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BIOMASS AND PRIMARY PRODUCTION OF SILVER FIR STANDS IN UKRAINIAN CARPATHIANS

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INTRODUCTION

The current state and structure of forests in the Carpathian mountains, the existing scale of anthropogenic changes caused by the peculiarities of use of wood resources indicate the need for new approaches to forest management in Ukrainian Carpathians. In this direction, the concept of "close to nature forestry" deserves attention[1].

One of the most valuable native species of Ukraine, in particular its Carpathian region, is silver fir. According to P. S. Pasternak[2], silver fir is characterized by the highest intensity of biological cycling between forest stands and soil, being marked by the most favorable ratio of chemical elements in terms of their return to the soil, as compared to the main forest-forming tree species of the Carpathian region.

The formation of mixed fir-spruce and fir-beech stands favorably affects the biochemical processes occurring in the soil, the course of natural regeneration, the formation of powerful root systems and significantly increases the resistance of these stands against strong winds[3, 4]. According to M. A. Holubets[5], in the forestry of the Carpathian region, silver fir should be regarded as the most promising coniferous species, and its restoration in the stands of the region will strengthen the stability of Norway spruce stands and increase forest productivity[6].

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Scientific research of fir stands is quite common in the European scientific space. Thus, over the past 20 years, Polish researchers have carried out studies to determine the impact of various environmental factors on the natural regeneration of silver fir in the highlands and mountains[7, 8]. European researchers also focus on the variability of fir stands within Central Europe[9] and intraspecific differences in the structure of silver fir wood in the Ukrainian Carpathians[10].

In the context of global climate change, the issues of studying the resistance of fir stands[11, 12] to adverse environmental conditions and growth characteristics in conditions of moisture deficit are of particular relevance[13, 14].

In particular, scientists note significant drought resistance of fir stands, which allows to consider silver fir as a promising species for the reforestation efforts in mountain forests in the face of climate change[15, 16].

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In this context, studies of ecosystem functions of fir stands are of particular relevance, indicators of primary production serve as the information basis for assessing selected functions.

1. Silvicultural and biometric characteristics of Silver fir stands in Ukrainian Carpathians

Silvicultural characteristics of Silver fir stands is based on the information from the relational database "Stand Level Biometric Characteristics of Forests" run by the Ukrainian State Forest Management Planning Association IA "Ukrderzhlisproekt"[17].

Silver fir (Abies alba Mill.) is a typical Central European species, demanding to air and soil moisture. The optimal conditions for its growth are feature humid soils. Carpathian fir stands in the forests of Ukraine are a rare element of Central European flora. They are of great ecological, social and economic importance[18, 19].

According to the current state forest account of Ukraine, the share of fir stands is 6.4 % of the total area of forest covered land in Ukrainian Carpathians and 6.5 % of their total growing stock (Table 1).

Table 1

Distribution of quantitative characteristics of Silver fir stands by administrative regions

Administrative region	Number of stands	Area, thou. ha	Growing stock, Mio m3
Zakarpattia	1999	10.2	3.8
Ivano-Frankivsk	9554	33.5	8.3
Lviv	13657	50.9	14.2
Chernivtsi	6454	35.1	9.7
Total	31664	129.7	36.0

Age structure of the Silver fir stands is presented in Table 2.

Currently, Ukrainian Carpathians are dominated by young and mid-aged fir stands, the share of which is 37.5 % and 29.3 % respectively. These are stands of natural origin, among which 95 % are mixed and 5 % are pure stands.

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Table 2

Distribution of quantitative characteristics of Silver fir 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	468.0 / 5.9	1251.9 / 13.5	1096.1 / 13.1	3845.2 / 34.9	6661.2 / 67.4
II	1219.3 / 69.8	5866.7 / 182.2	5818.3 / 210.7	5035.4 / 167.1	17939.7 / 629.8
III	1237.0 / 174.2	3824.9 / 388.5	6196.2 / 711.9	3015.9 / 342.5	14274 / 1617.1
IV	1104.6 / 278.5	2310.4 / 494.7	4810.7 / 882.5	1984.6 / 447.2	10210.3 / 2102.9
V	489.3 / 166.3	2212.8 / 687.6	4458.2 / 1264.5	1011.1 / 323.7	8171.4 / 2442.1
VI	336.8 / 152.1	3101.2 / 1071.5	4722.7 / 1651.1	1016.8 / 372.8	9177.5 / 3247.5
VII	363.9 / 183.8	2783.2 / 951.2	5160.3 / 1938.0	951.4 / 408.5	9258.8 / 3481.5
VIII	307.3 / 155.9	2682.4 / 1000.0	5210.5 / 2056.5	1647.4 / 660.3	9847.6 / 3872.7
IX	396.0 / 214.0	3044.9 / 1044.0	4820.3 / 1827.0	3927.4 / 1524.6	12188.6 / 4609.6
X	463.7 / 258.3	1866.0 / 670.7	2862.2 / 1139.5	4979.3 / 2072.6	10171.2 / 4141.1
XI	519.8 / 306.1	1375.4 / 507.4	2018.2 / 856.5	4733.0 / 2067.7	8646.4 / 3737.7
XII	609.9 / 341.0	878.1 / 354.6	1505.0 / 626.0	1694.8 / 765.9	4687.8 / 2087.5
XIII	405.5 / 223.5	1043.1 / 393.9	1036.8 / 449.8	842.9 / 387.9	3328.3 / 1455.1
XIV and older	2302.3 / 1235.6	1249.1 / 513.4	1233.2 / 592.3	364.6 / 170.9	5149.2 / 2512.2
Total	10223.4 / 3764.9	33490.1 / 8273.1	50948.7 / 14219.5	35049.8 / 9746.8	129712 / 36004.3

As already mentioned, white fir has suffered from human activity more than any other native forest-forming species during a long historical period.

