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Net Primary Production of Forest Vegetal Biomass in Kyiv Region

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ABSTRACT

Net primary production (NPP) is considered by the world scientific community as an important indicator that reflects the features of the condition and peculiarities of the functioning of forest ecosystems. It also allows quantifying the potential of forests in performing their ecosystem functions. The information basis of the research consists of data from the industrial database of the Ukrainian State Forest Management Planning Association – IA "Ukrderzhlisproekt". The dataset contains the biometric description of stands in the study region. Also, a system of mathematical models, algorithmic support, and software for quantitative assessment of net primary production are utilized within this research. As a result, the research determines the quantitative values of the total volume and specific intensity of formation of net primary production in the forests of Kyiv region. The total volume of NPP in the forests of the region exceeds 6.5 million tons of dry matter, of which 56% is accounted for by forests dominated by Scots pine. The highest mean values of primary production per unit area are observed in stands composed of tree species belonging to the hardwood broadleaved species group (black locust, hornbeam, European ash, and common oak, 1550–1910 $g \cdot m^{-2}$. The highest intensity of organic matter production is observed in the stands of V to VIII age classes. Highly productive stands generate a major part of forest NPP in the study region. Among forest types, the highest intensity of the bioproduction process is observed in fresh hornbeam-oak and fresh hornbeam-oak site types – 1872 $g \cdot m^{-2}$ and 1646 $g \cdot m^{-2}$, respectively. The forests subordinated to the State Agency of Forest Resources of Ukraine concentrate the largest volumes of annually formed organic matter. The lowest productivity is typical for forest plant communities under the control of the Ministry of Defense of Ukraine. The research results will serve as an informational basis applicable to the formation of a strategy for sustainable use of ecosystem functions of the forests in the study region.

Keywords: biomass, net primary production, forest stands, Kyiv region.

INTRODUCTION

The carbon sequestration function of forest plant communities serves as one of the key criteria for securing the national low-carbon development [Strategy..., 2018] and upkeeping international obligations in the context of the Paris climate agreement [The Paris agreement, 2016]. The activity of live biomass in forests secures their environment-stabilizing role [Zverkovskyy, 2018]. Forests serve as the most efficient reservoir for long-term accumulation and keeping atmospheric carbon in the process of growth, and in wooden constructions and wood-based products with a long lifespan [Ince 2021; Sun 2021].

At the same time, live biomass and dead organic matter in forest stands act as a basis for accumulation of stock of forest combustible materials, which serve as a carbon emission source in cases of forest fires occurrence [Soshenskyi, 2021]. It is therefore possible to define the efficiency of forest management under climate change conditions by forest carbon capacity management within the paradigm of sustainable forest management [Shvidenko 2014; Vasylyshyn 2016].

The forests of the studied region are a key natural object that not only ensures the ecological balance of the environment in conditions of excessive anthropogenic load but also serves as an important source of raw materials for the

development of the regional economy. In this context, the quantitative assessment of their carbon capacity in vegetal biomass components will become an important informative factor in the process of forming regional environmental and forestry initiatives.

The research of carbon flows in forest ecosystems is currently the object of study for both domestic and foreign researchers. In particular, a comprehensive assessment of the carbon storage capacity of forest plant communities and the impact of disturbances in the forests of Ukrainian Polissia on their carbon budget was carried out by scientists of the Department of Forest Mensuration and Forest Management of the National University of Life and Environmental Sciences of Ukraine together with colleagues from the International Institute for Applied System Analysis [Lakyda 2018, 2019].

An updated assessment of the carbon budget of Ukraine's forests was carried out in 2019 on the basis of a forest map of Ukraine with a spatial resolution of 60 m, according to which the capacity of the forest ecosystems of Ukraine was estimated at the level of 90 million tons of organic matter annually, or 504 g of carbon per 1 m^2 [Lesiv, 2019].

Taking into account the consequences of future climate change on the territory of the EU countries and their impact on the regional balance of carbon emissions, some scientists [Fady, 2020] believe that it is worth avoiding the creation of forests in places with a significant probability of fires and areas prone to drought, which are currently expanding significantly throughout Europe. At the same time, in order to mitigate the consequences of natural disturbances in forest ecosystems, scientists from Central Europe [Zimova 2020] used the iLand model to simulate the impact of rotation length on the vulnerability of a 16,000 ha forest landscape damaged by windfalls and affected by bark beetles. As a result of the study, a clear relationship was established between carbon stock in the forest, indicators of biodiversity, and the rotation length. In particular, a 40% reduction in rotation length made it possible to reduce the mentioned disturbances by 14%.

