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Organic Carbon in the Plant Biomass of Forests in Kyiv region

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Abstract. The carbon capacity of forest phytocenoses serves as one of the basic criteria for potential opportunities to ensure low-carbon development of the country and fulfil international obligations in the context of the Paris climate agreement. The information base of the study was information from the database of the Ukrainian State Forest Management Planning Association, which contains a specific tax characteristic of stands in the Kyiv region, and a system of mathematical models for quantitative assessment of phytomass and mortmass of forests.

As a result, quantitative values of organic carbon volumes in phytomass and mortmass of forests of the Kyiv region and Kyiv city are established. The total amount of carbon accumulated in the plant biomass of the region's forests is 61.8 million tonnes, of which 60% is accounted for by pine stands. The share of carbon accumulated in the mortar of forests of the Kyiv region is 10.5%. The highest density of deposited carbon per unit area is characterised by ash and oak stands with indicators of 10,08 and 9,921 kg*$(m^2)^{-1}$ accordingly. More than 40% of organic carbon is accumulated in the plant biomass of bonitet class I stands, which mainly grow in relatively poor forest conditions (barrens). Recreational-protective forests of the region have the highest organic carbon densities per unit area – 10.53 and 10.49 kg*$(m^2)^{-1}$ accordingly. Among the objects of the nature reserve fund, the dominant positions in terms of the volume of the indicator under study belong to nature reserves – 82.7% and about 8% is accounted for by national nature parks. In the total carbon structure of mortmass (6.5 million tonnes), more than 60% is forest litter. Therewith, the carbon content of mortmass plantings of coniferous tree species is 4.1 million tonnes or 62.9%.

The results obtained in the course of the study will serve as an information basis for forming a strategy for regional low-carbon development

Keywords: biomass, carbon, deposition, environmental monitoring, mortmass, plantings, phytomass

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Introduction

One of the key criteria for ensuring National Low-Carbon Development (Strategy, 2018) and compliance with international obligations in the context of the Paris Agreement (The Paris agreement, 2016) is the carbon capacity of forest phytocenoses. Currently, forests are the most efficient reservoir for long-term accumulation and retention of atmospheric carbon during their growth, and in wooden building structures and wood products with a substantial service life (Ince, Tayancli & Derogar, 2021; Sun et al., 2021).

Therewith, the phytomass and mortmass of forest stands are the basis for the establishment of reserves of forest combustible materials, and, accordingly, the source of carbon emissions as a result of forest fires (Soshenskyi et al., 2021). That is why forest carbon capacity management, as a component of sustainable forest management, determines the effectiveness of forestry management in the context of global climate change (Shvidenko et al., 2014; Vasylyshyn, 2016).

The forests of this region are a key natural object that not only ensures the ecological balance of the environment in conditions of excessive man-made load but also serves as an important source of raw materials for the development of the regional economy. In this context, the quantification of carbon capacity in plant biomass components will be an important information factor in the establishment of regional environmental and forestry initiatives.

The examination of carbon fluxes in forest ecosystems is now the object of study by both Ukrainian and foreign researchers. In particular, a comprehensive assessment of the carbon deposition capacity of forest phytocenoses and the impact of disturbances in the forests of Polesia of Ukraine on their carbon budget was conducted by researchers 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 Systems Analysis (Lakyda et al., 2018, 2019).

The updated assessment of the carbon budget of the forests of Ukraine was made in 2019 based on the forest map of Ukraine with a resolution of 60 m, according to which the capacity of forest ecosystems of Ukraine is estimated at 90 million tonnes of organic matter per year, or 504 g of carbon per 1 m^2 (Lesiv et al., 2019).

Considering the consequences of future climate changes on the territory of EU countries and their impact on the regional balance of carbon emissions, individual researchers (Fady et al., 2020) believe that it is necessary to avoid creating forests in places of a high probability of fires and drought-prone areas, which are now substantially expanding throughout Europe. Therewith, to mitigate the consequences of natural disturbances in forest ecosystems, researchers from Central Europe (Zimova et al., 2020) used the iLand model for the modelling of the impact of logging turnover on the vulnerability of 16 thousand hectares of forest landscape damaged by windbreaks and affected by bark beetles. As a result of the study, a clear relationship was established between forest carbon reserves, biodiversity indicators and the duration of logging turnover. In particular, reducing the turnover of logging by 40% allowed reducing the mentioned violations by 14%.