While the area under spruce forests intensively increased, the natural distribution of fir in the forests of the region was catastrophically reduced. The most significant losses of fir stands occurred in the post-war years. According to literature data, in the period from 1947 to 1956 the area of fir stands decreased by 38.8 %, and in the period 1956–1965 it decreased by 47.3 thousand hectares[20].

The main reason for the decrease of share of fir in the Carpathian forests was clearcutting, which destroyed the undergrowth formed under the canopy of mother trees. On the clearcuts there were conditions in which silver fir could not naturally regrow due to its bio-ecological features. Thus, widespread introduction of clear-cutting in the practice of forestry in the Carpathians has led to the widespread replacement of indigenous, mixed with fir oak, beech and spruce stands with derivatives, pure or mixed, quite often with secondary species[21].

The replacement of indigenous stands with derivatives was accompanied not only by a decrease in the biological sustainability of forests, but also by a decrease in the intensity of the cycle of substances in the forest-soil system, a decrease in the productivity of stands, as well as the loss of diversity of industrial assortments.

The main indicator of forest productivity, according to the majority of forest scientists, is their site index class. The mean site index class of the Carpathian fir stands is I.2, which characterizes them as highly productive ones. Currently, the region is dominated by fir stands of I^a and I site index classes, which cover 77.4 % of the area of fir stands. In general, 17.0 % of the stands are characterized by II site index class, almost 2.5 % feature I^b and higher classes and less than 1 % are of IV and lower site index classes.

Like Norway spruce, silver fir in Ukrainian Carpathians acts as forest-forming species only in fairly fertile and fertile conditions. 99.9 % of the area of fir stands is concentrated in these site fertility classes (Table 3).

The region is dominated by fir stands with relative stocking of 0.7 (25.6 %). By mean biometric indices, fir stands are somewhat inferior to spruce stands. In particular, they are characterized by a lower mean growing stock per 1 ha of forest covered land (278 m^3 against 337 m^3) and relative stocking (0.67 against 0.69).

In general, silver fir forms stands dominated by this species, as well as serves as an admixture in stands dominated by other species. This increases their biological stability and productivity. Fir stands are mainly highly productive, mid-aged, medium-stocked stands of natural origin, which often grow in humid, fairly fertile conditions.

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[21] Василишин Р. Д. Хід росту повних ялицевих деревостанів Українських Карпат. *Науковий вісник Національного лісотехнічного університету*. 2013. Вип. 23.6. С. 87–92.

Table 3

Distribution of area of Silver fir 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 fertile site types					
Zakarpattia	4024.2	6.4	4017.8	–	–
Ivano-Frankivsk	30206.8	231.2	25371.0	580.4	–
Lviv	28790.2	879.4	27860.5	50.3	–
Chernivtsi	19099.3	288.8	18741.8	68.7	–
fertile site types					
Zakarpattia	6199.2	24.4	6174.8	–	–
Ivano-Frankivsk	7247.9	86.5	7152.8	8.6	–
Lviv	22158.5	114.5	21980.7	63.3	–
Chernivtsi	15916.2	179.2	15635.5	101.5	–
total within the region					
Fairly infertile site types	93.9	–	93.9	–	–
Fairly fertile site types	78096.3	1405.8	75991.1	699.4	–
Fertile site types	51521.8	404.6	50943.8	173.4	–

2. Potential of biomass of mountain fir forests

The base and one of the most important indicators for assessing bioproductivity and carbon budget of forest plant communities is their biomass. This is a quantitative characteristic of a stand, which is not measured during practical mensuration directly in the forest, but is calculated using mathematical models based on experimental data of temporary sample plots.

For the purpose of modeling and quantitative assessment of live biomass of mountain fir forests in Ukrainian Carpathians, the data from 43 temporary sample plots (TSP) were used, on which biometric assessment of 200 model trees was carried out with a fraction level live biomass assessment. Model trees, as well as temporary sample plots, fully represent the studied stands.

The allometric function (y=a·xb), or the function of parabolic growth, is widely used in studies of this direction. Its advantage is high flexibility and at the same time constant passage through the zero point, i.e. it does not require left-hand restrictions. Despite some drawbacks, such properties position alometry as one of the basis ways to approximate dependencies within biological objects. This type of function is dominant in studies of bioproductivity of forests in Ukraine.

The general form of the mathematical model used to model the quantitative parameters of live biomass components of fir 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; $a_1.a_2.....a_5$ – regression coefficients.

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

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	1.4500	-0.2545	0.0833	0.4347	0.0050	-0.8056	0.89
Bark	0.1554	-0.5607	0.5117	0.0282	0.0066	-0.3727	0.87
Branches	0.1553	-0.6189	0.8527	-0.3404	0.0015	0.0126	0.78
Foliage	0.3868	-0.7913	0.8232	-0.3423	-0.0025	0.0766	0.81
Roots	3.0810	-0.5531	0.699	0.641	0.0053	-2.6127	0.75
Undergrowth, understorey	$5.30 \cdot 10^{-5}$	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

All studied components of live biomass are described by regression equations with a high level of approximation (R^2>0.75). The equations for root systems are characterized by somewhat lower but significant at 5 % level multiple correlation relations. At the same time, the actual values of the F-criterion significantly exceed its critical values (2.0), and therefore with a probability of 0.95 it can be argued that the obtained models are adequate to the original empirical data.