An important role also belongs to monitoring studies that ensure effective management of the carbon storage capacity of forest stands. An example of such research can be the scientific efforts of Romanian [Dumitrascu, 2020] and Spanish [Gomez-Garcia, 2020] researchers who successfully combine field research data with forest inventory data to establish predictive estimates of annual amounts of sequestered carbon in forest ecosystems.

The presence of a significant number of scientific works within this research direction indicates the importance and relevance of the further study of carbon sequestration and emission processes in forest ecosystems. The aim of this research is to evaluate the net primary production of vegetal biomass of forests in the Kyiv region.

MATERIALS AND METHODS

In terms of information support and provision, this study is based on the data of the stand-level biometric characteristics of forests for more than 200,000 forest plots in the research region. The data is contained in the relational database "Forest Fund of Ukraine". The operator and administrator of the data is the Ukrainian State Forest Management Planning Association – IA "Ukrderzhlisproekt". The details of the species composition of the areas covered with forest vegetation are provided in Table 1.

The evaluation of the net primary production of the forests in the Kyiv region was implemented by applying the "semi-empirical" method proposed by Prof. Anatoly Shvidenko [Shvidenko, 2007; Shvidenko, 2014]. The approach considers the net primary production of an ecosystem at a certain age as an analogy of the volume of

Table 1. Distribution of the number of forest plots in the Kyiv region by the dominant forest-forming tree species

Tree species	Quantitative index		Tree species	Quantitative index	
	Plots	%		Plots	%
Silver birch	24078	11.8	Black locust	3708	1.8
Black alder	13002	6.4	Scots pine	122494	60.1
European hornbeam	2129	1.0	European ash	1964	1.0
Common oak	24788	12.2	Other tree species	11797	5.8
Total				203960	100.0

an annual increase in total live biomass production (or total live biomass growth), i.e. the mass of organic matter produced by the ecosystem per unit time (1 year).

The total live biomass production ($LBTP_t$) of a forest ecosystem during time t in this case is expressed as a dependence [Vasylyshyn, 2014; Shvidenko, 2014]:

$$LBTP_t = LBTP_t^{st} + LBTP_t^{br} + \\ +LBTP_t^{fol} + LBTP_t^{rt} + \\ +LBTP_t^{usv} + LBTP_t^{gff} \quad (1)$$

where: upper indices denote the following live biomass fractions: st – stem over bark, br – wood of branches over bark, fol – foliage (leaves or needles), rt – roots, usv – understory vegetation, and gff – green forest floor.

We have assessed the live biomass in the forests of the research region by applying the regional level live biomass models [Shvidenko, 2014] to the research dataset that describes biometric parameters of forest stands.

RESULTS AND DISCUSSION

Net primary production is considered by the world scientific community as an important indicator that reflects the features of the state and functioning of forest ecosystems. This indicator enables to quantitatively assess the possibilities of positive influence of forests on the Earth's climatic system and on global biogeochemical cycles.

During the research of the ecological functions of the forests in the Kyiv region, we have established that their net primary production amounts to 6,539,000 tons of dry matter. At the same time, the average value of net primary production reaches 1062 g per one square meter. The group of coniferous tree species is the most widely represented in the NPP distribution (Table 2), where more than 56% of its volume is concentrated.

The group of hardwood broadleaves is also characterized by a high share (32%, including 75% in oak forests). Analyzing the NPP components structure, we note that root systems account for 28% of its annually formed volumes. An almost equal NPP share is observed for the fraction of trunk wood and bark and foliage – 24.2% and 25.2%, respectively. Understory vegetation produces 17.1% of the total net primary production. The obtained data are consistent with the similar indicators for boreal and temperate forests reported in scientific literature [Shvidenko, 2014].

The species structure of net primary production (Fig. 1) shows the dominance of Scots pine stands – 55.8%, followed by common oak stands – 24.3%. The highest average values of net primary production per unit area are observed in tree species of the hardwood broadleaved group – black locust, European hornbeam, European ash and common oak, the index is in the range of 1550 – 1910 g·m^{-2}. For Scots pine, the average NPP value corresponds to the one calculated for the forests of the study region in whole.