Monitoring studies also play an important role in ensuring effective management of the carbon-saving capacity of forest stands. An example of such writings is the papers of Romanian (Dumitrascu et al., 2020) and Spanish (Gomez-Garcia, 2020) researchers who successfully combine field research data with aorest cadastre data to establish predictive estimates of annual amounts of carbon deposited in forest ecosystems.

The presence of a substantial number of scientific papers in this area of research indicates the importance and relevance of further research on carbon uptake and emission processes in forest ecosystems.

The purpose of the study is to estimate the volume of organic carbon in the components of phytomass and mortmass of forests in the Kyiv region and the city of Kyiv.

Materials and Methods

The information basis of the study was information from the database of the Ukrainian State Forest Management Planning Association, formed according to the data of the current accounting of forests of Ukraine, which contains a specific tax characteristic of plantings (more than 200 thousand forest plots) of the studied region (Table 1).

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

Type of woody plants	Quantitative indicator		Type of woody plants	Quantitative indicator	
	pcs.	thousand ha		pcs.	thousand ha
Silver birch	24 078	68.97	Robinia pseudoacacia	3708	10.15
Common alder	13 002	36.04	Scots pine	122,494	384.65
Common hornbeam	2129	7.26	Common ash	1964	6.77
Common oak	24 788	82.64	Other tree species	11 797	19.11
Total				203,960	615.59

The methodology for estimating the volume of organic carbon in plant biomass components is based on the division estimation of phytomass and mortmass reserves using a system of mathematical models (Bilous, 2018; Schepaschenko et al., 2017; Shvidenko et al., 2014) and subsequent assessment of deposited carbon by quantitative parameters of its content in absolutely dry organic matter components of biomass plantings of the main forest-forming species of the region (Lakyda et al., 2018). For other wood species, the mentioned indicators of deposited carbon are established based on the weighted average values of these species.

Results and Discussion

The carbon capacity of forest stands now not only serves as a measure of the impact of climate change on forest ecosystems but also determines the possibility of a positive impact of forests on the concentration of greenhouse gases in the Earth's atmosphere.

In the course of the study, it was established that the estimate of the total amount of carbon deposited in the plant biomass of forests in the Kyiv region (123.1 million tonnes of absolutely dry matter, in particular, 111.0 – phytomass; 13.1 – mortmass) is 61.8 million tonnes, including 55.3 million tonnes in phytomass (Table 2). In general, more than 65% of the deposited carbon is accumulated in the plant biomass of coniferous plantations in the region. Hard-leaved stands account for about 20%, and almost 14% is concentrated in phytomas and mortmass of soft-leaved stands.

Table 2. Total carbon content in plant biomass of forests of the Kyiv region

Species group	Deposited carbon in plant biomass, thousand tonnes	
	phytomass	mortmass
Coniferous trees	36 592,6	4097.0
Hard-leaved	10 974,0	1527.7
Soft-leaved	7688.8	872.4
Other tree species	28.5	9.5
Total	55 284,0	6506.6

The share of mortmass in the total structure of accumulated organic carbon in the plant biomass of forests in the Kyiv region is 10.5%.

In the overall structure of organic carbon of the forests of the studied region, the dominant positions are occupied by pine stands, in which more than 60% (38.1 million tonnes) of its volumes are accumulated. The following positions belong to oak and birch stands with an indicator of 15.5% and 7.8%, respectively. The share of alder stands is about 4.5%, while the share of hornbeam, sedge, and ash stands slightly exceeds 1% (Fig. 1).