Using as an information basis the proposed model tools and quantitative values of the indicators of the individual biometric characteristics of fir stands, the corresponding stocks of their live biomass were determined (Table 5).

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Regional peculiarities of formation of fir stands live biomass density indicate the dominance of fir stands in Zakarpattia region, where the mentioned indicator is 19.0 kg $(m^2)^{-1}$, in Lviv region – 15.2 kg $(m^2)^{-1}$, and in Chernivtsi and Ivano-Frankivsk regions – 14.7 and 13.8 kg $(m^2)^{-1}$, respectively.

Table 5

Regional distribution of live biomass of Silver fir 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	1.67	0.21	0.17	0.19	0.01	0.01	2,25	19.0
Ivano-Frankivsk	3.41	0.57	0,52	0,49	0.02	0,02	5,02	13.8
Lviv	5.74	0.98	0.91	0.81	0.03	0,03	8.50	15.2
Chernivtsi	4.04	0.61	0.52	0.52	0.02	0.02	5.72	14.7
Total	14.86	2.36	2.11	2.00	0.07	0,09	21.49	14.9

In total, more than 21 million tons of live organic matter have been accumulated in the fir stands of Ukrainian Carpathians. Almost 40 % of biomass is concentrated in Lviv region, and more than 20 % is accumulated in Chernivtsi and Ivano-Frankivsk regions. More than 70 % of biomass is formed in the trunk wood of the studied stands.

To predict the biomass stocks for mountain forests dominated by silver fir within the framework of this study, normative and reference tables of dynamics of their bioproductivity are proposed. They have been developed on the basis of mathematical dependences that describe the dynamics of the main biometric indices of fir stands[23, 24], using the models of conversion coefficients provided in Table 4.

Fragments of the proposed normative and reference tables for modal fir stands of the Ukrainian Carpathians of I^a site index class are presented in Tables 6, 7 and 8.

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[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 fir 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	3.0	0.5	1.1	1.8	5.9	1.3	7.1	0.03	0.1	7.3	14.6	1.96	2.65
20	23.8	3.3	6.3	8.7	38.8	7.9	46.7	0.1	0.2	47.0	77.5	5.44	7.88
30	61.5	7.6	13.7	16.8	92.0	18.2	110.2	0.2	0.2	110.5	188.8	6.74	12.37
40	104.4	12.0	20.2	22.7	147.2	28.3	175.5	0.2	0.3	176.0	332.9	6.20	15.11
50	143.8	15.7	24.8	25.7	194.3	36.5	230.8	0.3	0.3	231.4	493.6	4.96	16.35
60	177.6	18.6	27.8	26.8	232.2	44.1	276.3	0.4	0.4	277.1	662.1	4.05	16.93
70	205.0	20.9	29.4	26.5	260.9	50.2	311.2	0.5	0.4	312.0	829.9	3.09	16.68
80	227.0	22.7	30.2	25.5	282.6	55.3	337.9	0.5	0.5	338.9	993.1	2.39	16.12
90	245.1	24.1	30.3	24.1	299.4	59.5	358.9	0.6	0.5	360.0	1149.7	1.93	15.46
100	260.4	25.3	30.2	22.5	313.1	63.3	376.4	0.7	0.6	377.6	1299.0	1.64	14.71
110	273.4	26.2	29.6	20.9	323.8	65.2	389.0	0.7	0.6	390.4	1438.2	1.21	13.67
120	285.3	27.1	28.9	19.3	333.6	66.9	400.5	0.8	0.6	402.0	1570.0	1.13	12.99
130	296.8	28.0	28.3	17.9	343.0	68.6	411.7	0.9	0.7	413.2	1695.1	1.12	12.33
140	308.2	28.9	27.7	16.6	352.5	70.3	422.8	0.9	0.7	424.4	1814.6	1.10	11.79

Table 7

Dynamics of bioproductivity of mixed fir 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	3.1	0.5	1.1	1.8	6.0	1.2	7.3	0.03	0.10	7.4	20.9	1.99	3.50
20	24.2	3.3	6.4	8.9	39.5	7.8	47.3	0.09	0.17	47.6	88.6	5.49	8.14
30	62.6	7.7	13.9	17.1	93.5	17.8	111.3	0.16	0.22	111.6	197.2	6.80	11.90
40	106.1	12.1	20.4	23.0	149.5	27.8	177.3	0.23	0.27	177.8	333.4	6.28	14.23
50	146.2	15.9	25.1	26.1	197.4	36.0	233.4	0.30	0.31	234.0	484.8	5.04	15.42
60	180.6	18.9	28.1	27.2	235.9	43.5	279.4	0.38	0.36	280.2	644.5	4.10	16.09
70	208.5	21.2	29.8	26.9	265.2	49.6	314.8	0.46	0.40	315.6	805.3	3.14	16.04
80	231.0	23.0	30.5	25.8	287.4	54.6	342.0	0.53	0.45	342.9	963.7	2.44	15.73
90	249.6	24.4	30.7	24.4	304.6	58.8	363.5	0.60	0.50	364.6	1118.1	1.97	15.31
100	265.3	25.6	30.5	22.8	318.7	62.6	381.3	0.67	0.55	382.5	1267.2	1.68	14.74
110	278.6	26.6	29.9	21.2	329.7	64.5	394.2	0.73	0.58	395.5	1407.8	1.23	13.86
120	290.9	27.5	29.3	19.6	339.7	66.3	406.0	0.80	0.61	407.4	1542.3	1.16	13.29
130	302.6	28.4	28.6	18.1	349.4	67.9	417.3	0.85	0.64	418.8	1670.9	1.14	12.68
140	314.3	29.4	28.0	16.8	359.1	69.7	428.8	0.91	0.67	430.3	1794.3	1.12	12.18

