EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2025, 26(11), 161–170
https://doi.org/10.12912/27197050/211817
ISSN 2719–7050, License CC-BY 4.0

Received: 2025.09.09
Accepted: 2025.10.15
Published: 2025.11.01

Recreation potential and oxygen productivity of peri-urban forests of Kyiv city

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ABSTRACT

The relevance of the study is determined by the need to manage the forest resources of Kyiv city to maximize the efficiency of their ecological functions. Particular attention is paid to the oxygen-producing capacity of forests, which plays a key role in the context of a significant anthropogenic load. The silvicultural peculiarities of forest stands that affect their aesthetic properties are investigated. Recreational indicators of the forests of the northwestern part of Kyiv in the territory of the municipal enterprise "Sviatoshyn Forest and Park Economy" in places of mass recreation are established, in particular, the prevailing types of landscapes and objects of the nature reserve fund. Based on the research, the recreational suitability of areas of mass and intensive recreation was determined. The total oxygen productivity of the forest stands of the study area was determined to be more than 160 thousand tons of oxygen, with a weighted average oxygen productivity of 1 ha of the studied forest ecosystems reaching 15.5 t·ha^{-1} per year. The annual average net oxygen productivity in the forests of the study area is differentiated depending on the predominant tree species and is characterized by a value of 6.7 t·ha^{-1}, while the highest values are inherent in stands dominated by ash (9.7 t·ha^{-1}), oak (8.2 t·ha^{-1}) and hornbeam (7.5 t·ha^{-1}).

Keywords: oxygen productivity, zone of mass recreation and intensive recreation, recreational indicators.

INTRODUCTION

The main purpose of the forests of the green zone of Kyiv is to perform ecological functions. The key task of these forests is to regulate and stabilize soil, climatic and hydrological conditions not only within the green zone of the city, but also beyond it. Therefore, the management of forest resources in Kyiv's forests should focus on maximizing the efficiency of their ecological functions, which determined the relevance of the study.

The central link in solving the environmental problems of cities is suburban forests, which perform social, ecological, and environmental functions (Tokareva, 2012; Tokareva et al., 2021). In this context, the oxygen-producing capacity of forests is of particular importance (Shvidenko et al., 2014; Li et al., 2022). This function of urban forests and green spaces is aimed at increasing the concentration of oxygen in the air of megacities and plays a key role in ensuring sanitary and hygienic living standards for the population in conditions of significant anthropogenic pressure on the environment (Millennium Ecosystem Assessment, 2005; Vasylyshyn et al., 2023). Urban forests are an important component that form the recreational potential of cities (Zhao et al., 2023; Jim and Chen Wendy, 2009), providing a set of factors aimed at creating a comfortable urbanized environment (Bolick et al., 2023; González-Hernández et al., 2023). An actual object of research in this area is the urban forests of Kyiv, which currently form a significant recreational potential (Lakyda at al., 2022). The northwestern part of the urban green zone of Kyiv is occupied by the forests of the municipal enterprise "Sviatoshyn Forest and Park Economy".

A special requirement for forest management in urban, suburban and periurban forests should be the preservation and improvement of the natural beauty of the landscape. One of the main issues of preserving the environmental balance of suburban forests is the study and maintenance of their species diversity. Maintaining and improving biodiversity in forest ecosystems is an integral indicator of forest management efficiency and a key condition for sustainable forest management.

In the context of scientific and technological progress, which is characterized by accelerated development of productive forces and intensive use of natural resources, the problems of protection and rational use of forest recreational areas have become particularly relevant. Currently, much attention is paid to the preservation and restoration of the natural environment in order to improve living conditions and human health (Song et al., 2023). In this regard, there is a need to develop healthcare facilities, as well as sanatoriums, rest homes, boarding houses, and improve services in them. Therefore, the role of forests, especially those directly adjacent to large cities and settlements, has increased, as well as their protective, sanitary, aesthetic, and other functions (Bressane and Loureiro, 2025). In order to create favorable living conditions for the population in cities, it is advisable to bring forests closer to buildings, combine large parks and forest areas into a single architectural complex. The suburban zone, which is a continuation of the urban area, is subject to special improvement, the formation of a natural landscape, and the provision of healthy and comfortable recreation (Sexton and Lawhorn, 2025).

