Received: 01.04.2022, Revised: 07.07.2022, Accepted: 11.08.2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(3), 32-40

UDC 630*5:502 (477.42)
DOI: 10.31548/forest.13(3).2022.32-40

Bioproductivity of the forests of the Cheremsky Nature Reserve

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Abstract. Climate change undermines the stability of natural ecosystems and adversely affects human life. Forest biocenoses can regulate the gas exchange of the atmosphere, accumulate and sequester carbon dioxide emissions, which are dangerous for the environment, in the phytomass components for a long time. The purpose of this study is to investigate the dynamics of bioproductivity of stands of the main forest-forming species of the Cheremsky Nature Reserve by components of phytomass and the carbon deposited in them. To solve the tasks of the study, the method of P.I. Lakyda was used. Experimental data of temporary trial plots, which fully characterize the forest massifs of the object under study, were used for modelling. The ratio coefficients R_v were calculated for stem wood ($R_{v(sw)}$); stem bark ($R_{v(sb)}$); branches ($R_{v(b)}$); leaves (needles) ($R_{v(l)}$). It was established that all above-ground components of Scots pine phytomass are described by regression equations. The coefficients of determination turned out to be insignificant, for the wood and bark of the stems of silver birch and common alder. In the structure of the phytomass of the forest stands of the reserve, the largest share (72.0%) falls on coniferous stands, a much smaller share – on soft-wood stands (26.0%) and the smallest – on hard-wood stands (2.0%). Over 13 years, the density of phytomass of stands and the carbon sequestered in it increased 1.4 times. Every year, forest biocenoses of the reserve release 6,989 tonnes of oxygen (4.2 $t \cdot ha^{-1}$) into the atmosphere. The main volume of oxygen (91.8%) is produced by coniferous stands. Based on the collected research material for stands of the main forest-forming species of the Cheremsky Nature Reserve, the following were calculated: ratios of above-ground phytomass components to their stock in the bark; mathematical models for evaluating the dynamics of phytomass components; standards for calculating oxygen productivity. The results of the study of the bio- and oxygen productivity of the forests of the Cheremsky Nature Reserve will be a significant contribution to effective management of the forest reserves, as well as to solving problems related to climate change at the regional and global levels

Keywords: mathematical models, conversion coefficients, phytomass of tree stands, sequestered carbon, oxygen productivity

Introduction

The growth of the Earth's population, the lack of food and drinking water supplies, the limitation of fossil energy resources and global climate change are the main challenges and threats facing humanity and require sound solutions aimed at reducing adverse consequences. In this sense, the forests of the planet "feel" the negative degrading effect of these phenomena and, therewith, are an effective tool in stabilizing the environment, solving trophic, and energy problems [1, 2].

Recently, the attention of humanity has been increasingly focused on one of the critical issues – global climate change, which is closely related to the so-called "greenhouse effect", upon which there is an increase in the concentration of greenhouse gases in the atmosphere. This process occurs due to the constant growth of anthropogenic load on the environment, as a result of which the volume of emissions of these gases, of which 80-90% is CO_2, exceeds their flow. The authors of the paper [3] believe that the concentration of carbon dioxide in the atmosphere can be reduced as a result of reducing emissions or by removing it from the atmosphere and sequestering it in terrestrial and aquatic biocenoses.

The phytomass of tree stands principally determines the course of processes in forest biocenoses. While carbon dioxide emissions are hazardous and poisonous for the environment and humanity, it is the phytomass components

Suggested Citation:
Hotsyk, O. (2022). Bioproductivity of the forests of the Cheremsky Nature Reserve. *Ukrainian Journal of Forest and Wood Science*, 13(3), 32-40.

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that can accumulate and sequester those emissions for a long time. That is why studies of the carbon potential in forest ecosystems are aimed primarily at estimating the phytomass of tree stands. Furthermore, this indicator is also used for ecological monitoring of sustainable forest management, modelling of forest productivity and assessment of their carbon sequestration capacity[2].

The estimation of the phytomass of tree stands is substantially different from the conventional estimation of stem wood reserves. Today, data on stocks and productivity of phytomass are few compared to data on forest taxing, where massive banks of data on stem wood stocks have been accumulated. There are numerous indicators of list taxing of temporary and permanent trial areas. Numerous regional stand development tables (SDT) have been compiled for stands with different wood species [4].

At the first stages of research, the phytomass of the tree stand was estimated by spreading the results of the calculated phytomass on separate trial areas to significant forest regions. Therewith, the final results were inflated [2]. Gradually, the estimation methods were improved. Currently, methods are used that combine data from the State Forestry Fund Accounting (SFFA) on stem wood stocks and standards with data on forest phytomass based on multivariate regression models, which estimate the phytomass or its conversion coefficients based on the main indicators included in SFFA and SDT [1-3].