Table 8

Dynamics of bioproductivity of mixed fir 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	3.2	0.5	1.1	1.9	6.3	1.1	7.4	0.03	0.09	7.5	19.5	1.95	3.27
20	23.8	3.2	6.3	8.6	38.7	7.1	45.8	0.09	0.16	46.0	83.9	5.28	7.77
30	61.1	7.5	13.6	16.7	91.3	17.6	109.0	0.16	0.22	109.3	190.0	6.89	11.75
40	104.8	12.1	20.5	23.0	148.3	30.3	178.6	0.23	0.29	179.1	328.4	6.86	14.64
50	146.8	16.2	26.0	26.8	199.7	43.2	242.8	0.30	0.37	243.5	489.1	6.03	16.57
60	182.4	19.4	29.4	28.2	239.9	52.2	292.1	0.38	0.42	292.9	658.0	4.42	17.07
70	211.8	21.9	31.4	28.1	271.2	59.4	330.6	0.45	0.47	331.5	829.8	3.43	17.18
80	235.8	23.9	32.3	27.2	295.3	65.2	360.5	0.53	0.52	361.5	1000.5	2.68	16.99
90	255.6	25.5	32.7	25.8	314.1	70.1	384.2	0.60	0.57	385.3	1167.8	2.16	16.61
100	272.4	26.9	32.7	24.3	329.3	74.3	403.6	0.66	0.62	404.9	1330.3	1.82	16.10
110	287.0	28.0	32.2	22.6	341.8	76.8	418.5	0.73	0.66	419.9	1485.3	1.42	15.31
120	300.4	29.1	31.6	21.0	353.0	79.0	432.0	0.79	0.69	433.4	1634.4	1.31	14.74
130	313.1	30.1	31.0	19.5	363.5	81.1	444.7	0.85	0.73	446.3	1777.6	1.27	14.15
140	325.6	31.1	30.3	18.1	374.0	83.3	457.3	0.90	0.76	458.9	1915.7	1.24	13.66

3. Information support for assessing net primary production of Silver fir stands in Ukrainian Carpathians

The quantitative characteristic of the features of bioproduction process is net primary production, which also serves as an indicator of the environment's response to climate change[25]. Assessment of net primary production of fir forests of Ukrainian Carpathians was carried out using the semi-empirical method of Prof. Anatoly Shvidenko[26] developed at the International Institute for Applied Systems Analysis (IIASA). The results of the assessment are presented in Table 9.

Table 9

Net primary production of Silver fir stands in Ukrainian Carpathians

Administrative region	**NPP by components, thou. 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**	
Zakarpattia	32.8	8.9	48.2	30.5	2.2	3.3	125.8	1202
Ivano-Frankivsk	99.7	29.6	140.6	80.7	6.6	12.1	369.3	1077
Lviv	168.5	46.6	238.8	132.3	9.7	17.3	613.2	1169
Chernivtsi	104.1	31.7	146.5	87.4	7.1	11.8	388.6	1083
Total	405.1	116.7	574.1	330.8	25.5	44.5	1496.8	1126

In general, fir stands in Ukrainian Carpathians annually produce about 1.4 million tons of organic matter, which averages about 1120 g· $(m^2)^{-1}$·year^{-1}, which is 5 % lower than the mean for forests of the Carpathian region as a whole. The highest density for fir stands is typical in Zakarpattia and is more than 1200 g· $(m^2)^{-1}$·year^{-1}. At the same time, it should be noted that the NPP density of coniferous tree species in the region in general is only 895 g· $(m^2)^{-1}$·year^{-1}.

To assess the quantitative indices of stem production of fir stands in the Ukrainian Carpathians, as a result of the study, static reference tables are proposed (Tables 10–11).

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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. DOI: 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.

