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BIOMASS AND PRIMARY PRODUCTION OF EUROPEAN SPRUCE STANDS IN UKRAINIAN CARPATHIANS

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INTRODUCTION

Today, the Ukrainian Carpathians remain one of the few natural national assets and are a center of biodiversity, a territory with original primeval forests and unique mountain landscapes. Occupying one of the most important places in the regional economy, forests of the region are also a natural stabilizer of the environment and perform important soil protective, water and climate regulative functions. Their social importance grows every year with the increase in development of recreation and tourism. Many scientific works are devoted to the ecological role and functional purpose of the forests of the Carpathian region of Ukraine, among which it is worth noting fundamental scientific research by S. A. Hensiruk[1], M. A. Holubets[2], I. F. Kalutskyi[3], V. S. Oliinyk[4,5], K. K. Smahliuk[6], S. M. Stoiko[7,8], V. I. Parpan[9] and many others[10,11]).

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[1] Генсірук С.А. Ліси Українських Карпат та їх використання. Київ : Урожай, 1964. 290 с.

[2] Голубець М.А. Проблеми сталого розвитку в Карпатському регіоні. *Зелені Карпати*. 2007. № 1–2 (25–26). С. 1–6.

[3] Калуцький І.Ф. Вітровали на північно-східному макросхилі в Українських Карпатах. Монографія. Львів : Манускрипт, 1998. 204 с.

[4] Олійник В.С. Категорії пошкоджень ґрунту під час лісозаготівель у Карпатах. *Лісівництво і агролісомеліорація*. 2004. Вип. 107. С. 75–78.

[5] Олійник В.С. Методичні особливості вивчення і оцінки гідрологічної ролі гірських лісів Карпат. *Науковий вісник Національного аграрного університету*. 2000. Вип. 25. С. 159–166.

[6] Смаглюк К.К. Оценка экологических последствий хозяйственного преобразования горных лесов Карпат. Лесоведение. 1978. № 2. С. 3–9.

[7] Стойко С.М. Наслідки антропогенної трансформації лісових екосистем Карпат та шляхи елімінації шкідливих екологічних процесів. *Український ліс*. 1993. № 2. С. 11–17.

[8] Стойко С.М. Причини катастрофічних паводків у Закарпатті та системи екологічних профілактичних заходів їх попередження. *Український ботанічний журнал*. 2000. Т. 57, № 1. С. 11–20.

[9] Парпан В.І. Концептуальні засади гірського лісознавства та лісівництва. *Науковий вісник Національного лісотехнічного університету України*. 2013. Вип. 23.5. С. 22–28.

[10] Лакида П.І., Бокоч В.В., Василишин Р.Д., Терентьєв А.Ю. Біопродуктивність лісових фітоценозів Карпатського національного природного парку. Монографія. Корсунь-Шевченківський : ФОП Гавришенко В. М., 2015. 154 с.

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

At present, the issue of researching the mountain forests of the Carpathians remains relevant in the global scientific development of forest science.

According to T. V. Parpan[12], forest cover of the Carpathians has significantly transformed, in particular, during several decades, beech-fir forests were replaced by pure spruce stands. As a result, local biochemical cycles changed and the ecostabilizing function of mountain forests decreased.

The special interest for researchers in the Carpathians are the pristine forests due to the fact that they remain a unique natural element of the forest cover of the region. Thus, researchers from England[13], using Sentinel-2 satellite images and space LiDAR imaging[14], were able to identify old-growth spruce, beech and pine stands in Ukrainian Carpathians, investigate their vertical structure and, on this methodological basis, proposed an effective method for identifying old-growth forests in Europe.

The current state of Carpathian spruce stands also depends significantly on recreational load. In the conditions of intensive development of tourist activities, Carpathian spruce stands undergo certain destructive erosion processes that affect their water regulative function[15].

Ecosystem functions of forests in Ukrainian Carpathians currently remain one of the most relevant directions of research of the region's ecosystems, in particular their carbon storage and oxygen production capacity[16,17,18,19]. In this

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[12] Parpan T.V. Bioecological principles of maintaining stability in mountain forest ecosystems of the Ukrainian Carpathians. *Visnyk of Dnipropetrovsk university-biology ecology*. 2016. Vol. 24 (2). P. 371–377.

[13] Spracklen B. D, Spracklen D. V. Identifying European Old-Growth Forests using Remote Sensing: A Study in the Ukrainian Carpathians. *Forests.* 2019. Vol. 10 (2). DOI 10.3390/f10020127.

[14] Spracklen B., Spracklen D. Determination of Structural Characteristics of Old-Growth Forest in Ukraine Using Spaceborne LiDAR. *Remote Sensing*. 2021. Vol. 13 (7). DOI 10.3390/rs13071233.

[15] Ivanenko Y., Lobchenko G., Maliuha V., Yukhnovskyi V. Spruce forest litter structure, distribution, and water retention along hiking trails in the Ukrainian Carpathians. *Journal of Forest Science*. 2022. Vol. 68 (7). P. 241–252. DOI 10.17221/12/2022-JFS.

[16] Василишин Р.Д. Еколого-енергетичний потенціал лісів Українських Карпат та його стале використання. Монографія. Київ : ТОВ »ЦП «Компринт», 2018. 303 с.

[17] Kruhlov I., Thom D., Chaskovskyy O., Keeton W., Scheller R. Future forest landscapes of the Carpathians: vegetation and carbon dynamics under climate change. *Regional Environmental Change.* 2018. Vol. 18(5). P. 1555–1567. DOI 10.1007/s10113-018-1296-8.

[18] Василишин Р.Д., Слюсарчук В.В., Лакида І.П., Терентьєв А.Ю. Букові деревостани Буковинського Передкарпаття: особливості росту та енергетичний потенціал. Монографія. Житомир : ТОВ »Видавничий дім «Бук-Друк», 2021. 168 с.

[19] Василишин Р.Д. Нормативно-довідкові матеріали для оцінювання екосистемних функцій лісів Українських Карпат. Довідник. Житомир : ТОВ »Видавничий дім «Бук-Друк», 2021. 224 с.

context, the research of biomass and net primary production of spruce stands serves as an information basis for forming a regional forest management strategy based on sustainable development principles.

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

Silvicultural characteristics of spruce stands has been prepared on the basis of information from the relational database «Stand Level Biometric Characteristics of Forests" run by the Ukrainian State Forest Management Planning Association IA «Ukrderzhlisproekt"[20].

European spruce (*Picea abies* L.) is one of the most common tree species in the Ukrainian Carpathians. Its stands occupy up to one third of the forest fund area. It grows both on flatlands and in the high mountains (over 1100 m above sea level), forming pure and mixed highly productive stands.

Over the past 200 years, the boundaries of the current distribution of spruce in Ukraine have expanded far towards the foothills and flatlands[21]. In the Pre-Carpathian region, artificial restoration of forests, which was carried out here exclusively by planting spruce monocultures on harvested forest plots formerly occupied by beech, oak-fir and fir stands, led to a significant increase in the area of spruce stands in the mountains, where their area currently reaches 274.3 thou. hectares (Table 1).