The purpose of this study is to investigate the dynamics of bioproductivity of stands of the main forest-forming species of the Cheremsky Nature Reserve by components of phytomass and the carbon deposited in them. To fulfil the purpose of this study, it was necessary to solve the following tasks: develop mathematical models for estimating the components of the above-ground phytomass of trees and stands of the main forest-forming species of the Cheremsky Nature Reserve according to their inventory indicators; to investigate the dynamics of phytomass and carbon in the tree stands of the reserve and to estimate the oxygen productivity of the forests of the object under study.

This study is the first to calculate conversion coefficients of ratios of phytomass components of tree stands to their stock in the bark for the Cheremsky Nature Reserve. Dependences have also been established and a system of mathematical models has been developed to estimate the phytomass components of tree stands and the carbon sequestered in them by the main forest-forming species. The dynamics of total phytomass and sequestered carbon in tree stands were modelled and evaluated. The main trends in oxygen productivity of forests were covered and their potential was estimated.

Theoretical Overview

Climate change and environmental pollution undermine the stability of natural ecosystems and adversely affect human life. Stocks of phytomass and primary products are the main features that characterize the bioproductivity of forests and show their capability to regulate atmospheric gas exchange and the global carbon cycle [5-7]. Management of the carbon balance of forest phytocenoses both within the country and at the regional level is possible if there is a representative information base of forest ecosystem functions [8].

Forest ecosystems can support the natural balance of the planet's ecosystem, as they are capable of accumulating and long-term retention of dangerous and poisonous substances for humans and the environment [7]. That is why the biosphere role of forests as a natural absorber of greenhouse gases is gaining priority. Proceeding from this, a comprehensive study of the ecological role of the forest is relevant, which is closely interconnected with studies of their bioproductivity, the main components of which are phytomass and the carbon sequestered in it [1].

Today, a network of protected areas has been created in Ukraine, whose activities are aimed at investigating the state of natural complexes, restoring and preserving the natural state of the environment. Research on the bioproductivity of tree stands in such territories to preserve unique biodiversity, as well as to solve certain environmental issues, is quite promising. The problems of transformation of natural ecosystems and their preservation are also inherent in the Cheremsky Nature Reserve.

Considering the fact that the Cheremsky Nature Reserve was created on December 19, 2001, few scientific studies have been covering its forest ecosystems. However, the ecosystem services of the forests of other objects of the nature reserve fund have been evaluated by researchers for a long time [9-11].

The forest ecosystem is a sophisticated dynamic diffuse system, in which it is impossible to accurately distinguish the effect of various individual factors that are in close interaction with each other [12]. Forest ecosystems are characterized by constant variability in space. The economic activity of people largely determines the variability of the features of the microenvironment within its boundaries, which makes the research quite difficult [5]. Although a considerable amount of research on bioproduction processes in forest biocenoses has already been carried out, the mechanisms of anthropogenic influence on the state and productivity of tree stands are still understudied. It is necessary to investigate forest biogeocenoses comprehensively, considering all the diversity of connections between their parts and the processes occurring within them. Therefore, modern ideas of the system approach are used for its analysis and solution [13-15].

Modelling of forest biogeocenoses allows predicting the results of the selected scenario, giving preference to a safer and more useful scenario for the system under study. The use of models allows quickly predicting the consequences of directed actions decades and even centuries in advance without harmful consequences of experimentation for the natural environment [13; 15].

Forests perform important ecological functions, including climate regulation, soil protection, water protection, sanitary and hygienic, recreational, etc. It is based on the analysis of these functions that their ecological potential is estimated. Among the main criteria for estimating the ecological potential of forest phytocenoses are their carbon-sequestering and oxygen-producing functions [3].

Assessment of the carbon balance of forests has gained great popularity among researchers. Today, there are several methods of calculating the carbon sequestering function of forests. These include [3; 6]:

1. Weight method – a calculation method based on the available reserves of phytomass, which ensures carbon accounting in statics and dynamics.

2. Chlorophyll method – the content of chlorophyll in all organs of arboreal plants per unit area of forest plots covered with forest vegetation is calculated.

3. The method of determining the mass of photosynthetically bound and sequestered carbon in tree stands (the above-mentioned indicators and phytomass growth are determined synchronously by a direct indicator of the arrival of solar radiation).

4. Use of remote sensing methods.

5. Methodology of M.I. Chesnokov and V.M. Dolgosheev, the essence of which is to use the amount of oxygen that is released as a result of the formation of one tonne of completely dry matter and phytomass in a completely dry state (it is the most practical) [3; 10; 11].

Presently, there is a considerable number of studies that differ in research methodology [3], but all of them are aimed at predicting the carbon and oxygen balance to keep the stability of the planet's climate system.

Materials and Methods

The phytomass components of the tree stands of the main forest-forming tree species of the Cheremsky Nature Reserve (NR) were modelled by establishing single- and multifactorial dependences of the phytomass components on the inventory indicators of the tree stands, which are presented in the materials of the forest cadastre. Aggregated experimental material of temporary experimental plots, which fully characterize the current state of the forest areas of the research object, was used as initial data for modelling. A total of 64 temporary experimental plots (TEP) were used, of which 45 were established in natural stands and 19 – in artificial stands. The number of TEPs by main tree species and origin is distributed as follows: Scots pine – 39 TEPs (20 in natural stands and 19 in artificial stands), common alder – 14 TEPs and silver birch – 11 TEPs in natural stands. To solve the problems of the study, the method of P.I. Lakyda was used [2]. The collected experimental material allows developing identical mathematical models to estimate the phytomass components of model tree stands in statics and dynamics and, based on them, to characterize the total volumes of phytomass (by fractions) and the amount of accumulated carbon in the forest stands of the object under study.

