for mountain beech forests are reference tables of bioproductivity dynamics, developed on the site index scale basis. The scientific basis for the development of this kind of standards are models of conversion factors and mathematical dependences of dynamics of the main biometric indices of beech stands[23].

Fragments of reference tables for pure and mixed beech stands of natural and artificial origin, characterized by I^a site index class, which are typical for the conditions of Ukrainian Carpathians, are presented in Tables 10, 11 and 12. In this case, the reference tables for mixed stands characterize the stand as a whole, providing the share of secondary tree species.

[23] Василишин Р.Д. Ліси Українських Карпат: особливості росту, біологічна та енергетична продуктивність. Монографія. Київ : ТОВ «ЦП «Компринт», 2016. 418 с.

Table 10

Dynamics of bioproductivity of pure beech stands of natural origin (site index class I[a])

Age, years	Live biomass of a stand, t·ha^{-1}										Total live biomass productivity, t·ha^{-1}	Current annual increment of live biomass, t·ha^{-1}·year^{-1}	
	stand							undergrowth and understorey	green forest floor	total		of a present stand	by total productivity
	stem	incl. bark	branches	foliage	total aboveground	roots	total						
10	14,2	1,4	5,0	2,3	21,5	10,7	32,1	0,2	1,4	33,7	65,0	5,28	9,58
20	54,4	4,4	13,6	3,2	71,1	26,4	97,6	0,4	1,8	99,8	200,6	7,33	14,90
30	104,8	7,8	22,1	3,7	130,6	40,9	171,5	0,7	2,1	174,4	368,3	7,35	17,36
40	154,2	10,9	29,4	4,0	187,6	52,4	240,0	1,1	2,3	243,3	548,5	6,45	18,18
50	197,0	13,5	35,4	4,1	236,5	61,0	297,5	1,4	2,4	301,4	730,4	5,26	18,14
60	231,1	15,8	41,0	4,2	276,2	68,8	345,0	1,8	2,6	349,4	911,5	4,31	18,01
70	257,0	17,6	45,8	4,2	307,0	75,1	382,1	2,1	2,8	387,0	1088,6	3,33	17,57
80	276,0	19,2	50,0	4,2	330,1	80,2	410,4	2,4	2,9	415,7	1261,2	2,53	17,12
90	289,2	20,4	53,8	4,2	347,1	84,6	431,7	2,7	3,1	437,5	1429,5	1,91	16,72
100	297,9	21,5	57,3	4,2	359,3	88,5	447,7	3,0	3,2	454,0	1594,5	1,45	16,41
110	303,4	22,3	60,3	4,2	367,9	91,3	459,2	3,3	3,3	465,7	1755,7	1,03	16,04
120	306,3	23,0	63,2	4,2	373,7	94,0	467,7	3,5	3,4	474,6	1914,7	0,78	15,85
130	307,3	23,6	66,1	4,3	377,6	96,5	474,2	3,7	3,4	481,3	2072,4	0,60	15,75
140	306,8	24,1	69,0	4,3	380,2	99,1	479,3	3,9	3,5	486,7	2229,7	0,48	15,72

Table 11

Dynamics of bioproductivity of mixed beech stands of natural origin (site index class I[a])

Age, years	Live biomass of a stand, t·ha^{-1}										Total live biomass productivity, t·ha^{-1}	Current annual increment of live biomass, t·ha^{-1}·year^{-1}	
	stand							undergrowth and understorey	green forest floor	total		of a present stand	by total productivity
	stem	incl. bark	branches	foliage	total aboveground	roots	total						
10	11,5	1,1	3,9	1,8	17,3	8,4	25,7	0,15	1,32	27,1	57,8	4,68	8,75
20	49,7	4,0	12,1	2,9	64,7	23,6	88,3	0,42	1,75	90,5	189,6	7,30	14,72
30	101,0	7,4	20,9	3,6	125,5	38,7	164,2	0,73	2,02	166,9	359,1	7,68	17,67
40	152,9	10,7	28,7	3,9	185,5	51,1	236,6	1,07	2,22	239,9	544,3	6,88	18,74
50	198,4	13,4	35,2	4,1	237,7	60,6	298,3	1,42	2,36	302,1	732,5	5,65	18,78
60	234,9	15,8	41,1	4,2	280,2	68,9	349,1	1,76	2,55	353,4	919,7	4,60	18,61
70	262,6	17,8	46,2	4,2	313,0	75,5	388,5	2,10	2,72	393,3	1102,3	3,53	18,11
80	282,8	19,4	50,5	4,2	337,5	80,9	418,4	2,43	2,87	423,7	1279,6	2,66	17,57
90	296,7	20,7	54,4	4,2	355,4	85,3	440,7	2,73	3,01	446,4	1452,0	1,99	17,10
100	305,8	21,8	58,0	4,2	368,0	89,2	457,3	3,02	3,14	463,4	1620,2	1,48	16,72
110	311,5	22,6	61,0	4,3	376,8	92,1	468,9	3,28	3,22	475,4	1784,2	1,04	16,30
120	314,4	23,3	64,0	4,3	382,7	94,8	477,4	3,51	3,29	484,2	1945,5	0,77	16,07
130	315,3	23,8	66,9	4,3	386,5	97,3	483,8	3,72	3,35	490,9	2105,2	0,58	15,94
140	314,7	24,4	69,9	4,4	388,9	99,8	488,7	3,91	3,40	496,1	2264,2	0,43	15,80