Climate change over the past decade manifested in abnormally high temperatures during the growing season and prolonged dry periods. This has led to a transformation of the hydrological regime of large areas along with hydrotechnical drying of forest lands. The named factors have negatively affected the structure and functions of forests as well as and their viability. There is an unprecedented decline in the biological resistance of forests to stressors and the massive spread of harmful insects and diseases, which leads to large-scale pathological phenomena and forest degradation (Iavniy and Puzrina, 2018; Puzrina et al., 2023).

The object of the research was the forests of the northwestern part of urban green zone of Kyiv city.

The purpose of the study is to assess the recreational resources and oxygen productivity of the forests of the northwestern part of urban green zone of Kyiv city.

MATERIAL AND METHODS

During the field work, temporary sample plots were established to determine all the indicators of landscape assessment and mensuration. Organized landscape mensuration blocks have one goal in the future – the use and economic purpose in the landscape structure and organization of recreation areas. The organization of landscape mensuration blocks was carried out in such a way that as a result of economic activities in 10–12 years, if possible, they would differ between neighboring landscape areas, so that each area would acquire a characteristic individuality of its own.

To determine the distribution of stand areas by age groups, the results obtained were compared with the optimal ones (Table 1).

When assessing landscape types, we used the classification defined by the DSTU standard "Recreational Forest Use" (DSTU, 2010) which distinguishes between closed, semi-open, and open landscape types. In turn, each of them is divided into three groups.

Closed landscapes: IA – single-tier tree stands with horizontal canopy cover, density of 0.6 and above, pure and mixed, predominantly of the same age with uniform distribution of trees in the area of their growth. The visibility of closed landscapes does not exceed 20 m; IB – multi-aged two- and more-tiered tree stands, taking into account the understory vegetation with a height of more than 1.5 m, mainly mixed, sometimes pure with several generations, with group placement of trees in the area of their growth. Horizontal canopy cover is 0.6 and above; IC – thickened young trees up to 20 years old.

Semi-open space landscapes are divided as follows: IIA – single-age tree stands with uniform tree placement with canopy cover of 0.3–0.5 with sparse undergrowth and underbrush up to 1.5 m or without underbrush and undergrowth; IIB – plantations with group or curtain placement of trees, both pure and mixed, with a canopy cover of 0.3–0.5. and in groups – 0.6–0.7; IIC – young trees over 1.5 m high with canopy cover of 0.5–0.4. and in clumps and groups – 0.7–1.0.

Table 1. Optimal distribution of forest area by age groups, %

Species groups	Age groups			
	Young	Mid-aged	Maturing	Mature and overmature
Forests of nature protection. scientific. historical and cultural purposes				
Conifers	28.6	42.8	14.3	14.3
Hardwoods	23.0	54.4	11.5	11.1
Softwoods	24.9	49.9	12.5	12.7
Total	27.8	44.4	13.9	13.9
Recreational and health-improving forests				
Conifers	28.6	42.8	14.3	14.3
Hardwoods	24.2	51.5	12.0	12.3
Softwoods	26.0	48.0	12.8	13.2
Total	28.2	43.6	14.1	14.1
Total for the forestry enterprise				
Conifers	28.6	42.8	14.3	14.3
Hardwoods	23.1	54.1	11.5	11.3
Softwoods	25.1	49.6	12.5	12.8
Total	27.9	44.2	14.0	13.9

Note: Based on Instructional and Methodological Guidelines for Forest Management (2022).