The mathematical dependencies of the change of coefficients within each tree species were determined according to the method of multiple regression using the package of statistical software *STATISTICA*.

To obtain the combined characteristics of the inventory structure of the forest stands of the Cheremsky NR, data from three periods of forest management in 2005, 2011, and 2018, carried out by the production association "Ukrderzhlisproekt", were selected, aggregated, and processed. To analyse the nature of changes in the productivity of tree stands, data consisting of the characteristics of individual parameters of the forest fund were used:

1. Distribution of areas and stocks of forest plots covered with forest vegetation by groups of main forest-forming tree species.

2. Distribution of tree stands by age groups (young, middle-aged, maturing, mature, and over-mature) within the group of tree species.

3. Average quality of tree stands (according to M.M. Orlov [16]) within a group of tree species.

The total amount of phytomass in the forests of the Cheremsky NR and the carbon budget in them were calculated on a personal computer in the *Microsoft Office Excel* program.

The intensity of oxygen production by the tree stands of the Cheremsky NR were calculated according to the method of I.Ya. Liepa [17].

When modelling the dependence of the phytomass of stands on their inventory indicators, conversion coefficients were used [4]:

$$R_v = \frac{M_f}{M},$$

where R_v is the conversion factor of the taxation index; M_f – mass of phytomass fraction, thous. t; M – stem stock in the bark, thous. m^3.

A general working array of experimental data of TEPs was prepared, which includes the following inventory indicators: average age *(A, years)*; average diameter *(D, cm)*; average height *(H, m)*; site index class *(I)*; relative stocking *(S)*; stock *(M, m^3·ha^{-1})*.

The ratio coefficients R_v were calculated for the following phytomass components of the plantation: stem wood ($R_{v(sw)}$); stem bark ($R_{v(sb)}$); branches (wood and bark of crown branches) ($R_{v(b)}$); leaves (needle) ($R_{v(l)}$).

The average diameters *(D)*, average heights *(H)* and relative stocking *(S)* of the stands of the main forest-forming species of the Cheremsky NR were used as arguments for the regression equations.

The mathematical models of the relationship between the conversion coefficients of the stands of the Cheremsky NR with their total phytomass were searched using a dependency with the following general form:

$$R_v = f(D, H, S),$$

where R_v are the corresponding conversion factors (wood, bark, leaves (needles), etc.); *f(D, H, S)* are functions of inventory indicators of the tree stand (diameter, height, relative stocking).

The following type of allometric dependence was used to model the change in R_v coefficients [4]:

$$R_v = a_o \cdot D^{a1} \cdot H^{a2} \cdot S^{a3},$$

where D is the average diameter of the tree stand, cm; H is the average height of the tree stand, m; S is the relative stocking of the tree stand; a_0, a_1, a_2, a_3 are regression coefficients.

The complete characteristics of the equation parameters of the ratio coefficients R_v of the phytomass fractions of the stands of the main forest-forming species of the Cheremsky NR are presented in Table 1.

Table 1. Multiple regression equations of conversion coefficients R_v of estimation of phytomass components of stands of the main forest-forming species of the Cheremsky NR

Regression model	R^2	Regression model	R^2
Scots pine, artificial			
$R_{v(sw)}=0.349 \cdot D^{0.028} \cdot H^{0.064} \cdot S^{0.028}$	0.70	$R_{v(b)}=1.353 \cdot D^{-0.395} \cdot H^{-0.511} \cdot S^{-0.787}$	0.61
$R_{v(sb)}=0.296 \cdot D^{-0.445} \cdot H^{-0.095} \cdot S^{-0.132}$	0.72	$R_{v(l)}=2.271 \cdot D^{-0.295} \cdot H^{-1.550} \cdot S^{-0.203}$	0.78
Scots pine, natural			
$R_{v(sw)}=0.336 \cdot D^{-0.003} \cdot H^{0.101} \cdot S^{-0.038}$	0.79	$R_{v(b)}=0.124 \cdot D^{2.115} \cdot H^{-2.436} \cdot S^{0.129}$	0.13
$R_{v(sb)}=0.535 \cdot D^{0.091} \cdot H^{-0.802} \cdot S^{0.296}$	0.78	$R_{v(l)}=0.054 \cdot D^{-0.124} \cdot H^{-0.386} \cdot S^{-0.002}$	0.17
Silver birch			
$R_{v(sw)}$= Dependency not established (average value – 0.437)	–	*$R_{v(sb)}$= Dependency not established (average value – 0.082)*	–
$R_{v(l)}=20.498 \cdot D^{0.117} \cdot H^{-2.591} \cdot S^{0.167}$	0.96	$R_{v(b)}=0.976 \cdot D^{-0.153} \cdot H^{-0.430} \cdot S^{-0.810}$	0.85
Common alder			
$R_{v(sw)}$= Dependency not established (average – 0.419)	–	*$R_{v(sb)}$= Dependency not established (average value – 0.101)*	–
$R_{v(b)}=8.428 \cdot D^{0.017} \cdot H^{-1.591} \cdot S^{-1.241}$	0.98	$R_{v(l)}=0.185 \cdot D^{-1.081} \cdot H^{0.070} \cdot S^{-0.708}$	0.86