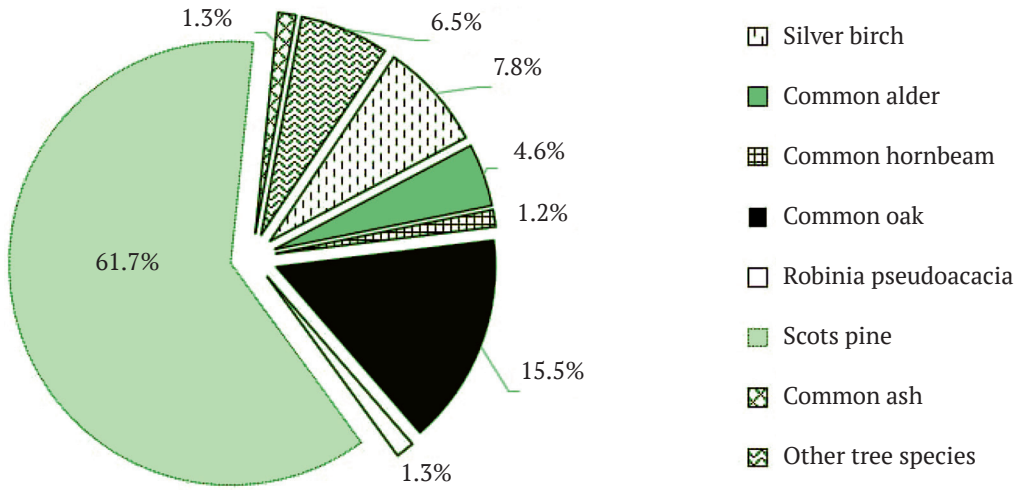

Figure 1. Structure of organic carbon reserves in plant biomass of forests of Kyiv region

It is established that ash and oak stands are characterised by the highest density of deposited carbon per unit area (Table 3). Quantitative values of the carbon density index in phytomass for these plantings reach 10,08 and 9,921 kg*$(m^2)^{-1}$ accordingly. In general, the mentioned indicator within the plantings of the dominant forest-forming species varies from 6,52 kg*$(m^2)^{-1}$ for alder stands up to 10,08 kg*$(m^2)^{-1}$ for ash trees. The average value of the density index of carbon deposited in phytomass within the plantings of the region is at the level of 8.82 kg*$(m^2)^{-1}$. For mortmass, the mentioned indicator is much lower and amounts to about 1.1 kg*$(m^2)^{-1}$, while the dominant positions in terms of carbon density accumulated in mortmass belong to oak and ash stands. The indicators of deposited carbon density in the plant biomass of forests in the region obtained in the process of separate assessment are almost 8% higher compared to the values obtained by researchers based on consolidated data from current forest accounting (Shvidenko et al., 2014). Therewith, according to the absolute values of organic carbon volumes in the plant biomass of forests in the Kyiv region, the mentioned deviation does not exceed 7%.

Table 3. Species differentiation of deposited carbon density in plant biomass of forests of the Kyiv region

Dominant tree species in the plantation	Deposited carbon density, kg*$(m^2)^{-1}$	
	phytomass	mortmass
Silver birch	6.65	0.55
Common alder	6.52	0.96
Common hornbeam	8.51	1.05
Common oak	9.92	1.42
Robinia pseudoacacia	6.54	0.54
Scots pine	9.36	1.07
Common ash	10.08	1.40
Average within the region	8.82	1.06

In the study region, more than% of organic carbon is accumulated in the plant biomass of stands of the I class of bonitet (Table 4).

Almost 30% are in class II bonitet stands, and a quarter is accounted for by high-performance plantings of Ia and above classes.This distribution is quite naturally determined by the regional bonitet and age structure of stands within the forest areas covered with forest vegetation of the Kyiv region.

Table 4. Distribution of carbon reserves in the plant biomass of forests of the Kyiv region within the bonitet classes

Bonitet class	Deposited carbon in plant biomass, thousand tonnes	
	phytomass	mortmass
I^a and above	13 324,8	1548.1
I	23 378,6	2637.0
II	15 062,5	1786.7
III	2914.7	413.4
IV	425.3	81.6
V and below	178.0	39.7
Total	55 284,0	6506.6

Therewith, analysing the distribution of organic carbon within the categories of forests, which is presented in Table 5, it is worth paying attention to the dominance of recreational forests – over 50% of the volume of carbon deposited. The share of operational forests does not exceed 25%. Regarding the density of organic carbon per unit area, the highest values in the region are typical for recreational and protective forests – 10.53 and 10.49 $kg*(m^2)^{-1}$ accordingly.

Table 5. Distribution of carbon reserves in plant biomass of forests of Kyiv region within forest categories

Category of forests depending on their functions	Deposited carbon in plant biomass, thousand tonnes	
	phytomass	mortmass
Forests for conservation, scientific, historical-cultural purposes	6470.2	731.3
Recreational forests	27 850,0	3137.2
Protective forests	7244.7	946.1
Operational forests	13 719,1	1692.0
Total	55 284,0	6506.6

Objects of the nature reserve fund (NRF) also play an important role in the process of forming the carbon storage capacity of forests in a particular region. In the region under study, the share of organic carbon in the phytomass and mortmass of forests within the mentioned sites is almost 9%, which is 5.5 million tonnes. Among the objects of the NRF, the dominant positions in terms of the volume of the studied indicator belong to nature reserves – 82.7% and about 8% is accounted for by national nature parks (Fig. 2).