Table 10

Production of stems of Silver fir 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	0.0367	0.1100	0.1833	0.2567	0.2934	0.3667
3.0	4.0	0.0240	0.0720	0.1200	0.1680	0.1919	0.2399
3.0	5.0	0.0173	0.0518	0.0864	0.1209	0.1382	0.1727
4.0	4.0	0.0312	0.0937	0.1561	0.2186	0.2499	0.3123
4.0	5.0	0.0228	0.0684	0.1140	0.1597	0.1825	0.2281
4.0	6.0	0.0176	0.0529	0.0882	0.1234	0.1411	0.1763
5.0	4.0	0.0383	0.1148	0.1914	0.2680	0.3062	0.3828
5.0	6.0	0.0221	0.0662	0.1103	0.1544	0.1765	0.2206
5.0	8.0	0.0149	0.0446	0.0743	0.1041	0.1189	0.1487
6.0	6.0	0.0265	0.0794	0.1324	0.1854	0.2119	0.2648
6.0	8.0	0.0181	0.0542	0.0903	0.1264	0.1445	0.1806
6.0	10.0	0.0134	0.0401	0.0669	0.0936	0.1070	0.1337
7.0	7.0	0.0253	0.0760	0.1266	0.1772	0.2026	0.2532
7.0	9.0	0.0183	0.0548	0.0913	0.1277	0.1460	0.1825
7.0	11.0	0.0140	0.0420	0.0700	0.0980	0.1120	0.1401
8.0	8.0	0.0246	0.0736	0.1227	0.1718	0.1963	0.2454
8.0	10.0	0.0185	0.0553	0.0922	0.1291	0.1475	0.1845
8.0	12.0	0.0146	0.0437	0.0728	0.1019	0.1165	0.1456
9.0	8.0	0.0278	0.0834	0.1391	0.1947	0.2225	0.2781
9.0	10.0	0.0210	0.0631	0.1052	0.1472	0.1683	0.2104
9.0	12.0	0.0167	0.0501	0.0835	0.1169	0.1335	0.1669
9.0	14.0	0.0137	0.0411	0.0685	0.0958	0.1095	0.1369
10.0	10.0	0.0236	0.0710	0.1183	0.1656	0.1892	0.2366
10.0	12.0	0.0188	0.0566	0.0943	0.1320	0.1509	0.1886
10.0	14.0	0.0155	0.0466	0.0777	0.1087	0.1242	0.1553
12.0	12.0	0.0233	0.0699	0.1164	0.1630	0.1863	0.2328
12.0	14.0	0.0193	0.0579	0.0965	0.1352	0.1544	0.1931
12.0	16.0	0.0164	0.0491	0.0819	0.1146	0.1310	0.1638
14.0	12.0	0.0278	0.0835	0.1391	0.1948	0.2226	0.2782
14.0	14.0	0.0232	0.0696	0.1160	0.1624	0.1856	0.2320
14.0	16.0	0.0198	0.0594	0.0989	0.1385	0.1582	0.1978
14.0	18.0	0.0171	0.0515	0.0858	0.1201	0.1373	0.1715
16.0	14.0	0.0272	0.0816	0.1360	0.1904	0.2176	0.2720
16.0	16.0	0.0233	0.0699	0.1165	0.1630	0.1863	0.2329
16.0	18.0	0.0203	0.0608	0.1014	0.1419	0.1622	0.2028

Table 10 (continuance)

1	2	3	4	5	6	7	8
16.0	20.0	0.0179	0.0537	0.0894	0.1252	0.1431	0.1789
16.0	22.0	0.0160	0.0478	0.0804	0.1116	0.1276	0.1594
18.0	16.0	0.0269	0.1076	0.1345	0.1883	0.2152	0.2690
18.0	18.0	0.0235	0.0705	0.1175	0.1645	0.1880	0.2350
18.0	20.0	0.0208	0.0624	0.1040	0.1455	0.1663	0.2079
18.0	22.0	0.0186	0.0558	0.0929	0.1301	0.1487	0.1858
18.0	24.0	0.0168	0.0503	0.0838	0.1173	0.1340	0.1675
20.0	16.0	0.0306	0.0918	0.1530	0.2142	0.2448	0.3059
20.0	20.0	0.0238	0.0714	0.1189	0.1665	0.1903	0.2378
20.0	24.0	0.0192	0.0578	0.0963	0.1348	0.1541	0.1926
20.0	28.0	0.0160	0.0482	0.0802	0.1123	0.1284	0.1605
22.0	18.0	0.0302	0.0906	0.1510	0.2114	0.2416	0.3020
22.0	22.0	0.0241	0.0724	0.1206	0.1689	0.1930	0.2412
22.0	26.0	0.0199	0.0598	0.0996	0.1394	0.1594	0.1992
22.0	30.0	0.0168	0.0505	0.0842	0.1179	0.1347	0.1684
22.0	34.0	0.0145	0.0435	0.0725	0.1015	0.1159	0.1449
24.0	20.0	0.0300	0.0901	0.1500	0.2101	0.2401	0.3001
24.0	24.0	0.0245	0.0735	0.1225	0.1715	0.1961	0.2450
24.0	28.0	0.0206	0.0617	0.1028	0.1439	0.1645	0.2056
24.0	32.0	0.0176	0.0528	0.0880	0.1232	0.1408	0.1760
24.0	36.0	0.0153	0.0459	0.0765	0.1071	0.1224	0.1530
24.0	40.0	0.0135	0.0404	0.0673	0.0942	0.1077	0.1346
26.0	24.0	0.0272	0.0817	0.1362	0.1907	0.2179	0.2724
26.0	28.0	0.0229	0.0688	0.1146	0.1605	0.1834	0.2292
26.0	32.0	0.0197	0.0590	0.0984	0.1377	0.1574	0.1968
26.0	36.0	0.0171	0.0514	0.0857	0.1200	0.1371	0.1714
26.0	40.0	0.0151	0.0453	0.0756	0.1058	0.1209	0.1511
26.0	44.0	0.0135	0.0404	0.0672	0.0941	0.1076	0.1345
26.0	48.0	0.0121	0.0362	0.0603	0.0844	0.0965	0.1206
26.0	52.0	0.0109	0.0327	0.0545	0.0762	0.0871	0.1089
28.0	28.0	0.0253	0.0761	0.1268	0.1775	0.2028	0.2535
28.0	32.0	0.0218	0.0655	0.1091	0.1527	0.1745	0.2182
28.0	36.0	0.0190	0.0571	0.0952	0.1333	0.1524	0.1905
28.0	40.0	0.0168	0.0505	0.0841	0.1178	0.1346	0.1683
28.0	46.0	0.0142	0.0426	0.0710	0.0994	0.1137	0.1421
28.0	50.0	0.0128	0.0384	0.0640	0.0897	0.1024	0.1281
28.0	56.0	0.0111	0.0332	0.0554	0.0775	0.0886	0.1108
28.0	62.0	0.0097	0.0290	0.0484	0.0678	0.0775	0.0968
30.0	32.0	0.0240	0.0720	0.1201	0.1681	0.1921	0.2401
30.0	38.0	0.0198	0.0592	0.0987	0.1382	0.1579	0.1974