Table 12

Dynamics of bioproductivity of mixed beech stands of artificial origin (site index class I[a])

Age, years	Live biomass of a stand, t·ha^{-1}										Total live biomass productivity, t·ha^{-1}	Current annual increment of live biomass, t·ha^{-1}·year^{-1}	
	stand							undergrowth and understorey	green forest floor	total		of a present stand	by total productivity
	stem	incl. bark	branches	foliage	total aboveground	roots	total						
10	10,3	0,9	3,3	1,6	15,2	7,0	22,1	0,15	1,18	23,4	49,3	4,26	7,63
20	46,6	3,6	10,9	2,7	60,2	21,2	81,4	0,41	1,63	83,4	169,6	7,04	13,59
30	96,1	7,0	19,6	3,4	119,1	36,2	155,3	0,73	1,98	158,1	328,9	7,54	16,68
40	145,7	10,3	27,7	3,8	177,2	49,4	226,6	1,07	2,27	229,9	505,3	6,78	17,91
50	188,4	13,2	34,8	4,0	227,1	60,2	287,3	1,43	2,52	291,3	686,3	5,58	18,11
60	222,4	15,5	40,5	4,0	266,9	68,3	335,2	1,78	2,71	339,7	864,7	4,29	17,71
70	247,7	17,4	45,2	4,1	297,0	74,6	371,6	2,12	2,89	376,6	1038,1	3,23	17,17
80	265,7	18,9	49,2	4,1	319,0	79,5	398,6	2,45	3,04	404,1	1205,9	2,38	16,62
90	277,8	20,1	52,8	4,1	334,7	83,6	418,3	2,76	3,18	424,2	1368,8	1,74	16,15
100	285,4	21,0	56,0	4,1	345,5	87,1	432,6	3,05	3,31	438,9	1527,7	1,28	15,79
110	290,0	21,7	58,7	4,1	352,8	89,6	442,4	3,31	3,39	449,1	1682,3	0,87	15,38
120	292,2	22,3	61,3	4,1	357,6	91,8	449,4	3,55	3,46	456,4	1834,5	0,64	15,16
130	292,5	22,8	63,9	4,1	360,6	94,0	454,6	3,76	3,52	461,9	1985,3	0,48	15,05
140	291,6	23,2	66,6	4,2	362,4	96,2	458,5	3,94	3,56	466,0	2135,4	0,38	15,01

For a better understanding of the quantitative indices provided in the reference tables, it is necessary to pay attention to the meaning of such key indices as live biomass of a present stand and by total productivity of the live biomass. In this context, the first index reflects the amount of live organic matter that is present in a stand of a certain age, while the total live biomass productivity of a stand at a certain age shows the cumulative amount of all live biomass created during the existence of a stand. This is important for the practical use of the proposed tables.

Forest bioenergetics is an innovative direction of modern forestry research, which is closely related to research of bioproductivity of forest plant communities[24]. One of the objects in this direction is energy potential of woody biomass and optimization of its use aiming at replacing fossil fuels in compliance with the conceptual principles of sustainable development.

To assess the energy potential of woody biomass of beech stands in Ukrainian Carpathians, indices of specific energy content in live biomass components are proposed based on their basic density indices[25].

Table 13

Specific energy content in live biomass components of stem and crown branches of European beech trees under conditions of Ukrainian Carpathians

Live biomass component	Energy content in bone-dry matter of live biomass components, GJ·$(m^3)^{-1}$		
	wood	bark	wood over bark
Stem	10,782	8,690	10,621
Crown branches	10,156	8,547	9,852

In accordance with the data, presented in Table 13, it is possible to conclude that stem wood has the highest energy content. One cubic meter of this live biomass fraction, based on the analyzed index, is equivalent to 340 m^3 of natural gas.