Table 1

Distribution of quantitative characteristics of spruce stands by administrative regions

Administrative region	Number of stands	Area, thou. ha	Growing stock, Mio m^3
Zakarpattia	31491	155.6	59.6
Ivano-Frankivsk	69685	274.3	89.4
Lviv	25486	88.0	26.9
Chernivtsi	20488	73.7	23.4
Total	147150	591.6	199.3

Age structure of the spruce stands is presented in Table 2.

[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.

[21] Дебринюк Ю.М. Розповсюдження та формова різноманітність Picea abies [L.] Karst. *Науковий вісник НЛТУ України*. 2008. Вип. 18.2. С. 7–17.

Table 2

Distribution of quantitative characteristics of spruce 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	5059.5 / 85.3	2874.7 / 28.4	1401.7 / 15.8	1324.0 / 13.0	10659.9 / 142.5
II	10834.4 / 713.6	17972.8 / 910.1	6435.6 / 254.9	5120.1 / 149.0	40362.9 / 2027.6
III	11803.9 / 1926.9	23656.3 / 4371.8	7254.4 / 853.9	6678.2 / 730.5	49392.8 / 7883.1
IV	11440.2 / 3083.8	23441.7 / 6028.1	9736.4 / 2018.7	9611.1 / 2041.8	54229.4 / 13172.4
V	15788.3 / 6038.1	47411.7 / 15650.7	17346.2 / 5128.4	11620.9 / 3775.3	92167.1 / 30592.5
VI	29301.9 / 13957.5	53754.4 / 20846.1	14191.6 / 4993.3	11293.4 / 4414.3	108541.3 / 44211.2
VII	14338.2 / 7049.5	18889.7 / 7266.1	8641.4 / 3229.8	6058.2 / 2533.4	47927.5 / 20078.8
VIII	13268.6 / 6735.3	18766.6 / 7930.7	7435.9 / 3169.8	5644.7 / 2458.4	45115.8 / 20294.2
IX	8743.6 / 4562.7	13425.8 / 5557.3	4731.4 / 2061.4	5117.2 / 2215.5	32018.0 / 14396.9
X	6208.9 / 3172.9	8822.7 / 3658.5	4070.5 / 1921.9	5062.9 / 2220.1	24165.0 / 10973.4
XI	4819.7 / 2387.6	8124.2 / 3308.2	3519.1 / 1736.5	3847.4 / 1755.9	20343.4 / 9188.2
XII	3883.5 / 1871.0	6192.0 / 2593.4	1958.0 / 967.4	1572.5 / 724.6	13606.0 / 6156.4
XIII	2827.8 / 1275.8	7629.2 / 2982.5	674.2 / 287.0	618.1 / 268.3	11749.3 / 4813.6
XIV and older	17263.5 / 6740.8	23304.7 / 8307.9	562.4 / 213.0	160.2 / 63.8	41290.8 / 15325.5
Total	155582.0 / 59600.8	274266.5 / 89439.8	87958.8 / 26851.9	73728.9 / 23363.8	591569.2 / 199256.3

From the data presented in Table 2, it can be seen that by age structure mid-aged spruce stands are the most common in the region (46.9%). These are, mainly, stands of artificial origin, which were planted in the post-war years after a significant exploitation load on the forests of the region.

In the vast majority of the region, there are highly productive spruce stands – I^a and I site index classes, which cover 64.2% of the area of spruce stands. The largest number of such stands are concentrated in Ivano-Frankivsk (27.5%) and Zakarpattia (16.3%) regions. The share of European spruce stands featuring II site index class is 19.6%, another 7% are stands of I^b and higher site index classes. Less than 3% of the total area of the investigated tree species is accounted for by low-productivity stands.

The distribution of spruce stands by relative stocking within administrative regions indicates a predominance of stands with a relative stocking of 0.7 and 0.8. The share of these stands is 52.4%, including 24.2% in Ivano-Frankivsk region, 13.4% in Zakarpattia region, 7.7% and 7.2% in Chernivtsi region and Lviv region, respectively. The share of European spruce stands with a relative stocking of 0.5 and below is 16%, of which 6.4% are located in Ivano-Frankivsk region.

European spruce is a forest-forming species only in fairly fertile and fertile site types, where 79 and 16% of the areas of spruce stands are concentrated, respectively. In other types of forest growth conditions, it can be present as secondary stand component (Table 3).

European spruce is a typical mesotrophic species, which in extremely infertile conditions fragmentarily forms pure spruce stands, but reaches optimal productivity in fertile conditions. According to moisture conditions, it is a mesophyte, but it is often present in damp types of growth conditions.

It is worth noting that spruce stands occupy the largest area in moist (98.4%) forest growth conditions. The share of other conditions (fresh, damp, wet) is less than 2% of the total area of spruce stands. The most common are moist beech-fir-spruce forests (53%), moist highland mixed spruce forests (23%), moist beech-fir-spruce forests (15%) and moist pure spruce forests (5%). The mentioned forest types make up more than 95% of the area of spruce stands in Ukrainian Carpathians.

It can be concluded that spruce stands in the Carpathians are highly productive, mid-aged, medium-stocked stands that often grow in moist, fairly fertile conditions. More than 60% of spruce stands are of artificial origin, of which a significant part are of secondary origin, and therefore the problem of effective reforestation and improvement of biological stability remains relevant, given the numerous cases of dieback of such stands.

Table 3

Distribution of area of spruce 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
infertile site types					
Zakarpattia	–	–	–	–	–
Ivano-Frankivsk	526.0	–	526.0	–	–
Lviv	1.6	1.6	–	–	–
Chernivtsi	–	–	–	–	–
fairly infertile site types					
Zakarpattia	3833.2	–	3806.5	26.7	–
Ivano-Frankivsk	23353.7	279.3	22748.7	325.7	–
Lviv	135.0	12.1	103.3	19.6	–
Chernivtsi	1317.1	–	1317.1	–	–
fairly fertile site types					
Zakarpattia	119062.7	560.9	118360.2	141.6	–
Ivano-Frankivsk	226264.1	1335.4	222096.5	2832.2	–
Lviv	60506.5	693.3	59685.4	127.8	–
Chernivtsi	62628.1	821.0	61613.3	193.8	–
fertile site types					
Zakarpattia	32686.1	1047.4	31637.3	1.4	–
Ivano-Frankivsk	24155.7	85.6	24019.8	50.3	–
Lviv	27315.7	315.7	26974.0	26.0	–
Chernivtsi	9783.7	637.9	9071.0	70.3	4.5
total within the region					
Infertile site types	527.6	1.6	526.0	–	–
Fairly infertile site types	28639.0	291.4	27975.6	372.0	–
Fairly fertile site types	468461.4	3410.6	461755.4	3295.4	–
Fertile site types	93941.2	2086.6	91702.1	148.0	4.5

2. Potential of biomass of mountain spruce forests

The biomass of mountain spruce forests is formed of live biomass and dead organic matter, which are quantitative weight characteristics of stands. The share of live biomass of spruce forests in the total structure of tree biomass is more than 90% and it is estimated using mathematical models based on experimental data collected at temporary sample plots.