Figure 2 demonstrates the age structure of bioproduction potential of the Kyiv region's forests. The highest volumes of produced organic matter are observed in the range from V to VIII age classes, which for Scots pine stands intended for exploitation corresponds to the groups of mid-aged and maturing stands. This aspect has a logical explanation, since forest stands of the specified age groups are characterized by the highest

Table 2. Species and components structure of net primary production

Species groups, tree species	Net primary production by components, thou. tons of dry matter					Total
	Stem wood and bark	Branch wood and bark	Foliage	Roots	Understory vegetation	
Conifers	1096.4	200.4	754.2	957.2	656.6	3664.8
Including Scots pine	1091.9	199.3	747.7	953.3	655.7	3647.9
Hardwood broadleaves	320.4	109.9	636.6	693.0	351.4	2111.3
Including common oak	223.3	76.1	475.4	533.8	280.2	1588.7
Softwood broadleaves	166.6	44.7	256.8	177.8	114.1	760.1
Including silver birch	103.7	24.3	142.1	104.1	60.8	435.1
Black alder	42.5	11.3	68.7	55.4	37.5	215.4
Other tree species	0.4	0.2	0.9	0.7	0.6	2.8
Total	1583.8	355.2	1648.5	1828.7	1122.8	6539.0

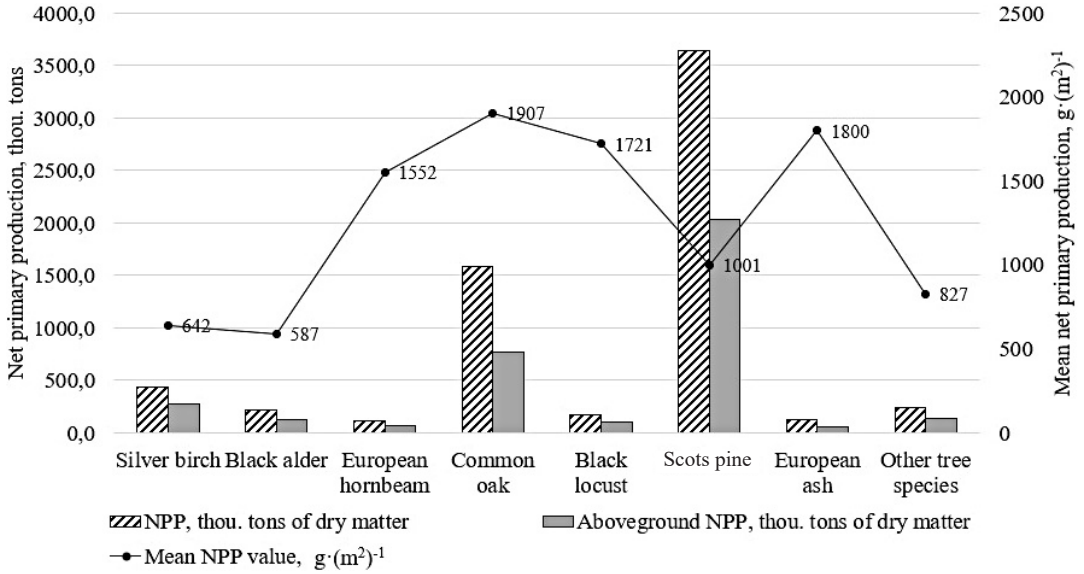

Figure 1. Quantitative and qualitative characteristics of net primary production by dominant tree species

volumes of live biomass production not only within the studied region, but also according to the data of other researchers for Ukraine in general [Shvidenko, 2007; Shvidenko, 2014; Lesiv, 2018, Vasylyshyn, 2021]. Generally, the amount of net primary production formed by stands of I–IV age classes is about 25% of the total. There is also a trend towards an increase in the average value of NPP with an increase in age. However, after the forest plant communities reach the VIII age class, a gradual decrease in the specified indicator becomes noticeable.

The distribution of NPP by tree species and productivity classes (Prof. Orlov's site index classes, Table 3) shows that the largest volumes of production are observed in stands dominated by Scots pine that feature I and higher site index classes. For common oak, the trend is somewhat different – the highest values are typical for stands having II and I site index classes.

When summarizing the analysis of Table 3, it becomes worth noting that both for forest plant communities dominated by individual tree species, and for the forests of the Kyiv region in whole, highly productive stands form the majority of net primary production. Thus, within the research region, more than 90% of biomass production is formed in highly productive stands, which is primarily related to the actual distribution of forests by age and productivity.