The presented indices of specific energy content form a basis for the development of static tables of energy content in live biomass components[26].

[24] Лакида П.І., Шевчук О.В., Василишин Р.Д. Енергетичний потенціал лісів Київського Полісся та його стале використання. Монографія. Консунь-Шевченківський: ФОП Майдаченко І.В., 2020. 168 с.

[25] Василишин Р.Д. Продуктивність та еколого-енергетичний потенціал лісів Українських Карпат: дис. ... доктора с.-г. наук: 06.03.02. Київ, 2014. 460 с.

[26] Лакида П. І. та ін. Нормативи оцінки компонентів надземної фітомаси деревостанів головних лісотвірних порід України. Довідник. Корсунь-Шевченківський : ФОП В. М. Гавришенко, 2013. 457 с.

For these reference materials, the inputs for the tables are represented by the following indices: mean diameter, mean height and relative stocking. The adequate results can be obtained using these reference tables only in a certain parametric range, which is determined by quantitative biometric indices of temporary sample plots: mean height from 4 to 28 m, mean diameter 4–32 cm. Fragments of these reference tables for relative stocking of 0.7 are presented in Tables 14–15.

Table 14

Total energy content of live biomass of stems over bark, TJ·ha^{-1}

Mean diameter, cm	Mean height, m												
	4	6	8	10	12	14	16	18	20	22	24	26	28
4	0,33	0,55	0,79	1,06	1,33	1,62	1,92	2,23	2,55	2,88	3,22	3,57	3,92
6	0,32	0,54	0,79	1,04	1,32	1,60	1,90	2,21	2,53	2,85	3,19	3,53	3,88
8	0,32	0,54	0,78	1,04	1,31	1,59	1,89	2,19	2,51	2,83	3,16	3,50	3,85
10	0,32	0,54	0,77	1,03	1,30	1,58	1,87	2,18	2,49	2,81	3,14	3,48	3,83
12	0,32	0,53	0,77	1,02	1,29	1,57	1,87	2,17	2,48	2,80	3,13	3,47	3,81
14	0,32	0,53	0,77	1,02	1,29	1,57	1,86	2,16	2,47	2,79	3,12	3,45	3,79
16	0,32	0,53	0,76	1,02	1,28	1,56	1,85	2,15	2,46	2,78	3,10	3,44	3,78
18	0,32	0,53	0,76	1,01	1,28	1,56	1,85	2,14	2,45	2,77	3,10	3,43	3,77
20	0,31	0,53	0,76	1,01	1,28	1,55	1,84	2,14	2,45	2,76	3,09	3,42	3,76
22	0,31	0,53	0,76	1,01	1,27	1,55	1,84	2,13	2,44	2,76	3,08	3,41	3,75
24	0,31	0,52	0,76	1,01	1,27	1,54	1,83	2,13	2,43	2,75	3,07	3,40	3,74
26	0,31	0,52	0,76	1,00	1,27	1,54	1,83	2,12	2,43	2,74	3,06	3,39	3,73
28	0,31	0,52	0,75	1,00	1,26	1,54	1,82	2,12	2,42	2,74	3,06	3,39	3,72

Today, in many European countries, wood of branches is recognized as an important additional source of raw materials, which is widely used not only in pulp and paper industry, but also for bioenergy production. In Ukraine, wood and bark are considered non-merchantable raw materials, they are practically not used at all, and mainly remain at harvest plots after logging. Given the global trends in development of renewable energy sources, biomass of branches can become one of the sources of thermal energy in Ukraine, which would require appropriate reference materials to assess their energy content. It should be noted that about 65–75 % of energy accumulated in live biomass of stands is concentrated in stems, and 25–35 % – in components of tree crowns.