For the purpose of modeling and quantitative assessment of live biomass of mountain spruce forests in Ukrainian Carpathians, the data from 265 temporary sample plots (TSP) were used, on which biometric assessment of 279 model trees was carried out with a fraction level live biomass assessment.

To model live biomass stocks of spruce stands in Ukrainian Carpathians within the scope of the research, we have used the ratio between the mass of individual fractions of live biomass (Ph_{fr}) and growing stock of a stand, i.e. biomass expansion factors. As a result, the product of the corresponding biomass expansion factors and growing stock of a stand allows to obtain quantitative values of its live biomass.

The general form of the mathematical model used to model the quantitative parameters of live biomass components of spruce stands in Ukrainian Carpathians is as follows[22]:

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

where R_v – relation of mass of separate live biomass fractions (stem, wood of crown branches, foliage, roots) to growing stock of a stand; 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.

The characteristics of model parameters for biomass expansion factors Rv of live biomass fractions in spruce stands are presented in Table 4.

All the investigated live biomass components are described by regression equations with a high level of approximation (R^2>0.75). Equations for root systems are characterized by multiple correlation relations that are somewhat lower, but significant at the 5% level.

[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 4

Parameters of equations of biomass expansion factors

Live biomass fractions	Parameters of equation						R^2
	a_0	a_1	a_2	a_3	a_4	a_5	
Stem over bark	1,0734	-0,3081	-0,0227	0,3650	0,0071	-0,2734	0,90
Bark	1,0166	-0,9320	0,2737	0,8947	0,0140	-1,2238	0,88
Branches	0,0890	-0,4277	0,3910	-0,5934	0,0005	0,3636	0,80
Foliage	0,0996	-0,3586	0,4828	-0,2916	-0,0015	-0,6799	0,79
Roots	3,0810	-0,5531	0,3699	0,6641	0,0053	-2,6127	0,75
Undergrowth, understorey	$5{,}30\cdot10^{-5}$	1,5008	2,1088	0,2923	-0,0050	-0,3740	0,47
Green forest floor	0,0057	0,7050	2,6234	1,3107	-0,0013	-3,3367	0,56

The dynamic trends of dependence of live biomass of stem over bark on growing stock of European spruce stands is similar to the *V*-shaped curve of change in basis density with age. At the same time, there is a clear differentiation of this ratio within the relative stocking of stands and an insignificant one by site index classes. As for the components of live biomass crowns, it is possible to trace the logical changes of the studied coefficients, namely the increase of their absolute values with the decrease of relative stocking and site index classes. That is, the share of components of crowns in the overall live biomass structure of low-stocked, low-productivity stands is higher compared to high-productivity, highly-stocked stands.

Quantitative values of live biomass of spruce stands in Ukrainian Carpathians were determined on the basis of the obtained model toolkit and the stand-level biometric characteristics of the studied forested areas (Table 5).

The variation of live biomass density of spruce stands features regional peculiarities. In Zakarpattia, the mentioned indicator is 19.2 $kg\cdot(m^2)^{-1}$, in Bukovyna – 17.2 $kg\cdot(m^2)^{-1}$, in Prykarpattia and in Lviv region – 17.1 and 15.9 $kg\cdot(m^2)^{-1}$, respectively.

As for the component structure, the share of live biomass of stem wood and bark is 60.4%. Live biomass of tree crowns in the overall structure of spruce forest plant communities occupies 13.8%, of which 8.4% is wood of branches over bark and 5.4% is foliage. The share of root systems is 25%, and only 0.7% is for understorey vegetation.

Table 5

Regional distribution of live biomass of spruce 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, $kg \cdot (m^2)^{-1}$
Zakarpattia	21.5	2.7	1.7	8.2	0.1	0.1	34.4	19.2
Ivano-Frankivsk	31.3	4.4	2.8	13.3	0.2	0.2	52.3	17.1
Lviv	8.9	1.4	0.9	4.0	0.04	0.1	15.3	15.9
Chernivtsi	7.9	1.2	0.8	3.4	0.04	0.04	13.3	17.2
Total	69.6	9.7	6.3	28.9	0.4	0.4	115.2	17.4

Normative and reference tables of dynamics of biological productivity serve as a scientific toolkit for forecasting biomass stocks of mountain spruce forests. They are built on a site index class basis using models of biomass expansion factors and mathematical dependencies of dynamics of the main biometric indices of spruce stands[23,24].

Fragments of the proposed normative and reference tables for pure and mixed natural and artificially created modal spruce stands in Ukrainian Carpathians of I^a site index class are presented in Tables 6, 7, 8, and 9.

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

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

Table 6

Dynamics of bioproductivity of pure spruce 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	7.1	1.2	1.9	1.2	10.2	4.1	14.3	0.03	0.1	14.5	26.9	2.80	4.04
20	29.4	3.4	6.5	4.3	40.2	13.2	53.4	0.1	0.2	53.7	88.4	4.60	6.96
30	60.2	5.7	11.6	7.7	79.4	22.9	102.4	0.2	0.3	102.8	172.4	5.00	8.94
40	93.4	7.9	16.0	10.4	119.8	31.1	150.8	0.2	0.3	151.4	270.7	4.68	10.14
50	125.7	9.9	19.3	12.3	157.4	37.0	194.4	0.3	0.3	195.0	377.1	4.10	10.80
60	154.6	11.7	21.9	14.0	190.6	44.0	234.5	0.4	0.4	235.3	492.1	3.77	11.67
70	180.5	13.3	23.8	15.2	219.5	49.9	269.3	0.5	0.4	270.2	611.1	3.27	11.98
80	203.7	14.8	25.0	15.9	244.6	55.0	299.6	0.5	0.5	300.6	732.1	2.86	12.14
90	224.8	16.3	25.7	16.3	266.8	59.5	326.3	0.6	0.5	327.4	854.1	2.55	12.22
100	244.3	17.9	26.1	16.5	286.9	63.5	350.4	0.7	0.5	351.6	976.0	2.33	12.17
110	263.5	19.5	26.1	16.3	305.9	66.2	372.1	0.7	0.6	373.4	1095.3	2.12	11.86
120	282.1	21.1	26.0	16.0	324.1	68.7	392.8	0.8	0.6	394.2	1212.9	2.05	11.72
130	300.6	23.0	25.8	15.7	342.0	71.0	413.1	0.9	0.6	414.6	1328.7	2.03	11.52
140	319.3	25.0	25.5	15.3	360.1	73.3	433.4	0.9	0.7	435.0	1442.5	2.01	11.32