When analyzing the distribution of net primary production by site index and relative stocking

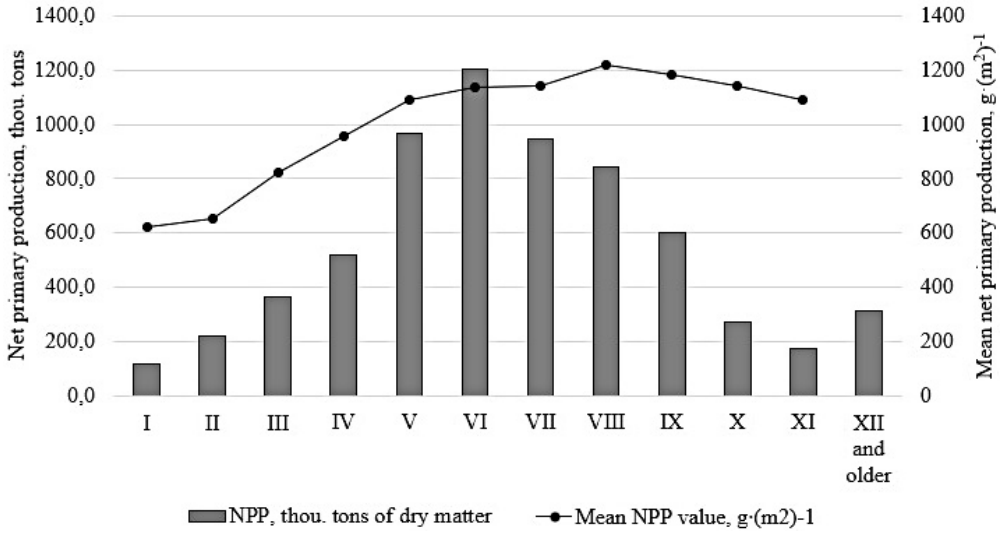

Figure 2. Intensity of bioproduction process by age classes

Table 3. Net primary production distribution by site index classes and dominant tree species

Tree species	Net primary production by site index classes, thou. tons of dry matter					Total
	Ia and higher	I	II	III	IV and lower	
Silver birch	57.4	125.8	189.9	53.2	8.8	435.1
Black alder	17.6	50.7	120.2	25.2	1.7	215.4
European hornbeam	4.6	20.0	67.4	21.6	1.7	115.4
Common oak	57.2	619.2	719.8	171.1	21.5	1588.7
Black locust	73.6	70.5	23.7	5.0	2.2	175.0
Scots pine	1114.9	1677.3	699.8	130.9	25.1	3647.9
European ash	40.9	63.1	16.7	1.4	0.1	122.3
Other tree species	66.9	59.5	40.8	16.4	55.6	239.2
Total	1433.1	2686.1	1878.3	424.8	116.7	6539.0

classes (Fig. 3), it is necessary to pay attention to the upward trend of the analyzed indicator in relation to productivity and relative stocking, that is, NPP is higher in stands with higher productivity and relative stocking. There is a gradual increase in the average values of net primary production with increasing relative stocking of stands. The lowest values of NPP per unit area are characteristic of sparse forests (relative stocking 0.3, NPP 759 $g \cdot m^{-2}$.

Stands with relative stocking of 1.0 and above feature a mean NPP reaching 1182 $g \cdot m^{-2}$, and for stands of the most represented relative stocking classes – 1088 $g \cdot m^{-2}$. The formation of about 40% of NPP is concentrated in stands with a relative