Notes: *sw* – stem wood, *sb* – stem bark, *b* – branches, *l* – leaves (needles)

The significance of the influence of the factors on the phytomass components under study was estimated by the confidence intervals of the regression coefficients at the 5% level.

Results and Discussion

As a result, it was established that all above-ground components of Scots pine phytomass of natural and artificial origin are described by regression equations. The determination coefficients for stem wood and stem bark of silver birch and common alder turned out to be insignificant. Considering that the phytomass conversion coefficients of tree stems are the conditional density of stem wood, the model essentially describes the parametric and geographical variability of the conditional density. Given certain biological features of tree species, this variability cannot be high [17]. Therefore, their average values were used in future calculations.

Since in the study of the biotic productivity of the Cheremsky NR forests the phytomass of understorey vegetation ($R_{v(uv)}$) and the underground phytomass of tree stands ($R_{v(up)}$) of the main forest-forming tree species were not investigated, multiple regression equations of conversion coefficients obtained by P.I. Lakyda were used [18].

Considering the level of data aggregation for the conversion of completely dry phytomass into sequestered carbon and based on the results of the analysis of literary sources [7; 18] average transfer coefficients were adopted: 0.50 – for wood and bark, 0.45 – for leaves and the understorey.

Based on the developed models (Table 1) and data from the forest cadastre, the total amounts of phytomass and carbon in the forest stands of the Cheremsky NR were obtained (Table 2).

According to the indicators presented in Table 2, during 2005-2018, the area of forest areas covered with forest vegetation stayed unchanged. Therewith, the supply of stem wood increased from 244.9 thous. m^3 in 2005 to 336.2 thous. m^3 in 2018 (by 91.3 thous. m^3, or by 37.3%). Accordingly, the volume of the total phytomass of stands increased by 57.2 thous. t (36.5%) and the carbon accumulated in it by 28.4 thous. t (36.5%).

Table 2. Total amounts of phytomass and carbon in the forests of Cheremsk NR

Accounting year	Area of forest areas covered with forest vegetation, ha	Stem wood stock, thous. m^3	Phytomass		Carbon	
			thous. tonnes	density, $kg \cdot (m^2)^{-1}$	thous. tonnes	density, $kg \cdot (m^2)^{-1}$
2005	1,809.3	244.90	156.6	8.7	77.8	4.3
2011	1,809.3	281.64	179.5	9.9	89.2	4.9
2018	1,809.3	336.20	213.8	11.8	106.2	5.9

Figure 1 shows the dynamics of changes in the average density of phytomass and carbon in the tree stands of the Cheremsky NR. According to this figure, over the course of 13 years, these indicators gradually acquired higher values (from 8.7 $kg \cdot (m^2)^{-1}$ to 11.8 $kg \cdot (m^2)^{-1}$ for phytomass and from 4.3 $kg \cdot (m^2)^{-1}$ up to 5.9 $kg \cdot (m^2)^{-1}$ for carbon).

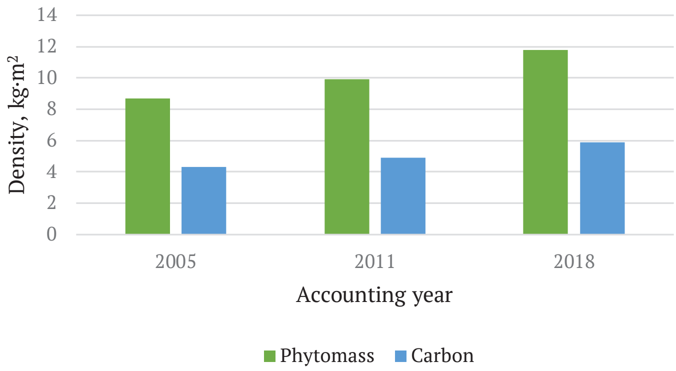

Figure 1. The dynamics of changes in the average density of phytomass and carbon in the forests of the Cheremsky NR

As of 2018, the carbon density in the forest stands of the Cheremsky NR for forest areas covered with forest vegetation reaches 5.9 kg·(m^2)$^{-1}$ on average. Moreover, in coniferous stands, the carbon density (6.1 kg·(m^2)$^{-1}$) is the closest to the average carbon density for the forest areas covered with forest vegetation in the Cheremsky NR. This indicator was the lowest in soft-wood stands (5.2 kg·(m^2)$^{-1}$), while it was the highest in hard-wood stands (7.6 kg·(m^2)$^{-1}$). Moreover, carbon density increases most intensively in hard-wood tree species (from 5.1 kg·(m^2)$^{-1}$ in 2005 to 7.6 kg·(m^2)$^{-1}$ in 2018), less intensively – in needles (from 4.5 kg·(m^2)$^{-1}$ in 2005 to 6.1 kg·(m^2)$^{-1}$ in 2018), and in soft-wood species – only by 0.6 (m^2)$^{-1}$.