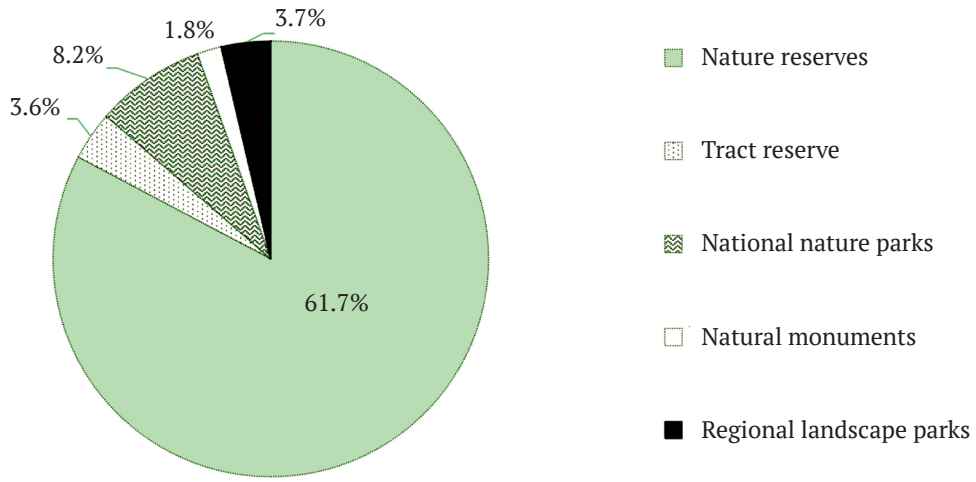

Figure 2. Structure of organic carbon reserves in plant biomass of forests within the objects of the nature reserve fund of the Kyiv region

The intensity of carbon deposition of forest stands substantially depends on the types of forest conditions in which they grow. In the course of the study, it was identified that the highest values of organic carbon density in phytomass are characteristic of plantings in fresh su-hruds (C_2) and wet hruds (D_3), where its values are more than 10 kg*(m^2)$^{-1}$. Therewith, the minimum values of this indicator are inherent in very dry and wet barren forests – 3.22 and 3.32 kg*(m^2)$^{-1}$ accordingly.

In total, about 10% of the organic carbon of plant biomass is accumulated in the barrens of the Kyiv region (Table 6). Therewith, about 50% of its reserves are concentrated in the biomass of plantings in su-barens (conditions, similar to barrens but with more pronounced oligotrophic vegetation), where Scots pine stands dominate. As for the density of deposited carbon, here the highest values are characteristic of stands in hruds (*D*) and su-hruds (*C*) – over 9.84 and 9.27 kg*(m^2)$^{-1}$ accordingly.

Table 6. Distribution of carbon reserves in plant biomass of forests of Kyiv region within trophotopes

Trophotop	Deposited carbon in plant biomass, thousand tonnes	
	phytomass	mortmass
Barrens (*A*)	5975.4	700.1
Su-barrens (*B*)	25650.8	2842.5
Hruds (*C*)	17933.0	2207.1
Su-hruds (*D*)	5724.8	757.0
Total	55284.0	6506.6

The component structure of carbon deposited in the phytomass of forests in the Kyiv region is dominated by tree trunks, the share of which is 71.4% (Table 7). This component of wood biomass is now the most important in terms of ensuring long-term accumulation and retention of atmospheric carbon.

Table 7. Distribution of carbon reserves in the phytomass of forests of the Kyiv region by components

Species group, tree type	Deposited carbon in phytomass, thousand tonnes						
	wood and trunk bark	wood and the bark of branches	needles (leaves)	roots	understory undergrowth	live ground cover	total
Coniferous trees	27 106,8	2307.4	524.0	5812.2	241.8	600.4	36 592,6
including Scots pine	25 391,5	2149.3	486.1	5461.8	228.5	567.9	34 285.1
Hard-leaved	7437.6	1493.7	156.9	1581.0	130.9	173.9	10 974,0
including common oak	5812.4	1144.5	106.6	1176.1	106.7	134.1	8480.5
Soft-leaved	4899.6	877.6	232.6	1439.3	81.6	158.1	7688.8
including silver birch	2774.3	605.0	168.2	786.3	43.5	89.6	4466.9
common alder	1681.7	179.6	33.0	488.0	30.3	52.1	2464.8
Other tree species	17.1	3.3	0.4	6.0	0.5	1.1	28.5
Total	39 461.1	4682.0	914.0	8838.5	454.8	933.6	55 284.0

8.5% of organic carbon is concentrated in the phytomass of branches, and more than 15% is concentrated in the phytomass of roots.