Table 15

Total energy content in live biomass of crown branches, TJ·ha^{-1}

Mean diameter, cm	Mean height, m												
	4	6	8	10	12	14	16	18	20	22	24	26	28
4	0,039	0,033	0,029	0,03	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
6	0,092	0,077	0,068	0,06	0,06	0,05	0,05	0,05	0,05	0,04	0,04	0,04	0,04
8	0,17	0,14	0,13	0,11	0,11	0,10	0,09	0,09	0,08	0,08	0,08	0,08	0,07
10	0,27	0,23	0,20	0,18	0,17	0,16	0,15	0,14	0,14	0,13	0,13	0,12	0,12
12	0,40	0,34	0,30	0,27	0,25	0,23	0,22	0,21	0,20	0,19	0,19	0,18	0,17
14	0,56	0,47	0,41	0,38	0,35	0,32	0,31	0,29	0,28	0,27	0,26	0,25	0,24
16	0,74	0,62	0,55	0,50	0,46	0,43	0,41	0,39	0,37	0,35	0,34	0,33	0,32
18	0,96	0,80	0,71	0,64	0,59	0,55	0,52	0,50	0,47	0,46	0,44	0,42	0,41
20	1,20	1,00	0,88	0,80	0,74	0,69	0,65	0,62	0,59	0,57	0,55	0,53	0,51
22	1,46	1,23	1,08	0,98	0,91	0,85	0,80	0,76	0,73	0,70	0,67	0,65	0,63
24	1,76	1,48	1,30	1,18	1,09	1,02	0,96	0,92	0,88	0,84	0,81	0,78	0,76
26	2,09	1,75	1,55	1,40	1,30	1,21	1,14	1,09	1,04	1,00	0,96	0,93	0,90
28	2,45	2,05	1,81	1,64	1,52	1,42	1,34	1,27	1,22	1,17	1,12	1,08	1,05

Utilization of the abovementioned reference materials can be effective in cases when tree stems of the studied stands are used as an energy resource, and the components of live biomass of crowns will remain at harvesting sites (for further biodegradation) to minimize the negative impact on nutrient circulation between forest stands and soil. Another scenario would be the one when forest management foresees procurement of industrially valuable assortments, thus only harvesting residues (namely branches) can be used for energy purposes.

3. Information support for assessing primary production of European beech stands in Ukrainian Carpathians

Net primary production (NPP) is one of the most important indices and bioproductivity components. Assessment of quantitative NPP indices is a necessary precondition for valuation of a number of ecosystem functions of forest plant communities over a certain territory. This index serves as an indicator of environmental feedback on climate change[27, 28, 29]. Its quantitative parameters for European beech stands in Ukrainian

[27] Лакида П. І. Фітомаса лісів України. Монографія. Тернопіль : Збруч, 2002. 256 с.

[28] Shvidenko A., Schepaschenko D., Nilson S. Modeling Net Primary Production of Northern Eurasia forests: A new method & new estimate. *ECEM'07*. Trieste, 2007. P. 485–486.

[29] Shvidenko A., Buksha I., Krakovska S., Lakyda, P. Vulnerability of Ukrainian Forests to Climate Change. *Sustainability*. 2017. Vol. 9 (7). P. 1152–1158. https://doi.org/10.3390/su9071152.

Carpathians are presented in Table 16. NPP assessment has been carried out in accordance with the methodology proposed by A.Z. Shvidenko[30].

Table 16

Net primary production of European beech stands in Ukrainian Carpathians

Species group, dominant species	NPP by components, Mio tons·year^{-1}							NPP density, g·m^{-2}·year^{-1}
	wood and bark of stems	wood and bark of branches	foliage	roots	undergrowth, understorey	green forest floor	total	
Hardwood broadleaves	2,42	0,98	3,84	5,58	1,00	1,93	15,75	1414
Including European beech	1,58	0,70	2,38	3,80	0,71	1,29	10,46	1438

The highest values of NPP density in Ukrainian Carpathians are characteristic to European beech stands – 1438 g·(m^2)$^{-1}$·year^{-1}, which is 40 % higher than the mean value for Ukraine's forests and 74 % higher than the mean NPP density of Norway spruce stands in the region (822 g·(m^2)$^{-1}$·year^{-1}).

To assess the indices of primary production of beech stands in Ukrainian Carpathians, the tools based on representative experimental research data should be applied. In particular, these are static tables for assessment of primary production of tree stems in beech stands (Tables 17–18) and reference tables of dynamics of net primary production of beech stands of different origin (Table 19).

The static reference tables contain information on the volumes of live biomass production by the present growing stock of a stand over bark. They are developed as a function of mean height of a stand (*H*), mean diameter of a stand (*D*), and mean width of an annual growth ring.

The values in the tables reflect the live biomass production in tons per 1 m^2 of basal area (*G*). To assess production of stem of a certain stand, the value obtained from the table shall be multiplied by the actual basal area of this stand.

[30] Shvidenko A., Schepaschenko D., Nilson S. et al. Semi-empirical models for assessing biological productivity of Northern Eurasian forests. *Ecological Modelling.* 2007. № 204 (1–2). P. 163–179.