Figure 2 shows the dynamics of changes in the density of phytomass by groups of forest-forming tree species in the forests of the Cheremsky NR. During the 13 experimental years, the density of phytomass in the tree stands of all groups of forest-forming tree species gradually increased (from 8.7 kg·(m^2)$^{-1}$ to 11.8 kg·(m^2)$^{-1}$), and, therefore, their bioproductivity increased. The most intensive growth of this indicator is observed in hard-wood stands (by 1.5 times) – from 10.3 kg·(m^2)$^{-1}$ to 15.1 kg·(m^2)$^{-1}$. It is somewhat smaller (1.4 times) in needless (from 9.1 kg·(m^2)$^{-1}$ to 12.4 kg·(m^2)$^{-1}$) and from 7.63 kg·(m^2)$^{-1}$ to 10.4 kg (m^2)$^{-1}$ in soft-wood stands.

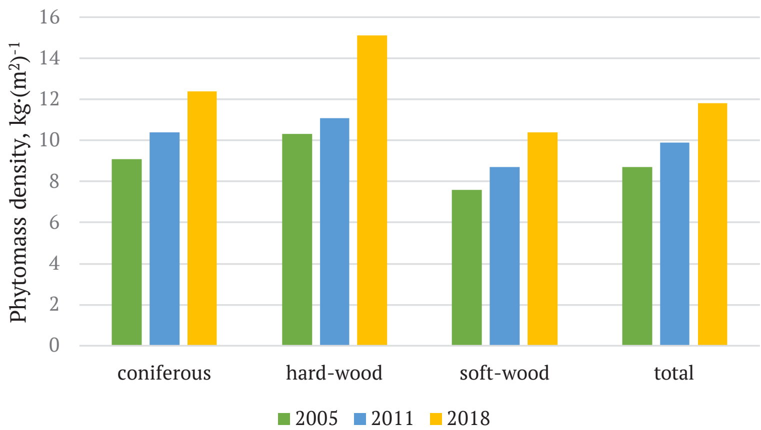

Figure 2. Dynamics of changes in phytomass density by groups of forest-forming tree species in the forests of Cheremsky NR

In general, in the tree stands of the reserve for 2005-2018, as a result of the change in the age class composition of stands and the growth of the average stock, the density of phytomass and sequestered carbon increased by 1.4 times.

According to Figure 3, wood and bark of tree stems comprise the largest share of the total phytomass of the forests of the Cheremsky NR. A much smaller, but solid share falls on the roots and a small amount – on the wood and bark of branches, understorey vegetation and leaves (needless).

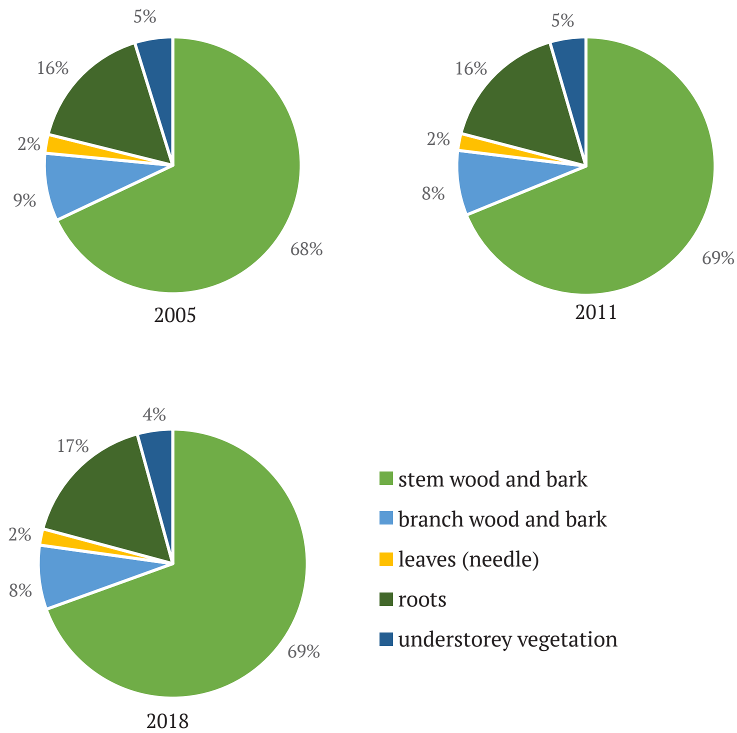

Figure 3. Dynamics structure of phytomass components of Cheremsky NR stands

Along with the increase in the total stock of stem wood during the period under study (see Table 2), the share of stem phytomass in 2005-2018 increased in the total structure of tree stands by only 1.0% (from 68.0% in 2005 to 69.0% in 2018). These indicators are somewhat higher compared to the average in Ukraine (in the forests of Ukraine, the phytomass of stems is 66.0% of the total phytomass of forests [19]). This is quite natural, since the forests of the Cheremsky NR are dominated by middle-aged tree stands, which grow intensively and quickly accumulate stem stock. Therewith, there are mature and maturing tree stands, the supply of stem wood of which is the largest.