Components of the forest mormass of the region, such as tree stand, coarse woody debris, and forest litter, also serve as a fairly substantial carbon depot within forest ecosystems. In total, more than 6.5 million tonnes of organic carbon are accumulated in the forests of the Kyiv region, of which 64.3% are in the forest litter (Table 8). Notably, mortmass is also a substantial source of carbon emissions, especially during forest fires and its biodegradation.

Table 7. Distribution of carbon reserves in the phytomass of forests of the Kyiv region by components

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In the total carbon structure of mortmass of the forests in the region, an important place belongs to dry branches – 1.3 million tonnes, or about 19%, but the mentioned component of mortmass is subject to rapid biodegradation under certain conditions.

In the region of the study, the carbon content of mortmass of coniferous tree stands is 4.1 million tonnes, or 62.9%, while the share of mortmass components of the studied stands, which can potentially hold organic carbon for a long time (tree stand, forest litter), reaches about 75% of the total mortmass of coniferous stands. For hard-leaved and soft-leaved plantings, this ratio is 80.0% and 72%, respectively.

Conclusions

According to the results of the conducted studies, it was established that the total volume of organic carbon deposited in the plant biomass of forests in the Kyiv region is 61.8 million tonnes, including 55.3 million tonnes in phytomass. The share of mortmass in the total structure of accumulated organic carbon in the plant biomass of forests in the Kyiv region is 10.5%.

The structure of organic carbon deposited in the region's plant biomass is dominated by pine stands, which accumulate more than 60% of the total reserve. The component structure is dominated by tree trunks, the share of which is 71.4%. In the total carbon structure of mortmass (6.5 million tonnes), more than 60% belongs to forest litter. Therewith, the carbon content of mortmass plantings of coniferous tree species is 4.1 million tonnes, or 62.9%.

The forest categories are dominated by recreational forests, which account for more than 50% of the volume of carbon deposited. The share of operational forests does not exceed 25%. Recreational and protective forests are also characterised by the highest organic carbon densities per unit area – 10.53 and 10.49 kg*$(m^2)^{-1}$ accordingly.

The results obtained in the course of the study will serve as an information basis for forming a strategy for regional low-carbon development.

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Органічний вуглець у рослинній біомасі лісів Київщини

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Анотація. Вуглецедепонувальна здатність лісових фітоценозів слугує одним із базових критеріїв потенційних можливостей забезпечення низьковуглецевого розвитку країни та виконання міжнародних зобов'язань у контексті Паризької кліматичної угоди. Інформаційною базою дослідження слугувала інформація з бази даних ВО «Укрдержліспроєкт», що містить повидільну таксаційну характеристику деревостанів Київщини, а також система математичних моделей для кількісного оцінювання фітомаси й мормаси лісів.

У результаті встановлено кількісні значення обсягів органічного вуглецю у фітомасі та мортмасі лісів Київської області та м. Києва. Загальний обсяг вуглецю, акумульований у рослинній біомасі лісів регіону, становить 61,8 млн т, з яких 60 % припадає на соснові деревостани. Частка вуглецю, накопиченого у мортмасі лісів Київщини, складає 10,5 %. Найвищою щільністю депонованого вуглецю на одиниці площі характеризуються ясеневі та дубові насадження з показниками 10,08 і 9,921 кг·(м^2)$^{-1}$ відповідно. Понад 40 % органічного вуглецю акумульовано у рослинній біомасі деревостанів I класу бонітету, які переважно ростуть у порівняно бідних лісорослинних умовах (суборах). Рекреаційно-оздоровчі та захисні ліси регіону мають найвищі показники щільності органічного вуглецю на одиниці площі – 10,53 та 10,49 кг·(м^2)$^{-1}$ відповідно. Серед об'єктів природно-заповідного фонду домінантні позиції за обсягами досліджуваного показника належать заказникам – 82,7 %, ще близько 8 % припадає на національні природні парки. У загальній структурі вуглецемісткості мормаси (6,5 млн т) понад 60 % становить лісова підстилка. Водночас вуглецемісткість мормаси насаджень хвойних деревних видів складає 4,1 млн т, або 62,9 %.

Одержані в процесі дослідження результати слугуватимуть інформаційною основою для формування стратегії регіонального низьковуглецевого розвитку

Ключові слова: біомаса, вуглець, депонування, екологічний моніторинг, мортмаса, насадження, фітомаса