Table 10 (ending)

1	2	3	4	5	6	7	8
30.0	44.0	0.0166	0.0498	0.0830	0.1163	0.1329	0.1661
30.0	50.0	0.0142	0.0426	0.0710	0.0995	0.1137	0.1421
30.0	56.0	0.0123	0.0369	0.0616	0.0862	0.0985	0.1232
30.0	62.0	0.0108	0.0324	0.0539	0.0755	0.0863	0.1078
30.0	68.0	0.0095	0.0286	0.0476	0.0666	0.0762	0.0952
34.0	38.0	0.0236	0.0709	0.1181	0.0584	0.1890	0.2363
34.0	44.0	0.0200	0.0599	0.0998	0.1398	0.1597	0.1997
34.0	50.0	0.0171	0.0515	0.0858	0.1201	0.1373	0.1716
34.0	56.0	0.0149	0.0448	0.0746	0.1045	0.1194	0.1493
34.0	60.0	0.0137	0.0410	0.0684	0.0958	0.1095	0.1368
34.0	66.0	0.0121	0.0362	0.0604	0.0846	0.0967	0.1209
34.0	72.0	0.0107	0.0322	0.0537	0.0752	0.0860	0.1074
38.0	58.0	0.0169	0.0509	0.0848	0.1187	0.1357	0.1696
38.0	64.0	0.0150	0.0449	0.0749	0.1049	0.1199	0.1499
38.0	70.0	0.0133	0.0400	0.0667	0.0933	0.1067	0.1334
38.0	76.0	0.0119	0.0358	0.0597	0.0835	0.0955	0.1193
38.0	82.0	0.0107	0.0322	0.0536	0.0751	0.0858	0.1073
38.0	88.0	0.0097	0.0290	0.0484	0.0677	0.0774	0.0967
42.0	82.0	0.0126	0.0379	0.0632	0.0885	0.1011	0.1264
42.0	88.0	0.0114	0.0343	0.0571	0.0800	0.0914	0.1142
42.0	94.0	0.0104	0.0311	0.0518	0.0725	0.0828	0.1036
42.0	98.0	0.0097	0.0291	0.0485	0.0680	0.0777	0.0971
46.0	114.0	0.0089	0.0266	0.0443	0.0620	0.0708	0.0885
46.0	116.0	0.0086	0.0258	0.0430	0.0601	0.0687	0.0859
46.0	120.0	0.0081	0.0242	0.0404	0.0566	0.0647	0.0809
46.0	122.0	0.0078	0.0235	0.0392	0.0549	0.0628	0.0784
46,0	124.0	0.0076	0.0228	0.0381	0.0533	0.0609	0.0761
48,0	140.0	0.0065	0.0193	0.0322	0.0451	0.0515	0.0644

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, 28].

[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.

[28] Vasylyshyn R. D., Lakyda I. P., Vasylyshyn O. M. biomass and primary production of European spruce stands in Ukrainian Carpathians. *Modern aspects of scientific research in the context of modernization of biological and natural science education* : Collective monograph.

Table 11

Production of stems of Silver fir 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	0.2073	–	–	–	–	–
4.0	4.0	0.3748	0.4373	0.4685	–	–	–
4.0	5.0	0.2738	0.3194	0.3422	–	–	–
4.0	6.0	0.2116	0.2469	0.2645	–	–	–
5.0	4.0	0.0634	0.5359	0.5742	0.2547	–	–
5.0	6.0	0.2647	0.3089	0.3309	0.3751	0.4192	0.4633
5.0	8.0	0.1784	0.2081	0.2230	0.2527	0.2825	0.3122
6.0	6.0	0.3178	0.3707	0.3972	0.0542	0.5031	0.5561
6.0	8.0	0.2168	0.2529	0.2709	0.3071	0.3432	0.3793
6.0	10.0	0.1605	0.1872	0.2006	0.2273	0.2541	0.2808
7.0	7.0	0.3038	0.3545	0.3798	0.4304	0.4810	0.5317
7.0	9.0	0.2190	0.2555	0.2738	0.3103	0.3468	0.3833
7.0	11.0	0.1681	0.1961	0.2101	0.2381	0.2661	0.2941
8.0	8.0	0.2945	0.3435	0.3681	0.4171	0.4663	0.5153
8.0	10.0	0.2213	0.2582	0.2767	0.3136	0.3505	0.3874
8.0	12.0	0.1748	0.2039	0.2184	0.2475	0.2767	0.3058
9.0	8.0	0.3337	0.3893	0.4172	0.4728	0.5284	0.5841
9.0	10.0	0.2524	0.2945	0.3155	0.3576	0.3997	0.4417
9.0	12.0	0.2003	0.2337	0.2504	0.2838	0.3172	0.3505
9.0	14.0	0.1643	0.1917	0.2054	0.2328	0.2601	0.2875
10.0	10.0	0.2839	0.3312	0.3549	0.4021	0.4495	0.4968
10.0	12.0	0.2263	0.2640	0.2829	0.3206	0.3583	0.3960
10.0	14.0	0.1864	0.2174	0.2329	0.2640	0.2951	0.3261
12.0	12.0	0.2794	0.3260	0.3493	0.3958	0.4424	0.4890
12.0	14.0	0.2317	0.2703	0.2896	0.3282	0.3668	0.4054
12.0	16.0	0.1965	0.2293	0.2457	0.2784	0.3112	0.3439
14.0	12.0	0.3339	0.3895	0.4173	0.4730	0.5287	0.5843
14.0	14.0	0.2784	0.3248	0.3480	0.3944	0.4408	0.4872
14.0	16.0	0.2374	0.2769	0.2967	0.3363	0.3758	0.4154
14.0	18.0	0.2058	0.2402	0.2573	0.2916	0.3259	0.3602
16.0	14.0	0.3264	0.3808	0.4080	0.4624	0.5168	0.5712
16.0	16.0	0.2795	0.3261	0.3494	0.3960	0.4425	0.4891
16.0	18.0	0.2433	0.2839	0.3042	0.3447	0.3853	0.4258