Open landscapes are divided as follows: III A – clearings and areas with single trees, sparse regeneration of trees and shrubs of various heights. Trees evenly spaced across the growing area have well-developed broad crowns. IIIB – areas with forest regeneration up to 1,5 m high, regardless of density; IIIC – areas without tree vegetation.

The methodology for assessing the oxygen productivity of urban forests is based on a plot-by-plot assessment of net primary production of forest ecosystems using the semi-empirical method proposed by Shvidenko et al. (2014), through the assessment of net primary production, i.e. the mass of organic matter produced by the ecosystem per unit of time (Vasylyshyn et al., 2023) and indicators of oxygen production intensity, which characterize oxygen volume released in the process of producing one ton of organic matter (Lakyda et al., 2022).

RESULTS

In accordance with the Resolution of the Cabinet of Ministers of Ukraine of 16.05.07 №733 "Procedure for dividing forests into categories and allocation of specially protected forest areas", the division of forests into categories, their functional purpose, forest management regime and forest use regime, the forests of the municipal enterprise "Sviatoshyn Forest and Park Economy" (ME Sviatoshyn FPE) are divided into forests of nature protection, scientific, historical and cultural purposes (with a special regime of use on flatlands) and recreational and health-improving forests (with a special regime of use on flatlands).

Forests of nature protection, scientific, historical and cultural purposes with a special regime of use include: national nature parks (protected area, regulated recreation area, stationary recreation area); natural monuments; and nature reserves. Recreational and health-improving forests with a special regime of use include forests within cities, towns and other settlements, forest parks of the green zone forests. The division of the forests of ME Sviatoshyn FPE is shown in Figure 1.

The largest share of the territory of ME Sviatoshyn FPE is formed by National Nature Parks, namely the regulated recreation area – 38.1% and forests within settlements (green zone forests) – 33.2%, respectively.

To determine the distribution of stand areas by age groups, the results were compared with the optimal ones (Table 2).

The main landscape-forming species is Scots pine, whose stands form landscapes of light coniferous and mixed coniferous forests. The most common forest types are fresh oak-pine dominated fairly infertile forest (45.5%) and fresh hornbeam-pine dominated fairly fertile forest (38.8%). The

