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Biodiversity of woody plants in a small town: The example of Kagarlyk (Ukraine)

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Abstract. Assessing the biodiversity of woody plants in small Ukrainian towns is essential for informed urban greening strategies, especially in the context of climate resilience and the lack of systematic street tree inventories. The purpose of the work was to determine the species composition and level of biodiversity of woody plantings of the small city and compare the results obtained with previously studied small cities of the region. The research was conducted

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in 2023-2024 in Kagarlyk town, Kyiv region, Ukraine. A systematic approach, general scientific and special methods, in particular dendrological, were used. An inventory of various types of green spaces in Kagarlyk downtown was conducted, based on the results of which the woody species diversity index (SDI) was determined both for individual studied objects and for the studied town's territory as a whole. It was established that the studied woody plantings of Kagarlyk, especially street and school areas, are characterised by a low level of biodiversity of woody species. A higher level of biodiversity was characteristic of the park and adjacent to residential buildings areas. The overall biodiversity index of urban woody plantings was low, at 7, which is lower than in previously studied towns. It was found that the level of species diversity of woody plantings in Kagarlyk town is low: the SDI index is 6.9, with 51% of all trees belonging to just two species – *Aesculus hippocastanum* and *Fraxinus excelsior*. The highest level of diversity was recorded in the park and near-residential areas, while street and school plantings showed particularly low values, indicating the need for diversification of species composition. The predominance of *Aesculus hipocastanum* and *Fraxinus excelsior* does not guarantee the long-term sustainability of the town's green spaces. The results will allow assessing the relative resilience of the urban area to new natural challenges, in particular to global climate change

Keywords: park-monument of landscape art; school territory; species diversity index; street plantings; woody species

Introduction

Urban vegetation contributes to the ecologically balanced development of the city territory, and its structure is key to the possibility of preserving biodiversity. In turn, the species diversity of urban plantings is a significant ecological factor by which the impact on the environment is assessed, and is also a key factor in the resistance of green plantings to pests, diseases and climate change (Cowett & Bassuk, 2017). Therefore, increasing the diversity of street trees is considered a step towards ecologically balanced development, and assessing diversity is an integral part of sustainable management. In urban conditions, there is a complex impact of negative factors on woody plants, which requires a differentiated approach to the selection of their species composition, taking into account stability and planting categories. A rich species composition of plants is promoted in view of the performance of various, both sanitary and hygienic, and psychophysiological functions by green plantings. Various indices are usually used to assess the diversity of street trees, among which the inversion of the Simpson index is considered one of the best indicators. The combination of climate change and accelerated urbanisation creates new challenges for urban land-use planning and contributes to growing interest in restoring urban ecosystems. The main objective of the EU Biodiversity Strategy is to contribute to limiting climate change and increasing Europe's resilience, which generates a new demand for sustainable, adaptive, environmentally safe cities and addressing critical vulnerabilities. Green infrastructure plays a key role in this (Moraci *et al.,* 2025).

Climate adaptation in cities is a complex issue and one of the main collective challenges of society, where the relationship between city managers and citizens faces many challenges (Romero-Muñoz *et al.*, 2024). Z. Türkay & A. Tezer (2024) noted that urbanisation reduces the diversity of local species on a regional scale, but the overall species richness of plants in cities is often extremely high. However, global ecosystem biodiversity and their ecosystem services are declining. Thus, global risks associated with climate change are exacerbated. According to M. Clemente *et al.* (2025), street trees and urban forestry have now become central topics in international discussions and government policies aimed at combating climate change and promoting sustainable development. Cities are implementing strategic programs to increase street tree populations to enhance resilience and mitigate the environmental impacts of urbanisation. However, the trend toward increasing species diversity in street tree plantings requires a balance between preserving the unique character of each neighborhood and meeting the need for resilient, stable, and climate-adapted species. Strategic planning should combine the preservation of historic landmarks with forward-looking solutions, ensuring that the urban landscape remains unique and resilient.

According to B. Ma *et al.* (2021), urban planning should be biodiversity-based and use inventory data to design balanced and sustainable green spaces. the most common inventory is for street and park trees. In the study by M. Sarigu *et al.* (2025) noted that in Assemi (Italy), the highest biodiversity was found in the “Green Zones” and “Schools”, which are vital reserves of urban biodiversity, while providing opportunities for learning and recreation. Authors researched thst streets present less biodiversity due to space constraints and design priorities focused on shading and aesthetic appeal. This reduction in diversity can increase vulnerability to environmental stresses. M. Sarigu *et al.* emphasised the importance of prioritising native species adapted to local bioclimatic conditions, which prevents resource depletion and protects local biodiversity from risks of invasion. At the same time, over-reliance on a limited number of adapted species can pose risks and lead to the homogeneity of the urban flora and limited resilience to environmental stresses. The high percentage of exotic species confirms the impact of globalisation; in particular, the use of fashionable ornamental species.

A. Mizgajski *et al.* (2023) demonstrated that in Lviv (Ukraine), new plantings have a large proportion of local tree species. In contrast, in the cities of Southern Ukraine, introduced species adapted to local conditions are mainly used to create parks and gardens (Melnyk *et al.*, 2021). O. Zibtseva (2021) established that the level of biodiversity of tree species in small Ukrainian cities is influenced by their proximity to large cities, in particular to the capital, and closer and more economically developed small cities often have higher biodiversity indicators. In the studied small cities of the Kyiv region, the highest level of biodiversity is characterised by the territories of newly created public gardens and the adjacent territories of multi-apartment residential buildings. In addition, the share of introduced tree species of various objects in small cities often exceeds the share of local tree species (Feschenko *et al.*, 2021).

A. St-Denis *et al.* (2024) emphasised the importance of urban tree diversity for increasing ecosystem resilience, as low tree species diversity in streets can lead to significant loss of plant cover in the event of large-scale disturbances such as drought or exotic pest or disease. The authors proposed a new software SylvCiT for decision-making on urban tree plantings. SylvCiT provides a clear spatial portrait of the urban forest: species richness, functional diversity, structural diversity, identifies underrepresented tree species, and provides recommendations for increasing diversity to increase resilience to global change.

The relevance of research on the biodiversity of tree plantations of a typical forest-steppe

Ukrainian small city is enhanced by the lack of reliable information on the quality of existing green spaces in small cities. However, modern challenges, both global and local, and the future post-war reconstruction of cities will require clear knowledge of the current situation in order to develop promising plans for the restoration of sustainable urban ecosystems. The aim of this study was to assess the diversity and species composition of woody plants in a small urban environment.

Materials and Methods

Research object. Characteristics of the Kagarlyk territory. Kagarlyk town, mentioned as early as 1142, currently occupies an area of 2130.7 hectares and has a population of over 13100. The town is located 77 km from the capital of Ukraine within the forest-steppe zone (Zibtseva *et al.*, 2024) (Fig. 1).

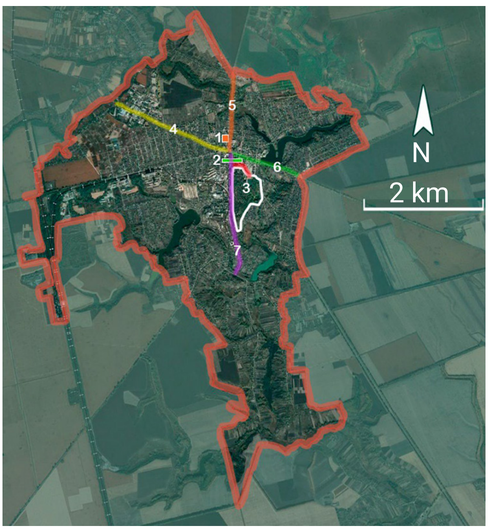

Figure 1. The scheme of Kagarlyk town location on the territory of Kyiv region, Ukraine

Note: 1 – near-house territorie; 2 – school territorie; 3 – park-monument; 4 – Kashtanova Str.; 5 – Stolychna Str.; 6 – Nezalezhnosti Str.; 7 – Parkova Str.
Source: developed by the authors

Kagarlyk is a compact town with a radial planning structure. Residential development is represented mainly by blocks of low-rise estate buildings and medium-rise buildings in the central part of the town. The town is focused mainly on agricultural production and is moderately efficient in terms of economic efficiency. Kagarlyk is notable among other small cities in the Kyiv region for its relatively high provision of public green spaces, which amounts to 73.0 m^2 per capita. In the central part of the town there is a park-monument of landscape art of national importance "Kagarlytsky" with an area of 29.5 hectares. In total, Kagarlyk has 100.8 hectares of public green spaces. This is one of the few small cities where the normative indicators of urban greening are met: the greening norm (the normative minimum number of public green spaces in m^2 per capita) and the level of greening (Zibtseva, 2021). At the same time, the town does not have a developed suburban green zone in the form of protective forest areas, and is mostly surrounded by plowed fields, which is also typical for small Ukrainian cities. Also negative environmental phenomena in the Kagarlyk's territory are the systematic destruction of wetlands, the prospective halving of the area of urban forests, and the increase in fragmentation of urban forests, which will potentially reduce the eco-stability of the urban area.

Methodology. The study of the biodiversity of tree species was based on an inventory of various types of green spaces conducted within the territory of Kagarlyk.Green spaces for general use (parks), limited use (near-house and school territories), and special-purpose green spaces (street plantings) were studied. An inventory of woody plantings was conducted on the streets of the central part of the town, since street woody plantings are usually absent on the periphery. Also, an inventory of woody plants in the school territory and the near-house territory of an apartment building was conducted in the central part of the town. In addition, data from inventories of the park-monument of landscape art "Kagarlytskyi" conducted by various researchers (in particular, Yu. M. Klymenko (1999) from the National Botanical Garden of the National Academy of Sciences of Ukraine named after M.M. Hryshko). The study was conducted in accordance with the Convention on Biological Diversity (1992).

During the inventory on the territory of each object, the number of specimens and species of trees, shrubs and lianes, their age, and condition were determined. The assessment of the condition of trees was carried out visually on a five-point scale, where 1 point indicated plants in excellent condition, 2 points – woody plant in good condition, 3 – woody plant in satisfactory condition, 4 – woody plant that are drying out and 5 points – withered woody plant (Kuruneri-Chitepo & Shackleton, 2011). To assess species diversity, the woody plant species diversity index (SDI) – the inverse of the Simpson index – was calculated, allowing for linear comparisons of tree species diversity levels at different sites (Sun, 1992):

$$SDI = \frac{\sum Nj \times (\sum Nj - 1)}{\sum Nj(Nj-1)}, \quad (1)$$

where *Nj* – is the number of trees of a certain species in the total number of woody plants. A higher *SDI* value indicates a higher level of diversity, and an SDI value close to 20 indicates the stability of the stands.

Results and Discussion

Traditionally for small cities, the street landscaping with trees is presented only on the central main streets in Kagarlyk town (Fig. 2).

Figure 2. Street landscaping of Kagarlyk town
Note: downtown and surroundings
Source: photo of the author O. Shandrenko

For example, on one of these main streets – Parkova street – there are seven tree species, among which the largest number of specimens (42.2%) belongs to *Aesculus hipocastanum*, 31.3% – *Fraxinus excelsior*, 15.6% – *Acer platanoides*. In addition, 3.1% of tree specimens are *Tilia cordata*, *Betula pendula* та *Acer negundo* L. and 1.6% – на *Populus tremula* (Table 1).

Table 1. Characteristics of tree plantations in Parkova Street

Species name	Quantity, %	Age, years	Diameter, cm	Height, m	Condition, points
Aesculus hipocastanum	42.2	50	32 ± 2.9	12 ± 2.0	3 ± 0.4

Table 1, Continued

Species name	Quantity, %	Age, years	Diameter, cm	Height, m	Condition, points
Fraxinus excelsior	31.3	60	46±8.8	13±1.9	3±0.5
Acer platanoides	15.6	50	34±6.5	10±2.2	3±0.5
Acer negundo	3.1	40	80	16	3
Tilia cordata	3.1	40	16	8	3
Betula pendula	3.1	40	32	12	4
Populus tremula	1.6	60	54	18	3
Total SDI	100				3.4

Source: developed by the authors

Contrary to the current regulatory ratio of trees and shrubs (1:10), shrubs in street landscaping occur only singly. The condition of street trees is mostly satisfactory. The age of street trees, as a rule, ranges from 40 to 60 years. The SDI biodiversity index is low and for Parkova Street taken separately is only 3.4. In total, according to the results of the inventory of the five central streets of Kagarlyk, 26 tree and shrub species were identified in street plantings, dominated by *Aesculus hippocastanum* (a total of 44.1% of specimens among the inventoried trees), *Tilia cordata* (17.6%) and *Fraxinus excelsior* (15.6%). Among the presented species, only *Fraxinus excelsior* is characterised by relative drought resistance (Fig. 3).

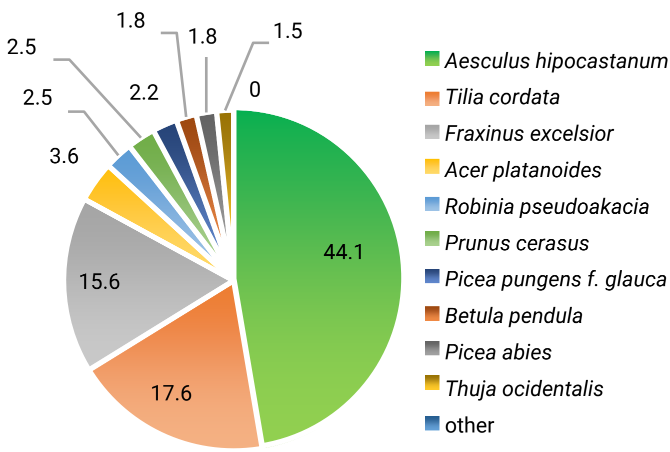

Figure 3. Species structure of the studied street plantings of Kagarlyk town
Source: developed by the authors

In general, in the studied street plantings of Kagarlyk town, only three coniferous tree species were found singly: *Thuja ocidentalis, Picea pungens f. glauca* and *Picea abies,* and were found only three deciduous shrub species: *Syringa vulgaris* L., *Spirea Vanhoutea* and *Forsythia europae* Deg. et Bald., and only within two streets (Table 2).

Table 2. General characteristics of the biodiversity of street plantings in Kagarlyk town

Street name	Number of species	Prevailing species		SDI
		Species name	%	
Parkova	7	*Aesculus hippocastanum*	42.2	1.83
		Fraxinus excelsior	31.3	
		Acer platanoides	15.6	
Stolichna	10	*Tilia cordata*	54,3	2.96
Kashtanova	20	*Aesculus hippocastanum*	21.5	6.57
Nezalezhnosti	7	*Acer platanoides*	16.7	4.43
		Tilia cordata	41.6	
Stadionna	1	*Aesculus hippocastanum*	100.0	-
All streets	26	*Aesculus hippocastanum*	44.1	3.95
		Tilia cordata	17.6	
		Fraxinus excelsior	15.6	

Source: developed by the authors

Half of the species represented in street plantings are drought-resistant, but woody plants with medium moisture requirements predominate in terms of number of specimens. Kagarlytsky Park was founded in the 19th century on an area of 40 hectares. It received the status of a park-monument of landscape art of national importance in 1972. At the time of the park's foundation, 113 species of dendroflora were represented here, and in the 1960s-1990s, the park had from 35 to 74 species. As of 2009, Kagarlytsky Park had an area of 34 hectares and included 63 taxa (Spriaghailo, 2010). In 2015, the State Enterprise "National Research and Development Institute of Urban Planning" developed a project for the reconstruction of the park, which is gradually being implemented. Currently, the presence of dendroflora species may differ slightly, which was influenced by both the storm of 2023 and the reconstructive restoration measures that have been carried out since 2020.

Figure 4 shows the species structure of tree plantations in the Kagarlytskyi Park-Monument of Landscape Art. In general, the park is quantitatively dominated by introduced plants, including *Styphnolobium japonicum* L., *Pseudotsuga menziesii* (Mirb.) Franco, *Pinus strobus* L., *Larix sibirica* Ledeb., *Celtis occidentalis* L. and others. The biodiversity index SDI of the park plantations is 7.0, which is explained by the significant predominance only of several species, namely a significant share of *Fraxinus excelsior*, *Aesculus hippocastanum, Carpinus betulus* L. and *Acer platanoides* L., which account for more than half of the represented tree specimens, as well as the presence of numerous only single specimens of a number of species.

It is obvious that in the near future the biodiversity of the park will increase somewhat, which is explained by the attention and landscaping activities of recent years. To determine the biodiversity of trees in green spaces of limited use, tree plantations on the school grounds (Table 3) and the adjacent territory of an apartment building (Table 4) were examined.

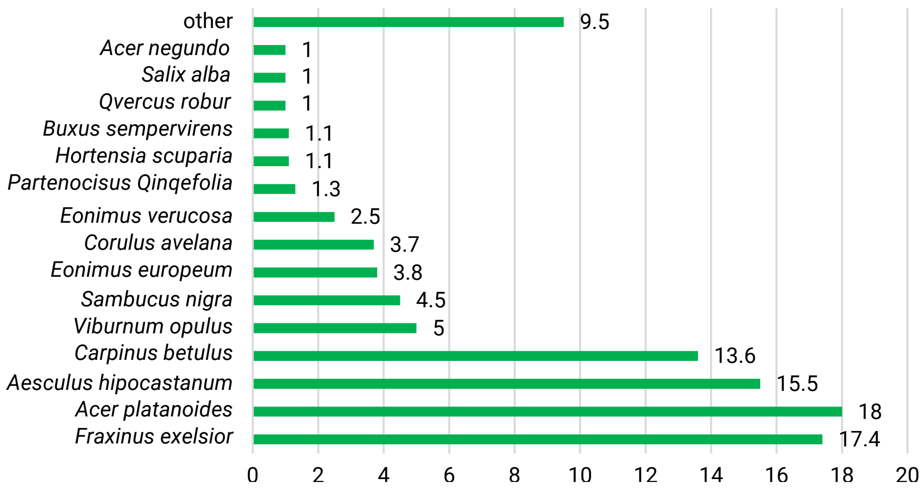

Figure 4. Species structure of tree plantations of Kagarlytskyi Park, %

Source: developed by the authors

Table 3. Characteristics of woody plantings on the school area in Kaharlyk town

Species name	Quantity, %	Age, years	Diameter, cm	Condition, points
Tilia cordata	46.8	50	36	3
Picea abies	13.3	60	40	3
Aesculus hippocastanum	13.3	30	24	3
Prunus cerasifera Ehrh.	13.3	40	24	3
Juglans regia L.	13.3	10	16	2
Total SDI	100			4.2

Source: developed by the authors

The SDI of the school area is currently very low, at the level of 4.3, which clearly does not encourage students to be interested in the natural wealth and diversity of woody plants. The SDI of the researched area of the apartment building in the central part of the town is traditionally (based on previous observations) the highest for the urban area, but also relatively not high and is 10.4.

In the area close the apartment building (Table 4) are singly presented *Prunus persica* (L.) Batsch., *Morus alba* L.¸ *Prunus domestica* L., *Picea pungens* Engelm., *Tilia cordata* Mill., *Malus pumila* Mill., *Cotoneaster lucidus* Schltdl., *Berberis thunbergii* DC., *Forsythia europaea* Degen & Bald, *Spiraea* × *vanhouttei* (Briot.) Zabel., the number of each species from 0.7 to 1.5%.

Table 4. Biometric characteristics of woody plantings in the area close the apartment building

Species name	Quantity, %	Age, years	Condition, points
Rubus idaeus L.	22.2	5	2
Viburnum opulus L.	16.3	12	1

Table 4, Continued

Species name	Quantity, %	Age, years	Condition, points
Syringa josikaea Jacq. ex Rchb	7.4	10	2
Vitis vinifera L.	7.4	15	1
Malus domestica Bork	5.9	16±3.5	1.4±0.5
Parthenocissus quinquefolia L.	5.9	15	1
Juglans regia L.	4.4	21±6.3	1.5±0.5
Rhus typhina L.	3.0	9±2.5	1
Prunus cerasus L.	3.0	15	2
Rosa arvensis Huds.	3.0	10	2
Rosa hybrida L.	3.0	5	2
Prunus armeniaca L.	2.2	25	2
Hydrangea paniculata Siebold.	2.2	5	1
Buxus sempervirens L.	2.2	5	2
other	11.0	5–25	1
Total SDI	100		10.4

Source: developed by the authors

Figure 5 shows the general species structure of the studied woody plantations in the territory of Kagarlyk town, and Table 5 shows the number of identified species per site and the proportion of tree specimens of introduced species.