Table 17

Production of stems of European beech stands in Ukrainian Carpathians (0,2–2,0), tons·(m^2G)$^{-1}$

H, m	D, cm	Annual growth ring width, mm					
		0,2	0,6	1,0	1,4	1,6	2,0
1	2	3	4	5	6	7	8
4,0	4,0	0,0434	0,1303	0,2171	0,3039	0,3473	0,4342
5,0	4,0	0,0536	0,1609	0,2682	0,3755	0,4292	0,5364
5,0	6,0	0,0309	0,0929	0,1548	0,2168	0,2477	0,3097
6,0	6,0	0,0369	0,1106	0,1843	0,2581	0,2949	0,3687
6,0	8,0	0,0260	0,0780	0,1300	0,1820	0,2080	0,2601
7,0	7,0	0,0354	0,1061	0,1769	0,2476	0,2830	0,3537
7,0	9,0	0,0263	0,0788	0,1314	0,1840	0,2102	0,2628
8,0	8,0	0,0343	0,1029	0,1715	0,2402	0,2745	0,3431
8,0	12,0	0,0215	0,0646	0,1076	0,1506	0,1721	0,2151
9,0	8,0	0,0384	0,1153	0,1922	0,2690	0,3075	0,3843
9,0	12,0	0,0241	0,0723	0,1206	0,1689	0,1930	0,2412
9,0	14,0	0,0203	0,0609	0,1015	0,1421	0,1623	0,2030
10,0	10,0	0,0328	0,0986	0,1643	0,2300	0,2628	0,3286
10,0	14,0	0,0225	0,0675	0,1124	0,1575	0,1799	0,2249
10,0	16,0	0,0194	0,0582	0,0970	0,1358	0,1552	0,1940
12,0	12,0	0,0319	0,0957	0,1595	0,2233	0,2552	0,3190
12,0	16,0	0,0232	0,0696	0,1159	0,1623	0,1854	0,2318
14,0	14,0	0,0312	0,0937	0,1561	0,2186	0,2498	0,3123
14,0	18,0	0,0237	0,0711	0,1185	0,1659	0,1896	0,2370
14,0	20,0	0,0211	0,0634	0,1057	0,1480	0,1691	0,2113
16,0	18,0	0,0270	0,0810	0,1351	0,1891	0,2161	0,2702
16,0	22,0	0,0217	0,0652	0,1087	0,1522	0,1739	0,2174
18,0	20,0	0,0270	0,0811	0,1353	0,1894	0,2164	0,2705
18,0	24,0	0,0222	0,0667	0,1112	0,1557	0,1779	0,2224
20,0	20,0	0,0300	0,0900	0,1500	0,2100	0,2400	0,3000
20,0	28,0	0,0210	0,0628	0,1047	0,1466	0,1676	0,2094
20,0	32,0	0,0182	0,0546	0,0909	0,1273	0,1455	0,1819
22,0	24,0	0,0271	0,0813	0,1356	0,1898	0,2169	0,2711
22,0	32,0	0,0200	0,0600	0,1000	0,1399	0,1600	0,1999
22,0	40,0	0,0159	0,0475	0,0792	0,1108	0,1266	0,1583
24,0	28,0	0,0251	0,0753	0,1255	0,1756	0,2007	0,2508
24,0	36,0	0,0192	0,0578	0,0963	0,1349	0,1541	0,1927
24,0	44,0	0,0156	0,0469	0,0782	0,1095	0,1252	0,1565
26,0	28,0	0,0271	0,0814	0,1358	0,1901	0,2172	0,2715
26,0	36,0	0,0208	0,0626	0,1043	0,1461	0,1669	0,2086
26,0	44,0	0,0169	0,0508	0,0847	0,1186	0,1356	0,1695