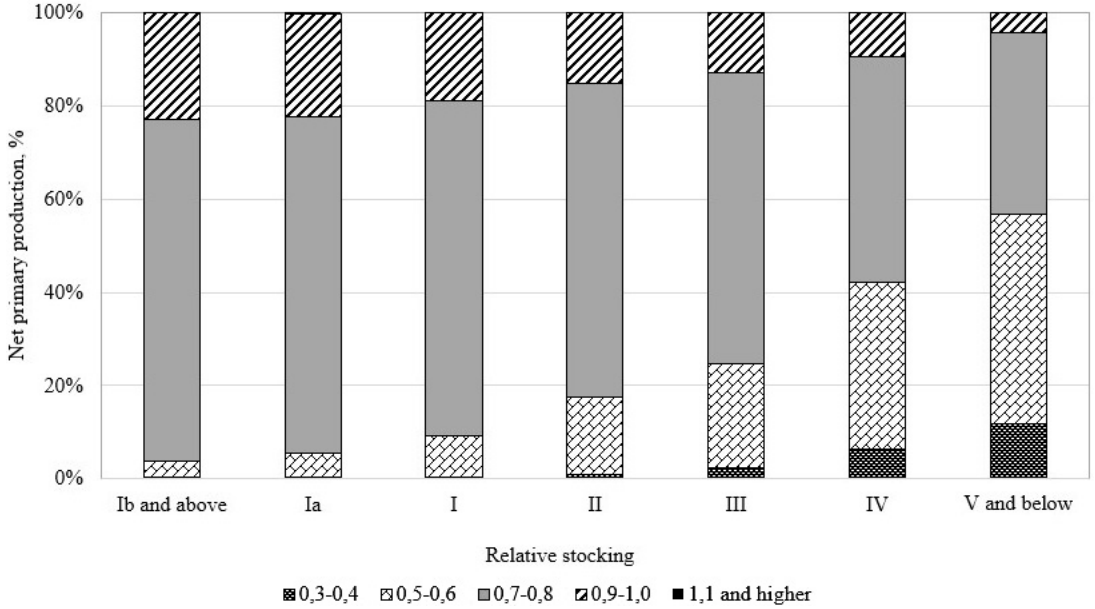

Figure 3. Distribution of net primary production by relative stocking within site index classes

Table 4. Intensity of bioproduction process by types of forest growth conditions

Site moisture classes	Net primary production by site fertility classes, thou. tons of dry matter				Total
	Infertile	Fairly infertile	Fairly fertile	Fertile	
Very dry	1.7	–	–	–	1.7
Dry	73.3	21.3	12.6	3.0	110.2
Fresh	592.7	2022.5	1436.0	989.8	5041.0
Moist	26.0	516.5	509.1	39.5	1091.2
Damp	1.9	48.9	206.6	20.0	277.4
Wet	0.1	3.8	10.4	3.2	17.5
Total	695.7	2613.0	2174.8	1055.5	6539.0

Table 5. Distribution of net primary production by main forest types and origin of stands

Forest types	Net primary production by origin of stands, thou. tons of dry matter			Total	Mean, g·m^{-2}
	Vegetative	Seed natural	Seed artificial		
Moist fairly fertile hornbeam-oak-pine sites	99.9	86.7	62.2	248.8	975
Moist fairly infertile oak-pine sites	137.7	270.7	186.8	595.2	875
Fresh fertile hornbeam sites	127.0	112.6	732.1	971.8	1872
Fresh fairly fertile hornbeam sites	105.1	103.6	281.9	490.5	1646
Fresh fairly fertile hornbeam-oak-pine sites	70.7	92.9	490.9	654.5	1165
Fresh fairly infertile oak-pine sites	49.7	457.4	1368.2	1875.3	964
Fresh fairly infertile pine sites	11.1	132.2	438.3	581.6	858
Damp fairly fertile alder sites	115.5	11.8	9.2	136.5	604
Dry infertile pine sites	0.2	17.6	56.1	73.9	706
Other forest types	267.8	268.2	374.7	910.8	–
Total	984.9	1553.7	4000.4	6539.0	1051

stocking of 0.8, and more than 55% – in highly stocked stands.

In the frame of the research, we have also analyzed the impact of forest growth conditions on the intensity of bioproduction process (Table 4).

In fairly infertile and fairly fertile sites, which feature stands of the highest productivity, net primary production makes up about 73% of its total amount in the region. In particular, within the specified site fertility classes, the share of NPP produced by stands in fresh and moist conditions accounts for more than 93% of the total.

Among the forest types, the highest intensity of bioproduction process is observed in fresh fertile hornbeam sites and fresh fairly fertile hornbeam sites – 1872 g·m^{-2}. and 1646 g·m^{-2}, respectively (Table 5).

Despite this, the largest volumes of produced organic matter are typical for fresh fairly infertile oak-pine sites, where about 29% of the total amount of net primary production is concentrated. Fresh fairly infertile oak-pine sites are also characterized by the highest NPP volumes formed by stands of natural seed origin. For wet fairly infertile oak-pine sites, fresh fertile hornbeam sites and damp fairly fertile alder sites, significant volumes of net primary production are present in stands of vegetative origin.