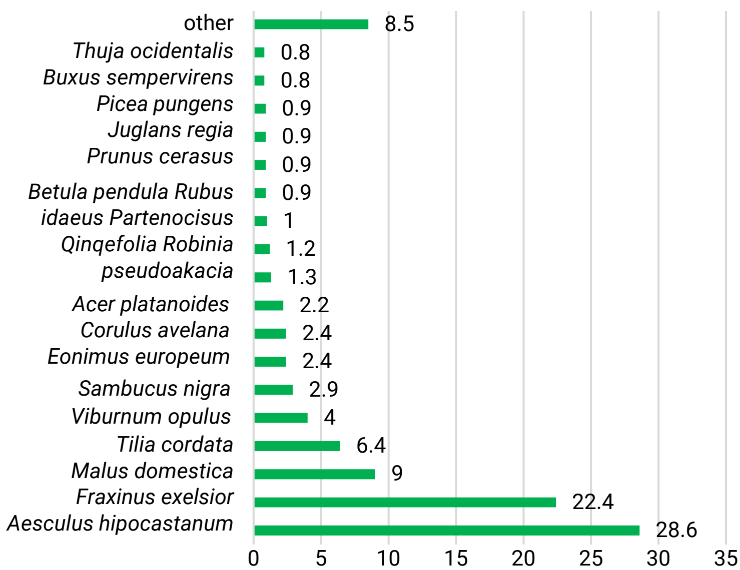

Figure 5. General species structure of the studied woody plantations of Kagarlyk town, %
Source: developed by the authors

Table 5. Biodiversity of woody plantings in the central part of Kagarlyk town

Object (woody plantings)	**SDI**	**Number of species, pieces**	**Share of introducers, %**
Park	7.0	74	78
Apartment building	10.4	24	50
School	4.2	5	27
Streets	4.0	26	45
Together	6.9	83	55

Source: developed by the authors

Thus, more than half (51%) of the tree specimens fall on two species: *Aesculus hippocastanum* and *Fraxinus excelsior,* and on five species (with *Malus domestica, Tilia cordata, Viburnum opulus)* – 70.4%. The SDI for tree plantings varies across the study sites from 4 to 10.4, and on average for the central part of the city is about 7. It is generally accepted that green areas, if rationally organised, significantly affect the most important indicators of environmental quality, and scientifically substantiated selection of tree species resistant to the conditions of the urban environment is the key to ensuring high efficiency and durability of created urban green spaces. At the same time, species diversity is an indicator of the resistance of green spaces to anthropogenic and any other pressure. Given the gaps in research on the territories of small cities, the biodiversity of woody plantations in such small Ukrainian cities as Vyshhorod, Ukrainka and others was previously studied. These studies revealed a predominantly low level of dendroflora biodiversity in small cities; however, the highest indicators were typically recorded in the small city of Vyshhorod, located near the capital, which was taken as a reference point for comparisons. In all cases, green spaces in residential areas – the largest category of green spaces in Ukrainian small towns – demonstrated relatively higher levels of dendroflora biodiversity.

M. Salinitro *et al.* (2019) have come to the conclusion that climate change and the presence of artificially irrigated areas have led to an increase in both hygrophilous and drought-tolerant species within cities. According to A. Roloff *et al.* (2009), a total of 250 urban tree species are used in parks and gardens in Central Europe. The authors proposed a matrix for selecting tree species for landscaping European cities, taking into account projected climate change. In small "cold cities" in China, it is recommended to focus on the use of indigenous tree and shrub species, as well as garden and evergreen plants (Guo *et al.*, 2014). 69 species were identified in the center of Zaporizhzhia, Ukraine (Dubovaya & Fendyur, 2009). V. Bessonova & T. Peresypkina (1997) demonstrated in particular, *Populus boleana* L., *Robinia pseudoacacia* L, *Acer pseudoplatanus* are common in street plantings, and in the private sector – *Cerasus magaleb* L., *Juglans regia* L., *Armeniaca vulgaris* Lam. The dendroflora of Chornomorsk has up to 173 species, which is an order of magnitude higher than the number of natural species and three times the number of species that grew in this territory before the construction of the city began. O. Pikhalo (2010) identified 182 species and 82 ornamental forms of trees and shrubs in the historical part of Kyiv, 118 of which are introduced species. However, there is quantitative data on the mostly small number of species in street plantings in the post-Soviet space, where cities are usually dominated by 10-15 tree species, often invasive, which pose a threat to indigenous phytodiversity and require careful steps to involve them in local phytocenoses (Rogovskyi, 2009).

M. Kolström *et al.* (2011) noted that measures aimed at reducing vulnerability to climate change can be aimed either at reducing sensitivity to adverse climate change or at increasing adaptive capacity to changing environmental conditions. And adaptation measures are crucial. According to C. Leuschner *et al.* (2024) one of the options for adapting to increasing climate stress is the selection of more resistant, uncommon local tree species. Thus, low vulnerability to climate was shown by adult trees *Quercus petraea*, *Acer platanoides*, *Fraxinus excelsior*, *Tilia cordata* and *Carpinus betulus*, among which drought resistance decreases in the given sequence.

The constant deterioration of environmental conditions requires the use of plants with increased drought resistance, viability, and powerful biological potential. L. Tischenko *et al.* (2024) found that *Quercus* species have increased drought tolerance and therefore have great potential for urban areas. A wide range of tolerance has been found for *Acer* species. In contrast, *Pinus sylvestris* was the least drought-tolerant of the tree species studied. *Picea abies* (L.) Karst. and *Fagus sylvatica* were also found to be highly sensitive to drought. *Fagus sylvatica* and *Tilia tomentosa* show higher climatic vulnerability than temperate oaks: *Quercus petraea, Q. frainetto,* and *Q. Cerris* (Kasper *et al.*, 2023). *Larix decidua* Mill. is very vulnerable to drought (George *et al*., 2017).

Under changing climate conditions, drought can become a critical obstacle for urban trees, especially on roadsides and paved areas (Stratópoulos *et al.*, 2019). For tree plantings in harsh and challenging urban environments, an important selection criterion is the ability to develop a strong and dense root system, which is an important feature of drought tolerance. Acer campestre is known to have high drought tolerance. In contrast, *Tilia cordata* 'Greenspire' and *Carpinus betulus* 'Fastigiata' were found to be drought-tolerant. According to studies by M. Hirsch *et al.* (2023) transport emissions do not affect the drought tolerance of urban tree species. However, *Acer platanoides* and *Tilia cordata* were particularly drought-tolerant. *Platanus × hispanica* and *Quercus robur* were more tolerant, while *Carpinus betulus* was moderately tolerant.

A team of scientists P. Sicard *et al.* (2018) found that individual tree characteristics, such as species and size, and crown openness, significantly influence their growth in cities and can alter the ability of trees to tolerate drought stress. They recommended choosing non-allergenic species with high ozone removal capacity, resistant to pests, diseases, and drought for urban plantings, namely plants from the genera *Acer sp., Carpinus sp., Prunus sp., Larix decidua*. Local recommendations for the selection of tree species for landscaping should take into account not only their bioecological characteristics, but also specific natural (in particular soil) and urban planning conditions. J. Konarska *et al*. (2023) recommended using *Quercus palustris* and *Tilia europaea* for areas with good growing conditions, and *Aesculus hippocastanum recommended* using for areas with impermeable cover without shading.

O. Zibtseva *et al.* (2024) paid special attention to the study of the biodiversity of street plantings, which, according to the Ukrainian classification, belong to special-purpose green plantings as those subject to maximum pollution (by motor vehicles) and therefore perform primarily an ecological, not a recreational function. In addition, from the perspective of spatial planning, street urban plantings capable of functioning as green infrastructure corridors – ensuring its connectivity – are of particular importance, especially given their documented insufficiency in small cities based on previous studies. Therefore, increased requirements should be imposed on the biodiversity of street plantings, which should ensure their resistance to changing environmental factors and the consequences of global climate change.

According to literature sources, the low diversity of street trees in urban conditions makes the tree population more vulnerable to new stressful conditions. According to W. Sun (1992), the average SDI of 53 street tree populations in different US cities ranged from 9.5 to 13.3 on average. According to the results of current studies of green spaces in Kagarlyk, the total SDI for all studied town's woody plantings was 7, i.e. it was 1.3-1.9 times lower. In general, two species were critical for the small city, the share of which exceeds 15%: *Aesculus hippocastanum* and *Fraxinus excelsior*. This is especially dangerous considering that over the last decade *Aesculus hippocastanum* has been massively affected by the *Cameraria ohridella*, and *Fraxinus excelsior* trees are threatened by the *Agrilus planipennis*. The 5% tree planting criterion proposed by N.L. Bassuk (Sun, 1992) on Kagarlyk's streets is also exceeded *Malus domestica* and *Tilia cordata*. Currently, the well-known 10-20-30 rule for urban plantings has not been implemented in the system for regulating the quality of landscaping in Ukrainian cities. For comparison, 38 species and forms of trees and shrubs were identified in the street plantings of Vyshhorod town, Kyiv regio (Zibtseva, 2021), and the level of biodiversity of Vyshhorod's street plantings is almost three times higher than that of Kagarlyk. However, in both towns the condition of street plantings is currently close to satisfactory.

In the work by E. Grybovich *et al.* (2018) the dynamics of the species composition and the results of research on 19 non-native tree species in four parks of the city of Poltava are presented: Korpusny Sad, Petrovsky Park, Poltava City Park, and Peremoha Park. In four parks-monuments of landscape art of Poltava city there are 50-70 woody species (Grybovich *et al.*, 2018), and in parks-monuments of landscape art of Vinnytsia – from 35 to 120 woody species (Sypliva, 2016). In the park-monument of landscape art of local significance "Fastivsky" there are 43 woody species (Levandovska & Khryk, 2024). Most of the territory of "Fastivsky" park-monument (94.12%) is covered with forests of *Quercus robur* L. (50.8%) and *Pinus sylvestris* L. (21.3%) of artificial origin. The park-monument acquires a special natural value due to oak stands of 101–106 years old and middle-aged exotic trees *Catalpa bign*onioides Walt., *Cuninghamia lanceolata* Hook., *Larix decidua* Mill., *Pinus strobus* L., *Phellodendron amurense* Maxim. In most parks there is a decrease in biodiversity and homogenisation of species composition.

Current study confirms previous findings that relatively higher richness and biodiversity indicators are usually characteristic for woody plantings of residential areas. In contrast to Vyshhorod (Zibtseva, 2021), where ornamental woody plants predominate in residential areas, in Kagarlyk, 65.9% of trees are represented by fruit plants.The extremely low level of tree biodiversity in Kagarlyk town on the school grounds, where only 5 tree species were found (SDI is 4.2), among which the share of introduced species is only 27%. Insufficient attention to the school grounds is unjustified, since diverse landscaping can interest students and encourage them to study natural sciences. In contrast, 45 species and forms of woody and shrub plants were found on the grounds of Vyshhorod's schools. As a result, the total number of woody species and forms in the studied area of Kagarlyk town was 83 against 100 in Vyshhorod town and 27 woody species in Ukrainka town located 35 km north of Kagarlyk (also the Forest-Steppe town with a population of 16 thousand). The share of introduced woody species in the territory of Kagarlyk is 55%, while in the territory of Vyshhorod is 75%. The lowest share of introduced species in Kagarlyk is characteristic for the studied school and street plantings. These same plantings (street and school) are characterised by a lower, satisfactory condition, while park and house plantings are mostly in good condition. The Master plan of Kagarlyk town plans to create another 79 hectares of public green spaces (squares, forest park, park), as a result of which the total number of public green spaces will be 179.8 hectares and will be 112.3 m^2 per capita. However, insufficient attention is paid to street landscaping, no specifically outlined quantitative and qualitative tasks are put forward. It is considered advisable to prioritise street landscaping, particularly with regard to its species composition and the presence of a regulatory number of shrubs.

It necessary to recommend diversifying the structure of urban tree plantations (species and age composition) to prevent potential threats and challenges, in particular due to the increasing aridity of the climate. Currently, such drought-resistant species native to the Forest-Steppe of Ukraine as *Quercus robur, Acer campestre, Prunus spinosa, Crataegus monogyna, Rosa canina, Rhamnus cathartica, Cornus mas*. It is also advisable to further use in the landscaping of the city such drought-resistant and moderately drought-resistant species as: *Prunus armeniaca* L.*, P. Cerasifera* Ehrh., *Robinia pseudoacacia* L.*, Malus niedzwetzkyana* Dieck., *Picea pungens* Engelm., *Juniperus sabina* L.*, J. Virginiana* L., *Betula pubescens* Ehrh., *Sorbus aucuparia* L.*, Berberis thunbergii* DC., *Crataegus* Tourn. ex L., *Ribes aureum* Pursh., *Cotoneaster* Medik., *Cotinus coggygria* Scop.

The conducted study has demonstrated that the species composition of woody plants in Kagarlyk town is characterised by moderate overall diversity, with a predominance of a few species, particularly *Aesculus hippocastanum* and *Fraxinus excelsior*. The species richness and SDI values vary significantly across green space types, being lowest in school plantings and highest in residential areas. Despite a sufficient quantity of green spaces, the qualitative indicators of biodiversity – especially in street and educational plantings – remain unsatisfactory, which increases the vulnerability of urban ecosystems to climate change and anthropogenic pressures. These findings highlight the urgent need to diversify urban dendroflora and strengthen street landscaping policy as part of integrated green infrastructure development.

Conclusions

Reliable information not only on the quantitative but also on the qualitative indicators of woody plantings, obtained as a result of their inventory, is a necessary prerequisite for ensuring environmentally balanced development of urbanised areas. In small cities of Ukraine, an inventory of street woody plantings has never been carried out. Analysis of the inventory data of woody plantings, conducted in Kaharlyk town, Kyiv region, showed that 83 species and forms of trees and shrubs are represented in the town's greenery. The index of woody species diversity of urban spaces is low, only 6.9. At the same time, the highest diversity index is characterised by woody plantings in parks and adjacent areas, and the lowest - street and school areas. The most common in the town are the trees *Aesculus hippocastanum* and *Fraxinus excelsior*, and that threatens the sustainability of urban landscape.

According to the results, the SDI for street plantings averaged 4.0, with the lowest value of 1.83 recorded on Parkova Street and the highest value of 6.57 on Kashtanova Street. In Kagarlytsky Park, the SDI reached 7.0, although more than 50% of specimens belonged to just four species. On the school grounds, only five species were identified, with an SDI of 4.2, while the area near the apartment building had 24 species and an SDI of 10.4. Overall, 51% of all trees in the study were concentrated in just two species: *Aesculus hippocastanum* and *Fraxinus excelsior*. These results highlight the need for diversification of species composition, especially in street and school plantings.

First of all, the street plantings of Kagarlyk need better landscaping with drought-resistant trees and shrubs for all town's streets, not just its central part. Also, the landscaping of school areas with the inclusion of various species and forms of trees and shrubs requires priority attention. It is recommended to continue to diversify the structure of urban woody plantings to prevent potential threats and challenges. The created urban plantings should reduce the dominance of any one species, avoid species that are particularly sensitive to pests, and take into account the prospective increase in aridity of the climate.

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Conflict of Interest

None.

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Анотація. Оцінка біорізноманіття деревних рослин у малих містах України має важливе значення для розробки обґрунтованих стратегій озеленення міст, особливо в контексті стійкості до зміни клімату та відсутності систематичних інвентаризацій вуличних дерев. Метою роботи було визначити видовий склад та рівень біорізноманіття деревних насаджень малого міста та порівняти отримані результати з раніше дослідженими малими містами регіону. Дослідження проводились у 2023-2024 рр. у м. Кагарлик Київської області. Використано системний підхід, загальнонаукові та спеціальні методи, зокрема дендрологічні. Проведено інвентаризацію різних типів зелених насаджень центральної частини міста Кагарлик, за результатами якої визначено індекс видового різноманіття деревних порід (SDI) як для окремих досліджуваних об’єктів, так і для досліджуваної території міста в цілому. Встановлено, що досліджувані лісові насадження Кагарлика, особливо вуличні та шкільні території, характеризуються низьким рівнем біорізноманіття деревних видів. Вищий рівень біорізноманіття характерний для парку та прилеглих до житлової забудови територій. Загальний індекс біорізноманіття міських деревних насаджень був низьким – 7, що нижче, ніж у раніше досліджених містах. Виявлено, що рівень видового різноманіття деревних насаджень у місті Кагарлик є низьким: індекс SDI становить 6,9, при цьому 51 %

усіх дерев припадає лише на два види – *Aesculus hippocastanum* та *Fraxinus excelsior*. Найвищий рівень різноманіття зафіксовано в парку та на прибудинкових територіях, натомість вуличні й пришкільні насадження характеризуються особливо низькими показниками, що свідчить про потребу в диверсифікації видового складу. Переважання *Aesculus hipocastanum* та *Fraxinus excelsior* не гарантує довгострокової стійкості зелених насаджень міста. Отримані результати дозволять оцінити відносну стійкість міської території до нових природних викликів, зокрема до глобальних змін клімату

Ключові слова: парк-пам’ятка садово-паркового мистецтва; територія школи; індекс видового різноманіття; вуличні насадження; деревні породи

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Influence of environmental factors on the surface condition of thermally modified ash wood in polyvinyl acetate adhesive joints

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Abstract. The aim of this work was to study polyvinyl acetate adhesive joints of "thermally modified ash/pine wood" concerning changes in the surface condition of thermally modified ash wood (correlated with changes in the strength of the samples) under prolonged exposure to external factors. Test samples of adhesive joints were placed on a test rack for external exposure. Every three months, they were removed to record destructive changes in the thermally modified wood surface using scanning electron microscopy, assess changes in wettability and the duration of water droplet penetration into the structure (by measuring changes in contact angles over time), and determine changes in the strength of the adhesive joints. It was established that photochemical damage to thermally modified ash wood is the "trigger mechanism" for its further degradation changes. Samples exposed during summer periods exhibited more pronounced destructive changes in the thermally modified surface and a significant decrease in the strength of adhesive joints (from 6.56 MPa to 6.05 MPa after the first cycle and from 5.93 MPa to 5.62 MPa after the second cycle). The study showed that due to a cascade of destructive mechanisms, the structure of thermally modified ash wood, after 24 months of exposure to natural conditions, sustained damage to a depth of 0.05-0.2 mm (while the strength of the adhesive joints decreased from 7.12 MPa to 5.13 MPa), the surface became more hydrophilic, which led to a reduction in the time required for water penetration into its structure. Accordingly, the contact angle on such the surface reached θ = 17° after 480 seconds, while on the surface of thermally modified ash wood, which was not exposed to natural factors, a similar value was reached only after 570 s

Keywords: external factors; temperature-humidity loads; solar radiation; scanning electron microscopy; destructive changes; contact angle; water droplet penetration

Introduction

Adhesive wood structures are widely used in the production of joinery-construction products, flooring, and various other applications. These structures can be utilised both indoors and outdoors. When exposed to outdoor conditions, they are subjected to various environmental factors that can negatively affect both the wood and the adhesive joints. To mitigate these effects, thermally modified (TM) wood – derived from less valuable or less commonly used species in the woodworking and furniture industries – is often used as the outer layer of such adhesive structures. This is due to its enhanced properties, investigated by D. Jones & D. Sandberg (2020) and A. Ugovšek *et al.* (2018), as well as its aesthetic appeal, as highlighted by A. Mastouri *et al.* (2023).