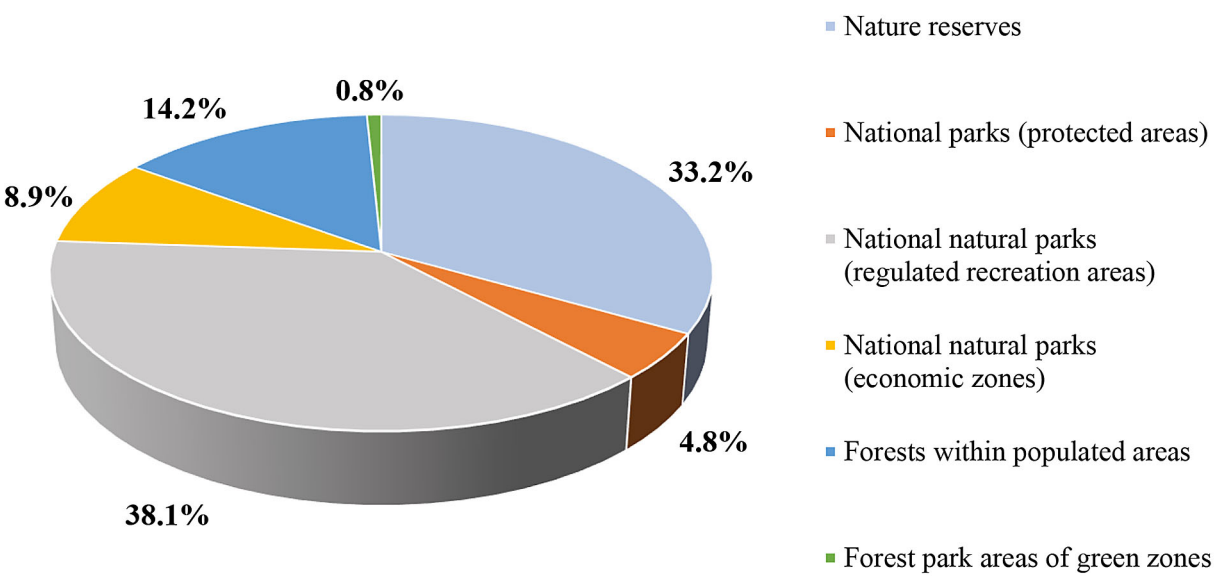

Figure 1. Distribution of forest area by categories, %

Table 2. Existing distribution of forest area by age groups, %

Species groups	Age groups			
	Young	Mid-aged	Maturing	Mature and overmature
Forests of nature protection. scientific. historical and cultural purposes				
Conifers	11.3	54.6	11.6	2.5
Hardwoods	2.5	87.8	3.6	6.2
Softwoods	4.9	46.0	13.0	36.1
Total	10.1	58.2	10.7	21.0
Recreational and health-improving forests				
Conifers	3.2	61.2	11.4	24.2
Hardwoods	3.8	72.9	3.7	19.6
Softwoods	18.7	23.2	14.7	43.4
Total	3.7	60.8	11.0	24.5
Total for the forestry enterprise				
Conifers	10.1	55.5	11.6	22.8
Hardwoods	2.6	86.4	3.6	7.4
Softwoods	6.9	42.7	13.2	37.2
Total	9.2	58.6	10.7	21.5

Note: Based on forest management planning materials.

distribution of stands by age classes is uneven, with predominance of mid-aged stands. The area of overmature pine stands that have practically lost or are losing their environmental, aesthetic and other functions is 15.5%. Such forest stands require gradual replacement. The average site index class of the enterprise's stands is I^a.9, which objectively reflects the growing conditions. The mean relative stocking of stands is 0.69.

The existing division of stands by age groups differs significantly from the optimal one. In general, there are almost 3 times fewer young stands than the optimal value, while the number of mid-aged ones is slightly higher. There is a deficit of mature stands dominated by hardwood species, and for softwood species the percentage of mature stands is 3 times higher than the optimal.

The forest fund of the enterprise is characterized by a fairly high degree of recreational load, as areas of intensive recreation and mass recreation make up 2388.8 hectares or 20% of the total area of forest stands. The area of extensive recreation, which amounts to 9329.0

hectares, should be considered as a reserve for the intensive recreation zone (Table 3).

The predominant landscape type in recreational forests is closed landscapes with horizontal closure of tree crowns, which is quite typical for all forests of Ukraine. The predominance of this type of landscape is noted in the mass recreation zone and the extensive recreation zone (Figure 2).

It should be noted that in the mass recreation zones, a significant share of the area belongs to the semi-open landscape, which is more attractive to visitors (Figure 3a). In the reserves zone, we note a significant share of open landscapes – 12.3%, represented by overmature low-stocked stands, which are a valuable part of forest-park landscapes (Figure 3b).

The share of landscape types is: closed 70.2%, semi-open 20.3% (Figure 3b) and open 9.5%. According to the optimal standards for Polissia zone of Ukraine, the ratio of landscape types should be 70–80%, 15–20%, and 5–10%, respectively. As you can see, the actual existing landscape structure is almost optimal, and therefore does not require special measures for improvement.

In general, the territory of recreational forests is characterized by uneven load, which was taken into account when designing measures for their landscaping. The unevenness of the load depends on the seasonal concentration of vacationers in limited areas, which sometimes harms forest ecosystems and leads to irrational use of recreational resources. With the proper organization of recreational areas, forest stands can accelerate and increase the efficiency of recreation and at the same time reduce the recreational load. To increase the recreational role of forests, the company needs to work on improving the existing recreational areas. Efficient use of the recreational territories can be ensured by regulation of forest visits by the population, reducing recreational loads, and increasing the health-improving effect of species with high bioenergy potential.