Continuation of Table 17

1	2	3	4	5	6	7	8
28,0	28,0	0,0292	0,0877	0,1461	0,2045	0,2337	0,2922
28,0	36,0	0,0225	0,0674	0,1123	0,1572	0,1797	0,2246
28,0	44,0	0,0182	0,0548	0,0912	0,1277	0,1459	0,1825
28,0	52,0	0,0154	0,0462	0,0769	0,1076	0,1230	0,1537
28,0	60,0	0,0133	0,0399	0,0665	0,0931	0,1063	0,1329
30,0	28,0	0,0313	0,0939	0,1564	0,2189	0,2503	0,3128
30,0	36,0	0,0241	0,0722	0,1203	0,1684	0,1925	0,2406
30,0	44,0	0,0195	0,0586	0,0977	0,1369	0,1564	0,1955
30,0	52,0	0,0165	0,0494	0,0824	0,1154	0,1318	0,1648
30,0	60,0	0,0143	0,0428	0,0712	0,0997	0,1140	0,1425
30,0	72,0	0,0119	0,0356	0,0593	0,0830	0,0949	0,1187
34,0	38,0	0,0258	0,0773	0,1288	0,1803	0,2061	0,2576
34,0	50,0	0,0194	0,0583	0,0972	0,1361	0,1555	0,1944
34,0	62,0	0,0156	0,0469	0,0782	0,1094	0,1251	0,1563
34,0	74,0	0,0131	0,0393	0,0655	0,0917	0,1048	0,1310
38,0	42,0	0,0260	0,0779	0,1298	0,1817	0,2077	0,2596
38,0	54,0	0,0201	0,0603	0,1005	0,1407	0,1607	0,2010
38,0	66,0	0,0164	0,0492	0,0821	0,1149	0,1314	0,1642
38,0	78,0	0,0139	0,0418	0,0696	0,0974	0,1113	0,1391
38,0	84,0	0,0129	0,0388	0,0647	0,0905	0,1035	0,1294
42,0	64,0	0,0187	0,0562	0,0937	0,1311	0,1499	0,1873
42,0	76,0	0,0158	0,0469	0,0789	0,1105	0,1263	0,1579
42,0	82,0	0,0147	0,0440	0,0733	0,1026	0,1173	0,1465
42,0	94,0	0,0128	0,0385	0,0642	0,0898	0,1026	0,1283
42,0	100,0	0,0121	0,0362	0,0604	0,0846	0,0966	0,1208
42,0	106,0	0,0114	0,0343	0,0571	0,0800	0,0914	0,1142

For practical application of reference tables, the width of an annual growth ring should be calculated as the arithmetic mean of measurements of the annual growth ring widths for 25–30 metering trees in the range D ± 2–4 cm. The measurements should be carried out using an increment borer.

Table 18

Production of stems of European beech stands in Ukrainian Carpathians (2,4–4,2), tons·$(m^2G)^{-1}$

H, m	D, cm	Annual growth ring width, mm					
		2,4	2,8	3,0	3,4	3,8	4,2
1	2	3	4	5	6	7	8
4,0	4,0	0,5210	–	–	–	–	–
5,0	4,0	0,6437	0,7510	0,8046	0,9120	–	–

Continuation of Table 18

1	2	3	4	5	6	7	8
5,0	6,0	0,3715	0,4335	0,4644	0,5264	–	–
6,0	6,0	0,4424	0,5161	0,5530	0,6267	0,7005	0,7742
6,0	8,0	0,3120	0,3641	0,3901	0,4421	0,4941	0,5461
7,0	7,0	0,4245	0,4952	0,5306	0,6014	0,6721	0,7429
7,0	9,0	0,3154	0,3679	0,3942	0,4467	0,4993	0,5518
8,0	8,0	0,4117	0,4803	0,5146	0,5832	0,6519	0,7205
8,0	12,0	0,2582	0,3012	0,3227	0,3657	0,4088	0,4518
9,0	8,0	0,4611	0,5380	0,5764	0,6533	0,7301	0,8070
9,0	12,0	0,2895	0,3377	0,3619	0,4101	0,4583	0,5066
9,0	14,0	0,2435	0,2842	0,3044	0,3451	0,3856	0,4262
10,0	10,0	0,3943	0,4600	0,4929	0,5586	0,6243	0,6900
10,0	14,0	0,2699	0,3149	0,3374	0,3824	0,4273	0,4723
10,0	16,0	0,2328	0,2716	0,2880	0,3298	0,3686	0,4074
12,0	12,0	0,3829	0,4467	0,4786	0,5424	0,6062	0,6700
12,0	16,0	0,2782	0,3246	0,3478	0,3941	0,4405	0,4868
14,0	14,0	0,3747	0,4372	0,4684	0,5309	0,5933	0,6557
14,0	18,0	0,2844	0,3317	0,3554	0,4029	0,4503	0,4977
14,0	20,0	0,2536	0,2959	0,3170	0,3593	0,4015	0,4438
16,0	18,0	0,3241	0,3782	0,4052	0,4592	0,5132	0,5673
16,0	22,0	0,2609	0,3044	0,3261	0,3696	0,4131	0,4566
18,0	20,0	0,3246	0,3787	0,4058	0,4599	0,5140	0,5681
18,0	24,0	0,2669	0,3114	0,3336	0,3781	0,4226	0,4671
20,0	20,0	0,3600	0,4200	0,4500	0,5101	0,5701	0,6301
20,0	28,0	0,2513	0,2932	0,3142	0,3560	0,3979	0,4399
20,0	32,0	0,2183	0,2546	0,2728	0,3092	0,3456	0,3819
22,0	24,0	0,3253	0,3795	0,4066	0,4608	0,5151	0,5693
22,0	32,0	0,2399	0,2799	0,2999	0,3399	0,3799	0,4198
22,0	40,0	0,1900	0,2216	0,2375	0,2691	0,3008	0,3325
24,0	28,0	0,3010	0,3512	0,3763	0,4264	0,4766	0,5268
24,0	36,0	0,2312	0,2697	0,2890	0,3275	0,3661	0,4046
24,0	44,0	0,1877	0,2190	0,2346	0,2659	0,2972	0,3285
26,0	28,0	0,3258	0,3802	0,4073	0,4616	0,5159	0,5702
26,0	36,0	0,2504	0,2921	0,3130	0,3547	0,3964	0,4381
26,0	44,0	0,2033	0,2372	0,2542	0,2881	0,3219	0,3559
28,0	28,0	0,3506	0,4090	0,4383	0,4967	0,5552	0,6135
28,0	36,0	0,2695	0,3145	0,3369	0,3818	0,4267	0,4716
28,0	44,0	0,2189	0,2555	0,2737	0,3102	0,3467	0,3832
28,0	52,0	0,1845	0,2153	0,2307	0,2614	0,2921	0,3229
28,0	60,0	0,1595	0,1861	0,1994	0,2260	0,2526	0,2792
30,0	28,0	0,3754	0,4380	0,4692	0,5318	0,5944	0,6569