Ash wood (*Fraxinus excelsior* L.), in particular, is a hardwood species widely distributed across Europe – its high genetic diversity was studied by J. Meger *et al.* (2024), and it is a key forest-forming species in Ukraine, where its successful natural regeneration was examined by V. Tkach *et al.* (2020). Despite its favorable properties – uniform light color, flexibility, hardness, and load resistance – it remains underutilised in woodworking and furniture production, primarily due to challenges in drying and machining. Researchers J. Niklewski *et al.* (2023) assessed the impact of environmental stressors such as ultraviolet (UV) radiation, precipitation, temperature and humidity fluctuations, wind, and abrasive forces on wood, finding that these factors contribute to discoloration, loss of luster, and surface degradation through progressive fiber erosion, often resulting in cracking. O. Pinchevska *et al.* (2022)

confirmed that these environmental factors reduce wood's resistance to various biotic and abiotic agents, thereby compromising structural integrity and shortening the service life of ash wood – a conclusion also noted by J. Stocks *et al.* (2019). Therefore, as outlined in the review by S. Zelinka *et al.* (2022) on wood modification and functionalisation technologies, improving the properties of ash wood through thermal modification – a process involving heating at 160-240°C in low-oxygen conditions – is a justified and effective solution for extending its durability in outdoor applications.

The combination of unmodified and TM wood in adhesive joints offers new opportunities for the production of various carpentry-construction products, including façade elements, doors, window frames, flooring, gazebos, and more. However, the increased surface hydrophobicity of TM wood presents a challenge when bonding TM elements to unmodified wood. Since there are no adhesives specifically developed for TM wood, manufacturers often resort to using inexpensive but potentially hazardous urea-formaldehyde adhesives.

B. Kshyvetskyy *et al.* (2024), who investigated the formation of cohesive and adhesive strength in non-structured and structured polyvinyl acetate (PVAc) films, noted that due to environmental concerns and the need for strong, durable bonds, the shift toward the use of PVAc adhesives with D4 durability class is justified. Moreover, the relatively flexible PVAc adhesive seam can compensate for deformations caused by differences in the moisture expansion of the bonded materials. This provides partial improvement in the elastic-deformation behavior of the adhesive joint and helps absorb shock loads, thereby reducing the risk of structural damage. Research conducted by B. Kshyvetskyy *et al.* (2023) demonstrated that these advantages of PVAc adhesives are crucial for ensuring the strength of adhesive wood joints and that PVAc adhesives are suitable for bonding TM wood to unmodified wood, particularly in structures intended for outdoor use.

Polyvinyl acetate adhesive joints using TM ash wood and unmodified pine wood have become increasingly common. These structural solutions, particularly in the production of window frames for both standard and roof windows, promote the more efficient use of pine wood – a valuable species recognised for its excellent technological, functional, and aesthetic properties. Additionally, these solutions enhance the durability of constructions by protecting natural wood with a TM outer layer while simultaneously improving its thermal insulation properties, as TM wood has lower thermal conductivity compared to unmodified.

Considering that the adhesion of PVAc adhesives to the surfaces of different wood species and to TM wood – obtained through the thermal modification of certain species under specific treatment parameters – varies, additional information is needed on the strength of TM ash/pine wood adhesive joints, especially when used in outdoor conditions. D. Godinho *et al.* (2021) conducted a review on thermally modified wood exposed to various weathering conditions and noted that, during outdoor exposure, the surface of TM ash wood is subjected to a complex combination of environmental factors – primarily fluctuations in humidity, direct precipitation, UV radiation, temperature changes, and additional mechanical impacts such as wind and airborne dust.

However, to date, relatively little attention has been given to investigating the changes in the surface characteristics of TM ash wood during prolonged outdoor exposure, as well as the condition of the aged wood surface in terms of water penetration into its structure. It is assumed that extended environmental exposure increases the water permeability of TM ash wood surfaces, which may subsequently lead to a reduction in adhesive joint strength. Therefore, the relevance of this study lies in the need to obtain comprehensive information about the changes occurring in adhesive joints under extended exposure to external factors. This includes both the degradation of the TM ash wood surface and the partly associated decline in adhesive joint strength – an area where detailed data is currently insufficient.

The aim of this work was to study polyvinyl acetate adhesive joints of TM ash/pine wood concerning changes in the surface condition of TM ash (correlated with changes in the strength of the samples) under prolonged exposure to external factors.

Materials and Methods

Testing of "thermally modified ash/pine wood" samples in an open environment. The total number of "TM ash/pine wood" (TM-Ash/W-Pine) polyvinyl acetate adhesive samples, formed in accordance with the DSTU EN 205:2014 (2014) standard, was 225. They were divided into two groups: 25 TM-Ash/W-Pine control samples, used to evaluate the condition of TM-Ash surfaces and to determine the initial bonding strengths, respectively; and 200 TM-Ash/W-Pine test samples, used to assess changes in TM-Ash surface condition after exposure to atmospheric factors and to determine changes in bonding strengths.

To investigate the impact of environmental factors on the thermally modified ash (TM-Ash) surface condition and, simultaneously, on the strength of the adhesive joints, 200 TM-Ash/W-Pine test samples were installed on a test rack 1 meter above the ground following EN 927-3 (2006). The samples were positioned 20 mm apart to ensure air circulation and placed at a 45° inclination, with the thermally modified ash wood surface facing outward and oriented southward. The research was conducted in the Western region of Ukraine (Lviv, Ukraine: 49°50′17″ N, 24°01′23″ E) – an area with a moderately continental climate characterised by mild temperatures and high humidity. The samples were installed on the test rack in November, and the exposure lasted 24 months in total. A batch of samples (25 pieces) was removed from the test rack every three months to observe changes in the TM-Ash surface condition (denoted as TM-Ash^n, where $n = 3, 6, 9...24$ months) and to determine the strength of the adhesive joints (denoted as TM-Ash^n/W-Pine, respectively).

Time-dependent water contact angle values measurement. TM-Ash surfaces from TM-Ash/W-Pine control samples and TM-Ash^{24} surfaces from TM-Ash^{24}/W-Pine test samples were cut to dimensions of 2 × 7 × 15 mm (thickness × width × length) for the surface wettability test. Using a syringe, a droplet of distilled water was placed at the center of the test surface. The experiment set-up consists of microscope, camera connected to a computer for image storage and processing. Sequential images of the droplet on the surface of the sample (in the direction of fibers) were obtained at regular intervals using the camera Casio Pro EX-F1. The contact angle values were determined from the images using an image analysis program (Fig. 1).

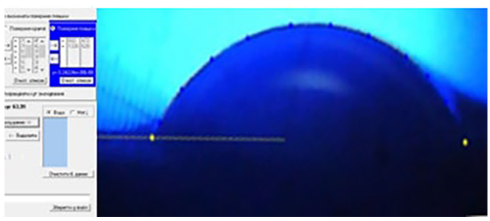

Figure 1. Determination of contact angle in image analysis program

Source: compiled by the authors

Scanning Electron Microscopy (SEM). Evaluation of the TM-Ash surface condition in TM-Ash/W-Pine control samples and the TM-Ash^n

surfaces of TM-Ash^n/W-Pine test samples (exposed to an open environment for $n = 3, 6, 9...24$ months) was conducted using a scanning electron microscope (SEM, JEOL IT 500 LV, Japan). For this, 5 × 5 × 2 mm samples were cut from the TM-Ash and TM-Ash^n surface structures and coated with a thin layer of gold to improve conductivity before observation. The operating parameters of the scanning electron microscope were as follows: accelerating voltage (EHT) – 14.7 kV; working distance (WD) – 10.5–14.5 mm. SEM images were captured at 500 × magnification.

Results and Discussion

Control samples TM-Ash/W-Pine and test samples TM-Ash^n/W-Pine, which, according to the research methodology, were removed from the rack after exposure in natural conditions for *n* months, were used for research on changes in the strength of adhesive joints and changes in the thermally modified ash wood surface condition.

The average strength of the TM-Ash/W-Pine control samples was 7.12 MPa. These results indicate their reliability, as they correspond to the chipping strength of pine wood along the grain. The ability to form strong polyvinyl acetate adhesive joints made from thermally modified wood were confirmed by research of M. Mamonova *et al.* (2022). It was noted that, despite the decreased wettability of thermally modified wood, an increased penetration depth of PVAc adhesive into the structure of wood, treated at rather low temperatures of 180°C, was observed. The findings also suggest the possibility of forming an adhesive seam with the lower permissible limit of strength when joining thermally modified wood elements treated at 180°C, 200°C, and 220°C – with structures of lower permeability.

The change in the strength of the TM-Ash^n/W-Pine test samples occurred in stages, depending on the duration of their exposure to environmental factors. At the same time, it should be noted that the intensity of natural factors' effects depended on the season. As studies have shown, the most hazardous factors for such polyvinyl acetate adhesive compounds were ultraviolet radiation –its intensity being the highest in the summer period – along with elevated temperatures and humidity. According to observations made during the experiment, the adhesive joints of wood formed with polyvinyl acetate adhesive began to change their behavior. This was noticeable both visually, as slight flaking began to appear along the edges of the samples between the wood and the adhesive, and through a reduction in strength. For example, after the summer research period, the strength of the adhesive samples decreased significantly: the strength of the adhesive samples decreased from 6.56 MPa (TM-Ash^6/W-Pine samples) to 6.05 MPa (TM-Ash^9/W-Pine samples). A rather significant change in the strength of the samples was also observed during the second summer exposure period, when the strength of the samples changed from 5.93 MPa (for TM-Ash^{18}/W-Pine) to 5.62 MPa (for TM-Ash^{21}/W-Pine). It should be noted that, overall, the average strength of adhesive samples aged in natural conditions for 24 months decreased from 7.12 to 5.13 MPa. The above changes in the strength of adhesive joints occur under the cyclic action of humidity, temperature fluctuations, solar radiation, precipitation, etc., during exposure. Considering the final strength values of the adhesive samples, it can be concluded that adhesive joints unprotected from external environmental effects withstand the impact of natural factors while maintaining their operational capacity.

Control samples TM-Ash/W-Pine and test samples TM-Ash^n/W-Pine were also used to study changes in the surface condition of thermally modified ash wood. For SEM observations of TM-Ash and TM-Ash^n surfaces, three adhesive samples were selected from the total number of TM-Ash/W-Pine control samples, as well as from each batch of TM-Ash^n/W-Pine test samples (aged in natural conditions for *n* months). TM-Ash and TM-Ash^n surfaces were prepared for SEM observations according to the above method. No significant differences in the surface structures of the three duplicate samples from each batch were detected by SEM observations. Therefore, Figure 2 shows SEM images of only one sample.

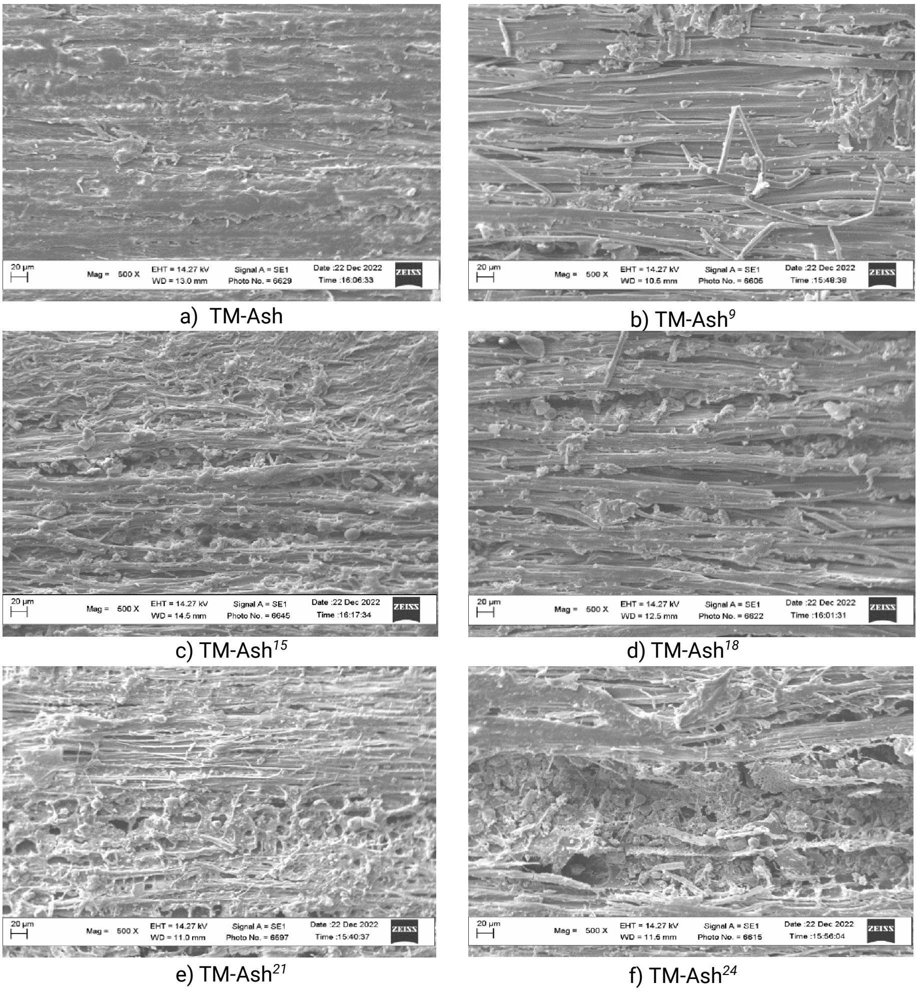

Figure 2. SEM images of TM-Ash and TM-Ashn surfaces at 500 × magnification
Source: compiled by the authors

As shown in Figure 2a, the TM-Ash surface is characterised by a relatively homogeneous and smooth structure, formed during thermal modification as the result of complex physicochemical transformations in the wood matrix under high temperatures, leading to a decrease in porosity and lignification. The TM-Ash surface element of the TM-Ash/W-Pine adhesive sample exhibited a brown color, as seen in Figure 3a. M. Gaff *et al.* (2023) emphasised the role of the breakdown of C = O and C = C bonds in hemicelluloses and lignin, which facilitates the formation of chromophoric structures responsible for the characteristic color changes in thermally modified wood.

It should be noted that no significant structural changes were observed on the surface of the thermally modified wood during the first nine months of exposure to natural conditions (as confirmed by SEM observations). However, over time, under the influence of various environmental factors, structural changes began to appear on the TM-Ash^{n} surfaces of adhesive samples (accompanied by a color shift – gradual graying was observed), which were recorded using SEM images presented in Fig. 2b-f. The first significant changes in the condition of the TM-Ash surface, as a direct indicator of the dynamics of wood degradation under the influence of environmental factors, were recorded in SEM images after nine months of exposure of adhesive samples to natural conditions. These changes were manifested in an increase in structural irregularities (Fig. 2b). This period corresponds to the highest average temperature (+25°C in July) and solar radiation, as well as the highest amount of precipitation (100 mm).

It can be assumed that intense ultraviolet (UV) radiation initiated the degradation process of the thermally modified wood surface through a series of photochemical reactions. Specifically, UV radiation accelerates surface oxidation, leading to the formation of functional groups such as carboxyl groups, and due to UV absorption, chemical reactions occur that result in the breakdown of lignin, which in turn contributes to increased surface wettability. Furthermore, the destructive effect of sunlight was supplemented by the action of other environmental factors. UV radiation also has a degrading effect on color pigments, leading to changes in the color of the thermally modified wood surface.

SEM images in Figure 2 illustrate further degradation changes in the thermally modified surface, with increasing intensity due to fluctuations in humidity and temperature, precipitation (rain, snow), and changes in wind force (with abrasive components such as dust). As a result, with prolonged exposure to natural conditions, the surface of thermally modified ash transformed into one with significant structural micro-irregularities.

Notably, substantial changes were observed in the TM-Ash^{21} surface (Fig. 2e), which had been exposed for two summer periods. The condition of the surface of the thermally modified ash wood at the final stage of research (TM-Ash^{24}) is presented in Figure 3b. The SEM images (Fig. 2f) reveal TM-Ash^{24} surface destruction extending into the wood structure. The measurements of the destructive surface changes indicated that the structure of thermally modified ash wood, after 24 months of environmental exposure, was damaged to a depth of 0.05-0.2 mm. However, no areas with deeper damage, such as crack formation, fractures, or fiber lifting, were detected. Therefore, the surface damage was classified as "superficial" due to the degree of erosion.

a *b*

Figure 3. The condition of the surfaces of the thermally modified ash wood at the initial and the final stages of research

Note: a) TM-Ash surface element of the TM-Ash/W-Pine adhesive sample; b) TM-Ash^{24} surface element of the TM-Ash^{24}/W-Pine adhesive sample
Source: compiled by the authors

The results of this study on changes in the surface condition of thermally modified ash wood under prolonged environmental exposure are consistent with findings reported by other researchers who studied the effects of natural outdoor weathering and accelerated aging on thermally modified wood of other species. Z. Vidholdová *et al.* (2023) investigated how thermally modified Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) changed in surface properties – such as color, roughness, and mold resistance – during 24 months of natural outdoor weathering. According to the authors, the surfaces of both thermally modified species gradually lost their original yellow-reddish hue and became increasingly gray, while surface roughness increased over time. The weathered wood was colonised by molds such as *Aspergillus niger* and *Penicillium brevicompactum*.

F. Kačík *et al.* (2025) examined the effects of accelerated aging on the lignin content in thermally modified spruce wood. Their findings indicated that the aging process results in a relative increase in lignin content, mainly due to the leaching of water-soluble extractives. Additionally, lignin in the aged samples exhibited a lower molecular weight compared to that in freshly thermally modified wood, indicating further degradation and the release of larger quantities of aromatic monomers.

Considering the structural changes observed on the TM-Ash^{24} surface through microscopic analysis – characteristic of the final stage of environmental exposure – its wettability and the time required for complete water droplet penetration were investigated using the established methodology. The TM-Ash surface, which underwent similar testing, was chosen as a comparative surface.

The contact angles (θ°) were measured at the initial moments when water droplets came into contact with the TM-Ash and TM-Ash^{24} surfaces after their spreading (Fig. 4a and Fig. 4b, respectively).

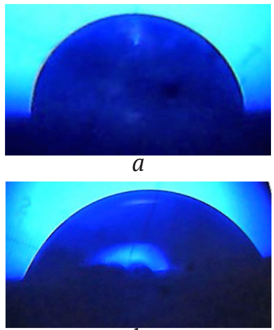

Figure 4. Water droplet
Note: a) on the TM-Ash surface; b) on the TM-Ash^{24} surface
Source: compiled by the authors

Measurements taken after 1 second showed a contact angle of θ = 92° for the TM-Ash surface, which is characteristic of a hydrophobic surface. This is consistent with the effects of thermal modification, which increases the hydrophobicity of wood cell walls by removing hydrophilic and hydroxyl groups from hemicelluloses. In contrast, a contact angle of θ = 75° was observed for the TM-Ash^{24} surface, indicating its hydrophilic nature (Fig. 5).

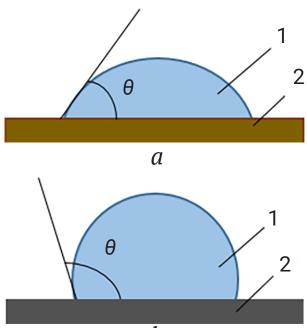

Figure 5. Hydrophilic and hydrophobic surfaces
Note: 1 – water; 2 – surface; 3 – contact angle (θ°)
Source: compiled by the authors

Figure 6 presents the contact angle vs. time data for the TM-Ash and TM-Ash*24* surfaces, considering all measurements. As can be seen from the graphical dependences, in general, long-term environmental exposure of thermally modified ash wood led to the decrease in contact angle values, indicating greater hydrophilicity of TM-Ash*24* surface.

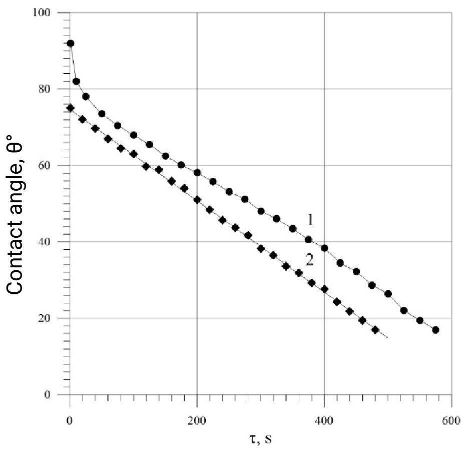

Figure 6. Dynamics of the change in the wetting angle over time for surfaces
Note: 1 –TM-Ash surface; 2 –TM-Ash*24* surface
Source: compiled by the authors

The contact angles and droplet volumes on both surfaces gradually decreased over time due to water penetration into the TM-Ash and TM-Ash24 structures. The results showed that the water droplets penetrated the TM-Ash*24* structure faster than the TM-Ash structure. Accordingly, the contact angle on the TM-Ash24 surface reached θ = 17° after 480 seconds, while on the TM-Ash surface after 570 seconds.

