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BIOTIC PRODUCTIVITY AND SEQUESTERED CARBON IN FORESTS OF UKRAINIAN POLISSYA

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Abstract. *The research is devoted to quantitative indices of bioproductivity process in forests of Ukrainian Polissya. In particular, the article presents the results of assessment of parametric structure of their biological and energy productivity. The research is based on current state forest account and mathematical toolbox as well as on application of research database of temporary sample plots. As a result, it became possible to ascertain trends of total live biomass stock (632,6 million tons), sequestered carbon (314,8 million tons) and accumulated energy (11,26 EJ) within administrative units of the researched region. Quantitative parameters of net primary production (19,2 million tons of carbon per annum) of forests in Ukrainian Polissya were determined as well.*

Keywords: *Ukrainian Polissya, biotic productivity, energy productivity, live biomass, sequestered carbon, net primary production.*

The current global trend towards a change of the dominant paradigm of social development from economic to environmental values has raised awareness of need for a new form of relation between the society and the environment. This has been reflected in the decisions of the global climate summit in Paris last year, which brought together leaders of more than 150 countries. As a result, the international community has initiated a multi-vector research aimed at securing stabilization of the Earth's climatic system and creating ecologically safe principles for use of natural resources. These issues are still relevant for region of Ukrainian Polissya, whose environmental conditions have undergone significant changes in course of a long and imbalanced economic use of resource potential of the region, including forest resources.

Forest in Polissya should be considered as a complex system, which acts as an important environment-forming factor by affecting natural balance. Therefore, research aimed on assessment of biotic productivity of forest plant communities provides one of basic parameters for ascertaining climate change mitigating impact of forests, which has high practical importance [3–7].

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The aim of research – to carry out a quantitative estimate of live organic matter (live biomass, LB), amount of sequestered carbon, net primary production and energy productivity for forests of Ukrainian Polissya as a basis for research of their biosphere role.

Materials and methods of research. Scientific research aimed at quantifying biotic and energy productivity of forest plant communities have combined application of a considerable number of methods and forms of scientific cognition.

The baseline in the study is formed by the methodology of collecting and processing experimental data, based on successful combination of mensurational and biometric techniques, and the provided theoretical generalizations are grounded on statistical and mathematical methods [1–3].

The base theoretical principles and practical techniques the applied methodology for assessment of biotic productivity of forests were successfully tested at the International Institute for Applied Systems Analysis (IIASA, Austria). The methodology has also been successfully implemented in course of several international projects: «Carbon, Climate and Managed Land in Ukraine: Integrated Data and Models of Land Use for NEESPI (Forest Sector)» (2006-2008 gg.), «Biomass Energy Europe» (2008-2010), «GESAPU – Geoinformation technologies, spatio-temporal approaches, and full carbon account for improving accuracy of GHG inventories» (2010-2014) [3, 6, 7].

Information toolbox used for this research is formed by relational database “Stand-wise mensurational characteristics of forests” (over 500 thousands stands) and empirical materials collected on 40 temporary sample plots established in coniferous, hardwood broadleaved and softwood broadleaved stands in the study region (in Volyn, Zhytomyr, Kyiv, Rivne, Sumy and Chernihiv regions).

Results. By implementing a combination of mathematical models of biomass expansion factors and data of state forest account of Ukraine, after applying a special calculation algorithm developed by IIASA scientists led by prof. A.Z. Shvidenko [1, 3, 5, 7], it became possible to assess stocks of organic matter that is fixed in plant tissues and amounts of sequestered carbon (Table 1).

1. Dynamics of live biomass and sequestered carbon in forests of Ukrainian Polissya

Year	Live biomass components, mio. tons (bon dry state)						Sequestered carbon, mio. tons
	leaves (needles)	wood and bark of branches	wood and bark of stem	roots	understorey	total	
2002	10,15	44,67	349,55	78,88	17,38	500,64	250,11
2011	11,44	52,77	447,85	101,41	19,13	632,62	314,78

While analyzing the data presented in Table 1, it should be noted that in forests of Ukrainian Polissya there is a positive trend of accumulation of live

organic matter. Over the study period its stock has gone up by 26.4%. Based on the current state forest account, a total stock of forest live biomass in Ukrainian Polissya was calculated. It exceeds 632 million tons of bone-dry organic matter, which is equivalent to 314.8 million tons of sequestered carbon or 11.26 EJ of accumulated energy. In terms of component structure, share of live biomass of trees is 97% of the total live biomass of forest plant communities (of which 80.9% – aboveground live biomass), while share of undergrowth and understorey is around 3% (including 2.2% – live soil cover (LSC)). The share of tree trunks in total amount of live biomass is about 70%, of which almost 8% account for bark. Percentage of live biomass of tree crowns in total amount of live organic matter of the plant communities is 10.1%, of which 8.3% – wood and bark of branches and 1.8% – foliage. The proportion of root systems is 16%.