Table 7

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

Age, years	Live biomass of a stand, $t \cdot ha^{-1}$										Total live biomass productivity, $t \cdot ha^{-1}$	Current annual increment of live biomass, $t \cdot ha^{-1} \cdot year^{-1}$	
	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	4.5	0.8	1.1	0.7	6.4	2.3	8.7	0.03	0.11	8.8	16.3	2.04	2.72
20	24.4	2.8	5.2	3.4	32.9	10.0	42.9	0.09	0.18	43.1	66.4	4.38	5.93
30	55.3	5.2	10.4	6.8	72.5	19.9	92.5	0.16	0.23	92.8	143.0	5.26	8.31
40	90.0	7.6	15.3	9.9	115.2	29.4	144.6	0.23	0.28	145.1	237.2	5.10	9.82
50	123.7	9.8	19.1	12.3	155.1	37.2	192.2	0.30	0.32	192.9	341.7	4.48	10.65
60	153.8	11.6	21.9	14.1	189.8	44.4	234.2	0.38	0.37	234.9	452.8	3.90	11.24
70	180.1	13.3	23.8	15.3	219.2	50.4	269.6	0.46	0.41	270.4	566.4	3.28	11.39
80	203.2	14.8	25.0	16.0	244.1	55.3	299.4	0.53	0.46	300.4	680.1	2.78	11.35
90	223.8	16.3	25.6	16.3	265.6	59.4	325.0	0.60	0.50	326.1	792.8	2.42	11.22
100	242.4	17.7	25.9	16.4	284.7	63.0	347.7	0.67	0.54	348.9	903.6	2.17	11.02
110	260.3	19.2	25.8	16.2	302.3	65.7	368.0	0.73	0.57	369.3	1011.1	1.98	10.67
120	277.6	20.8	25.7	15.9	319.1	68.1	387.3	0.80	0.61	388.7	1116.2	1.91	10.43
130	294.8	22.6	25.4	15.5	335.7	70.5	406.1	0.85	0.64	407.6	1218.7	1.89	10.18
140	312.1	24.5	25.1	15.2	352.3	72.8	425.1	0.91	0.67	426.7	1319.1	1.86	9.97

Table 8

Dynamics of bioproductivity of pure spruce stands of artificial origin (site index class I[a])

Age, years	Live biomass of a stand, $t \cdot ha^{-1}$										Total live biomass productivity, $t \cdot ha^{-1}$	Current annual increment of live biomass, $t \cdot ha^{-1} \cdot year^{-1}$	
	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	2.4	0.4	0.6	0.4	3.5	1.5	5.0	0.03	0.13	5.2	16.2	1.40	2.70
20	18.6	2.2	4.2	2.8	25.6	8.7	34.3	0.09	0.20	34.6	67.3	4.13	6.11
30	49.0	4.7	9.6	6.4	65.0	19.4	84.4	0.16	0.25	84.8	148.3	5.49	8.87
40	85.6	7.3	14.9	9.8	110.2	29.6	139.8	0.23	0.29	140.3	250.7	5.45	10.74
50	121.9	9.6	19.0	12.3	153.1	37.3	190.5	0.30	0.33	191.1	366.1	4.72	11.81
60	153.6	11.6	22.0	14.2	189.9	45.1	235.0	0.38	0.37	235.7	492.2	4.09	12.81
70	180.9	13.4	24.0	15.5	220.3	51.1	271.5	0.46	0.42	272.4	622.9	3.33	13.15
80	204.1	14.9	25.2	16.1	245.4	55.9	301.3	0.53	0.46	302.3	755.0	2.74	13.22
90	224.3	16.3	25.7	16.4	266.4	59.8	326.2	0.60	0.50	327.3	886.7	2.32	13.14
100	242.4	17.7	25.9	16.4	284.6	63.0	347.7	0.67	0.54	348.9	1016.8	2.05	12.94
110	259.6	19.2	25.7	16.1	301.4	65.3	366.6	0.73	0.57	367.9	1143.2	1.85	12.54
120	276.2	20.7	25.5	15.7	317.3	67.3	384.6	0.80	0.60	386.0	1266.6	1.78	12.26
130	292.6	22.4	25.1	15.3	333.0	69.2	402.2	0.85	0.64	403.7	1387.0	1.77	11.95
140	309.4	24.2	24.7	14.9	348.9	71.1	420.0	0.91	0.66	421.6	1504.5	1.75	11.66

Table 9

Dynamics of bioproductivity of mixed spruce 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	2.4	0.4	0.6	0.4	3.4	1.4	4.8	0.03	0.13	5.0	14.5	1.36	2.41
20	18.3	2.1	4.1	2.8	25.2	8.6	33.8	0.09	0.20	34.0	60.4	4.09	5.51
30	48.3	4.6	9.5	6.4	64.2	19.3	83.5	0.16	0.25	83.9	134.2	5.46	8.11
40	84.5	7.2	14.7	9.8	109.0	29.6	138.7	0.23	0.30	139.2	228.7	5.43	9.95
50	120.4	9.5	18.9	12.3	151.5	37.6	189.1	0.30	0.33	189.8	336.6	4.70	11.07
60	151.8	11.5	21.9	14.3	188.0	45.4	233.3	0.38	0.38	234.1	455.4	4.06	12.11
70	178.7	13.2	23.9	15.5	218.0	51.5	269.5	0.45	0.42	270.4	579.6	3.30	12.52
80	201.6	14.7	25.0	16.1	242.7	56.3	299.0	0.53	0.47	300.0	706.1	2.71	12.67
90	221.5	16.1	25.6	16.4	263.4	60.2	323.5	0.60	0.51	324.7	832.9	2.29	12.67
100	239.2	17.5	25.7	16.4	281.3	63.4	344.7	0.67	0.55	346.0	958.6	2.02	12.53
110	256.1	19.0	25.6	16.1	297.8	65.6	363.4	0.73	0.58	364.7	1081.4	1.82	12.20
120	272.5	20.5	25.3	15.7	313.5	67.6	381.1	0.80	0.61	382.5	1201.7	1.75	11.95
130	288.7	22.1	24.9	15.3	328.9	69.5	398.4	0.85	0.64	399.9	1319.3	1.74	11.68
140	305.1	23.9	24.6	14.9	344.5	71.4	416.0	0.91	0.67	417.5	1434.3	1.73	11.42

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

Net primary production (NPP) determines the peculiarities of bioproduction process and serves as an information basis for assessing carbon-sequestrative and oxygen-productive functions of forest plant communities. It also acts as an indicator of the environment's response to climate change[25]. Evaluation of net primary production of European spruce forests in Ukrainian Carpathians was carried out using the semi-empirical method proposed by A.Z. Shvidenko[26]. The approach has been approbated at the International Institute for Applied Systems Analysis (IIASA). The assessment results are presented in Table 10.

Table 10

Net primary production of European spruce 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**	
Conifers	2.49	0.58	1.98	2.41	0.23	0.53	8.24	895
including European spruce	1.68	0.37	1.21	1.71	0.16	0.24	5.38	840

Spruce stands in Ukrainian Carpathians produce about 5.4 million tons of organic matter annually, which on average is 840 g·(m^2)$^{-1}$·year^{-1}. This is more than 20% lower than the mean indicator for Ukrainian forests in general. At the same time, the density of NPP for coniferous tree species in the region (895 g·(m^2)$^{-1}$·year^{-1}) is slightly higher than the corresponding indicator for coniferous stands (835 g·(m^2)$^{-1}$·year^{-1}) for Ukraine.