Riga, Latvia : Baltija Publishing, 2022. P. 40–62. DOI https://doi.org/10.30525/978-9934-26-257-9-3.

Table 11 (continuance)

1	2	3	4	5	6	7	8
16.0	20.0	0.2146	0.2504	0.2683	0.3040	0.3398	0.3756
16.0	22.0	0.1913	0.2232	0.2391	0.2711	0.3029	0.3348
18.0	16.0	0.3228	0.3766	0.4035	0.4573	0.5111	0.5649
18.0	18.0	0.2820	0.3290	0.3525	0.3995	0.4465	0.4935
18.0	20.0	0.2495	0.2911	0.3119	0.3534	0.3950	0.4366
18.0	22.0	0.2230	0.2602	0.2788	0.3159	0.3531	0.3903
18.0	24.0	0.2011	0.2346	0.2513	0.2848	0.3184	0.3519
20.0	16.0	0.3671	0.4284	0.4589	0.5201	0.5813	0.6425
20.0	20.0	0.2854	0.3330	0.3568	0.4043	0.4519	0.4994
20.0	24.0	0.2311	0.2696	0.2889	0.3275	0.3659	0.4045
20.0	28.0	0.1926	0.2247	0.2407	0.2728	0.3049	0.3370
22.0	18.0	0.3624	0.4228	0.4530	0.5134	0.5738	0.6342
22.0	22.0	0.2895	0.3377	0.3619	0.4101	0.4584	0.5066
22.0	26.0	0.2390	0.2789	0.2988	0.3386	0.3785	0.4183
22.0	30.0	0.2021	0.2358	0.2526	0.2863	0.3200	0.3536
22.0	34.0	0.1739	0.2029	0.2174	0.2464	0.2753	0.3043
24.0	20.0	0.3601	0.4202	0.4502	0.5102	0.5702	0.6302
24.0	24.0	0.2941	0.3431	0.3676	0.4166	0.4656	0.5146
24.0	28.0	0.2467	0.2879	0.3084	0.3495	0.3907	0.4318
24.0	32.0	0.2112	0.2464	0.2640	0.2992	0.3344	0.3696
24.0	36.0	0.1836	0.2142	0.2374	0.2690	0.3007	0.3323
24.0	40.0	0.1615	0.1884	0.2018	0.2288	0.2557	0.2826
26.0	24.0	0.3269	0.3813	0.4086	0.4630	0.5175	0.5720
26.0	28.0	0.2751	0.3210	0.3439	0.3897	0.4356	0.4814
26.0	32.0	0.2361	0.2755	0.2951	0.3345	0.3739	0.4132
26.0	36.0	0.2057	0.2400	0.2572	0.2914	0.3257	0.3600
26.0	40.0	0.1814	0.2116	0.2267	0.2569	0.2871	0.3174
26.0	44.0	0.1614	0.1883	0.2017	0.2287	0.2555	0.2824
26.0	48.0	0.1447	0.1689	0.1809	0.2050	0.2292	0.2533
26.0	52.0	0.1307	0.1525	0.1634	0.1851	0.2069	0.2287
28.0	28.0	0.3042	0.3549	0.3803	0.4310	0.4817	0.5324
28.0	32.0	0.2618	0.3054	0.3272	0.3709	0.4145	0.4581
28.0	36.0	0.2286	0.2667	0.2857	0.3238	0.3619	0.4000
28.0	40.0	0.2019	0.2356	0.2524	0.2860	0.3197	0.3534
28.0	46.0	0.1705	0.1989	0.2131	0.2415	0.2699	0.2983
28.0	50.0	0.1537	0.1793	0.1921	0.2177	0.2433	0.2689
28.0	56.0	0.1329	0.1551	0.1662	0.1883	0.2105	0.2326
28.0	62.0	0.1161	0.1355	0.1452	0.1646	0.1839	0.2033
30.0	32.0	0.2882	0.3362	0.3602	0.4082	0.4562	0.5043
30.0	38.0	0.2369	0.2764	0.2961	0.3356	0.3751	0.4146

Table 11 (ending)