The shorter water penetration time in the TM-Ash*24* structure indicates reduced water resistance, potentially accelerate further destructive processes under the influence of external factors. Moreover, prolonged environmental exposure is expected to increase the water permeability of TM ash wood surfaces, leading to material swelling, negatively affecting its mechanical strength, and partial moisture ingress into the adhesive seam. This, in turn, may result in a decline in adhesive bond strength (Rabko *et al.*, 2021).

However, it should be noted that even with the accelerated water absorption observed on the TM-Ash24 surface, the total time required for droplets to penetrate the structures of both thermally modified samples is significantly longer compared to unmodified ash wood. Unmodified ash wood, being a ring-porous material, was used as the control in this study. The average time for complete droplet penetration was found to be 57 seconds, which aligns with the results reported by M. Žlahtič & M. Humar (2016), who noted that for various wood specimens, the contact angle could not be measured after 60 seconds because the droplets had fully penetrated the surface. The findings of this study regarding the reduced water penetration in TM ash wood are consistent with those reported by A. Lunguleasa & C. Spirchez (2025), who examined the effects of heat treatment on ash wood properties. Their results demonstrated a significant decrease in water absorption and swelling in samples treated at 185°C for 3 hours, compared to untreated wood.

O. Horbachova *et al.* (2025) investigated the swelling behavior of both untreated ash wood and thermally modified ash wood. Swelling was quantified as the percentage increase in size and volume resulting from moisture absorption, measured from the absolutely dry state to the fiber saturation point. The authors obtained results, showing that swelling varied considerably: for untreated ash wood, it was 7.49%, while for wood modified at 200°C, it was 1.75% relative to the initial dimensions.

Thus, as complex experimental studies of adhesive samples have shown, environmental factors negatively affect both the adhesive joint of thermally modified ash wood and non-modified pine bonded with PVAc adhesive composition with the degree of water resistance D4, as well as the surface of thermally modified ash wood when unprotected. Such studies are important because manufacturers offer various constructions and products (facade elements, doors, window frames, terrace decking, gazebos, etc.), where the combination of thermally modified ash wood and pine is achieved through bonding with PVAc adhesives. In particular, window frames and doors with an outer layer made of thermally modified ash wood, which provides better protection against moisture and biological degradation, offer significant advantages in terms of energy efficiency, durability, and aesthetic appeal. However, they serve as a barrier between external and internal environments. In such constructions installed in buildings, the adhesive joint is protected from direct exposure to external factors, while the surfaces of thermally modified and unmodified wood are subjected to different climatic conditions. As a result, the external environment is characterised by dynamic and unpredictable weather fluctuations, playing a crucial role in the durability of the thermally modified surface, whereas the internal environment maintains relatively stable climatic conditions. Therefore, further research remains essential to predict the long-term behavior of adhesive joints and the surface of thermally modified wood in such constructions to ensure their proper service life.

Conclusions

It has been established that prolonged exposure to cyclic temperature-humidity loads and solar radiation over 24 months caused a decrease in the strength of “thermally modified ash/pine wood” polyvinyl acetate adhesive joints from 7.12 MPa to 5.13 MPa. Samples exposed during summer periods exhibited a significant decrease in the strength: from 6.56 MPa to 6.05 MPa after the first cycle and from 5.93 MPa to 5.62 MPa after the second cycle.

Using scanning electron microscopy, the dynamics of destructive changes on the surface of thermally modified ash wood due to external factors were recorded over 24 months. It was found that photochemical damage to thermally modified ash wood acts as a “trigger mechanism” for further destruction of the surface condition under the influence of external factors, including fluctuations in humidity and temperature (narrowing and expansion of the material’s structure), precipitation (moisture penetration into the material), changes in wind force, and the presence of abrasive components in the form of dust (surface wear).

The study revealed that the structure of thermally modified ash wood, subjected to environmental conditions for 24 months (TM-Ash^{24}), was damaged to a depth of 0.05-0.2 mm due to a cascade of destructive mechanisms. The surface damage was classified as “superficial” due to the degree of erosion. The results of the study showed that water droplets penetrated such a structure faster than the structure of thermally modified ash wood, which was not exposed to natural factors (TM-Ash). Accordingly, the contact angle on the TM-Ash^{24} surface reached θ = 17° after 480 seconds, while on the TM-Ash surface after 570 seconds. The decrease in water penetration time into the TM-Ash^{24} structure indicates the reduced water resistance of this material, which can potentially accelerate further destructive processes under the influence of external factors.

The information on the surface destruction dynamics of thermally modified ash wood and changes in adhesive joint strength is comprehensive and useful for predicting the durability of polyvinyl acetate adhesive joints in TM-Ash/W-Pine. The research results indicate that TM-Ash/W-Pine adhesive joints (using thermoplastic polyvinyl acetate adhesives with with durability class

D4) should not be used in natural conditions with an unprotected surface of thermally modified wood and exposed adhesive joint areas.

It is crucial that a direction for further research has been outlined regarding the strength of TM-Ash/W-Pine adhesive joints under two different climatic environments (indoor climatic conditions and outdoor exposure). The obtained results will have practical significance in ensuring the effectiveness of adhesive bonding and enhancing the overall reliability of structures combining thermally modified and unmodified wood.

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Conflict of Interest

None.

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Вплив факторів зовнішнього середовища на стан поверхні термомодифікованої деревини ясеня у полівінілацетатних клейових з'єднаннях

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Анотація. Метою роботи було дослідження полівінілацетатних клейових з'єднань «термічно модифікована деревина ясеня/сосна» щодо змін стану поверхні термічно модифікованої деревини ясеня (що корелюються із зміною міцності зразків) за умов тривалого впливу зовнішніх факторів. Тестові зразки клейових з'єднань розміщувалися на стенді для зовнішньої експозиції. З тримісячною періодичністю вони вилучалися із стенду для фіксування деструктивних змін поверхні термічно модифікованої деревини за допомогою скануючої електронної мікроскопії, оцінки змін її змочуваності та тривалості проникнення крапель води в структуру (шляхом фіксування зміни значень кутів змочування в часі), а також встановлення змін міцності клейових з'єднань. Встановлено, що фотохімічне пошкодження термічно модифікованої деревини ясеня є «пусковим механізмом» її подальших деструктивних змін. Зразки після літніх періодів експозиції, характеризувалися більш вираженими деструктивними змінами термічно модифікованої поверхні та суттєвим зниженням міцності клейових з’єднань (від 6,56 МПа до 6,05 МПа після першого циклу та від 5,93 МПа до 5,62 МПа після другого). Дослідження показали, що внаслідок каскаду деструктивних механізмів, структура термічно модифікованої деревини ясеня після 24 місяців витримки в природних умовах, зазнала поверхневих пошкоджень на глибину 0,05-0,2 мм (в той час як міцність клейового з’єднання зменшилась з 7,12 МПа до 5,13 МПа), поверхня стала більш гідрофільною, що призвело до скорочення часу проникнення води в її структуру. Відповідно, кут змочування на такій поверхні досягнув θ = 17° вже через 480 с, тоді як на поверхні термічно модифікованої деревини ясеня, що не піддавалася впливу природним факторам, аналогічного значення було досягнуто лише через 570 с

Ключові слова: зовнішні фактори; температурно-вологісні навантаження; сонячна радіація; скануюча електронна мікроскопія; деструктивні міни; кут змочування; проникнення крапель води

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Representatives of the genus *Chamaecyparis* Spach in the collections of botanical gardens in Kyiv

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Abstract. Despite their limited use in Kyiv's landscaping due to a perceived sensitivity, representatives of the genus *Chamaecyparis* Spach are actively represented in the city's botanical collections and are valued for the diversity of cultivars with ornamental traits. The purpose of the scientific research was to assess the existing diversity of species and cultivars in the collections of botanical institutions in Kyiv. The collection fund of *Chamaecyparis* Spach representatives in the botanical gardens of Kyiv was analysed: the National Botanical Garden of M.M. Gryshko National Academy of Sciences of Ukraine, the Botanical Garden of the National Taras Shevchenko University of Kyiv, and the Botanical Garden of the National University of Life and Environmental Sciences of Ukraine. It was determined that the largest collection is held at the National Botanical Garden of M.M. Gryshko, where *Chamaecyparis pisifera* (Siebold & Zucc.) Endl. is represented by 8 cultivars, *Chamaecyparis obtusa* (Siebold & Zucc.) Endl. by 5 cultivars, and *Chamaecyparis lawsoniana* (A. Murray bis) Parl. by 11 cultivars. In total, 37 cultivars were found in the botanical collections of Kyiv, with the highest number of taxa recorded in *Chamaecyparis lawsoniana* – 18 cultivars, the smallest in *Chamaecyparis obtusa* – 16 cultivars, and *Chamaecyparis pisifera* represented by 13 cultivars. A brief description of the species and cultivars presented in the collections is provided, the current state of the collection plantings is described, and the prospects for the addition of new taxa to the collections are discussed. It was established that collection plantings provide a

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basis for analysing the adaptation level of cultivars to local climatic conditions and represent specimens of various ages along with their physiological states, depending on age, origin, and maintenance practices. The diversity of plants in the collections, particularly those over 50 years old, demonstrates the sufficient resilience of most cultivars and species to adverse environmental factors and supports their broader use in urban landscaping. The research findings can be utilised to expand the assortment of ornamental coniferous plants in urban greening by introducing promising *Chamaecyparis* Spach cultivars adapted to the conditions of Kyiv

Keywords: species; cultivar; assortment; coniferous plants; coniferetum; dendrarium

Introduction

In contemporary landscape design, there is a growing demand for ornamental evergreen woody plants that maintain aesthetic appeal throughout the year and demonstrate adaptability to urban environmental conditions. Among these, representatives of the genus *Chamaecyparis* Spach hold particular value due to their wide range of cultivars, crown forms, foliage colours, and compact growth habits, making them suitable for both large-scale plantings and container culture. Despite their high ornamental qualities and steady demand in the private sector, their use in urban greening remains limited, partly due to the insufficient study of their ecological adaptability to the climatic conditions of central Ukraine. Therefore, analysing the taxonomic composition and conservation status of existing *Chamaecyparis* Spach collections in the botanical gardens of Kyiv becomes especially relevant, as these collections represent a potential source for introducing promising cultivars into urban landscapes.

Therefore, analysing the taxonomic composition and conservation status of existing *Chamaecyparis* Spach collections in the botanical gardens of Kyiv becomes especially relevant, as these collections represent a potential source for introducing promising cultivars into urban landscapes. A similar methodological approach was successfully applied to assess the ornamental value of *Araliaceae* species in Kyiv botanical gardens, highlighting the relevance of collection-based evaluation in urban greening efforts (Morozko & Kolesnichenko, 2024). Species of the genus *Chamaecyparis* Spach are evergreen plants highly valued for their year-round ornamental appeal. Due to their aesthetic qualities and practical utility, they are widely used around the world and attract interest from researchers across various fields. In their natural habitats, According to C.F. Li *et al.* (2015), *Chamaecyparis* formosensis is one of the principal forest-forming species in Taiwan, particularly in mountainous regions. C. Brischke *et al.* (2023) investigated the biological durability and moisture behaviour of *Metasequoia glyptostroboides* and *Chamaecyparis lawsoniana* under various exposure conditions. They found that both species exhibited high resistance to fungal decay. The authors concluded that their dimensional stability and durability make them suitable for use in outdoor environments. K.M. Górski *et al.* (2024) studied the chemical composition of essential oils derived from *Chamaecyparis obtusa*. The research revealed a wide spectrum of bioactive compounds with antimicrobial and antioxidant properties. The study highlighted the pharmacological potential of this species for future applications in medicine and biotechnology.

Y. Wang *et al.* (2022) investigated the evolutionary history of the relict conifer genus

Chamaecyparis using molecular phylogenetics. They demonstrated that incomplete lineage sorting and regional extinction events played a significant role in shaping its present-day distribution. The study provided new insights into the complex divergence patterns within the Cupressaceae family during the Paleogene period. N.V. Zaimenko *et al.* (2020) presented detailed information on the introduction and conservation practices implemented at the M.M. Hryshko National Botanical Garden of the National Academy of Sciences of Ukraine. Their work highlighted the scientific value of collection plantings and their role in preserving plant diversity under global environmental changes. The study also emphasised the importance of this institution as a centre for research and adaptive strategies in the context of ecological instability.

Research on the taxonomic composition of collections involving *Chamaecyparis* Spach in Ukrainian botanical collections has been comprehensively examined in recent literature. N.S. Boiko (2023) analysed the role of gymnosperm collections in Ukraine's *ex-situ* conservation system, emphasising the significance of *Chamaecyparis* taxa as part of national biodiversity preservation strategies. Their study also identified gaps in institutional coordination and pointed to the need for updated maintenance protocols across major arboreta. Similarly, S.I. Kuznetsov *et al.* (2020) offered an extensive catalogue of trees, shrubs, and vines used in Ukrainian landscape architecture, including several *Chamaecyparis* species. The authors underscored the adaptive potential of these conifers to local climatic zones, which supports their continued integration into urban greening and botanical garden planning. Updating information on the taxonomic structure of the collection plantings, assessing the current condition and development of these collections under climate change, and describing the morphometric characteristics of the cultivars is essential for their broader implementation in urban landscaping.

Based on recent taxonomic revisions, there are 5 recognised species of the genus *Chamaecyparis* Spach: *Chamaecyparis formosensis* Matsum., *Chamaecyparis thyoides* (L.) Britton, Sterns & Poggenb., *Chamaecyparis pisifera* (Siebold & Zucc.) Endl., *Chamaecyparis obtusa* (Siebold & Zucc.) Endl., and *Chamaecyparis lawsoniana* (A. Murray bis) Parl. For a long time, *Callitropsis nootkatensis* (D. Don) Oerst. was considered part of the genus *Chamaecyparis* Spach, but it now occupies a separate taxonomic position (POWO, g.d.).

In Europe and Ukraine, representatives of the genus *Chamaecyparis* Spach are widely distributed and used as ornamental plants for landscaping. A. Cedro *et al.* (2021) investigated the climate sensitivity of *Chamaecyparis pisifera* by analysing its tree-ring width patterns in Poland. Their results confirmed the responsiveness of this species to temperature and precipitation fluctuations, demonstrating its ecological plasticity and potential for adaptation in variable environments. This finding is relevant for understanding the resilience of *Chamaecyparis* species cultivated in Ukrainian urban landscapes under changing climatic conditions. Expanding the range of plants cultivated in Ukraine is an important area of work aimed at solving biodiversity conservation issues, rational use of plant resources, and optimising the state of green spaces. To broaden the plant range used in urban landscaping and enhance the aesthetic and artistic value of plantings in street compositions, more introduced species are being utilised. Modern trends in creating garden-park landscapes, though encouraging a revision of plant selection with a focus on biological species, still require the use of the entire existing within-species diversity of woody plants. The desire to create original compositions or complete plantings for specific functional purposes generates the need for specific taxa with defined habitus characteristics, crown forms, and distinct color ranges throughout the year. There is significant diversity of cultivars in the species of the genus *Chamaecyparis* Spach.

Despite the wide use of cultivars, especially in private landscaping, their use in urban areas is limited due to the insufficient study of ecological and biological traits under local conditions. The aim of the research was to identify the taxa present in the collections, assess their condition under the environmental conditions of Kyiv, and determine their future potential and applicability in urban landscaping

Materials and Methods

The study was based on an in-depth investigation of representatives of the genus *Chamaecyparis* Spach cultivated in the collections of three leading botanical institutions in Kyiv: the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, the Botanical Garden of the National Taras Shevchenko University of Kyiv named after Academician O.V. Fomin, and the Botanical Garden of the National University of Life and Environmental Sciences of Ukraine (NULES). These institutions serve as key centres for the introduction, acclimatisation, and preservation of ornamental woody plants in central Ukraine and offer a representative diversity of conifer taxa under *ex situ* conditions.

Field investigations were carried out during the 2024-2025 vegetation seasons. The research methodology included both qualitative and quantitative assessments of the taxonomic composition and condition of *Chamaecyparis* specimens. Data collection was based on the route-based field inventory method, which involved systematic surveying of all sections and exhibition zones within each botanical garden where *Chamaecyparis* taxa were present. Morphometric characteristics such as growth habit, crown form, foliage colour, and plant vitality were visually assessed and documented in field journals.

To ensure taxonomic accuracy, plant names were verified according to the latest classification standards provided by the Royal Botanic Gardens, Kew (POWO, n.d.), and synonymy was cross-checked using the World Flora Online plant List (WFO, 2025). Additionally, printed and digital catalogues from the botanical institutions were reviewed, along with archived publications and earlier inventory records, to trace the history of plant introductions and collection dynamics over time. The primary sources for this study were reseaches by T.A. Reshetnyak (1980), S. Kuznetsov (2015), and N.S. Boiko (2023).

The collected data were subsequently systematised and compared across institutions to identify patterns in species and cultivar representation, evaluate the completeness and condition of existing collections, and detect the presence of rare or unique cultivars. Special attention was given to cultivars demonstrating stress symptoms or decline, with descriptive notes recorded on microclimatic conditions, exposure, and associated factors potentially affecting plant health.

Results and Discussion

The study focused on analysing the taxonomic composition, structural features, and representativeness of plantings of the genus *Chamaecyparis* Spach within the *ex situ* collections of major botanical institutions. Representatives of the genus *Chamaecyparis* Spach are well represented in the collections of botanical gardens in Kyiv. The National Botanical Garden of M.M. Gryshko National Academy of Sciences of Ukraine was founded in September 1935 (Boiko, 2023). M. Kokhno (1987), in the catalogue of the collection, mentions that in 1987, the garden contained 9 taxa, mainly in the dendrarium and the "Vydubytsky slope" section. With the gradual development and opening of new exhibition areas, such as the "Decorative Forms of Woody Plants" and "Japanese Garden" sections, the collection has significantly increased. The coniferetum contains 3 species: *Chamaecyparis pisifera*, *Chamaecyparis obtusa*, and *Chamaecyparis lawsoniana*. In the dendrarium of the National Botanical Garden, we can highlight 3 main locations where representatives of the *Chamaecyparis* Spach genus are concentrated. These include the coniferetum section, where, in addition to the above-mentioned species, there are cultivars over 50 years old: *Ch. Lawsoniana* 'Allumi', *Ch. Pisifera* 'Filifera', *Ch. Pisifera* 'Plumosa', *Ch. Pisifera* 'Plumosa Aurea', and *Ch. Pisifera* 'Squarrosa'. Group plantings of *Ch. Lawsoniana* and *Ch. Pisifera* are also located in the "Vydubytsky slope" area. The majority of cultivars are situated in the "Decorative Forms of Woody Plants" section. The general condition of the plants is good; they are growing under favorable conditions. However, some cultivars of *Ch. pisifera* (mainly those with juvenile foliage) were severely affected during the heatwave of the summer of 2024. Some cultivars of *Chamaecyparis obtusa* were lost in the exhibition area but survived in the parent plantings of the decorative nursery. In total, the collection at the National Botanical Garden of M.M. Gryshko contains 24 cultivars, and their distribution by species is shown in the diagram (Figs. 1-2)

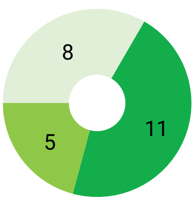

Figure 1. Distribution of cultivars of species from the genus *Chamaecyparis* Spach in the collection of the National Botanical Garden of M.M. Gryshko
Source: developed by the authors

Figure 2. *Ch. lawsoniana* and *Ch. pisifera* in the dendrarium of the National Botanical Garden of M.M. Gryshko (Vydubytsky Slope)
Source: photo by the authors

The Botanical Garden of the National Taras Shevchenko University of Kyiv, named after Academician O.V. Fomin, is one of the oldest botanical institutions in Ukraine, founded in 1839 (Boiko, 2023). The published catalogue of the garden's collection from 2007 was analysed, which indicated the presence of 3 species and 20 cultivars, consistent with the results of our surveys. In the dendrarium, *Chamaecyparis pisifera*, *Chamaecyparis obtusa*, and *Chamaecyparis lawsoniana* grow. It is worth noting the presence of certain specimens. The general condition of the plants is good; however, some specimens of *Ch. pisifera* (mainly those with juvenile foliage) were also severely affected during the heatwave of the summer of 2024. In the botanical garden of O.V. Fomin, a collection of 20 cultivars has been gathered, with *Chamaecyparis lawsoniana* being the most represented with 11 cultivars. The distribution of cultivars by species is shown in the diagram (Fig. 3).