Optimization of interaction between society and the environment is one of the basic directions of recreational forest management. To improve the efficiency of use of ecosystem services of recreational forests, it is necessary to develop new approaches and tools for making management decisions, a key component of which is to increase the attractiveness of recreational forests and forest landscapes, increase forest resilience to climate change and meet local demand for woody biomass.

A significant part of the area is occupied by the territories of the nature reserve fund, namely 85% of the total area of forest stands (Table 4).

All the objects of the nature reserve fund meet the designated purpose, and it should be noted that Holosiivskyi National Nature Park is located on the territory of the Emerald Network of Ukraine (Holosiivskyi National Nature Park UA0000043) (https://emerald.eea.europa.eu/).

In forests of nature protection, scientific, historical and cultural purposes, a special regime of use has been established and landscape mensuration and survey was carried out. In the most visited places, mass recreation zones have been created and differently designed separate recreation areas have been placed. They are equipped with appropriate sets of forest-park furniture and

Table 3. Distribution of recreational forests by landscape type, ha

Total	Including by landscape type									
	Closed			Semi-open			Open			
	IA	IB	Total	IIA	IIB	total	IIIA	IIIB	IIIC	Total
Mass recreation zone										
1004.0	565.6	120.3	685. 9	150.3	137.6	287.9	2.2	5.1	22.9	30.2
Intensive recreation zone										
1384.8	408.6	98.0	506.6	560.2	280.3	840.5	1.0	7.8	28.9	37.7
Extensive recreation zone										
9329.0	4192.0	598.0	4963.1	3568.2	926.6	4321.7	4.0	15.7	24.5	44.2
Reserves zone										
599.4	255.4	11.9	267.3	258.1	-	258.1	16.0	45.7	12.3	74.0
Total for the enterprise										
12317.2	5421.6	828.2	6249.8	4536.8	1344.5	5881.3	23.2	74.3	88.6	186.1

Note: Based on forest management planning materials.