According to Figure 4, a much smaller share in the structure of the phytomass components of the forests of the Cheremsky NR comprises root systems, wood and bark of branches, understorey vegetation, and leaves (needles) – to a minimal extent. Notably, in the overall structure of phytomass components of NR tree stands, the share of wood and bark of branches is half as much as the share of root systems (8% and 16%, respectively) (Fig. 3). Examination of the structure of phytomass components by groups of the main forest-forming tree species of this experimental object (Fig. 4) suggests that in hard-wood species, the share of wood and bark of branches is greater than the share of root systems. The distribution of phytomass of tree stands of the Cheremsky NR by groups of forest-forming tree species as of 2018 is presented in Fig. 5.

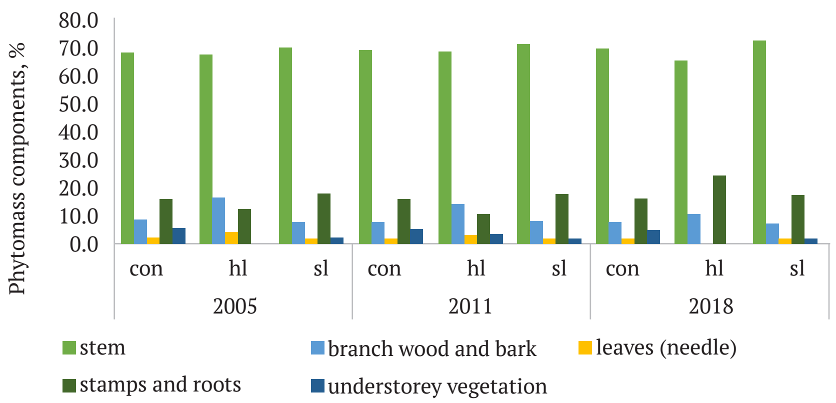

Figure 4. The structure of phytomass components by groups of the main forest-forming species of Cheremsky NR

Note: con – needles, hw – hard-wood, sw – soft-wood

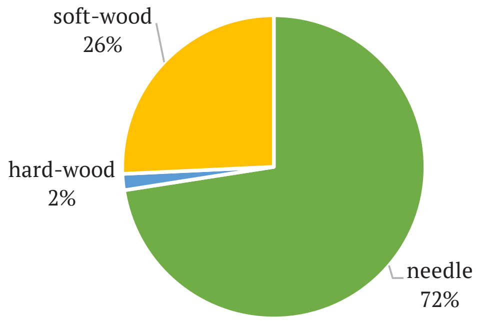

Figure 5. Phytomass distribution of tree stands of the Cheremsky NR by groups of forest-forming species as of 2018

According to this figure, the largest share in the phytomass structure of the nature reserve's forests is accounted for by coniferous stands (72.0%), a smaller share fell on soft-wood stands (26.0%) and the smallest – on hard-wood stands (2.0%).

Calculations of the intensity of oxygen production by tree stands of the Cheremsky NR were made according to the method of I.Ya. Liepa. The method is that based on the data on the composition of the total phytomass of the tree stands of the object under study for all components in a completely dry state, which is formed per unit of time, the volume of oxygen that released into the atmosphere due to photosynthesis is determined [17]. Admittedly, it is impossible to accurately determine the amount of oxygen produced, since part of it is spent on the decomposition of precipitation. But it is insignificant, so it is ignored.

According to N.I. Chesnokova and V.M. Dolgosheev, oxygen productivity per 1 t of completely dry matter of various species is approximately the same and is 1.393 t for pine, 1.413 t for spruce, 1.393 t for birch, and 1.423 t for aspen [11]. Therefore, this indicator was taken as 1.4 on average. Based on the results of calculations of the total phytomass of the tree stands of the Cheremsky NR, the annual change of the total phytomass per 1 ha was determined separately for 2005-2011 and 2011-2018. By multiplying the annual change in phytomass per 1 ha by the accepted oxygen productivity coefficient of 1 t of absolutely dry matter (1.4), the weight of oxygen released from each hectare in 1 year was obtained. Next, the obtained indicator was multiplied by the area of the experimental forest plots covered with forest vegetation and the total amount of oxygen produced by the tree stands of the Cheremsky NR in 1 year was found (Table 3).