1	2	3	4	5	6	7	8
30.0	44.0	0.1993	0.2325	0.2491	0.2823	0.3155	0.3488
30.0	50.0	0.1705	0.1990	0.2131	0.2416	0.2700	0.2984
30.0	56.0	0.1478	0.1724	0.1847	0.2094	0.2340	0.2586
30.0	62.0	0.1294	0.1510	0.1618	0.1833	0.2049	0.2265
30.0	68.0	0.1142	0.1333	0.1428	0.1618	0.1809	0.1999
34.0	38.0	0.2835	0.3307	0.3544	0.4016	0.4489	0.4961
34.0	44.0	0.2396	0.2795	0.2995	0.3395	0.3794	0.4193
34.0	50.0	0.2059	0.2402	0.2574	0.2917	0.3260	0.3603
34.0	56.0	0.1792	0.2090	0.2239	0.2538	0.2836	0.3135
34.0	60.0	0.1642	0.1915	0.2052	0.2326	0.2599	0.2873
34.0	66.0	0.1450	0.1692	0.1812	0.2054	0.2296	0.2538
34.0	72.0	0.1289	0.1504	0.1612	0.1827	0.2042	0.2256
38.0	58.0	0.2035	0.2374	0.2544	0.2883	0.3223	0.3562
38.0	64.0	0.1799	0.2098	0.2248	0.2548	0.2848	0.3147
38.0	70.0	0.1600	0.1867	0.2001	0.2267	0.2534	0.2801
38.0	76.0	0.1432	0.1671	0.1790	0.2029	0.2267	0.2506
38.0	82.0	0.1287	0.1502	0.1609	0.1824	0.2038	0.2252
38.0	88.0	0.1161	0.1355	0.1451	0.1645	0.1838	0.2032
42.0	82.0	0.1517	0.1769	0.1896	0.2149	0.2401	0.2654
42.0	88.0	0.1371	0.1599	0.1714	0.1942	0.2171	0.2399
42.0	94.0	0.1243	0.1450	0.1554	0.1761	0.1968	0.2175
42.0	98.0	0.1165	0.1359	0.1457	0.1651	0.1845	0.2039
46.0	114.0	0.1062	0.1240	0.1328	0.1505	0.1683	0.1860
46.0	116.0	0.1031	0.1203	0.1289	0.1460	0.1632	0.1804
46.0	120.0	0.0970	0.1132	0.1213	0.1375	0.1536	0.1698
46.0	122.0	0.0941	0.1098	0.1177	0.1333	0.1490	0.0578
46.0	124.0	0.0913	0.1065	0.1141	0.1294	0.1446	0.1598
48.0	140.0	0.0772	0.0901	0.0965	0.1094	0.1223	0.1352

Quantitative indices of stem production in these reference tables are differentiated depending on the mean stand height (H), mean stand diameter (D) and mean width of 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.

The proposed regulatory and reference tables serve as an information basis for assessing the quantitative values of individual ecosystem functions, which are preconditioned by the peculiarities of bioproduction process and are associated with the intensity of organic matter production in the trunk wood of fir stands of Ukrainian Carpathians.

CONCLUSIONS

Scientific research of biomass and ecological functions of the Carpathian mountain forests, which influence the formation of climate and hydrological resources of a large part of the continent, have become the information basis for the organization of sustainable forest management in the region and a component of regulatory support for Ukraine's compliance with the declared international agreements related to environmental issues. Today, the relevance of such studies has already gone beyond the regional issues and has become global.

According to the results of our study, it was found that fir stands in Ukrainian Carpathians occupy an area of more than 129 thousand hectares, where about 36 million m^3 of growing stock is concentrated. In general, the share of fir stands is 6.4 % of the total area covered with forest vegetation in Ukrainian Carpathians and 6.5 % of their total growing stock. The region is dominated by young and mid-aged fir stands, the share of which is 37.5 % and 29.3 % respectively. These are stands of natural origin, among which 95 % are mixed and 5 % are pure stands. The mean class of the Carpathian fir stands is I.2, which characterizes them as highly productive ones. Highly productive stands of I^a and I site index classes dominate here covering 77.4 % of the total area of fir stands.

In the Ukrainian Carpathians fir stands accumulated more than 21 million tons of live organic matter. Almost 40 % of biomass is concentrated in Lviv region, and more than 20 % is accumulated in Chernivtsi and Ivano-Frankivsk regions. The mean biomass density of fir stands in the region is 14.9 $kg \cdot (m^2)^{-1}$.

Net primary production of fir stands exceeds 1.4 million tons of organic matter, which averages about 1120 $g \cdot (m^2)^{-1} \cdot year^{-1}$, which is 5 % lower than the mean for the forests of the Carpathian region in whole. The highest NPP density of fir stands is typical for Zakarpattia and is more than 1200 $g \cdot (m^2)^{-1} \cdot year^{-1}$. To estimate the volumes of net primary production, as a result of this research, we propose static tables of stem wood production and standards of net primary production dynamics for fir stands differentiated by origin.

SUMMARY

The forests of Ukrainian Carpathians are an important structural component of economics of sustainable development in mountainous region, where forestry should be balancing environmental protection and socio-economic development of local communities. In this context, quantitative assessment of biomass and primary production of forest plant communities

serves as an information basis for implementation of the concept of sustainable forest management of mountain forests, which provides for use of forest resources on ecosystem-organized, integrated, environmentally balanced, and legally regulated by appropriate environmental regulations and restrictions basis.

In the course of this research, an analytical assessment of the state of fir forests of Ukrainian Carpathians was carried out, which allowed to identify a set of silvicultural and mensurational factors that affect the intensity of the bioproduction process in forest plant communities.

As a result of the research, quantitative indicators of live biomass and net primary production of fir forests as components of their bioproductivity were established. In addition, regulatory and information support has been proposed for assessment and forecasting of biomass and production of fir stands in the Carpathian region, in statics and dynamics. The obtained results will serve as an information basis for organizing of close-to-nature forestry in mountain forests.

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