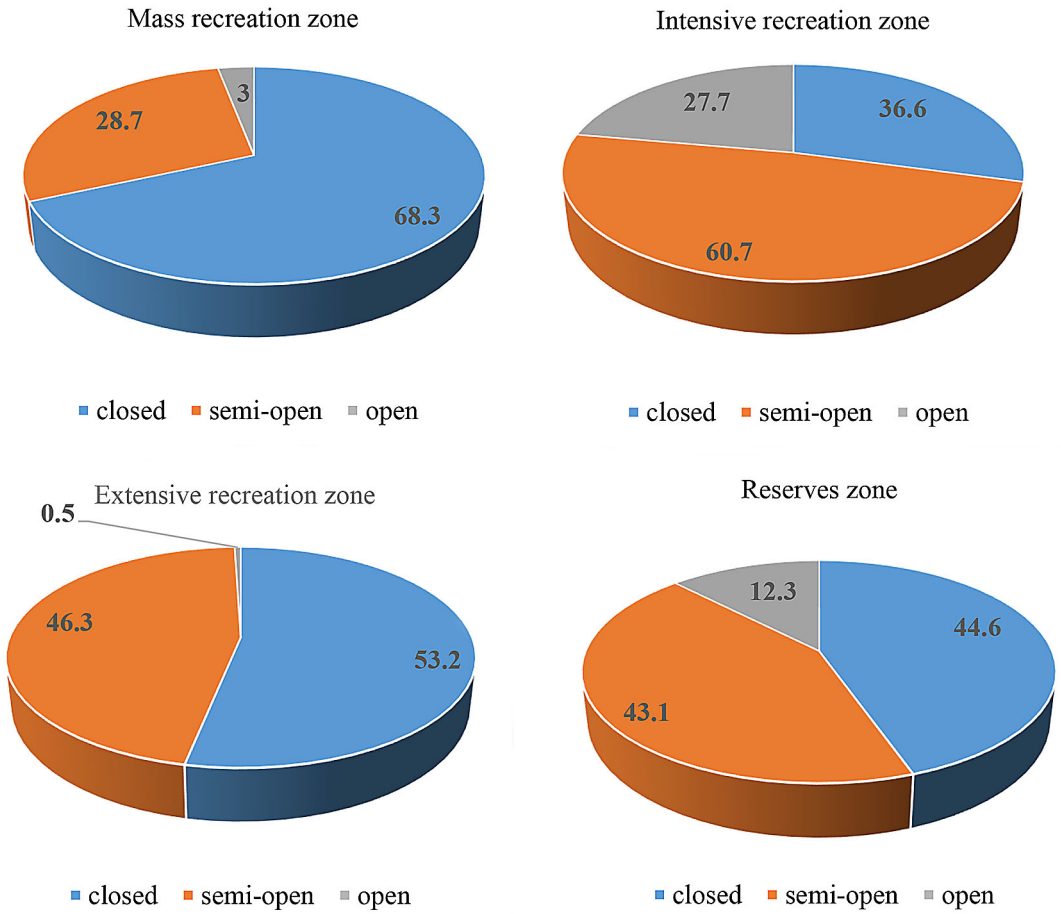

Figure 2. Distribution of forest area by landscape types, %

(a) (b)

Figure 3. Semi-open landscape of the intensive recreation zone (a), and open landscape of the reserve zone (b)

the required number of garbage bins, information stands, barriers, etc.

A separate type of forest stands is the forests of green zones, which include the territory outside the city limits occupied by forests and other green spaces. Forests of urban green areas are functional natural objects, the characteristic feature of which is a stabilizing effect on the urban environment. They are important factors in the formation and regulation of the urban and non-urban environment, which is carried out by influencing the temperature, ionizing regime of the air, as well as its humidity and chemical composition, including the absorption of carbon dioxide with the subsequent

Table 4. Nature reserve fund of SE Sviatoshyn FPE

Name	Area, ha	Composition	Purpose of creation
Parks-monuments of landscape art of national importance			
Sviatoshyn forest park	240.0	Stands of natural origin aged 150–180 years. consisting of Weymouth pine *Pínus strobus*. common oak *Quercus robur*. red oak *Quercus rubra*. European spruce *Picea* abies	Established for the protection of natural stands aged 150–180 years
Pushcha-Vodytsia forest park	162.0	*Catalpa bignonioides*. American linden *Tilia americana*. Amur velvet *Phellodendron amurense*	Created to preserve valuable groups and solitary exotics
Pushcha-Vodytskyi Resort Forest Park	198.0	Common oak *Quercus robur.* common pine *Pinus sylvestris* of natural origin	Established to preserve age-old stands of natural origin
Natural monument of national importance			
Romanivske bog	30.0	Includes about 100 species of plants. including those listed in the Red Book of Ukraine	Created for the purpose of preservation. protection and use for aesthetic. educational. scientific. environmental and health-improving purposes
General zoological reserve of local importance			
Lyubka river	163.0	An anthropogenically unloaded area where typical representatives of the fauna of Polissia have been preserved	Created to preserve valuable natural habitats
Reserve of local importance			
Mezhyhirske	5.0	Mixed stands of oak *Quercus robur.* pine *Pinus sylvestris* with the presence of medicinal plants	Established for the purpose of preservation. protection and use for aesthetic. educational. scientific. environmental and health-improving purposes
Landscape reserve of local importance			
Pushcha-Vodytsia	563.2	A natural center where valuable pine and oak forests 180–200 years old have been preserved	Created to preserve valuable natural communities
Natural monument of local importance			
Oak ”Bye-Bye”	–	Common oak *Quercus robur.* 350 years old. height 25 m. diameter 475 cm	Created to preserve a 350-year-old oak tree. which is of great scientific and aesthetic value due to its size. age and beauty
Natural monument of local importance			
Collection of forester S.V. Vinter	0.33	Two Weymouth pine trees *Pínus strobus* and three Siberian larch trees *Larix sibirica*	Established to preserve Weymouth pine and Siberian larch
Forest reserve of local importance			
Mezhyhirsko-Pushcha-Vodytskyi	2132.0	Natural plant communities	Established to preserve valuable natural communities
Landscape reserve of local importance			
Golden forest	856.8	Center of valuable natural complexes	Established for the purpose of preservation and reproduction of valuable natural complexes. gene pool of flora and fauna
National nature park			
Holosiivskyi	6462.6	The center of particularly valuable natural complexes and objects of the Forest-Steppe and Kyiv Polissia	The park was established to preserve. restore and rationally use especially valuable natural complexes and objects of the Forest-Steppe and Kyiv Polissia. which have important environmental. scientific. historical. cultural. aesthetic. recreational and health-improving value. as well as to improve the environmental conditions in Kyiv city.