Table 3. The volume of oxygen released by the Cheremsky NR tree stands

Forest management period	Area covered with forest vegetation, ha	Stem wood stock, thous. m^3	Phytomass		Annual change in phytomass, $t \cdot ha^{-1}$	The volume of oxygen released per year by 1 ha of forest, $t \cdot ha^{-1}$	The total amount of oxygen produced by the forest in 1 year, t
			total, thous. t	per 1 ha, $t \cdot ha^{-1}$			
2005	1809.3	244.90	156.6	86.6	2.1	2.9	5247
2011	1809.3	281.64	179.5	99.2			
2018	1809.3	336.20	213.7	118.1	2.7	3.8	6875

As evidenced by the data in Table 3, along with the increase in the productivity of forests, greater amounts of oxygen are released into the atmosphere.

According to the calculations, the forest biocenoses of the Cheremsky NR produce 6,875 t of oxygen every year (3.8 $t \cdot ha^{-1}$ on average). The distribution of oxygen production by the tree stands of the Cheremsky NR within groups of tree species as of January 1, 2018 is clearly shown in Figure 6. It indicates that the main volume of oxygen is produced by needles (69.8%), and 2.6 times less – by soft-wood stands (27.2%). Hard-wood tree stands, albeit with the highest phytomass and carbon density indicators, produce a meagre amount of oxygen (3.0%) in the Cheremsky NR, as they grow on a small area (24.4 ha) compared to other groups of tree species.

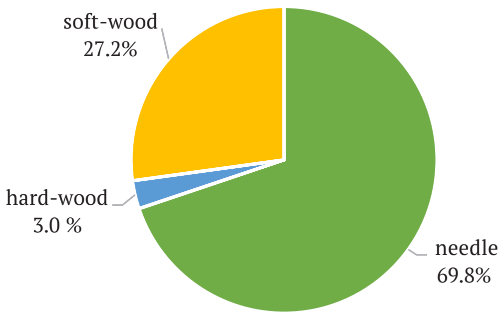

Figure 6. Oxygen productivity of stands of the Cheremsky NR within groups of forest-forming species as of January 1, 2018

This is explained by the fact that coniferous forests grow here on the largest territory (1,099.9 ha) and have the highest wood stock (218.42 thous. m^3). The share of softwood and hard-wood stands in the total stock of forest areas of the reserve is insignificant (66.53 and 4.65 thousand m^3). Therefore, they produce significantly less oxygen (6.1% and 2.1%, respectively). Coniferous tree stands emit more oxygen per unit area (6.2 t·ha^{-1}), hard-wood stands – slightly less (5.3 t·ha^{-1}), while soft-wood stands produce only 0.8 t·ha^{-1} oxygen.

Therefore, the most valuable from the perspective of oxygen production in the Cheremsky NR are coniferous forests, which emit 6,775 t of oxygen (6.2 t·ha^{-1}) into the atmosphere every year, while soft-wood stands produce only 449 t and hard-wood stands – 156 t of oxygen.

To date, the oxygen-producing function of forests has been investigated in other regions of Ukraine. Thus, H.A. Saharuk established that the oxygen productivity of the forests of the Shatskyi National Nature Park is 3.2 t·ha^{-1} per 1 year. I.P. Lakyda studied the urban forests of Kyiv, Yu.S. Miklush – forests of the green zone of Lviv, O.M. Melnyk – forest phytocenoses of the Pripyat-Stokhid National Nature Park. According to their data, the indicators of oxygen productivity in these objects are within 4.6-4.8 t·ha^{-1}·$year^{-1}$. However, the most productive are the forests of the Ukrainian Carpathians, which release 7.5 t·ha^{-1} of oxygen into the air every year [3].

For the forest vegetation zone of Polissia, the results of the oxygen-producing function of the forests of the Cheremsky NR (4.2 t·ha^{-1}) are average compared to the same indicators in other regions and can be used in the estimation of forest resources along with other indicators of ecological and economic areas. At the same time as releasing oxygen into the atmosphere, forests absorb carbon dioxide. Therefore, the estimation of the oxygen-producing function of the forests of the Cheremsky NR is a clear confirmation of their importance in improving the state of the air basin in the region under study.

Conclusions

The dependence of the phytomass components of tree stands of the main forest-forming tree species of the Cheremsky Nature Reserve on their main morphometric features was modeled using multiple regression analysis by establishing single- and multifactorial dependences of the phytomass components on the inventory indicators of the tree stands filed in the forest cadastre.

All above-ground components of Scots pine phytomass of natural and artificial origin are statistically significant. The coefficients of determination and other statistical indicators were found to be insignificant for the wood and bark of the stem of the silver birch and common alder. Therefore, their average values were used in further calculations.

During 2005-2018, the supply of stem wood increased from 244.9 thous. m^3 in 2005 to 336.2 thous. m^3 in 2018 (by 91.3 thous. m^3, or by 37.3%). Accordingly, the volume of the total phytomass of stands increased by 57.2 thous. t (36.5%) and the carbon accumulated in it by 28.4 thous. t (36.5%).

The largest share in the structure of the phytomass of the forest stands of the reserve falls on coniferous stands (72.0%), a much smaller share – on soft-wood stands (26.0%) and the smallest – on hard-wood stands (2.0%).