End of Table 18

1	2	3	4	5	6	7	8
30,0	36,0	0,2887	0,3367	0,3608	0,4089	0,4570	0,5051
30,0	44,0	0,2346	0,2737	0,2932	0,3323	0,3714	0,4105
30,0	52,0	0,1977	0,2307	0,2471	0,2801	0,3130	0,3460
30,0	60,0	0,1710	0,1995	0,2137	0,2422	0,2707	0,2992
30,0	72,0	0,1424	0,1661	0,1780	0,2017	0,2254	0,2492
34,0	38,0	0,3091	0,3607	0,3864	0,4380	0,4895	0,5410
34,0	50,0	0,2333	0,2721	0,2915	0,3304	0,3693	0,4082
34,0	62,0	0,1876	0,2189	0,2345	0,2658	0,2971	0,3283
34,0	74,0	0,1572	0,1834	0,1965	0,2227	0,2489	0,2751
38,0	42,0	0,3116	0,3635	0,3894	0,4413	0,4933	0,5452
38,0	54,0	0,2412	0,2813	0,3015	0,3416	0,3818	0,4220
38,0	66,0	0,1971	0,2299	0,2463	0,2792	0,3120	0,3449
38,0	78,0	0,1670	0,1948	0,2087	0,2365	0,2643	0,2922
38,0	84,0	0,1552	0,1811	0,1940	0,2199	0,2457	0,2716
42,0	64,0	0,2248	0,2623	0,2810	0,3184	0,3559	0,3933
42,0	70,0	0,2056	0,2399	0,2570	0,2912	0,3255	0,3598
42,0	76,0	0,1895	0,2211	0,2369	0,2685	0,3000	0,3316
42,0	82,0	0,1759	0,2052	0,2198	0,2491	0,2785	0,3078
42,0	88,0	0,1641	0,1915	0,2052	0,2325	0,2599	0,2872
42,0	94,0	0,1539	0,1796	0,1924	0,2181	0,2437	0,2694
42,0	100,0	0,1450	0,1692	0,1812	0,2054	0,2296	0,2538
42,0	106,0	0,1371	0,1600	0,1714	0,1942	0,2171	0,2399

Dynamic tables that reflect the trends of NPP change in modal stands of different site index classes are the basis for the forecast assessment of net primary production of forest plant communities. The relevant reference tables for European beech stands of the region are proposed in this research (Table 19).