Note: Based on forest management planning materials.

release of oxygen, etc. The functions performed by the forests of urban green areas can be grouped into the following groups: environmental (environment-forming or climate-regulating, sanitary and hygienic, protective), social (recreational, health-improving, aesthetic), and environmental (development of recreation, meeting the demand of the population in wood).

An important ecological function of the forests of the ME Sviatoshyn FPE is their ability to produce oxygen. According to the results of our research, the total oxygen productivity of forest plant communities of ME Sviatoshyn FPE exceeds 160 thousand tons of oxygen (Table 5). At the same time, the weighted average oxygen productivity of 1 hectare of the studied forest ecosystems reaches 15.5 t·ha^{-1} per year. Almost 80% of the total volume of oxygen produced is formed by Scots pine-dominated stands. The contribution of oak stands to the overall balance of oxygen production in the studied forests is about 17%.

The annual net mean oxygen productivity in the studied forests is differentiated depending on the predominant tree species and is characterized by a value of 6.7 t·ha^{-1}, while the highest values are inherent in stands dominated by ash (9.7 t·ha^{-1}), oak (8.2 t·ha^{-1}) and hornbeam (7.5 t·ha^{-1}).

The age-related peculiarities of changes in oxygen productivity of the studied forests are shown in Table 6. According to the information in Table 6, there are natural changes in oxygen productivity with the age of the studied stands. The mean oxygen productivity reaches a maximum by the V age class (41–50 years) – 19.2 t·ha^{-1}, and then gradually decreases. In the overall structure, about 20% of the annual oxygen volume is produced by stands of the VIII age class.

An important biometric characteristic of the studied stands, which affects the formation of indicators of their oxygen productivity, is their site index class. As a result of our study, a directly proportional dependence of a stand's site index class on oxygen productivity indicators has been found.

Table 5. Oxygen productivity of urban forests of the Municipal Enterprise "Sviatoshyn Forest-Park Economy" distributed by dominant forest-forming tree species

Tree species	Oxygen productivity of stands		
	total, thou. tons	mean, t·ha^{-1}	net mean, t·ha^{-1}
Silver birch	1.54	8.9	4.0
Black alder	1.27	9.3	3.3
European hornbeam	0.01	18.7	7.5
Common oak	27.74	19.2	8.2
Black locust	0.30	17.4	6.5
Scots pine	132.28	13.7	6.4
Common ash	0.01	19.1	9.7
Other tree species	3.11	–	–
Total / mean	166.25	15.5	6.7

Table 6. Oxygen productivity of urban forests of the Municipal Enterprise "Sviatoshyn Forest-Park Economy" distributed by age classes