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[25] 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.

[26] 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.

Assessment of indicators of trunk production of spruce stands in Ukrainian Carpathians can also be carried out by means of the following reference static materials (Tables 11–12).

The provided reference toolkit reflects the volumes of live biomass production based on the current growing stock of a stand over bark. The indicators of production of stems are displayed in the tables depending on mean height of a stand (*H*), mean diameter of a stand (*D*) and mean width of an annual ring.

The reference values of trunk production of European spruce stands are provided in tons per 1 m^2 of total basal area of a stand (*G*). To determine trunk production of a particular stand, the corresponding table value shall be multiplied by the actual basal area of the stand.

Table 11

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

H, м	D, см	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
3.0	3.0	0.0160	0.0481	0.0802	0.1123	0.1284	0.1444
3.0	4.0	0.0116	0.0347	0.0579	0.0810	0.0926	0.1158
3.0	5.0	0.0090	0.0269	0.0449	0.0628	0.0718	0.0897
4.0	4.0	0.0172	0.0515	0.0858	0.1201	0.1373	0.1716
4.0	5.0	0.0133	0.0399	0.0665	0.0931	0.1063	0.1329
4.0	6.0	0.0108	0.0323	0.0538	0.0754	0.0861	0.1077
5.0	4.0	0.0233	0.0699	0.1164	0.1630	0.1863	0.2329
5.0	6.0	0.0146	0.0438	0.0730	0.1022	0.1169	0.1461
5.0	8.0	0.0104	0.0312	0.0521	0.0729	0.0833	0.1042
6.0	6.0	0.0187	0.0562	0.0937	0.1312	0.1499	0.1874
6.0	8.0	0.0133	0.0401	0.0668	0.0935	0.1069	0.1336
6.0	10.0	0.0102	0.0307	0.0511	0.0715	0.0817	0.1124
7.0	7.0	0.0193	0.0579	0.0966	0.1352	0.1545	0.1931
7.0	9.0	0.0143	0.0430	0.0716	0.1002	0.1146	0.1432
7.0	12.0	0.0101	0.0302	0.0504	0.0705	0.0806	0.1008
8.0	10.0	0.0151	0.0454	0.0756	0.1058	0.1210	0.1512
8.0	12.0	0.0121	0.0363	0.0604	0.0846	0.0967	0.1209
8.0	14.0	0.0100	0.0299	0.0498	0.0698	0.0797	0.0997
9.0	10.0	0.0178	0.0533	0.0888	0.1243	0.1421	0.1776
9.0	12.0	0.0142	0.0426	0.0710	0.0993	0.1135	0.1419
9.0	14.0	0.0117	0.0351	0.0585	0.0819	0.0936	0.1170
10.0	10.0	0.0205	0.0615	0.1025	0.1435	0.1640	0.2050
10.0	12.0	0.0164	0.0492	0.0819	0.1147	0.1311	0.1638
10.0	14.0	0.0132	0.0405	0.0675	0.0945	0.1081	0.1351
10.0	16.0	0.0114	0.0342	0.0570	0.0797	0.0912	0.1139
12.0	10.0	0.0263	0.0789	0.1314	0.1840	0.2103	0.2629
12.0	12.0	0.0210	0.0630	0.1050	0.1470	0.1680	0.2100

Continuation of Table 11

1	2	3	4	5	6	7	8
12.0	16.0	0.0146	0.0438	0.0730	0.1022	0.1168	0.1460
12.0	18.0	0.0125	0.0376	0.0627	0.0878	0.1003	0.1254
14.0	14.0	0.0214	0.0641	0.1068	0.1495	0.1709	0.2136
14.0	16.0	0.0180	0.0540	0.0901	0.1261	0.1441	0.1801
14.0	18.0	0.0155	0.0464	0.0773	0.1083	0.1237	0.1546
14.0	20.0	0.0135	0.0404	0.0673	0.0943	0.1077	0.1346
16.0	16.0	0.0216	0.0648	0.1080	0.1512	0.1728	0.2160
16.0	18.0	0.0185	0.0556	0.0927	0.1298	0.1484	0.1855
16.0	20.0	0.0161	0.0484	0.0646	0.1130	0.1292	0.1614
16.0	22.0	0.0142	0.0427	0.0711	0.0996	0.1138	0.1422
16.0	24.0	0.0127	0.0379	0.0632	0.0885	0.1012	0.1265
18.0	18.0	0.0218	0.0653	0.1088	0.1524	0.1741	0.2177
18.0	20.0	0.0190	0.0569	0.0947	0.1326	0.1516	0.1895
18.0	22.0	0.0167	0.0501	0.0835	0.1168	0.1335	0.1669
18.0	24.0	0.0148	0.0445	0.0742	0.1039	0.1187	0.1484
18.0	26.0	0.0133	0.0399	0.0665	0.0931	0.1064	0.1331
20.0	16.0	0.0293	0.0878	0.1463	0.2049	0.2342	0.2927
20.0	20.0	0.0219	0.0656	0.1094	0.1531	0.1750	0.2187
20.0	24.0	0.0171	0.0514	0.0856	0.1199	0.1370	0.1712
20.0	30.0	0.0126	0.0378	0.0629	0.0881	0.1007	0.1258
22.0	16.0	0.0333	0.1000	0.1666	0.2333	0.2666	0.3333
22.0	20.0	0.0249	0.0747	0.1245	0.1743	0.1992	0.2490
22.0	24.0	0.0195	0.0585	0.0975	0.1365	0.1560	0.1949
22.0	28.0	0.0158	0.0473	0.0789	0.1104	0.1262	0.1577
22.0	32.0	0.0131	0.0392	0.0654	0.0778	0.1046	0.1308
22.0	36.0	0.0110	0.0331	0.0552	0.0773	0.0883	0.1105
24.0	24.0	0.0219	0.0658	0.1097	0.1536	0.1755	0.2194
24.0	28.0	0.0178	0.0533	0.0888	0.1243	0.1420	0.1775
24.0	32.0	0.0147	0.0441	0.0736	0.1030	0.1177	0.1472
24.0	36.0	0.0124	0.0373	0.0621	0.0870	0.0994	0.1243
24.0	40.0	0.0107	0.0320	0.0533	0.0746	0.0852	0.1065
24.0	44.0	0.0093	0.0277	0.0462	0.0647	0.0739	0.0924
26.0	24.0	0.0245	0.0734	0.1223	0.1712	0.1957	0.2446
26.0	28.0	0.0198	0.0594	0.0989	0.1385	0.1583	0.1979
26.0	32.0	0.0164	0.0492	0.0820	0.1148	0.1312	0.1641
26.0	36.0	0.0139	0.0416	0.0693	0.0970	0.1108	0.1385
26.0	40.0	0.0119	0.0356	0.0594	0.0831	0.0986	0.1233
26.0	44.0	0.0103	0.0309	0.0515	0.0721	0.0824	0.1030
26.0	48.0	0.0090	0.0271	0.0451	0.0632	0.0722	0.0902
26.0	52.0	0.0080	0.0239	0.0398	0.0558	0.0638	0.0797
26.0	56.0	0.0071	0.0213	0.0355	0.0496	0.0567	0.0709
28.0	28.0	0.0219	0.0657	0.1094	0.1532	0.1751	0.2189
28.0	34.0	0.0166	0.0499	0.0832	0.1164	0.1331	0.1664
28.0	40.0	0.0131	0.0394	0.0656	0.0919	0.1050	0.1313
28.0	46.0	0.0106	0.0319	0.0532	0.0745	0.0852	0.1065
28.0	50.0	0.0094	0.0281	0.0468	0.0656	0.0749	0.0937
28.0	56.0	0.0078	0.0235	0.0392	0.0549	0.0627	0.0784