Table 19

Dynamics of net primary production of European beech stands of different origin in Ukrainian Carpathians, $g \cdot (m^2)^{-1} \cdot year^{-1}$

Age, years	Site index class					
	I^b	I^a	I	II	III	IV
1	2	3	4	5	6	7
pure stands of natural origin						
10	1093	937	794	653	517	414
20	1624	1461	1279	1085	881	705
30	1848	1699	1521	1317	1097	889
40	1903	1778	1616	1428	1222	1010
50	1873	1770	1630	1471	1299	1099

Continuation of Table 19

1	2	3	4	5	6	7
860	1844	1754	1626	1477	1307	1123
70	1782	1707	1598	1469	1315	1149
80	1717	1659	1568	1457	1319	1168
90	1661	1616	1541	1448	1323	1188
100	1614	1584	1523	1444	1331	1208
110	1566	1545	1493	1424	1327	1214
120	1535	1525	1481	1420	1333	1226
mixed stands of natural origin						
10	1008	859	715	578	469	374
20	1614	1444	1255	1048	865	689
30	1889	1731	1541	1323	1109	895
40	1970	1834	1663	1461	1248	1028
50	1945	1832	1691	1523	1329	1117
60	1911	1812	1679	1519	1341	1145
70	1840	1760	1644	1505	1349	1168
80	1766	1703	1606	1487	1349	1186
90	1701	1653	1572	1471	1352	1202
100	1646	1614	1545	1461	1356	1218
110	1592	1570	1517	1438	1343	1220
120	1558	1545	1503	1432	1339	1232
mixed stands of artificial origin						
10	851	749	651	570	489	406
20	1446	1335	1202	1077	935	780
30	1731	1634	1505	1366	1204	1014
40	1822	1752	1642	1507	1343	1145
50	1812	1768	1685	1560	1408	1214
60	1760	1723	1651	1545	1410	1236
70	1687	1667	1608	1521	1402	1244
80	1618	1610	1566	1493	1390	1251
90	1556	1560	1529	1471	1380	1255
100	1507	1521	1503	1455	1374	1263
110	1459	1479	1467	1430	1362	1265
120	1428	1457	1451	1422	1362	1267

CONCLUSIONS

At present, Ukrainian Carpathians have significant reserves of forest resources while forming a unique natural complex. Research of ecological functions of the Carpathian forests, which affect the climate and hydrological resources of a significant part of Eurasian continent, has become a prerequisite for transition to sustainable forestry in the region and Ukraine's compliance with the declared international

agreements related to environmental issues. At the same time, the relevance of recent research has long gone beyond regional issues and became global.

As a result of the research, it was established that beech stands in Ukrainian Carpathians cover an area of over 2 million hectares, where about 580 million m^3 of growing stock is located. Almost 57 % of beech forests with a growing stock of 129.1 Mio m^3 are concentrated in Zakarpattia region, another 30 % in Ivano-Frankivsk and Lviv regions. In general, European beech stands in Ukrainian Carpathians cover 33.5 % of the forested area in the region. European beech forms pure and mixed stands of natural and artificial origin, which grow in moist, fairly rich and rich conditions.

In beech stands of the region the amount of accumulated biomass exceeds 220 Mio tons, its density reaches 30 $kg \cdot (m^2)^{-1}$. In Zakarpattia region the mentioned index equals 35,9 $kg \cdot (m^2)^{-1}$, in Bukovyna – 32,3 $kg \cdot (m^2)^{-1}$, in Lviv and Precarpathians – 30,8 and 30,2 $kg \cdot (m^2)^{-1}$ correspondingly.

The basis for forecasting biomass reserves of mountain beech forests are reference tables of bioproductivity dynamics, developed on the site index scale basis. At the same time, to assess the energy potential of woody bioomass, reference materials of energy content in live biomass components are proposed within this research.

Net primary production of the studied stands in the region is over 10 Mio tons of organic matter per annuum. The net primary production density in beech stands of Ukrainian Carpathians is 1438 $g \cdot (m^2)^{-1} \cdot year^{-1}$, which is 40% higher than the mean for Ukraine's forests in general. Static tables of production of stems and reference materials of dynamics of net primary production for beech stands of different origin should be used to evaluate the production of the forest stands.

SUMMARY

In the modern realities of human-nature interaction in the context of sustainable social development, forest plant communities play an important role, which is an critical factor in stabilizing the environment in the context of global climate change. They are also an important source of renewable natural resources.

In the course of the research, an analytical assessment of silvicultural and biometric characteristics of European beech forests in Ukrainian Carpathians was carried out. This allowed to assess their current state

and determine a set of factors that shape the features of formation of biomass and primary production potential.

The components of beech forests bioproductivity, namely their quantitative indices of live biomass and primary production have been established. A system of reference and information support for assessing and forecasting indices of biomass and production of beech stands in Ukrainian Carpathians is proposed. The system will serve as a tool for organizing the sustainable use of forest resources. The obtained results will provide an information basis for introduction of close to nature mountain forestry.

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