The average density of phytomass and carbon in the forests of Cheremsky NR during the 13 experimental years gradually increased: from 8.7 kg·$(m^2)^{-1}$ to 11.1 kg·$(m^2)^{-1}$ for phytomass and from 4.3 kg·(m^2) -1 to 5.5 kg·$(m^2)^{-1}$ for carbon.

As of 2018, the carbon density in the forests of the Cheremsky NR for forest areas covered with forest vegetation reaches 5.5 kg·$(m^2)^{-1}$ on average. This indicator was closest to the average value in coniferous stands (6.0 kg·$(m^2)^{-1}$), the lowest – in soft-wood stands (4.4 kg·$(m^2)^{-1}$) and the highest (6.3 kg·$(m^2)^{-1}$) – in hard-wood stands.

Carbon density increases more intensively in needles (from 4.5 kg·$(m^2)^{-1}$ in 2005 to 6.0 kg·$(m^2)^{-1}$ in 2018) and hard-wood tree species (from 5.1 kg·$(m^2)^{-1}$ in 2005 to 6.3 kg·$(m^2)^{-1}$ in 2018), and in soft-wood plants – less intensively (only by 0.6 $(m^2)^{-1}$).

During the period under study, the density of phytomass of tree stands and the carbon deposited in it increased 1.4 times in the forests of the reserve due to redistribution in the age class composition of forest stands and, as a result, an increase in the average stock per 1 ha.

Forest biocenoses of the Cheremsky Nature Reserve produce 6,989 t of oxygen every year (4.2 t·ha^{-1} on average). The main volume of oxygen is produced by coniferous stands (91.8%), as they grow here on the largest territory (1,099.9 ha) and have the highest wood stock (218.42 thous. m^3). The share of soft-wood and hard-wood stands in the total stock of forest areas of the reserve is insignificant (66.53 and 4.65 thous. m^3). Therefore, they produce much less oxygen (6.1% and .1%, respectively) Coniferous stands also emit more oxygen per unit area (6.2 t·ha^{-1}), hard-wood stands – a little less (5.3 t·ha^{-1}), while soft-wood stands produce only 0.8 t·ha^{-1} of oxygen.

The conducted studies of the forests of the Cheremsky Nature Reserve demonstrate the positive dynamics of the accumulation of phytomass volumes and the carbon sequestered in it (36.5% over the 13 years under study). In the future, the research will be aimed at predicting the increase in bioproductivity of the plantations of this object to improve their ecological functions and establish the possibilities of their impact on the environment.

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Біопродуктивність лісів Черемського природного заповідника

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Анотація. Кліматичні зміни підривають стабільність природних екосистем і негативно впливають на життя людини. Лісові біоценози здатні регулювати газообмін атмосфери, накопичувати й утримувати протягом тривалого часу в компонентах фітомаси небезпечні для навколишнього середовища викиди діоксиду вуглецю. Метою даного дослідження є вивчення динаміки біопродуктивності деревостанів головних лісотвірних видів Черемського природного заповідника за компонентами фітомаси та депонованого в них вуглецю. Для вирішення завдань роботи застосована методика П.І. Лакиди. Для здійснення процесу моделювання використані дослідні дані тимчасових пробних площ, які у повній мірі характеризують лісові масиви досліджуваного об'єкта. Розрахунок коефіцієнтів відношень R_v здійснювали для деревини стовбура ($R_{v(st)}$); кори стовбура ($R_{v(k)}$); гілок ($R_{v(g)}$); листви (хвої) ($R_{v(l)}$). Встановлено, що всі надземні компоненти фітомаси сосни звичайної описуються регресійними рівняннями. Для деревини й кори стовбурів берези повислої та вільхи клейкої коефіцієнти детермінації виявилися незначущими. У структурі фітомаси лісостанів заповідника найвагоміша частка (72,0 %) припадає на хвойні лісостани, значно менша – на м'яколистяні (26,0 %) і найменша – на твердолистяні насадження (2,0 %). За 13 років щільність фітомаси деревостанів та депонованого в ній вуглецю зросли в 1,4 рази. Щороку лісові біоценози заповідника виділяють в атмосферу 6989 т кисню (4,2 $т \cdot га^{-1}$). Основний об'єм кисню (91,8 %) продукують хвойні насадження. На основі зібраного дослідного матеріалу для деревостанів головних лісотвірних видів Черемського природного заповідника розраховані: коефіцієнти відношень компонентів надземної фітомаси до їхнього запасу в корі; математичні моделі оцінки динаміки компонентів фітомаси; нормативи розрахунку киснепродуктивності. Результати дослідження біо- та киснепродуктивності лісів Черемського природного заповідника стануть вагомим внеском для ефективного ведення господарства в заповідних лісах, а також при вирішенні проблем, пов'язаних зі змінами клімату на регіональному та глобальному рівнях

Ключові слова: математичні моделі, конверсійні коефіцієнти, фітомаса деревостанів, депонований вуглець, киснепродуктивність