Regional peculiarities of distribution of total amount of live biomass and sequestered carbon by administrative and territorial units of the study region are presented in Table 2.

2. Regional distribution of live biomass and sequestered carbon stocks in forests of Ukrainian Polissya

Administrative regions	Live biomass by components, mio. tons								Sequestered carbon, mio. tons
	wood and bark of stems	wood and bark of branches	leaves (needles)	roots	understory and undergrowth	live soil cover	total	live biomass density, kg·(m^2)$^{-1}$	
Volyn	59,82	7,11	1,66	13,77	0,73	2,06	85,15	13,62	42,35
Zhytomyr	106,57	12,60	2,74	24,37	1,32	3,35	150,96	15,08	75,11
Kyiv	78,72	9,22	1,95	17,25	0,86	2,23	110,24	16,81	54,87
Rivne	64,12	7,71	1,89	15,32	0,82	2,42	92,27	12,66	45,88
Sumy	55,11	7,25	1,25	12,06	0,69	1,41	77,77	18,31	38,72
Chernihiv	83,50	8,87	1,96	18,65	0,90	2,35	116,23	17,46	57,85
TOTAL	447,85	52,77	11,44	101,41	5,31	13,82	632,62	15,66	314,78

The majority of live biomass of forests of Ukrainian Polissya is concentrated in Zhytomyr (23.9%), Chernihiv (18.4%) and Kyiv regions (17.4%). At the same time, the highest density of forest live biomass is characteristic for Sumy (18.31 kg (m^2)$^{-1}$), Chernihiv (17.46 kg (m^2)$^{-1}$) and Kyiv regions (16.81 kg (m^2)$^{-1}$), which are much more productive in terms of live biomass production than in Volyn (13.62 kg (m^2)$^{-1}$) and Rivne regions (12,66 kg (m^2)$^{-1}$).

Variability of live biomass stocks of land covered with forest vegetation is substantial, both in regional terms and depending on tree species composition of stands. Distribution of total live biomass by groups of forest-forming tree species for the same period of forest account are shown Table 3.

3. Distribution of live biomass and sequestered carbon amounts in forests of Ukrainian Polissya by groups of forest-forming tree species and structural components

Group of tree species	Live biomass by components, mio. tons							Sequestered carbon, mio. tons
	wood and bark of stems	wood and bark of branches	leaves (needles)	roots	understory and undergrowth	live soil cover	total	
Coniferous	279,71	25,18	6,77	62,42	2,40	8,65	385,14	191,68
Hardwood broadleaves	100,94	17,74	2,07	20,80	1,93	2,87	146,35	72,83
Softwood broadleaves	67,07	9,83	2,59	18,16	0,96	2,27	100,88	50,15
Other tree species	0,14	0,02	0,01	0,04	0,01	0,02	0,24	0,12
TOTAL	447,85	52,77	11,44	101,41	5,31	13,82	632,62	314,78

When analyzing the presented in Table 3 quantitative indices of live biomass, it becomes possible to conclude that in Ukrainian Polissya more than 60 % of its stock is concentrated in coniferous stands. On average, LB density in those stands is about 16.2 $kg\cdot(m^2)^{-1}$, which is more than 6% lower than a mean value for coniferous stands in Ukraine (17.3 $kg\cdot(m^2)^{-1}$). In hardwood broadleaved stands, an average value of LB density equals 18.8 $kg\cdot(m^2)^{-1}$. In general, forest stands of the study region have sequestered over 314 million tons of carbon, including 191.7 million tons in coniferous, 72.8 million tons in hardwood broadleaved and 50.2 million tons in softwood broadleaved stands.

An important aspect of research of biotic productivity of forest plant communities is energetic interpretation of quantitative indicators of their live biomass. This statement is valid since processes associated with the inflow, transformation and utilization of energy represent key processes for ensuring effective functioning of any ecosystem on Earth, including forest ecosystems [1, 2, 7].