End of the table 11

1	2	3	4	5	6	7	8
28.0	62.0	0.0066	0.0200	0.0332	0.0465	0.0532	0.0665
30.0	28.0	0.0240	0.0721	0.1202	0.1683	0.1923	0.2404
30.0	34.0	0.0183	0.0548	0.0913	0.1279	0.1461	0.1827
30.0	40.0	0.0144	0.0432	0.0721	0.1009	0.1153	0.1442
30.0	46.0	0.0117	0.0351	0.0584	0.0818	0.0935	0.1169
30.0	50.0	0.0103	0.0309	0.0514	0.0720	0.0823	0.1029
30.0	56.0	0.0086	0.0258	0.0430	0.0602	0.0688	0.0861
30.0	62.0	0.0073	0.0219	0.0365	0.0511	0.0584	0.0730
34.0	34.0	0.0216	0.0649	0.1083	0.1515	0.1732	0.2165
34.0	40.0	0.0171	0.0513	0.0854	0.1196	0.1367	0.1708
34.0	46.0	0.0139	0.0416	0.0692	0.0970	0.1108	0.1385
34.0	52.0	0.0115	0.0344	0.0573	0.0802	0.0917	0.1146
34.0	58.0	0.0096	0.0289	0.0482	0.0675	0.0771	0.0964
34.0	64.0	0.0082	0.0246	0.0410	0.0574	0.0656	0.0820
34.0	70.0	0.0071	0.0212	0.0353	0.0494	0.0565	0.0706
38.0	40.0	0.0198	0.0596	0.0993	0.1390	0.1589	0.1986
38.0	46.0	0.0161	0.0483	0.0805	0.1127	0.1288	0.1611
38.0	52.0	0.0133	0.0400	0.0666	0.0933	0.1066	0.1333
38.0	58.0	0.0112	0.0336	0.0560	0.0784	0.0896	0.1120
38.0	64.0	0.0095	0.0286	0.0477	0.0668	0.0763	0.0954
38.0	70.0	0.0082	0.0246	0.0410	0.0574	0.0656	0.0820
38.0	76.0	0.0071	0.0213	0.0356	0.0498	0.0569	0.0711
42.0	58.0	0.0128	0.0385	0.0642	0.0898	0.1026	0.1283
42.0	64.0	0.0109	0.0327	0.0546	0.0764	0.0874	0.1092
42.0	70.0	0.0094	0.0282	0.0470	0.0657	0.0751	0.0939
42.0	76.0	0.0082	0.0244	0.0407	0.0570	0.0652	0.0814
42.0	82.0	0.0071	0.0213	0.0355	0.0498	0.0569	0.0711

For practical application of reference tables the width of an annual growth ring shall be calculated as the arithmetic mean of measurements of the annual growth ring widths for 25–30 meters high trees in the range of diameter of ± 2–4 cm. The measurements shall be carried out using an increment borer[27].

The proposed reference materials also serve as a toolkit for assessing the volumes of sequestered carbon and produced oxygen that are functionally linked with volumes of organic matter production in stem wood.

[27] Vasylyshyn R.D., Lakyda I.P. Biomass and primary production of European beech (Fagus sylvatica L.) stands in Ukrainian Carpathians. *New impulses for the development of natural sciences in Ukraine and EU countries:* Collective monograph. Riga, Latvia: Baltija Publishing, 2021. P. 1–28. DOI https://doi.org/10.30525/978-9934-26-141-1-1.

Table 12

Production of stems of European spruce stands in Ukrainian Carpathians (2.4–4.2). tons·$(m^2G)^{-1}$

H. м	D. см	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
3.0	5.0	0.1076	–	–	–	–	–
4.0	4.0	0.2059	–	–	–	–	–
4.0	5.0	0.1595	0.1861	0.1994	–	–	–
4.0	6.0	0.1292	0.1507	0.1615	–	–	–
5.0	4.0	0.2795	0.3260	0.3493	–	–	–
5.0	6.0	0.1753	0.2045	0.2191	0.2483	–	–
5.0	8.0	0.1250	0.1458	0.1562	0.1771	0.1979	0.2187
6.0	6.0	0.2249	0.2624	0.2811	0.3186	0.3561	0.3935
6.0	8.0	0.1603	0.1870	0.2004	0.2271	0.2538	0.2805
6.0	10.0	0.1226	0.1430	0.1532	0.1737	0.1941	0.2145
7.0	7.0	0.2318	0.2704	0.2897	0.3283	0.3669	0.4056
7.0	9.0	0.1718	0.2004	0.2148	0.2434	0.2721	0.3007
7.0	12.0	0.1209	0.1411	0.1512	0.1713	0.1914	0.2116
8.0	10.0	0.1815	0.2117	0.2268	0.2571	0.2873	0.3176
8.0	12.0	0.1450	0.1692	0.1813	0.2055	0.2297	0.2538
8.0	14.0	0.1196	0.1395	0.1495	0.1694	0.1893	0.2093
9.0	10.0	0.2131	0.2486	0.2664	0.3019	0.3374	0.3729
9.0	12.0	0.1703	0.1987	0.2129	0.2412	0.2696	0.2980
9.0	14.0	0.1404	0.1638	0.1755	0.1989	0.2223	0.2457
10.0	10.0	0.2460	0.2870	0.3075	0.3485	0.3895	0.4306
10.0	12.0	0.1966	0.2294	0.2458	0.2785	0.3113	0.3440
10.0	14.0	0.1621	0.1891	0.2026	0.2296	0.2566	0.2836
10.0	16.0	0.1367	0.1595	0.1709	0.1937	0.2165	0.2393
12.0	10.0	0.3155	0.3681	0.3944	0.4469	0.4995	0.5521
12.0	12.0	0.2520	0.2941	0.3151	0.3571	0.3991	0.4411
12.0	16.0	0.1752	0.2044	0.2190	0.2482	0.2774	0.3066
12.0	18.0	0.1504	0.1755	0.1881	0.2122	0.2382	0.2633
14.0	14.0	0.2563	0.2990	0.3204	0.3631	0.4058	0.4485
14.0	16.0	0.2161	0.2522	0.2702	0.3062	0.3422	0.3783
14.0	18.0	0.1856	0.2165	0.2320	0.2629	0.2938	0.3247
14.0	20.0	0.1616	0.1885	0.2020	0.2289	0.2558	0.2827
16.0	16.0	0.2592	0.3024	0.3240	0.3673	0.4105	0.4537
16.0	18.0	0.2225	0.2596	0.2782	0.3152	0.3523	0.3894
16.0	20.0	0.1937	0.2260	0.2422	0.2745	0.3068	0.3390
16.0	22.0	0.1707	0.1991	0.2133	0.2418	0.2702	0.2986
16.0	24.0	0.1517	0.1771	0.1897	0.2150	0.2403	0.2656
18.0	18.0	0.2612	0.3047	0.3265	0.3700	0.4136	0.4571
18.0	20.0	0.2274	0.2653	0.2842	0.3222	0.3601	0.3980
18.0	22.0	0.2003	0.2336	0.2504	0.2837	0.3171	0.3505
18.0	24.0	0.1781	0.2078	0.2226	0.2523	0.2820	0.3117
18.0	26.0	0.1597	0.1863	0.1996	0.2262	0.2528	0.2794
20.0	16.0	0.3513	0.4098	0.4390	0.4976	0.5561	0.6147
20.0	20.0	0.2624	0.3062	0.3280	0.3718	0.4155	0.4593