The results of assessment of distribution of net primary production by forests subordinated to different authorities are presented in Figure 4. The largest volumes of annually formed organic matter are concentrated in the forests subordinated to the State Agency of Forest Resources of

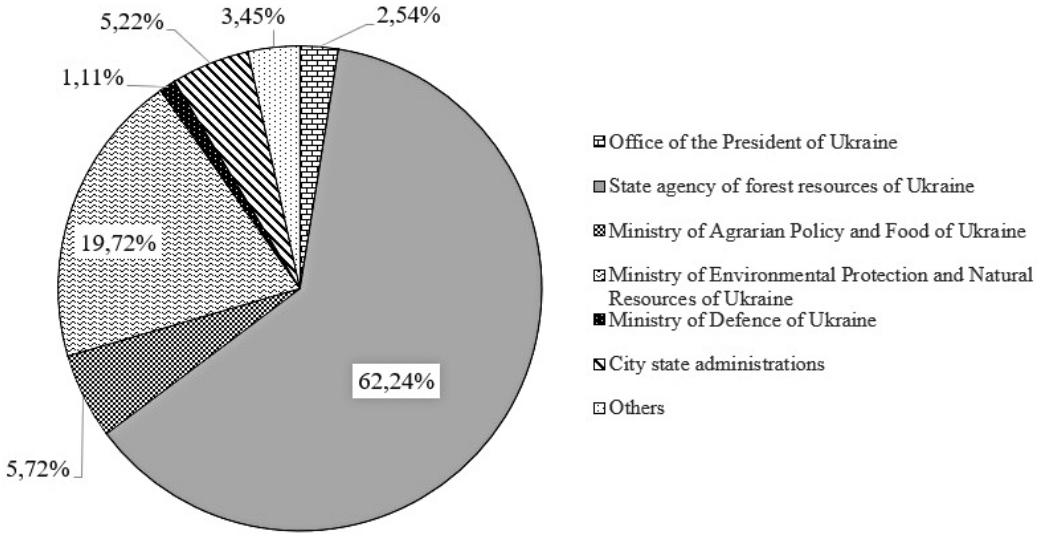

Figure 4. Distribution of volumes of net primary production of forests in Kyiv region by authority subordination, %

Ukraine. The lowest productivity is typical for forest plant communities controlled by the Ministry of Defense of Ukraine.

The above distribution is explained by the actual land use structure in the study region, as well as by silvicultural and biometric characteristics of forests of different subordination. To a certain extent, it is possible to trace differences in forest management purpose and tasks set by different authorities.

CONCLUSIONS

According to the results of the research, more than 6.5 million tons of dry organic matter were produced by live biomass of the forests in the Kyiv Region. The mean value of net primary production of forest ecosystems in the region is 1051 $g \cdot m^{-2}$. The most productive according to this indicator are the stands of V–XI age classes, the dependence of NPP on site index and relative stocking classes of forest stands is directly proportional. Among the forest types, the highest intensity of bioproduction process is observed in fresh fertile hornbeam sites and fresh fairly fertile hornbeam sites – 1872 $g \cdot m^{-2}$ and 1646 $g \cdot m^{-2}$, respectively.

The group of coniferous tree species, while concentrating more than 56% of NPP, is the most widely represented in its distribution. The participation share of the hardwood broadleaved group is also high (32%, including 75% in oak forests). An almost equal amount of net primary production is observed for fractions of root systems, trunks wood and bark, and photosynthetic apparatus (foliage) – 28%, 24.2% and 25.2%, respectively. The highest volumes of produced organic matter are observed in the range from V to VIII age classes. Highly productive stands are responsible for more than 90% of biomass production in the study region. The average NPP of the stands of the most represented relative stocking classes is 1088 $g \cdot m^{-2}$. The formation of more than 55% of the NPP volume is concentrated in highly stocked stands. The net primary production formed in fairly infertile and fairly fertile site types makes up about 73% of its total amount. Within the specified site fertility classes, fresh and moist conditions account for more than 93% of NPP. Among forest types, the highest intensity of bioproduction process is observed in fresh fertile hornbeam site types and fresh fairly fertile hornbeam site types – 1872 $g \cdot m^{-2}$ and 1646 $g \cdot m^{-2}$, respectively.

The research results will serve as an informational basis applicable to the formation of a strategy for sustainable use of ecosystem functions of the forests in the study region and enable a proper assessment and forecast of their biospheric role.

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