Today, the concept of energy has gained general scientific importance and, apart from the classic physical understanding, it is widely used in studies of ecosystems as a measure of characteristics of natural processes, and allows to bring environmental categories into the area of thermodynamics.

In this context, the research includes an estimate of energy content in components of live biomass of the studied stands (Table 4).

In terms of energy, there is 11.3 EJ (1 EJ = 1018 J) accumulated in live biomass of stands in Ukrainian Polissya. Over 70% of energy is concentrated in wood and bark of tree trunks – 7.9 EJ. Another 8% are accumulated in

branches of trees – 0.9 EJ, which is an important energy resource for obtaining thermal renewable energy.

4. Energy content in live biomass of forests of Ukrainian Polissya by groups of forest-forming tree species and structural components

Group of tree species	Total energy content in live biomass components, PJ						
	wood and bark of stems	wood and bark of branches	leaves (needles)	roots	understory and undergrowth	live soil cover	total
Coniferous	4977,98	448,22	120,55	1110,90	42,80	154,03	6854,47
Hardwood broadleaves	1796,35	315,64	36,86	370,13	34,41	51,10	2604,48
Softwood broadleaves	1192,22	174,70	46,08	322,81	17,01	40,42	1793,25
Other tree species	2,45	0,41	0,12	0,64	0,25	0,41	4,28
TOTAL	7969,00	938,98	203,60	1804,49	94,46	245,96	11256,48

Net primary production (NPP) is an important information component for evaluation of bioproductivity of forest ecosystems. This indicator represents an organic vegetal matter formed during photosynthesis and accumulated during plant's lifetime in aboveground and belowground compartments per unit time on unit area [3, 4, 7]. Assessment of quantitative characteristics of NPP is a prerequisite for evaluating carbon budget of forest plant communities on a particular area. This index serves as an indicator of environmental response to climate change [3].

Amounts of net primary production in forests of Ukrainian Polissya within groups of forest-forming tree species and LB components is provided in Table 5.

From the presented in Table 5 data it becomes clear that net primary production of forests in Ukrainian Polissya is rather high and amounts to 19.2 million tons of carbon per year, or on average of 475 g $C \cdot (m^2)^{-1} \cdot year^{-1}$. When comparing the latter figure, it is worth noting that in boreal forests of Europe, mean annual NPP equals 460 g $C \cdot (m^2)^{-1} \cdot year^{-1}$ [4, 7]. In Ukraine, the highest NPP density is characteristic for beech stands – 712 g $C \cdot (m^2)^{-1} \cdot year^{-1}$, which is 40% above the average for Ukrainian forests in general and nearly 50% higher than the average NPP density for forests in Polissya region of Ukraine.

Analysis of the obtained results proves that the distribution of NPP by live biomass fractions is typical for deciduous forests. A considerable proportion of NPP is concentrated in foliage (24.0 %) and underground live biomass (27.9 %), mainly due to activity of fine roots. A substantial part of NPP

is also located outside the tree layer – 29.0 %, another 15.1 % are represented by live soil cover and 3.9 % –undergrowth and understorey.

5. Net primary production of forests in Ukrainian Polissya by groups of forest-forming tree species and structural components

Group of tree species	NPP by structure components, mio. C tons·year^{-1}							Density of NPP,g C·m^{-2}· year^{-1}
	wood and bark of stems	wood and bark of branches	leaves (needles)	roots	understory and undergrowth	live soil cover	total	
Coniferous	2,931	0,570	1,925	2,585	0,272	1,802	10,086	417
Hardwood broadleaves	0,828	0,288	1,509	1,946	0,329	0,666	5,566	652
Softwood broadleaves	0,748	0,188	1,164	0,826	0,154	0,427	3,506	442
Other tree species	0,002	0,000	0,003	0,002	0,003	0,007	0,016	290
TOTAL	4,509	1,047	4,601	5,359	0,758	2,901	19,175	475

Regional distribution of NPP shows that the most productive stands are in Zhytomyr region (4.7 million tons C·year^{-1}). Among other regions, high NPP rates are also observed in Kyiv and Rivne regions (about 3.2 million tons C·year^{-1}). The highest NPP density is observed in forests of Sumy region – 582 g C·(m^2)$^{-1}$·year^{-1} and Kyiv region – 481 g C·(m^2)$^{-1}$·year^{-1}. The lowest index of forest productivity in Polissya region in terms of NPP is observed in forests of Volyn and Rivne regions – around 430 g C·(m^2)$^{-1}$·year^{-1}.