Continuation of Table 12

1	2	3	4	5	6	7	8
20.0	24.0	0.2055	0.2398	0.2569	0.2911	0.3254	0.3597
20.0	30.0	0.1510	0.1762	0.1888	0.2139	0.2391	0.2643
22.0	16.0	0.3999	0.4666	0.4999	0.5665	0.6332	0.6998
22.0	20.0	0.2988	0.3485	0.3734	0.4233	0.4730	0.5228
22.0	24.0	0.2339	0.2729	0.2924	0.3314	0.3704	0.4094
22.0	28.0	0.1893	0.2208	0.2366	0.2681	0.2997	0.3312
22.0	32.0	0.1569	0.1831	0.1961	0.2223	0.2484	0.2746
22.0	36.0	0.1325	0.1546	0.1657	0.1878	0.2098	0.2319
24.0	24.0	0.2633	0.3072	0.3291	0.3730	0.4169	0.4608
24.0	28.0	0.2130	0.2485	0.2663	0.3018	0.3373	0.3728
24.0	32.0	0.1766	0.2060	0.2207	0.2502	0.2796	0.3090
24.0	36.0	0.1491	0.1740	0.1864	0.2113	0.2361	0.2610
24.0	40.0	0.1278	0.1491	0.1598	0.1811	0.2024	0.2237
24.0	44.0	0.1109	0.1294	0.1386	0.1571	0.1756	0.1941
26.0	24.0	0.2935	0.3425	0.3669	0.4159	0.4648	0.5137
26.0	28.0	0.2375	0.2771	0.2968	0.3364	0.3760	0.4156
26.0	32.0	0.1968	0.2297	0.2461	0.2789	0.3117	0.3445
26.0	36.0	0.1663	0.1939	0.2078	0.2355	0.2632	0.2909
26.0	40.0	0.1479	0.1726	0.1781	0.2019	0.2256	0.2494
26.0	44.0	0.1236	0.1442	0.1545	0.1751	0.1957	0.2163
26.0	48.0	0.1083	0.1263	0.1353	0.1534	0.1714	0.1895
26.0	52.0	0.0956	0.1116	0.1195	0.1355	0.1514	0.1674
26.0	56.0	0.0851	0.0992	0.1064	0.1205	0.1347	0.1489
28.0	28.0	0.2626	0.3064	0.3283	0.3721	0.4158	0.4596
28.0	34.0	0.1996	0.2329	0.2495	0.2828	0.3161	0.3493
28.0	40.0	0.1576	0.1838	0.1969	0.2232	0.2494	0.2757
28.0	46.0	0.1278	0.1491	0.1597	0.1810	0.2023	0.2236
28.0	50.0	0.1124	0.1311	0.1405	0.1592	0.1780	0.1967
28.0	56.0	0.0940	0.1097	0.1176	0.1333	0.1489	0.1646
28.0	62.0	0.0798	0.0931	0.0997	0.1130	0.1263	0.1396
30.0	28.0	0.2884	0.3365	0.3605	0.4086	0.4567	0.5048
30.0	34.0	0.2192	0.2558	0.2740	0.3106	0.3471	0.3836
30.0	40.0	0.1730	0.2018	0.2156	0.2451	0.2739	0.3028
30.0	46.0	0.1403	0.1637	0.1753	0.1987	0.2221	0.2455
30.0	50.0	0.1234	0.1440	0.1543	0.1749	0.1954	0.2160
30.0	56.0	0.1033	0.1205	0.1291	0.1463	0.1635	0.1807
30.0	62.0	0.0876	0.1022	0.1095	0.1241	0.1387	0.1533
34.0	34.0	0.2598	0.3031	0.3247	0.3680	0.4114	0.4546
34.0	40.0	0.2050	0.2391	0.2562	0.2904	0.3246	0.3588
34.0	46.0	0.1662	0.1939	0.2078	0.2355	0.2632	0.2909
34.0	52.0	0.1375	0.1605	0.1719	0.1949	0.2178	0.2407
34.0	58.0	0.1157	0.1349	0.1445	0.1638	0.1831	0.2024
34.0	64.0	0.0985	0.1149	0.1231	0.1395	0.1559	0.1723
34.0	70.0	0.0847	0.0988	0.1058	0.1200	0.1341	0.1482
38.0	40.0	0.2384	0.2781	0.2980	0.3377	0.3774	0.4171
38.0	46.0	0.1933	0.2255	0.2416	0.2738	0.3060	0.3382
38.0	52.0	0.1599	0.1866	0.1999	0.2265	0.2532	0.2798

End of the table 12

1	2	3	4	5	6	7	8
38.0	58.0	0.1344	0.1568	0.1680	0.1904	0.2129	0.2353
38.0	64.0	0.1144	0.1335	0.1431	0.1621	0.1812	0.2003
38.0	70.0	0.0984	0.1148	0.1230	0.1395	0.1559	0.1723
38.0	76.0	0.0853	0.0996	0.1067	0.1209	0.1352	0.1494
42.0	40.0	0.1539	0.1796	0.1924	0.2181	0.2438	0.2694
42.0	46.0	0.1311	0.1529	0.1638	0.1857	0.2075	0.2293
42.0	52.0	0.1127	0.1315	0.1409	0.1597	0.1784	0.1972
42.0	58.0	0.0977	0.1140	0.1222	0.1385	0.1547	0.1710
42.0	64.0	0.0853	0.0996	0.1066	0.1209	0.1351	0.1493

CONCLUSIONS

The priority of ecological functions performance at the level of forest ecosystems in Ukrainian Carpathians requires the formation of a system of reference and information support, which will serve as a basis for making managerial decisions to organize economic activity based on the principles of ecosystems management and sustainable development. Quantitative assessment of biomass stocks and volumes of primary production, and the development of relevant reference basis for spruce stands of the research region are an integral part of the regional complex of forestry information support.