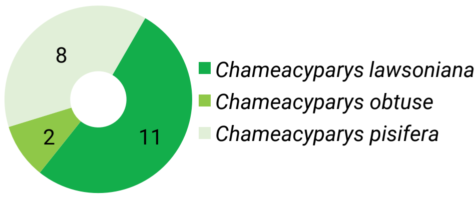

Figure 3. Distribution of cultivars of species from the genus *Chamaecyparis* Spach in the Botanical Garden of Academician O.V. Fomin
Source: developed by the authors

Like all members of the Cupressaceae family, plants of the genus *Chamaecyparis* are well-suited for creating topiary elements of varying complexity. In the collection of the Botanical Garden of Academician O.V. Fomin, the possibilities of using *Chamaecyparis pisifera* cultivars for maintenance in the "Niwaki" style are harmoniously presented (Figs. 4-5).

Figure 4. Topiary pruning of *Chamaecyparis* Spach representatives
Source: photo by the authors

Figure 5. *Chamaecyparis pisifera* cultivars (Botanical Garden of Academician O.V. Fomin)
Source: photo by the authors

The Botanical Garden of the National University of Life and Environmental Sciences of Ukraine was founded in 1928 (Boiko, 2023). The most recent published inventories indicate that as of 2010, 9 cultivars and 2 species were recorded (Kolesnichenko *et al.*, 2010). The results of the study show that the number of taxa in the garden has not changed. The garden contains species plants *Chamaecyparis pisifera* and *Chamaecyparis lawsoniana*, along with several cultivars of *Chamaecyparis pisifera* such as 'Filifera', 'Plumosa', and 'Squarrosa', all over 50 years old. Unfortunately, due to the density of the plantings and heavy shading, the condition of some plants is suppressed. In the Botanical Garden of NULES Ukraine, a collection of 9 cultivars has been gathered, with the distribution by species presented in the diagram (Fig. 6).

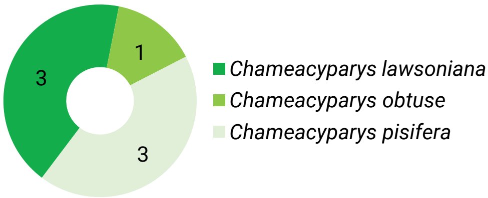

Figure 6. Distribution of cultivars of species from the genus *Chamaecyparis* Spach in the garden National University of Life and Environmental sciences of Ukraine
Source: developed by the authors

The number of taxa in the collections has increased. By analysing catalogs from previous editions and archival publications, we observe a significant growth in the collections, especially since 1990. This expansion has mainly been driven by greater access to global exchanges between botanical gardens, the involvement of plants from trade markets, and nurseries (Table 1). It has been established that the most common species in the collection plantings of botanical gardens are: *Chamaecyparis lawsoniana* and its cultivars – 'Allumi', 'Lutea', 'Globosa'; *Chamaecyparis pisifera* and its cultivars 'Bouleward' and 'Filifera Nana', which are found in all the studied collections. Based on t he conducted research and obtained results, it can be noted that the largest number of cultivars is collected at the National Botanical Garden of M.M. Gryshko: *Chamaecyparis pisifera* (Siebold & Zucc.) Endl. with 8 cultivars, *Chamaecyparis obtusa* (Siebold & Zucc.) Endl. with 5 cultivars, and *Chamaecyparis lawsoniana* (A. Murray bis) Parl. with 11 cultivars. The overall distribution of the number of cultivars in the collections of the botanical institutions of Kyiv is presented in the diagram (Fig. 7).

Table 1. Taxa of *Chamaecyparis* Spach in the Botanical Gardens of Kyiv

Taxonomic name	Representation in the collection		
	Botanical Garden of NULES	Botanical Garden of O.V. Fomin	Botanical Garden of M.M. Gryshko
Chameacyparis lawsoniana (A. Murray bis) Parl.	+	+	+
Ch. lawsoniana 'Allumi'	+	+	+
Ch. lawsoniana 'Lutea'	+	+	+
Ch. lawsoniana 'Globosa'	+	+	+
Ch. lawsoniana 'Blue Surprise'		+	
Ch. lawsoniana 'Chilworth Silver'		+	
Ch. lawsoniana 'Ellwoodii Gold'		+	
Ch. lawsoniana 'Glauca'		+	
Ch. lawsoniana 'Lombartsii'		+	
Ch. lawsoniana 'Nana Albospica'		+	
Ch. lawsoniana 'Stevartii'		+	
Ch. lawsoniana 'Triomf von Booskop'		+	+
Ch. lawsoniana 'Columnaris'			+
Ch. lawsoniana 'Ellwoodii'			+
Ch. lawsoniana 'Fletcheri'			+
Ch. lawsoniana 'Flaseri'			+
Ch. lawsoniana 'Glauca globus'			+
Ch. lawsoniana 'Monumenal'			+
Ch. lawsoniana 'Rogersii'			+
Chameacyparis obtuse (Siebold & Zucc.) Endl.	+		+
Ch. obtuse 'Nana Gracilis'	+		+

Table 1, Continued

Taxonomic name	Representation in the collection		
	Botanical Garden of NULES	Botanical Garden of O.V. Fomin	Botanical Garden of M.M. Gryshko
Ch. obtuse 'Aurea'		+	+
Ch. obtuse 'Coralliformis'			+
Ch. obtuse 'Crippsii'			+
Ch. obtuse 'Nana Aurea'			+
Ch. obtuse 'Tsatsumi gold'			+
Chameacyparis pisifera (Siebold & Zucc.) Endl.	+	+	+
Ch. pisifera 'Filifera'	+	+	
Ch. pisifera 'Filifera Aurea'	+	+	
Ch. pisifera 'Filifera Nana'	+	+	+
Ch. pisifera 'Aurea'	+	+	
Ch. pisifera 'Bouleward'	+	+	+
Ch. pisifera 'Plumosa'		+	+
Ch. pisifera 'Plumosa Aurea'		+	
Ch. pisifera 'Squarrosa'		+	+
Ch. pisifera 'Squarrosa Sulphurea'		+	
Ch. pisifera 'Aurea nana'			+
Ch. pisifera 'Squarrosa dumosa'			+
Ch. pisifera 'Squarrosa minima'			+
Ch. pisifera 'Sungold'			+

Source: developed by the authors based on N. Kokhno (1987), O.V. Kolesnichenko *et al.* (2010), N.S. Boiko (2023)

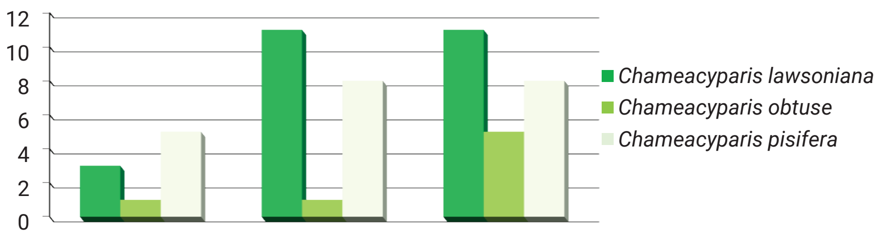

Figure 7. Distribution of cultivars in the collections of botanical gardens of Kyiv
Source: developed by the authors

According to the results of our research, it has been established that today in Kyiv, three species of the genus *Chamaecyparis* Spach are growing: *Chamaecyparis pisifera*, *Chamaecyparis obtusa*, and *Chamaecyparis lawsoniana*, as well as 37 cultivars. The largest number of taxa was recorded in *Chamaecyparis lawsoniana* – 18 cultivars, the smallest in *Chamaecyparis obtusa* – 6 cultivars, and *Chamaecyparis pisifera* is represented by 13 cultivars (Fig. 8).

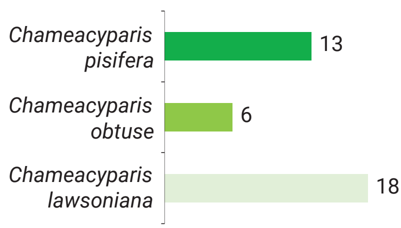

Figure 8. Total number of cultivars present in the research collections
Source: developed by the authors

Below is a brief description of the biological and morphometric characteristics of the original species, with Tables 2-4 providing details of the cultivars observed during the research.

Chamaecyparis lawsoniana – a tree up to 50, sometimes 70 m tall, with a beautiful narrow conical crown and dark green scaly foliage. The bark of the trunk is dark brown, longitudinally cracked. The bark of the annual shoots is green. The leaves are small, dark green on top and grayish beneath, arranged densely on the shoot in a single plane. The top of the tree is often bent sideways. The microstrobiles are dark purple, small, 4-4 mm long. Mature megastrobiles are brown, rounded, 7-10 mm in diameter. The seeds are winged, 4-5 mm wide. It has been cultivated in Ukraine since 1811 and is widely grown in botanical gardens. It grows quickly, but its early years are slow. It reproduces early. Native habitat: California, Oregon (Table 2).

Table 2. Brief characteristics of cultivars of *Chamaecyparis lawsoniana*

Cultivar	Short description
'Alumii'	Tree with a narrow, cone-shaped crown, up to 10 m in height. Branches initially grow at a sharp angle to the trunk but gradually become horizontal with age. Dense crown, foliage is bluish-gray.
'Blue Surprise'	Similar to *Ch.l.* Ellwoodii, but more compact with a narrow pyramidal shape.Needle-like foliage (semi-juvenile) with a rich bluish-silver hue.
'Columnaris'	Tree 5 to 10 m tall, with a narrow columnar crown form, dense. Branches grow straight and at a sharp angle to the trunk. The last-order shoots are thin and flat, with foliage pressed against the branches and a bluish-silver color.
'Chilworth Silver'	Similar to *Ch.l.* 'Ellwoodii', grows slowly, with a straight and dense crown. Foliage is bluish-gray.
'Fletcheri'	Columnar form, up to 8 m tall, sometimes with multiple trunks. Crown formed by upward-growing branches, dense. Foliage is bluish-green, semi-juvenile, and juvenile.
'Fraseri'	Tree of typical size, up to 10 m tall, with thick branches forming a dense, narrow conical crown. Foliage has a bluish tint.
'Ellwoodii'	Tree up to 5 m tall, with a cone-shaped crown (up to 1 m wide). Branches are densely arranged and grow at a sharp angle from the trunk. Juvenile foliage, bluish-green.
'Ellwoodii Gold'	Mutation of the original form, with golden-colored shoots of the latest order and foliage. Compact columnar crown.
'Glauca'	Tree of typical size and crown form, but with bluish-green or grayish foliage.
'Glauca Globus'	Globular form similar to *Ch.l. 'Globus'*, but with slightly bluer foliage. Bush size is 1-1.5 m in diameter, with short, thin shoots and drooping tips.
'Globosa'	Globe-shaped, wide crown. Branches directed upwards, with short, thick shoots that are slightly curved at the tips. Foliage is bright green.
'Lombartsii'	Columnar tree up to 10 m tall. Branches and shoots are branched. Foliage is multi-colored: golden-yellow above, yellowish-green below, which turns bluish with age, and darker in winter.
'Lutea'	Columnar tree up to 10-12 m tall, grows slowly, with a narrow crown. Shoots are yellowish. Foliage is short, bright yellow, darkens in winter.
'Nana Albospica'	Dwarf form, reaching 0.7-0.8 m in 10 years. Young shoots and foliage are short and white, forming a conical crown. With age, foliage turns pale green.
'Monumental'	Columnar tree up to 10 m tall. Shoots are bluish with reddish tips. Foliage is bluish-clear reddish.
'Rogersii'	Pyramidal tree up to 2 m tall, with rounded top. Foliage is thread-like, shiny, with a blue tint. Similar in color to *Ch.l. 'Allumii'*, but less intense.
'Stewartii'	Pyramidal form up to 10 m tall. Crown width up to 3 m, with branches growing at a sharp angle to the trunk. Foliage is golden-yellow.

Table 2, Continued

Cultivar	Short description
'Triomf von Boskoop'	Pyramidal tree up to 15 m tall, dense crown with branches growing at a sharp angle. Branch tips and shoots droop. Foliage is blue-green, turning silver-gray with age.

Source: developed by the authors based on A.C. Fiordi & E. Maugini (1977), D.B. Zobel & G.M. Hawk (1980), A. Nagao *et al*. (2019), J.H. Kitzmiller & R.A. Sniezko (2021)

Chamaecyparis obtusa – a tree up to 30 m in height, with a dense, broad, conical crown shape. The bark of the trunk is reddish-brown, smooth, while the bark of one-year-old shoots is bright green. The leaves are scale-like, blunt, tightly pressed to the shoot, and light green in color. The microstrobili are thick, slightly elongated. The mature megastrobili are spherical, up to 1 cm in diameter. The seeds are small with narrow wings. The natural range is in the mountains of Japan (at altitudes of 600-1500 m above sea level). Cultivated in Ukraine since 1878, though found in only a few botanical gardens (Table 3).

Table 3. Brief characteristics of cultivars of *Chamaecyparis obtusa*

Cultivar	Short description
'Aurea'	Pyramidal form reaching up to 5 meters in height. The branches have a yellow tint, and the foliage is golden-yellow.
'Coralliformis'	A low, slow-growing shrub-like form with a rounded or spreading crown, up to 0.5 meters in height. The foliage is arranged in thread-like clusters that are twisted. The foliage is bluish-green.
'Crippsii'	A pyramidal form with a wide base, of medium size. The tips of the branches are bright golden-yellow, turning yellowish-green over time.
'Nana Aurea'	A bush-like form reaching up to 2 meters in height, characterised by yellowish light-green foliage.
'Nana Gracilis'	A low, spreading, slow-growing form (up to 2 meters), reaching 0.6-0.7 meters in 10 years. The crown is pyramidal with a wide base. The foliage is beautiful, glossy, light green, arranged in shell-like clusters.
'Tsatsumi Gold'	A shrub-like form reaching up to 1 meter in height, with an irregular crown and golden-colored foliage.

Source: developed by the authors based on J.A. Hart & R.A. Price (1990), Y. Osone et al. (2020), D.B. Kang (2021), H. Kato-Noguchi *et al*. (2024)

Chameacyparis pisifera – a tree reaching up to 30 meters in height, with a broadly conical, airy crown. The bark of the trunk is reddish-brown or dark brown, longitudinally cracked even in young trees. The bark of one-year-old shoots is yellow-green, and of two-year-old shoots is light brown. The foliage is dark green on top and whitish underneath, arranged in a single plane on the shoots. The microstrobili are small, somewhat elongated, about 2 mm long. During the pollen maturation, the megastrobili are green, small, nearly spherical, up to 3 mm in diameter. Mature megastrobili are numerous, small, on short pedicels, spherical, 6-8 mm in diameter, yellowish-brown or dark brown, and mature in the first year. The seed scales are 8-10 (12), soft, non-woody, thin, stretched in width, concave at maturity, wrinkled at the top, slightly pointed, with notched edges. Seeds are 1-2 per scale; the wing is thin, transparent, very wide, with 5-6 resin glands on each side. Natural range: Japan. Grows primarily on moist soils. It grows well and reproduces abundantly (Table 4).

Table 4. Brief characteristics of cultivars of *Chamaecyparis pisifera*

Cultivar	Short description
'Aurea'	Typical habit, yellow-golden branches and foliage, which becomes yellowish-green with age or in shade.
'Aurea Nana'	Similar to the previous cultivar, but shorter and more compact.
'Boulevard'	Medium-sized tree (about 5 m in height and 3 m in crown diameter). The crown is pyramidal with a regular shape.
'Sungold'	Compact, similar to *Ch.p.* 'Filifera Aurea'. Reaches 1.5 m in 10 years.
'Squarrosa Sulphurea'	Similar to *Ch.p.* 'Squarrosa', but of medium size (reaches about 1 m in height and 0.7 m in crown width in 10 years). The crown is dense and conical.
'Squarrosa Minima'	Similar to *Ch.p.* 'Squarrosa', but with more compact dimensions.
'Squarrosa Dumosa'	Bushy, compact form reaching 1.5-2 m in height. The crown is dense with short branches. The foliage is grayish-green, changing to a bronze tint in winter.
'Squarrosa'	Wide-pyramidal dense crown with drooping branch tips. Juvenile blue-gray foliage.
'Plumosa Aurea'	Tree up to 12 m tall with a conical crown about 3 m wide. The foliage is matte yellow-golden, and young shoots are light yellow.
'Plumosa'	ree of typical size with a pyramidal crown. The shoots are compressed and threadlike. The foliage is semi-juvenile, transitional, longer and larger than the typical type, green in color, with a bronze tint in winter.
'Filifera'	Widely pyramidal form with a wide base crown, about 5 m tall. The distinguishing feature is the threadlike shoots of the last order and gray-green foliage.
'Filifera Nana'	Similar to *Ch. pisifera* 'Filifera', about 1 m in height.
'Filifera Aurea'	Widely pyramidal tree, reaching 0.9-1.0 m in height in 10 years. The branches and foliage are yellow-golden, drooping in a threadlike manner.

Source: developed by the authors based on C.F. Li *et al*. (2015), A. Nagao *et al*. (2019)

Of the five existing species of the *Chamaecyparis* Spach genus, three species are cultivated in the conditions of Kyiv. *Chamaecyparis formosensis* Matsum. and *Chamaecyparis thyoides* (L.) Britton, Sterns & Poggenb have not yet been encountered in any of the collections. The known number of cultivars worldwide exceeds several hundred. Based on this, the potential for incorporating new taxa into the collections has significant prospects.

Botanical gardens are central to plant introduction. The role of their collection plantings, especially at universities, is crucial, providing an indispensable foundation for students' practical training and specialised education. Beyond their educational function, plant collections, like other urban green spaces, are vital for ensuring the sustainable development of modern cities, promoting the stability and ecological efficiency of green infrastructure in anthropogenic environments. Over years of operation, these gardens have amassed unique plant collections, accumulated cultivation expertise, and explored prospects for introducing or breeding new varieties. Notably, Japan, the homeland of *Chamaecyparis obtusa* and *Chamaecyparis pisifera*, holds deep cultural and gardening traditions for these plants. Many traditional Japanese gardens feature ancient specimens and diverse forms of false cypress. In a foundational study by D. Hoshino *et al.* (2001), the authors investigated the age, size structure, and spatial distribution of dominant tree species in an old-growth *Chamaecyparis* obtusa forest in central Japan. Their findings highlighted the ecological significance and longevity of these trees, as well as their ability to form stable forest communities over centuries. These results underline the importance of long-term conservation and structured spatial planning when cultivating *Chamaecyparis* taxa in managed environments such as botanical gardens.