Conclusions. Research of ecosystem services of forest ecosystems is a prerequisite for practical implementation of multifunctional nature of forests and appears to be a structural component of sustainable forest management. One of key indicators of ecosystem functions of forests are quantitative parameters of live organic matter, net primary production and energy content, which describe nature conservative potential of forests. According to analysis of these indicators, forests of Ukrainian Polissya have a significant resource potential and serve as an important element of global natural protection system aimed at ensuring environmental stabilization and maintenance of Earth's climatic system within planetary stability thresholds.

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БІОПРОДУКТИВНІСТЬ ТА ДЕПОНОВАНИЙ ВУГЛЕЦЬ ЛІСІВ УКРАЇНСЬКОГО ПОЛІССЯ

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Анотація. *Досліджено кількісні показники біопродукційного процесу у лісах Українського Полісся. Зокрема у статті наведено результати оцінювання параметричної структури їхньої біологічної та енергетичної продуктивності на основі даних поточного державного обліку лісів і математичного інструментарію з використанням дослідної бази даних тимчасових пробних площ. Встановлено тренди загальних обсягів фітомаси (632,6 млн т), депонованого в ній вуглецю (314,8 млн т) та акумульованої енергії (11,26 ЕДж) у межах адміністративно-територіальних одиниць досліджуваного регіону. Визначено також кількісні параметри чистої первинної продукції (19,2 млн т вуглецю в рік) лісів Українського Полісся.*

Ключові слова: *Українське Полісся, біопродуктивність, енергопродуктивність, фітомаса, депонований вуглець, чиста первинна продукція.*

БИОПРОДУКТИВНОСТЬ И ДЕПОНИРОВАНЫЙ УГЛЕРОД ЛЕСОВ УКРАИНСКОГО ПОЛЕСЬЯ

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Аннотация. *Исследованы количественные показатели биопродукционных процессов в лесах Украинского Полесья. В частности, в статье приведены результаты оценивания параметрической структуры их биологической и энергетической продуктивности на основе данных текущего государственного учета лесов и математического инструментария с использованием исследовательской базы данных временных пробных площадей. Установлены тренды общих объемов*

фитомассы (632,6 млн т), депонированного в ней углерода (314,8 млн т) и аккумулированной энергии (11,26 ЭДж) для административно-территориальных единиц исследуемого региона. Определены количественные параметры чистой первичной продукции (19,2 млн т углерода в год) лесов Украинского Полесья.

Ключевые слова: *Украинское Полесье, биопродуктивность, энергетическая продуктивность, фитомасса, депонированный углерод, чистая первичная продукция.*

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ПОРІВНЯННЯ ТА ОЦІНКА ТОЧНОСТІ НОРМАТИВІВ ДЕРЕВ ТА ДЕРЕВОСТАНІВ РІЗНОЇ ВІКОВОЇ, РОЗМІРНО-ЯКІСНОЇ І ТОВАРНОЇ СТРУКТУРИ БУКОВИХ ЛІСІВ УКРАЇНСЬКИХ КАРПАТ

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Анотація*. На основі матеріалів 28 пробних площ було проведено перевірку розроблених нормативів для перестійних букняків – сортиментних таблиць, а також нормативів товарної структури для оцінки одновікових та різновікових деревостанів. Статистичний аналіз довів придатність розроблених нормативів для використання, а порівняння з аналогічними нормативами для стиглих букових деревостанів – значущу різницю між ними, що свідчить про необхідність виконаних досліджень.*

Ключові слова: *перестійні букові деревостани, сортиментні та товарні таблиці, статистичний аналіз, систематичні помилки.*

Актуальність. Під час користування сортиментними таблицями обов'язково постають запитання, пов'язані з точністю розроблених нормативів. Вважають нормальним, якщо різниця між об'ємом заготовленої на лісосіці деревини та її попередньою оцінкою на корені не перевищує 10 %. Це слугує основою для затвердження актів приймання лісосіки.

Мета дослідження – здійснити дослідну перевірку точності розроблених нормативів та запропонувати їх до впровадження у виробництво.

Матеріали і методи дослідження. Для розробки сортиментних таблиць загалом було використано: для отримання масових таблиць – матеріали обміру 622 модельних дерев, у тому числі 337 моделей бука віком понад 140 років – для оцінки розмірно-якісної структури дерев, що цілком

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