As a result of this research, we have established that European spruce stands in Ukrainian Carpathians occupy an area of more than 590,000 hectares and feature a total growing stock of nearly 200 million m^3. More than 45% of spruce stands with a growing stock of nearly 90 million m^3 are concentrated in the territory of Ivano-Frankivsk region. Another 25% are located in Zakarpattia region. In general, European spruce stands in Ukrainian Carpathians occupy almost a third of the area covered by forest vegetation. The region features highly-productive, mid-aged, medium-stocked stands, which often grow in moist, fairly fertile conditions. More than 60% of spruce stands are of artificial origin.

More than 115 million tons of biomass have been accumulated in spruce stands of the research region. Its density in the region is more than 17 $kg \cdot (m^2)^{-1}$. In Zakarpattia region, the mentioned indicator is 19.2 $kg \cdot (m^2)^{-1}$, in Bukovyna – 17.2 $kg \cdot (m^2)^{-1}$, in Prykarpattia and Lviv region – 17.1 and 15.9 $kg \cdot (m^2)^{-1}$, respectively.

Net primary production of European spruce stands in the region exceeds 5 million tons of organic matter per annuum. The density of net primary production of the researched stands in Ukrainian Carpathians is 840 $g \cdot (m^2)^{-1} \cdot year^{-1}$, which is more than 20% lower than the mean indicator for Ukrainian forests in general. In order to assess the volumes of net primary production, static tables of stem production and reference materials of net primary production dynamics for spruce stands of various origins are proposed in the research.

SUMMARY

Environmentalisation of forest mensuration science necessitates the formation of new approaches to accounting of forest resources, focusing on intangible resources, represented by ecosystem functions of forests. To manage them on the basis of sustainable development, it is necessary to provide information that reflects their quantitative characteristics and provides an opportunity to expand basic environmental knowledge about the role of forests in human life.

In the course of this study, an analytical assessment of silvicultural characteristics of European spruce forests in Ukrainian Carpathians has been carried out, which made it possible to single out a set of biometric factors that determine the intensity of bioproduction process in forest plant communities and enable prediction of the volume of biomass and net primary production.

As a result of the research, quantitative indicators of live biomass and net primary production of spruce forests were established as components of their biological productivity. Reference and information support are also proposed for assessing and forecasting indicators of biomass and production of spruce stands in Ukrainian Carpathians in statics and dynamics. The results will serve as an information basis for organizing close-to-nature silviculture in mountain forests on the basis of ecosystem management.

BIBLIOGRAPHY

1. Генсірук С.А. Ліси Українських Карпат та їх використання. Київ : Урожай, 1964. 290 с.
2. Голубець М.А. Проблеми сталого розвитку в Карпатському регіоні. *Зелені Карпати*. 2007. № 1–2 (25–26). С. 1–6.
3. Калуцький І.Ф. Вітровали на північно-східному макросхилі в Українських Карпатах. Монографія. Львів : Манускрипт, 1998. 204 с.
4. Олійник В.С. Категорії пошкоджень ґрунту під час лісозаготівель у Карпатах. *Лісівництво і агролісомеліорація*. 2004. Вип. 107. С. 75–78.
5. Олійник В.С. Методичні особливості вивчення і оцінки гідрологічної ролі гірських лісів Карпат. *Науковий вісник Національного аграрного університету*. 2000. Вип. 25. С. 159–166.
6. Смаглюк К.К. Оценка экологических последствий хозяйственного преобразования горных лесов Карпат. Лесоведение. 1978. № 2. С. 3–9.
7. Стойко С.М. Наслідки антропогенної трансформації лісових екосистем Карпат та шляхи елімінації шкідливих екологічних процесів. *Український ліс*. 1993. № 2. С. 11–17.

8. Стойко С.М. Причини катастрофічних паводків у Закарпатті та системи екологічних профілактичних заходів їх попередження. *Український ботанічний журнал*. 2000. Т. 57, № 1. С. 11–20.

9. Парпан В.І. Концептуальні засади гірського лісознавства та лісівництва. *Науковий вісник Національного лісотехнічного університету України*. 2013. Вип. 23.5. С. 22–28.

10. Лакида П.І., Бокоч В.В., Василишин Р.Д., Терентьєв А.Ю. Біопродуктивність лісових фітоценозів Карпатського національного природного парку. Монографія. Корсунь-Шевченківський : ФОП Гавришенко В. М., 2015. 154 с.

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

12. Parpan T. V. Bioecological principles of maintaining stability in mountain forest ecosystems of the Ukrainian Carpathians. *Visnyk of Dnipropetrovsk university-biology ecology*. 2016. Vol. 24 (2). P. 371–377.

13. Spracklen B. D, Spracklen D. V. Identifying European Old-Growth Forests using Remote Sensing: A Study in the Ukrainian Carpathians. *Forests*. 2019. Vol. 10 (2). DOI 10.3390/f10020127.

14. Spracklen B., Spracklen D. Determination of Structural Characteristics of Old-Growth Forest in Ukraine Using Spaceborne LiDAR. *Remote Sensing*. 2021. Vol. 13 (7). DOI 10.3390/rs13071233.

15. Ivanenko Y., Lobchenko G., Maliuha V., Yukhnovskyi V. Spruce forest litter structure, distribution, and water retention along hiking trails in the Ukrainian Carpathians. *Journal of Forest Science*. 2022. Vol. 68 (7). P. 241–252. DOI 10.17221/12/2022-JFS.

16. Василишин Р.Д. Еколого-енергетичний потенціал лісів Українських Карпат та його стале використання. Монографія. Київ : ТОВ »ЦП «Компринт», 2018. 303 с.

17. Kruhlov I., Thom D., Chaskovskyy O., Keeton W., Scheller R. Future forest landscapes of the Carpathians: vegetation and carbon dynamics under climate change. *Regional Environmental Change*. 2018. Vol. 18(5). P. 1555–1567. DOI 10.1007/s10113-018-1296-8.

18. Василишин Р.Д., Слюсарчук В.В., Лакида І.П., Терентьєв А.Ю. Букові деревостани Буковинського Передкарпаття: особливості росту та енергетичний потенціал. Монографія. Житомир : ТОВ »Видавничий дім «Бук-Друк», 2021. 168 с.

19. Василишин Р.Д. Нормативно-довідкові матеріали для оцінювання екосистемних функцій лісів Українських Карпат. Довідник. Житомир : ТОВ «Видавничий дім «Бук-Друк», 2021. 224 с.

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.

21. Дебринюк Ю.М. Розповсюдження та формова різноманітність *Picea abies* [L.] Karst. *Науковий вісник НЛТУ України*. 2008. Вип. 18.2. С. 7–17.

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.

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

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

25. 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.

26. 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.

27. Vasylyshyn R.D., Lakyda I.P. Biomass and primary production of European beech (Fagus sylvatica L.) stands in Ukrainian Carpathians. *New impulses for the development of natural sciences in Ukraine and EU countries:* Collective monograph. Riga, Latvia: Baltija Publishing, 2021. P. 1–28. DOI https://doi.org/10.30525/978-9934-26-141-1-1.

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