Limited attention has been given to studying the taxonomic composition of collections and the intraspecific diversity of the genus *Chamaecyparis* in Ukrainian botanical collections. A thorough study on *Chamaecyparis* representatives under introduction conditions in Ukraine was conducted by T.A. Reshetnyak (1980), who listed 51 cultivars. This work focused on the systematics, geographic distribution, and ecological-biological features of *Chamaecyparis*, outlining its introduction potential and proposing practical applications for landscape use. T.A. Reshetnyak provided one of the earliest structured overviews of cultivar diversity in the Ukrainian context. S.I. Kuznetsov (2015), in his work on the phenofund of *Pinophyta* in Ukraine at the beginning of the 21st century, noted that the number of cultivars and forms had reached 64 taxa by 2015. His analysis marked an important update in the taxonomic structure and composition of dendrological collections, tracking changes in assortment dynamics and highlighting the expansion trends across institutional plantings during the post-Soviet period. Research by N.S. Boiko (2023) on Ukrainian dendrological collections indicated the presence of 3 species of the genus *Chamaecyparis* and 110 cultivars, specifically: *Chamaecyparis lawsoniana* (62 cultivars), *Chamaecyparis obtusa* (15 cultivars), and *Chamaecyparis pisifera* (33 cultivars). This work provided a systematised inventory of gymnosperm accessions across leading Ukrainian botanical institutions, with a focus on taxonomic verification, cultivar diversity, and the institutional challenges of maintaining large-scale living collections. The author highlighted Kyiv's botanical centres as the most complete and dynamically developing, due to their established research infrastructure and ongoing accessioning of new decorative forms. These figures demonstrate a continuous increase in the assortment and quantity of plants in the collections of Kyiv's botanical institutions.

The latest published inventory of the botanical garden collection at the National University of Life and Environmental Sciences of Ukraine indicates that as of 2010, 9 cultivars and 2 species (*Chamaecyparis pisifera* and *Chamaecyparis lawsoniana*) were recorded by O.V. Kolesnichenko *et al.* (2010). The catalog compiled by O.V. Kolesnichenko *et al.* systematised the dendrological diversity of the garden and highlighted the stable presence of *Chamaecyparis* taxa within the broader arboreal collection. The work served as a reference point for tracking long-term changes in species composition and maintenance practices. Current research conducted in 2025 revealed that the quantitative indicators of cultivars and species on the garden's territory remained unchanged, though many young plants were observed being planted to maintain the collection in satisfactory condition. An analysis of the published catalog of the O.V. Fomin Botanical Garden collection at Taras Shevchenko National University of Kyiv by Z.H. Boniuk & R.M. Palagechi (2023) indicated the presence of 3 species and 20 cultivars in the collection, which aligns with the results of our surveys in 2025. The guidebook-reference edited by Z.H. Boniuk & R.M. Palagechi provided a detailed overview of the taxonomic diversity and distribution of woody plants within the garden, offering structured data on the introduction history, ecological preferences, and decorative characteristics of *Chamaecyparis* taxa. The inclusion of cultivar-specific information enabled direct comparison with current field observations and confirmed the long-term stability of the collection.

In the catalog of the M.M. Gryshko National Botanical Garden's collection, N. Kokhno (1987) noted that in 1987, 2 species and 18 taxa grew on the garden's territory, primarily in the arboretum and on the "Vydubychi Slope" section Subsequent research has determined that with the gradual development and opening of new expositional and botanical-ethnographic sections, such as "Decorative Forms of Woody Plants" and "Japanese Garden", the collection has significantly expanded. As of 2025, it comprises 3 species and 24 cultivars. In addition to *Chamaecyparis pisifera* and *Chamaecyparis lawsoniana*, specimens of *Chamaecyparis obtusa* have appeared in the collection, and 6 new cultivars have been added. Traditionally, *Chamaecyparis* representatives in Ukraine are considered less frost-resistant. However, based on observations and experience from maintaining collection plantings in botanical institutions from 2022-2025, the primary limiting factor is considered to be their demand for moisture regimes, particularly air humidity. In total, 41 cultivars have been described in the study of Kyiv's collection plantings, whereas N.S. Boiko (2023) indicated that over 100 cultivars are cultivated in Ukraine. The studied collection plantings feature cultivars of various habits, colors, and needle types, with a significant proportion of plants over 50 years old, demonstrating their high adaptive capacity to local climatic conditions.

Due to their high decorative qualities and diverse morphometric characteristics, species and cultivars of the genus *Chamaecyparis* can be widely used in creating landscape compositions. Globally, *Chamaecyparis* representatives are widely cultivated. As noted, Japan stands out as the homeland of *Chamaecyparis obtusa* and *Chamaecyparis pisifera*, where these plants have deep cultural and gardening traditions. In Europe, *Chamaecyparis* were introduced and also became very popular in ornamental horticulture, and extensive collections exist (Cedro *et al*., 2021). In the plantings of Kyiv's botanical gardens, group plantings, solitaires, alley plantings, and topiary forms are encountered. Although cultivars are in highest demand, *Chamaecyparis lawsoniana* and *Chamaecyparis pisifera* are the most widespread species in plantings. Representatives of the genus *Chamaecyparis* have gained widespread distribution in ornamental horticulture. Ukrainian researchers S.I. Kuznetsov *et al.* (2020) have repeatedly highlighted the possibilities for their extensive use in Kyiv's greening efforts, particularly in their 2020 work on selecting tree, shrub, and liana assortments for landscape construction in Ukraine. Enriching the taxonomic composition of ornamental plantings with new decorative plant species and forms is one of the important ways to improve the state of urban greening. The results of many years of testing introduced plants demonstrate the possibility of expanding the plant assortment for modern landscape construction.

The conducted research confirmed the stable presence and diversity of *Chamaecyparis* taxa within the *ex situ* collections of Kyiv's leading botanical institutions. A comprehensive analysis of current inventories, archival sources, and field data made it possible to determine not only the taxonomic composition and representation of species and cultivars but also to assess their adaptive responses under local urban conditions. The evaluation revealed both long-term successful specimens and those showing signs of stress, particularly under climate-induced extremes such as the 2024 summer heatwave. The comparative review of collections across the three gardens demonstrated significant interinstitutional variability in species composition, age structure, and cultivar diversity, yet collectively they present a substantial foundation for future introduction and selection programmes. The observed vitality, longevity, and decorative traits of numerous specimens confirm their potential suitability for broader application in urban landscaping. These findings reinforce the role of botanical gardens as both centres of ornamental plant conservation and active contributors to sustainable green infrastructure development in metropolitan environments.

Conclusions

During the course of the scientific research, the taxonomic composition of the collection of species and cultivars of the *Chamaecyparis* Spach genus in the botanical gardens of Kyiv was analysed. It was determined that the largest collection is housed in the M.M. Gryshko National Botanical Garden, where *Chamaecyparis pisifera* Sieb. et Zucc. is represented with 8 cultivars, *Chamaecyparis obtusa* Sieb. et Zucc. with 5 cultivars, and *Chamaecyparis lawsoniana* Parl. with 11 cultivars. In total, 37 cultivars were found in the botanical collections of Kyiv, with the highest number of taxa noted in *Chamaecyparis lawsoniana* – 18 cultivars, the lowest in *Chamaecyparis obtusa* – 16 cultivars, and *Chamaecyparis pisifera* represented by 13 cultivars. These data may slightly vary due to a number of objective reasons, such as the addition of new cultivars to the collection, plant losses, etc. A brief description of the morphometric and biological characteristics encountered during the research is provided. The intraspecific diversity of the *Chamaecyparis* Spach genus is vast, with a wide variety of cultivars, both with a typical habitus of the original species and with dwarf, compact crown sizes. The cultivars also vary in type, color, and seasonal coloration of the foliage.

Although the species of the *Chamaecyparis* Spach genus have relatively small natural ranges, due to their characteristics, particularly their ornamental qualities, they have gained widespread use in ornamental horticulture. The large intraspecific diversity of *Chamaecyparis* Spach species worldwide means that only a relatively small portion of the total number of cultivars has been collected in the botanical institutions, so there is enormous potential for the addition of new taxa. Further expansion and enrichment of the collections, including the introduction of new taxa, remains an important objective. In the future, based on continued observations and analysis of the plant condition within these collections, it will be possible to identify the most promising cultivars for widespread use in urban landscaping, selection of species suitable for container planting, and assessment of their potential for shaping topiary forms.

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Представники роду *Chamaecyparis* Spach у колекціях ботанічних садів міста Києва

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Анотація. Представники роду *Chamaecyparis* Spach, попри обмежене використання в озелененні Києва через уявну примхливість, активно представлені в ботанічних колекціях міста та цінуються завдяки різноманіттю культиварів із декоративними ознаками. Метою досліджень була оцінка існуючого різноманіття видів та культиварів в колекціях ботанічних установ м. Київ. Проаналізовано колекційний фонд представників роду *Chamaecyparis* Spach у Національному ботанічному саду (НБС) імені М.М. Гришка НАН України, ботанічному саду імені академіка О.В. Фоміна Київського національного університету імені Тараса Шевченка та ботанічному саду Національного університету біоресурсів і природокористування України. Визначено, що найбільша колекція зібрана в НБС імені М.М. Гришка, де представлені *Chameacyparis pisifera* (Siebold & Zucc.) Endl. та 8 культиварів, *Chameacyparis obtuse* (Siebold & Zucc.) Endl. та 5 культиварів, *Chameacyparis lawsoniana* (A. Murray bis) Parl. та 11 культиварів. Загалом в ботанічних колекціях м. Києва виявлено 37 культиварів, зокрема найбільша кількість таксонів відмічена у *Chameacyparis lawsoniana* – 18 культиварів, найменша – *Chameacyparis obtuse* – 16 культиварів, *Chameacyparis pisifera* представлений 13 культиварами. Подано стислу характеристику видів та культиварів, що представлені в колекціях, описаний сучасний стан колекційних насаджень та розглянуто перспективи поповнення колекцій новими таксонами. Встановлено, що колекційні насадження дозволяють аналізувати рівень адаптації культиварів до місцевих кліматичних умов, репрезентують різновікові екземпляри та їх фізіологічний стан залежно від віку, походження та умов догляду. Асортимент рослин наявних в колекціях, зокрема віком понад 50 років, свідчив про достатню стійкість більшості культиварів та видових рослин до несприятливих чинників та можуть бути більш широко вкористані для озеленення в міських умовах. Результати дослідження можна використати для розширення асортименту декоративних хвойних рослин у міському озелененні шляхом впровадження перспективних культиварів *Chamaecyparis* Spach, адаптованих до умов Києва

Ключові слова: вид; культивар; асортимент; хвоїні рослини; коніферетум; дендрарій

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Structure and utilisation of forest resource potential of Scots Pine stands in the Volyn Polissya

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Abstract. The relevance of the research was driven by the necessity for the rational use of the forest resource potential of Scots pine stands in the Volyn Polissya, one of the most forested regions of Ukraine with significant ecological, economic, and social importance. The aim of the study was to examine the stand structure and analyse the utilisation of Scots pine stands in the Volyn Polissya, as well as to explore ways to optimise forest management processes in the region. A comprehensive analysis of the spatial and age structure, as well as the productivity of Scots pine stands in the Volyn Polissya region, was carried out, with an assessment of timber stock utilisation by type of felling. It was found that approximately 64% of forested areas in the study region were covered by Scots pine stands. Artificial pine stands prevailed in terms of area, accounting for over 52%. The most widespread were middle-aged stands, which could be explained by active post-war forest regeneration. The majority of pine stands grew in fresh and moist subor forests, which were optimal for the species' development. The average annual volume of Scots pine timber harvested by forest enterprises in the region amounted to 1.9 million m^3, with the majority obtained through principal fellings and sanitary cuttings. Among thinnings, a significant share of timber harvesting came from commercial thinning (age of 41-70). The proportion of other types of felling, both related and unrelated to forest management, ranged from 1 to 2%. The average volume of harvested Scots pine

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timber per hectare ranged from 2 m^3 ha^{-1} for pre-commercial thinning (age of 11-20) to 173 m^3 ha^{-1} for principal fellings. The results of the study may be used to improve forest management practices and to formulate a strategy for the sustainable development of forestry in the Volyn Polissya

Keywords: forest inventory indicators; age structure; forest cover; standing volume; timber harvesting

Introduction

Effective forest resource management, which should ensure ecological balance and economic stability in the forestry sector, required thorough planning of forestry operations. This, in turn, was impossible without up-to-date and reliable information on forest resource availability and the extent of its utilisation. Given the current challenges related to climate change, anthropogenic pressure, and the adaptation of national forest policy to pan-European standards, there was a need for a detailed understanding of the structural characteristics, dynamics, and utilisation of the forest resource potential of forest stands.

The territory of Ukraine was divided into four natural zones – Polissya, Forest-Steppe, Northern and Southern Steppe, two mountain regions – the Ukrainian Carpathians and the Crimean Mountains. In their study, I. Ivaniuk *et al*. (2020) noted that Polissya, as one of the largest natural zones in terms of area, was also among the most forested regions. It hosted the largest forest area in the country – 42.2% – and thus the stands of the region had a significant influence not only on Ukraine's climate but also on that of the whole of Eastern Europe. The researchers also established the phytomass density and carbon sequestration capacity of the region's forests, as well as analysed their bioproductivity. V. Myroniuk *et al*. (2024) conducted a comprehensive assessment of Ukraine's forests, combining field data collection on inventory plots with statistical evaluation, remote sensing, and modelling. It was found that among forest vegetation zones, Polissya ranked second in terms of forest cover, behind only the Carpathians – about 40% and over 50% respectively. The state of forest ecosystems in Western Polissya and the impact of climate change on forest growth and development were analysed by V. Yanitskyi (2024). It was noted that rising average air temperatures, an increase in the number of warm months per year, and moisture deficits were disrupting the ecological balance in forest ecosystems, increasing damage from pests and diseases, as well as raising the number of forest fires. Based on its physical and geographical characteristics, Ukrainian Polissya was divided into several regions, one of which was the Volyn Polissya. This natural region of Polissya was located between the Western Bug and Sluch rivers and occupied most of the Volyn Region, as well as the north-western part of the Rivne Region. The area lay within the western slope of the Ukrainian Shield and the Volyn-Podillia Monocline. It was characterised by the wide presence of glacial and karst landforms, valley landscapes, wetlands, and a considerable number of lakes (more than 200) (Netrobchuk *et al.*, 2021).

The Volyn Polissya belonged to the physical-geographical regions with one of the highest forest cover percentages in Ukraine. Therefore, forests in this area played extremely important roles. The total area of forest lands in the Volyn Polissya zone exceeded 1.4 million hectares, of which around 73% were classified as commercial forests. Forested areas covered over 1.2 million hectares (approximately 85% of total forest land area). The study region was part of the mixed forest zone, where various coniferous and deciduous species grew. However, the dominant species over most of the area was Scots pine (Fesiuk, 2024). A.M. Zhezhkun (2022) noted that the formation of existing pine stands in the Polissya territory was connected to silvicultural practices, particularly principal felling methods. The study analysed the formation patterns of pine stands, their structure, and overall sanitary condition. In research on pine forests, scholars rarely distinguished the Volyn Polissya as a separate region, which confirmed the relevance of the selected research topic. At the same time, the peculiarities of distribution and problems associated with the cultivation of Scots pine (*Pinus sylvestris*) had received significant scientific attention due to the predominance of pine among forest stands across Ukraine. S.B. Kovalevskii *et al*. (2022) assessed the growth dynamics and productivity of Scots pine stands growing on soils with outcrops of crystalline parent rocks in Central Polissya. They confirmed the feasibility of establishing such stands on plots with varying depths of crystalline bedrock. In their study, V. Lavnyy *et al*. (2022) examined different methods for regenerating pine stands in Western Polissya. In particular, they analysed the effectiveness of natural regeneration of Scots pine through the application of various silvicultural measures, including thinning and principal felling. It was stated that proper planning of reforestation efforts significantly influenced the quality and resilience of the stands, as well as the productivity of forest stands in the region.

Research on forest protection and conservation had become increasingly relevant under global climate change conditions, accompanied by rising pest populations and the spread of forest diseases. In her study, V. Meshkova (2021) analysed factors contributing to the decline of Scots pine forests due to bark beetle infestation. In addition, an algorithm was developed for forecasting bark beetle outbreak centres, which could help improve pest management measures. Apart from the traditional timber-oriented perception of forest resource potential, the role of ecosystem services generated by forest stands, as part of the bioproductive process, was also important. The study by R. Vasylyshyn *et al*. (2023) on the primary productivity of forests in the Kyiv Region highlighted the region's significant potential for organic matter production and the performance of ecosystem functions. Particularly high levels of net primary productivity were recorded in hornbeam-oak forest types, indicating a close link between productivity, species composition, and age structure of forests.

Given the heavy dependence of the national economy on imported energy resources, forest stands had gained strategic importance for ensuring local energy security, serving as a vital source of renewable energy raw materials. The study by R. Vasylyshyn *et al*. (2022) analysed the annual biomass potential by major components (stemwood, logging and processing residues), considering the age structure of stands. This allowed for substantiating forest resource use directions within the context of transitioning to a low-carbon economy. At the same time, during the full-scale war launched by the Russian Federation against Ukraine, forest ecosystems had suffered significant disruptions, which greatly impacted the formation of their resource potential and their ability to perform ecosystem functions. A.D. Kuzyk & V.I. Tovarianskyi (2023) outlined the main factors of this impact and identified priority directions for post-war forest restoration, including demining, inventory, sanitary cuttings, and reforestation. Justifying the volume of forest use in line with the principles of sustainable forest management required analysis of many indicators, including the structure of forest stands. Therefore, the aim of this study was to assess the distribution of pine stands according to key inventory and silvicultural indicators and to analyse the volume of timber harvested from these stands through various types of felling.

Materials and Methods

The study adopted an analytical approach and was based on digital processing of statistical data on Scots pine stands linked to a specific territory – namely, the Polissya natural zone within the Volyn and Rivne regions. The spatial boundaries of the analysis covered the northern part of these regions, which, from a geobotanical perspective, corresponded to the mixed forest zone of Ukrainian Polissya. The research area included the following districts: Verkhnoprypiatskyi, Nyzhnostyrskyi, Liuboml-Kovel, Manevychi-Volodymyrets, Kolky-Sarny, Turiisk-Rozhyshche, Kivertsi-Tsuman, and Kostopil-Berezne.

The main sources of information were: 1) the relational database "Forest Inventory Characteristics" (RDB "FIC") (Ukrainian State Forest Management Planning Association, n.d.); 2) the Unified State Electronic Timber Accounting System (Timber Accounting System) (State Forest Resources Agency of Ukraine, n.d.b). Analytical reports were generated from the RDB "FIC" containing data on stand area and growing stock by the following silvicultural and mensurational indicators: age groups, site index classes, stocking density, and forest site types. Particular attention was given to the distribution of Scots pine stands by age groups (young, middle-aged, maturing, mature, and overmature stands). For this purpose, relevant data were extracted from the RDB "FIC", considering the area and growing stock for each group. Data filtering was performed based on the administrative affiliation of the forest compartments to the Volyn and Rivne regions, the Polissya natural zone, and the species composition of the main tree species – Scots pine. The data were structured as summary tables and further analysed graphically in Microsoft Excel.

To analyse the utilisation of the Scots pine resource potential, statistical data on timber harvesting volumes from the Timber Accounting System for the years 2023-2024 were used. These data included information on timber harvested by permanent forest users and owners of forests of various ownership forms and subordination, who conducted forestry activities within the Polissya natural zone of the above-mentioned regions. The following forest enterprises were included in the dataset: Volyn Military Forestry Enterprise; State Forestry Enterprise "Syaivo"; Agricultural and Water Management Cooperative "Selyanskyi Lis"; Agricultural Forestry Cooperative "Agrolis"; Agricultural Forestry Cooperative "Selyanskyi Lis"; Agricultural Forestry Joint Stock Company "Tur"; Agricultural Consumer Production Cooperative "Dibrova"; Agricultural Consumer Production Cooperative "Selyanskyi Lis"; Agricultural Consumer Service Cooperative "Kuzmivskyi"; Farm "Amila"; State Enterprise (SE) "Forests of Ukraine" (Berezne Forestry Branch, Vysotsk Forestry Branch, Volodymyr-Volynskyi Forest Hunting Branch, Horodok Forestry Branch, Dubno Forestry Branch, Kamin-Kashyrskyi Forestry Branch, Kivertsi Forestry Branch, Klesiv Forestry Branch, Kovel Forestry Branch, Kolky Forestry Branch, Kostopil Forestry Branch, Liubeshiv Forest Hunting Branch, Liuboml Forestry Branch, Manevychi Forestry Branch, Ratne Forest Hunting Branch, Rafalivka Forestry Branch, Rokytne Forestry Branch, Sarny Forestry Branch, Sosnivka Forestry Branch); and Shatsk National Nature Park (NNP). Additional filtering by species was performed to allow for the selection and analysis of data relating exclusively to Scots pine timber harvesting. The data were retrieved from the extended reporting module, applying filters for:

- types of felling: principal felling (clear-cutting), sanitary felling (clear and selective sanitary fellings), tending felling (pre-commercial and commercial thinning), and other types of felling (clearing for power lines, protective zone clearance, border strip felling, etc.);
- types and classes of timber quality: commercial timber (Class A, B, C, D), fuelwood for industrial use (IU), fuelwood for non-industrial use (NIU), and long-length logs.