Age class	Oxygen productivity of stands		
	total, thou. tons	mean, t·ha^{-1}	net mean, t·ha^{-1}
I	2.94	8.4	5.6
II	1.46	9.1	5.9
III	0.45	13.0	6.2
IV	0.52	18.2	8.5
V	3.46	19.3	9.2
VI	20.51	16.7	8.4
VII	32.15	16.1	7.6
VIII	17.26	15.7	6.7
IX	26.39	15.6	6.4
X	16.92	15.5	6.0
XI i above	44.19	–	–
Total / mean	166.25	15.5	6.7

Table 7. Oxygen productivity of urban forests of the Municipal Enterprise "Sviatoshyn Forest-Park Economy" distributed by site index classes

Site index class	Oxygen productivity of stands		
	total, thou. tons	mean, t·ha^{-1}	net mean, t·ha^{-1}
I^b and above	3.29	20.3	10.5
I^a	56.09	15.9	7.9
I	68.12	14.5	6.0
II	36.12	14.0	5.8
III	2.31	13.6	4.9
IV	0.14	11.5	4.4
V and below	0.17	10.3	3.9
Total / mean	166.25	15.5	6.7

This dependence is clearly seen in Table 7. More than 40% of the oxygen volume within the study area is annually produced by forests of the first site index class, which is 68.12 thousand tons.

The mean oxygen productivity clearly reflects the trend of dependence on the productivity of the studied stands. In particular, a decrease in this indicator was found with a decrease in the values of a stand's site index class. For stands of I^b and higher site index classes, this indicator is at the level of 20.3 t·ha^{-1}, which decreases to 10.3 t·ha^{-1} for stands of V and lower site index classes.

CONCLUSIONS

Suburban forests perform extremely important socio-ecological and environmental functions. Only suburban forests among all natural complexes can serve as the main factor in protecting and stabilizing the urban environment. Due to the need to improve the health of the urban population, the demand for recreational resources has increased significantly. For the metropolis of Kyiv, the recreational resource is suburban forests maintained by forest-parks economies and in which the current legislation prohibits final cuts, so maintaining a satisfactory condition of stands is achieved by care cuts and selective sanitary cuts.

Our study confirms that the forests of the northwestern part of the green zone of Kyiv play a key role in performing environmental functions, especially in regulating soil, climatic and hydrological conditions and ensuring sanitary and hygienic standards for the population. The studied forests have a high degree of recreational use, with zones of intensive recreation and mass recreation accounting for 20% of the total area. The predominant landscape type is closed (70.2%), while semi-open (20.3%) and open (9.5%) landscapes account for a smaller share, but the actual landscape structure is considered to be practically optimal. To increase the recreational role of forests, it is necessary to improve existing recreation areas, regulate public visits to forests to reduce pressure, and develop new approaches to assess and efficiently use ecosystem services. It is important to take into account the territories of the nature reserve fund, which account for 85% of the total forest area.

According to the results of the assessment, the total oxygen productivity of the stands in the northwestern part of the forests of the green zone of Kyiv is more than 160 thousand tons of oxygen per year. The weighted average oxygen productivity is 15.5 t·ha^{-1} per year, and the annual average net oxygen productivity is 6.7 t·ha^{-1}. The main producers of oxygen are Scots pine (almost 80%) and common oak-dominated stands (about 17 %). The highest oxygen productivity rates are observed in ash (9.7 t·ha^{-1}), oak (8.2 t·ha^{-1}) and hornbeam (7.5 t·ha^{-1}) stands. The oxygen productivity of forests varies with age, reaching a maximum of 19.2 t·ha^{-1} by age class V (41–50 years), followed by a gradual decline. A directly proportional relationship has been established between forest stands productivity (site index class) and oxygen productivity, with more than 40% of oxygen being produced by forests of the first site index class.

The analysis of scientific literature shows that the importance of suburban forests is gaining new meaning in the world. In this regard, there is a need to rethink the strategy of goals, principles and system of forest management in suburban forests in the context of sustainable development. The key priority of forest management in

suburban forests is to ensure their environmental functions, and the main criteria are to maintain the viability of forest ecosystems and strengthen the protective functions of forests.

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