The analytical processing of the data involved methods of comparative analysis, data structuring and normalisation, and calculation of specific indicators (e.g., average growing stock per hectare). All reports were harmonised in terms of measurement units and brought into a unified structure to enable accurate comparison.

Results and Discussion

According to the analysis of the database of the Ukrainian State Forest Management Planning Association (n.d.), it was established that artificially regenerated Scots pine stands predominated in the study region, comprising 52% of all Scots pine stands by area. Overall, Scots pine grew on 64% of forest-covered land areas. It should be noted that despite the prevalence of artificial forest regeneration methods in recent decades, naturally regenerated Scots pine stands accounted for approximately 48%, which was considered a positive factor in the context of climate change. Natural forests are known to demonstrate greater adaptability to environmental changes and higher resistance to pests and pathogens (Maurer & Kaidyk, 2016; Guegan *et al.*, 2023).

At the same time, it was important to consider that the higher area of artificially regenerated pine stands compared to naturally regenerated ones was due to several factors, including the relative simplicity of reforestation methods and the higher productivity of artificial stands. Other tree species that covered significant areas in the Volyn Polissya included: alder (15%), birch (13%), and oak (6%).

Scots pine was recognised for its ecological adaptability to various site conditions and was present in almost all edaphic types, while exhibiting different growth vigour and productivity depending on those conditions. The distribution of Scots pine stands in the study region by soil nutrient conditions was as follows:

- bory (A) – 27%;
- subory (B) – 64%;
- sugrudy (C) – 9%;
- grudy (D) – less than 0.1%.

By soil moisture conditions, the distribution of Scots pine stand areas was:

- dry and very dry (0-1) – 5%;
- fresh (2) – 44%;
- moist (3) – 37%;
- wet (4) – 10%;
- waterlogged (5) – 4%.

The largest areas among all forest lands covered with forest vegetation were occupied by pine stands growing in moist subory (Fig. 1). A significant share was also occupied by fresh subory, which accounted for nearly one quarter of the total area of Scots pine stands. Fresh and moist subory created favourable conditions for the development of Scots pine, as they contributed both to its intensive growth and natural regeneration, while also ensuring the formation of high-quality timber suitable for commercial use. Over 26% of Scots pine stands grew under bory conditions, and up to 1% in grudy conditions. In sugrudy conditions, where up to 9% of pine stands were located, in productive years and in the absence of significant grass cover, it was considered appropriate to prioritise natural regeneration of pine following felling in January-February as the primary method of reforestation.

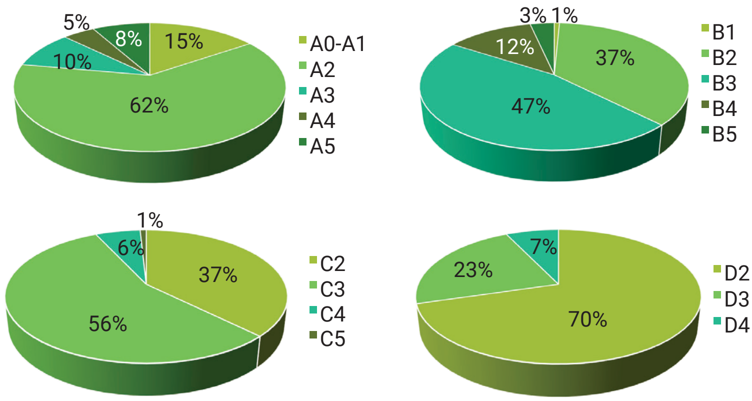

Figure 1. Distribution of Scots pine stand area by forest site type

Note: A0-A1 – very dry and dry bory, A2 – fresh bory, A3 – moist bory, A4 – wet bory, A5 – waterlogged bory, B1 – dry subory, B2 – fresh subory, B3 – moist subory, B4 – wet subory, B5 – waterlogged subory, C2 – fresh sugrudy, C3 – moist sugrudy, C4 – wet sugrudy, C5 – waterlogged sugrudy, D2 – fresh grudy, D3 – moist grudy, D4 – wet grudy

Source: compiled by the authors based on data from the Ukrainian State Forest Management Planning Association (n.d.)

In wet and waterlogged site conditions, Scots pine did not demonstrate intensive growth or high timber quality. Nevertheless, pine-dominated stands in such conditions accounted for 14% of the total forested land area. This indicated the need to reconsider the appropriateness of growing pine in these conditions and to explore opportunities for replacing such stands with more hygrophilous species such as alder. In these site conditions, alder as a dominant species ensured not only greater productivity and biological resilience of the stands but also enhanced forest ecosystem services (Lakyda *et al.*, 2019; Borsukevych, 2024).

According to Ukrainian State Forest Management Planning Association (n.d.), over 47% of the total pine stand area and more than 54% of the total growing stock within the Volyn Polissya region fell within the middle-aged group (Fig. 2). Other age groups were less represented in terms of both area and volume.

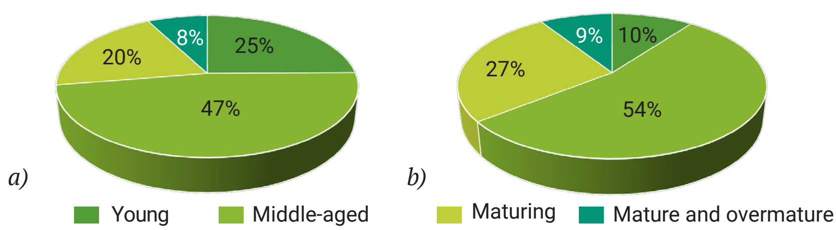

Figure 2. Distribution of pine stands by age group

Note: a) area distribution, b) growing stock

Source: compiled by the authors based on data from Ukrainian State Forest Management Planning Association (n.d.)

The predominance of middle-aged stands could be attributed to the widespread establishment of artificial Scots pine stands in the post-war period across Ukraine, including in the Volyn Polissya region, which provided particularly favourable conditions for Scots pine growth. Analysis of the data from Ukrainian State Forest Management Planning Association (n.d.) revealed that the average age of Scots pine stands was 53 years. The age structure distribution (Fig. 2) indicated an imbalance in stand composition by age group, which could lead to various complications in forest management due to the long production cycle. Additionally, disparities in the dynamics of average growing stock per hectare across different age groups were observed. The average growing stock in mature stands was 261 m^3 ha^{-1}, in overmature stands – 188 m^3 ha^{-1}, and in maturing stands – 292 m^3 ha^{-1}. The average stock for middle-aged stands, which occupied the largest area, was 250 m^3 ha^{-1}, while young stands had 90 m^3 ha^{-1}. The overall average growing stock of Scots pine stands in Volyn Polissya was 219 m^3 ha^{-1}. The average stocking density of Scots pine stands in the region was 0.73. The largest area was covered by stands with stocking densities of 0.7-0.8, making up around 70% of the total forested land. The diversity of pine stands across different site types resulted in varying productivity. Pine stands in the study region were classified into a range of site index classes, from I^d to V^a (Fig. 3).

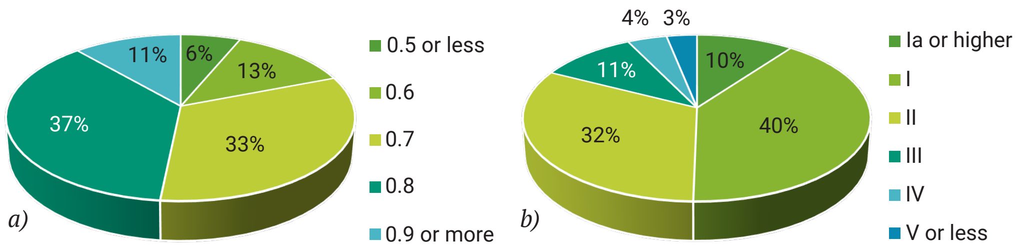

Figure 3. Area distribution of Scots pine stands
Note: a) by stocking density, b) by site index class
Source: compiled by the authors based on data from Ukrainian State Forest Management Planning Association (n.d.)

On over 92% of forested land, Scots pine stands belonged to site index classes I^a-III. Lower site index classes (IV and below) accounted for up to 8% of the area. The average site index class was I,7. Notably, over 98% of the total pine stand area was composed of high- and medium-density stands, which were nearly equally represented (48% and 50%, respectively). A significant portion of the total growing stock belonged to stands of site index classes I-III. The highest average growing stock per hectare was observed in stands of site class I^b – 340 m^3 ha^{-1}. The average growing stock for site classes I, II, and III was 241, 188, and 136 m^3 ha^{-1}, respectively.

Within the overall forest production accounting system, electronic timber tracking played an important role by enabling continuous monitoring of timber flows and preventing illegal logging (Mulyk *et al.*, 2024). Electronic timber accounting begins with the registration of timber directly at the logging sites (Order of the Ministry of Environmental Protection and Natural Resources of Ukraine No. 621, 2021). Analysis of data from the Unified State System of Electronic Timber Accounting (hereinafter – ETAS) for 2023-2024 revealed that approximately 1.9 million m^3 of Scots pine timber were harvested annually in the forests of Volyn Polissya. Nearly 80% of this volume, from both forest enterprises and other forest owners operating in the region, originated from sanitary fellings and principal fellings. Specifically, 1.45 million m^3 came from principal fellings and 1.51 million m^3 from sanitary fellings during the specified period (State Forest Resources Agency of Ukraine, n.d.b) (Fig. 4).

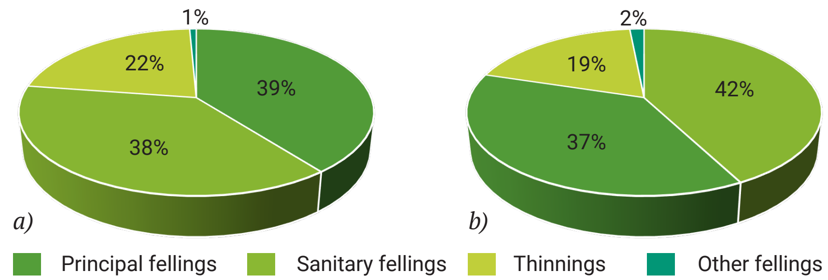

Figure 4. Distribution of pine timber harvesting volumes by felling type
Note: a) 2023 felling, b) 2024 felling
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

The significant share of sanitary fellings (38% in 2023 and 42% in 2024) indicated an unsatisfactory sanitary condition of pine stands in the region. In this context, the importance of natural regeneration and mixed stand formation was growing. Other types of fellings accounted for only 1-2% of total pine timber harvesting. These included maintenance of protected and infrastructure zones, forest road construction, and other silvicultural and forest health activities.

An analysis of average Scots pine timber harvested per hectare showed an overall increase in felling intensity in 2024 compared to 2023. On average, 33 m^3 ha^{-1} of Scots pine timber were harvested in 2023, increasing to 37 m^3 ha^{-1} in 2024. The highest average yield was recorded for principal fellings (clear-cut), which increased from 170 m^3 ha^{-1} to 173 m^3 ha^{-1}. Moreover, the total volume and average intensity of clear sanitary fellings also increased: from 136 m^3 ha^{-1} in 2023 to 161 m^3 ha^{-1} in 2024 (Fig. 5).

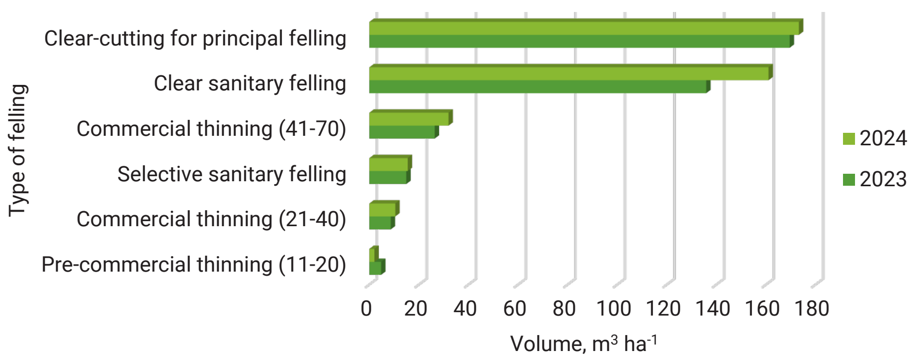

Figure 5. Average volume of Scots pine timber harvested by felling type
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

Among thinning operations, commercial thinning (age of 41-70) accounted for the largest share of harvested timber volume: 91% in 2023 and 88% in 2024 (Fig. 6). This confirms their key role in the harvesting of merchantable timber among thinning in Scots pine stands of the region, which is primarily determined by the age of the stands where they are conducted. However, there was a downward trend in harvested volumes from commercial thinning (age of 41-70) – a decrease of 55 thousand m³ in 2024 compared to 2023. At the same time, the volume of commercial thinning (age of 21-40) increased by 10 thousand m³, possibly reflecting a shift in silvicultural focus or resulting from the uneven age structure of pine stands. A decrease of over 3 thousand m³ from pre-commercial thinning (age of 11-20) might indicate a lack of merchantable timber. Furthermore, the absence of data on pre-commercial thinning (age of up 10) in ETAS could suggest that the resulting timber was non-marketable and therefore not recorded in official statistics.

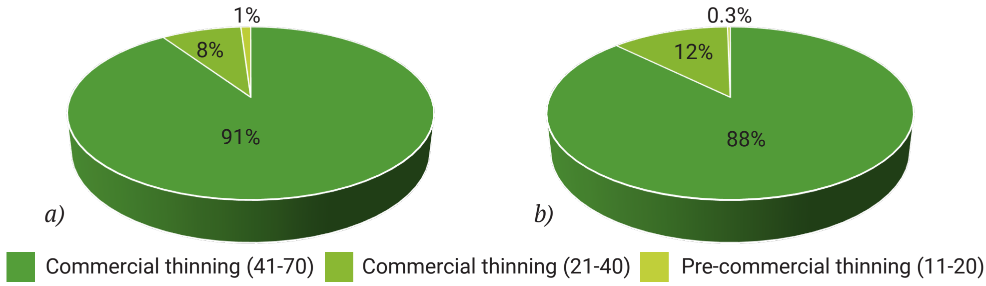

Figure 6. Distribution of Scots pine timber harvested from thinning operations
Note: a) 2023, b) 2024
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

Sanitary fellings represented one of the main sources of timber harvesting in Scots pine stands within the study area. In 2023, over 445 thousand m³ of Scots pine timber were harvested from selective sanitary fellings, compared to over 470 thousand m³ in 2024. A similar trend was observed for clear sanitary fellings: in 2024, their total volume reached 340.3 thousand m³ – an increase of 84.5 thousand m³ compared to 255.8 thousand m³ in 2023 (Fig. 7).

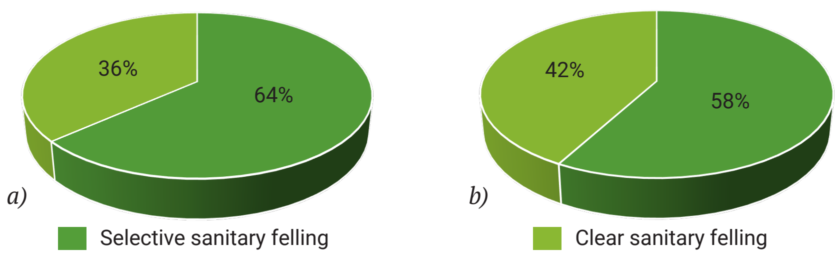

Figure 7. Distribution of Scots pine timber volumes from sanitary fellings
Note: a) 2023, b) 2024
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

Annual volume of principal fellings in the administrative territories of Volyn and Rivne regions exceeded 1.5 million m³. The distribution of the felling volume by forest types was as follows: coniferous – 64%, softwood deciduous – 28%, and hardwood deciduous – 8%. The actual volumes of timber harvesting within the Volyn Polissya during 2023-2024 indicated that over 1.1 million m³ of timber were harvested annually from principal fellings, with approximately 65% of this amount accounted for by Scots pine.

A notable fact was that only clear-cutting operations were conducted in the studied region during this period, with felling area widths ranging from 51 to 100 metres (Order of the State Committee of Forestry of Ukraine No. 364, 2009). Naturally, in flatland areas such as Volyn Polissya, this method remained predominant due to its organisational simplicity. However, considering the impacts of climate change, which posed significant challenges for forestry, it became necessary to integrate principles of ecologically oriented forestry into the forest management activities of enterprises. One of the core directions of this approach was the transition towards selective systems of harvesting (Yavorovskyi *et al.*, 2019). Thus, the implementation of new, more environmentally sound approaches to principal fellings appeared to be justified. Figures 8 and 9 present the total volume of pine timber harvested in the study region in 2023 and 2024, grouped by wood types (merchantable timber, fuelwood, long-length logs) and disaggregated by felling types. Analysis of these data demonstrated that the type of felling directly affected the quality composition of harvested timber. During the studied period, the average share of merchantable timber amounted to 60%. Over 3% of the harvested timber was recorded as long-length logs. To obtain a more detailed understanding of the utilisation of forest resources in the region, it was necessary to perform an additional analysis of all operations recorded in the ETAS related to this timber, particularly the bucking of long-length logs.

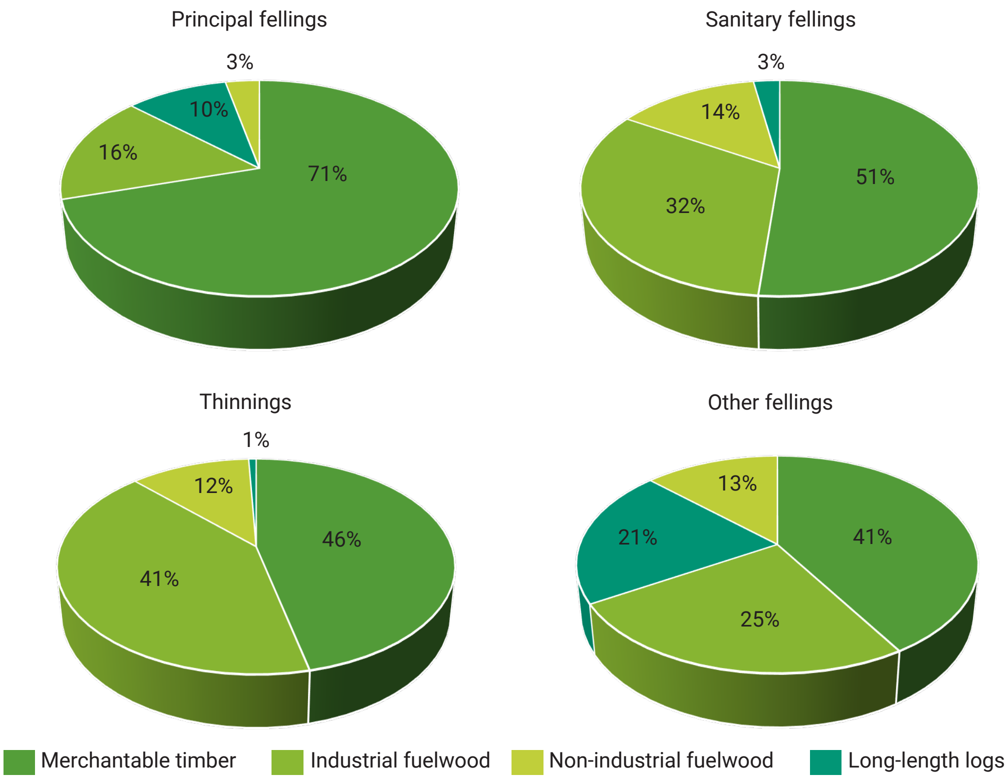

Figure 8. Distribution of pine timber volume by wood type, 2023

Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

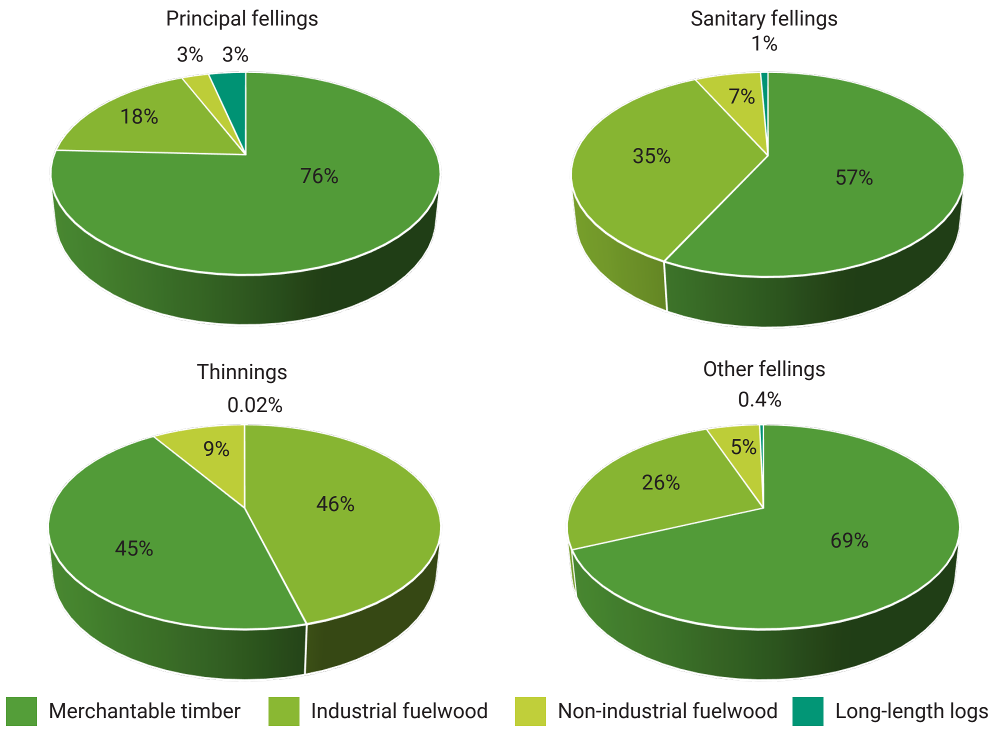

Figure 9. Distribution of pine timber volume by wood type, 2024

Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

The largest proportion of merchantable timber was obtained from principal fellings, amounting to 71% in 2023 and 76% in 2024. This indicated that principal fellings remained the main source of harvested merchantable timber. Sanitary fellings also contributed a significant amount of timber. Although the wood type distribution within these fellings was less optimal for commercial use, the share of merchantable timber remained considerable even in these operations, which were aimed at removing diseased and damaged trees. Specifically, in 2023 and 2024, the share of merchantable timber obtained from sanitary fellings was 51% and 57% respectively. As for thinning, they yielded the lowest amount of merchantable timber. Most of the timber from thinnings belonged to the fuelwood category, particularly for industrial use. Nonetheless, the share of merchantable timber during thinning remained notable – 46% in 2023 and 45% in 2024. This could be explained by the trends discussed above, especially the significant volumes of timber harvested from commercial thinning (age of 41-70), where the stands approached the age of technical maturity, making it possible to obtain merchantable timber even during care cuttings.

Figures 10 and 11 illustrate the distribution of pine merchantable timber by quality class in 2023 and 2024, taking into account the types of felling. As in the previous analysis by wood type, the quality of merchantable timber largely depended on the type of felling. Over the study period, the majority of pine merchantable timber belonged to quality class C, which averaged 60%.

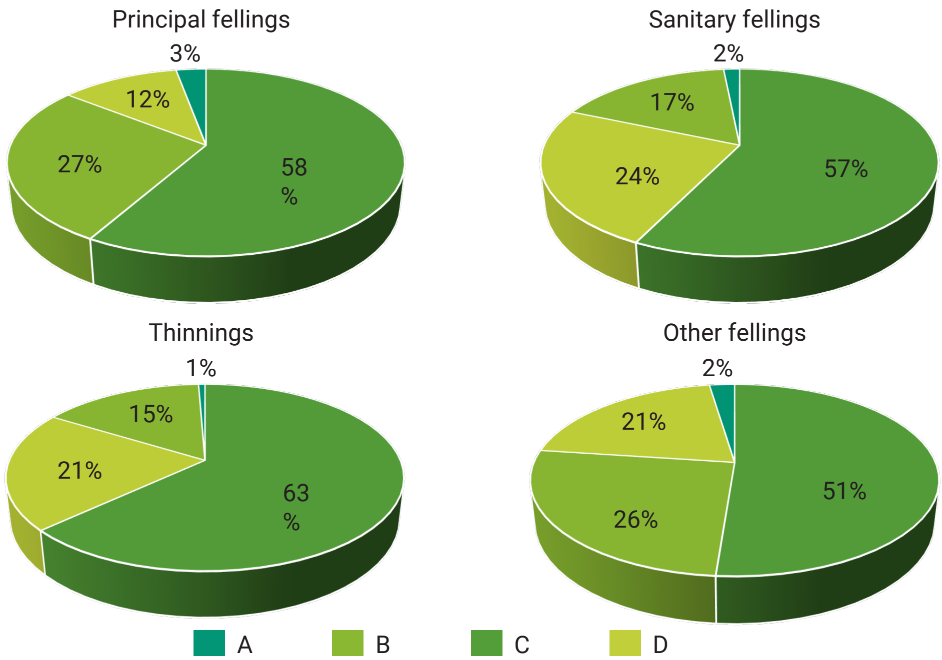

Figure 10. Distribution of pine merchantable timber by quality class, 2023
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

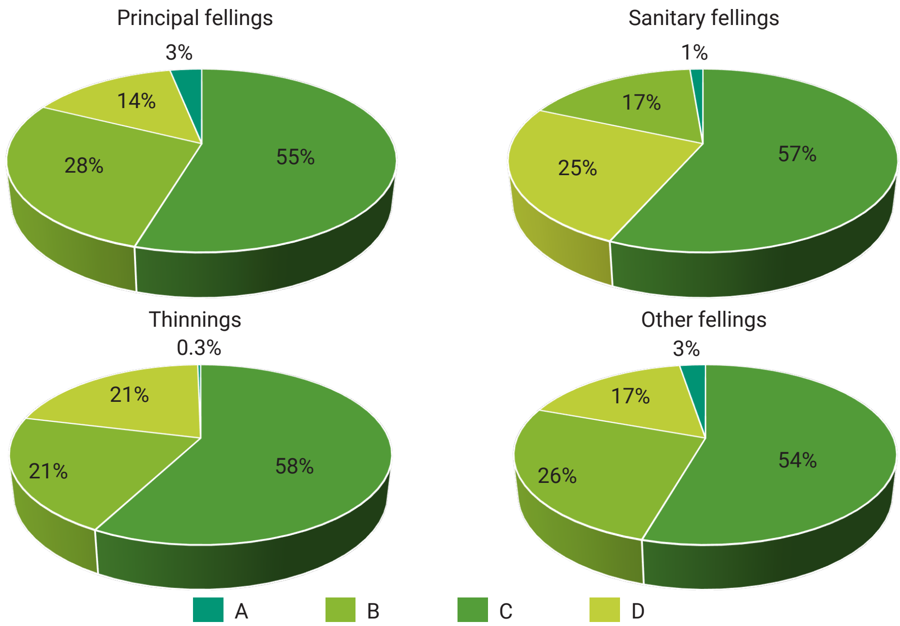

Figure 11. Distribution of pine merchantable timber by quality class, 2024
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

The share of the highest-quality merchantable timber (classes A and B) throughout the study period amounted to approximately 25%. The greatest amount of such timber was obtained from principal fellings, where their proportion reached 30% in 2023 and 31% in 2024. A relatively high proportion of premium-grade merchantable timber was also obtained from other types of felling, where classes A and B together accounted for up to 30%. Thinnings in the region yielded a significant amount of class C merchantable timber. The share of class D merchantable timber exhibited minor variations across different felling types during 2023 and 2024. In particular, in 2024, the volume of class D merchantable timber in other fellings decreased by 4%, possibly indicating an improvement in the quality of harvested timber. Within the overall structure of merchantable timber by quality class, the highest shares of lower-quality timber originated from thinnings and sanitary fellings.

According to the State Forest Resources Agency of Ukraine (n.d.a), the majority of Ukraine's forests were located in the Polissya and Ukrainian Carpathian regions, with around 33% covered predominantly by Scots pine. It was also reported that approximately half of all forests in Ukraine were of artificial origin, which required intensive management. These findings corresponded with the results of this study: in particular, it was established that Volyn Polissya accounted for over 13% of the country's forest area, and the forest cover of this region significantly exceeded the national average. A similar pattern was observed with regard to forest origin – artificially established forests comprised a considerable portion of the region's structure, aligning with national trends. However, in Volyn Polissya, the majority of forests were suitable for economic use: around 73% of forest land belonged to the category of exploitable forests. For comparison, only about 50% of forests nationwide were subject to limited-use regimes.

According to the State Forest Resources Agency of Ukraine (2024), middle-aged stands prevailed in Ukraine's age structure (47.5%), while the share of mature and overmature stands amounted to 18.7%, and the average forest age exceeded 60 years. At the same time, this study established that the average age of pine stands in Volyn Polissya was 53 years – slightly below the national figure. The share of middle-aged pine stands in this region exceeded 47% by area and 54% by growing stock, which closely corresponded to the nationwide structure. Regarding timber stock, the national average was approximately 235 m^3 ha^{-1}, whereas in Volyn Polissya's pine stands it amounted to 219 m^3 ha^{-1}. These results indicated a general similarity in the age structure and forest inventory characteristics between the regional and national levels, albeit with slightly lower productivity in the studied region.

Ukraine's Polissya is one of the most forested natural-geographical regions of the country, characterised by diverse site conditions and a subdivision into smaller ecological units. Therefore, it was appropriate to compare the findings of this study with similar research conducted in other parts of the Ukrainian Polissya. In particular, Y.Yu. Siruk *et al*. (2015) reported that in Central Polissya, pine occupied 59% of forest-covered areas, which was 5% lower than in the current study. Large areas were also covered by softwood deciduous species – alder and birch – and the share of oak in Central Polissya (16%) significantly exceeded that in Volyn Polissya (6%). The productivity of pine stands in Central Polissya ranged from site index class V, 2 under wet pine forest conditions (A5) to site index class Ia,3 in fresh loamy soils (C2). The majority of forested areas were found on fresh and moist subory and sugrudy. This suggested that the forest soils in Central Polissya were generally more fertile, while pine stand productivity was comparable, indicating favourable growing conditions for Scots pine in both regions.

The share of natural-origin pine forest plots in Eastern Polissya (which included Sumy and Chernihiv regions) amounted to approximately 20%, which was significantly lower than in Volyn Polissya (48%). In both regions, the largest pine areas were concentrated in moist subory, favouring high stand productivity – a significant share of forests grew under site index classes Ia-I (Lakyda & Matushevich, 2013). Notably, Volyn Polissya had a higher share of site index class II pine stands – around 32% compared to 12% in Eastern Polissya. High- and medium-density stands made up the vast majority of pine forests in both regions – exceeding 95%.

According to the State Statistics Service of Ukraine (n.d.), over 30 million cubic metres of timber were harvested in Ukraine during 2023-2024, of which 15.1 million cubic metres were Scots pine. Approximately 25% of this volume was attributed to the Volyn Polissya region. The share of merchantable timber in the total harvesting structure increased both in the research region and across Ukraine. At the same time, in Volyn Polissya this indicator significantly exceeded the national average: 58% compared to 44% in 2023, and 62% compared to 46% in 2024. The main sources of timber supply in Ukraine remained principal fellings and sanitary fellings. The proportion of principal fellings at the national level was higher than in Volyn Polissya: 43-44% versus 39-37% respectively in 2023-2024. Meanwhile, the share of sanitary fellings, accounting for about 40%, indicated issues with the sanitary condition of Ukraine's forests, particularly the Scots pine stands of the studied region.

According to the study by A.S. Torosov & I.N. Zhezhkun (2021), in 2019 among the administrative oblasts located within Ukrainian Polissya, the highest volumes of roundwood harvesting were recorded in Zhytomyr (17.4%), Kyiv (9.8%), Rivne (8.5%), and Volyn (7.3%) regions. Furthermore, in terms of sawn timber production, Rivne (8.8%) and Volyn (14.4%) regions were among the top four leaders nationwide. These figures demonstrated a substantial concentration of logging and primary wood processing in Volyn Polissya, confirming the high forest resource potential of the region and correlating with the identified high productivity of Scots pine stands.

A comparative analysis of the qualitative structure of harvested timber revealed significant differences between Volyn Polissya and the Slobozhanskyi region (Uvarov, 2024). In the study region, the share of merchantable timber was about 60%, which was significantly higher than in the Slobozhanskyi Forest Office of the SE "Forests of Ukraine" (37%). Additionally, Volyn Polissya showed a higher share of higher-quality timber: quality class A accounted for 2% (compared to 1%), class B – 23% (compared to 10%), while in the Slobozhanskyi region quality classes C and D dominated (together 89%). In Volyn Polissya, class C timber also prevailed (56%), but the share of the lowest class D was noticeably lower – around 20%.

The comparison of the study's findings with similar data from Zhytomyr region, which belongs to the same natural-geographical region of Polissya, enabled a broader understanding of the differences in forest resource structure and timber harvesting within the region. In Zhytomyr region, according to I.H. Patseva *et al.* (2023), the total forest fund area was 1.09 million hectares, of which 952.6 thousand hectares were covered with forest vegetation. Among tree species, Scots pine dominated (59.1% of the forest-covered area), which was also reflected in its predominance in total timber harvesting – 2,188.6 thousand cubic metres, exceeding 80% of all harvested timber. The share of merchantable timber was around 52%, which was lower than in Volyn Polissya (60%).

Scots pine stands in Volyn Polissya played a key role in shaping the region's forest resource potential, both in quantitative and qualitative terms. An in-depth analysis of forest inventory indicators revealed an uneven age structure and a high proportion of middle-aged stands, indicating the need to revise forest management planning strategies and implement adaptive long-term management measures. The assessment of pine distribution by site conditions revealed the dominance of productive trophic types (fresh and moist subory), which created an optimal environment for the development of high-quality stands suitable for targeted forestry use. The structure of fellings in the region indicated a significant dependence of timber harvesting on sanitary measures, which, along with the identified stand condition, signalled a need for systematic forest rehabilitation and a shift towards more nature-oriented reforestation methods. The high proportion of merchantable timber harvested during principal fellings confirmed the significant economic potential of the region's pine forests, while the qualitative composition of timber from sanitary fellings and thinnings pointed to room for improving resource efficiency. The electronic timber accounting system enabled the identification of annual changes and the clarification of productivity for different types of felling, providing a basis for informed forest management decisions. The results obtained confirmed the representativeness of the region for studying nationwide trends in the forestry sector, while also revealing specific features linked to the prevalence of production forests, high forest cover, and established approaches to forest utilisation.

Conclusions

The average forest inventory indicators of Scots pine stands in Volyn Polissya were as follows: average age – 53 years; average growing stock – 219 m^3 ha^{-1}; average stocking density – 0.73; average site index class – I,7. Scots pine stands in Volyn Polissya exhibited an uneven age structure, necessitating a set of long-term forestry measures to achieve optimality, including a revision of harvesting volumes. It was also necessary to reassess the appropriateness of continuing the cultivation of stands in site index classes V and lower, unless they fulfilled important ecological or other functions. In moist site conditions, it was deemed advisable to replace pine with more moisture-loving species to fully utilise the potential of such forest lands.

Low-density stands occupied less than 2% of the total area. Nevertheless, their presence indicated the need to implement forestry measures to prevent such plots from transitioning into the sparse forest category. These measures might include reconstruction, promoting natural regeneration, and establishing partial forest cultures. During 2023-2024, 1.45 million cubic metres of Scots pine were harvested in the forests of Volyn Polissya from principal fellings and 1.51 million cubic metres from sanitary fellings. The average volume harvested per hectare over 2023-2024 was 35 m^3, with the following distribution by main types of felling: principal felling – 171 m^3, clear sanitary felling – 149 m^3, commercial thinning (age of 41-70) – 29 m^3, selective sanitary felling – 15 m^3, commercial thinning (age of 21-40) – 10 m^3, pre-commercial thinning (age of 11-20) – 4 m^3.

The dimensional and qualitative structure of Scots pine timber harvested in Volyn Polissya varied significantly depending on the type of felling. Principal fellings yielded the largest volumes of merchantable timber, particularly of quality classes A and B, while sanitary fellings and thinnings typically yielded lower-quality timber. The research findings underscored the need to improve forestry practices to enhance the efficiency of forest resource use and the condition of forest stands in the region. Future research aims to update the analysis based on up-to-date forest inventory materials, national inventory data, and the authors' own research findings. This will enable the evaluation of growth dynamics and structural changes in Scots pine stands in Volyn Polissya, and refine the directions for an in-depth analysis of the state and utilisation of forest resources in the region.

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Conflict of Interest

None.

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Структура та використання лісоресурсного потенціалу соснових насаджень Волинського Полісся

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Анотація. Актуальність дослідження зумовлена необхідністю раціонального використання лісоресурсного потенціалу соснових насаджень Волинського Полісся як одного з найбільш лісистих регіонів України з вагомим екологічним, економічним і соціальним значенням. Метою дослідження було вивчення таксаційної структури та аналіз використання соснових насаджень Волинського Полісся, пошук шляхів оптимізації процесу ведення лісового господарства в регіоні. Проведено комплексний аналіз просторової, вікової структури та продуктивності соснових насаджень Волинського Полісся з оцінкою використання їх запасів за видами рубок. Встановлено, що в регіоні дослідження близько 64 % площі лісових ділянок вкритих лісовою рослинністю зайняті сосновими насадженнями. Переважаючими за площею були штучні соснові насадження, які становили понад 52 %. Найбільш розповсюдженими були середньовікові насадження, що могло пояснюватися активним лісовідновленням у післявоєнні роки. Найбільше соснових насаджень зростало у свіжих і вологих суборах, які були оптимальними для росту цієї породи. Щорічний обсяг заготівлі деревини породи сосна лісогосподарськими підприємствами досліджуваного регіону в середньому становив 1,9 млн м^3, а більшість цієї деревини надходила від рубок головного користування та санітарних рубок. Серед рубок догляду значна частка заготівлі деревини припадала на прохідні рубки. Частка інших рубок, пов’язаних і не пов’язаних з веденням лісового господарства, становила 1-2 %. Середній обсяг заготівлі деревини породи сосна з 1 га перебував в межах від 2 м^3/га для рубок прочищення до 173 м^3/га для рубок головного користування. Результати дослідження можуть бути використані для вдосконалення лісогосподарських методів і формування стратегії сталого розвитку лісового господарства Волинського Полісся

Ключові слова: таксаційні показники; вікова структура; лісистість; запас; заготівля деревини

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Bacterioses of woody plants in the local urban phytocenoses of Kyiv: Symptoms, etiology, and distribution

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Abstract. Urban ecosystems of modern cities are characterised by a high level of anthropogenic load, which negatively affects the state of green spaces. Woody plants are particularly vulnerable to negative impacts, which occupy a key role in ensuring the ecological stability of the urban environment. The phytosanitary condition of trees is an important indicator of the health of the city ecosystem; therefore, its monitoring and analysis are urgent tasks in modern ecology. The aim of the study was a comprehensive study of the bacteriosis of woody plants in local urban phytocenoses of Kyiv, including the analysis of the characteristics of symptoms, identification of pathogens, and patterns of disease spread. The research was conducted during the 2024 growing

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season in the green areas of the "Respublika Park" and "Retroville" shopping and entertainment complexes. The work used modern microbiological methods for identifying pathogens of bacteriosis, as well as classical methods of phytosanitary inspection. To clarify the current systematic position and current name of taxa, information from the interactive databases "Index Fungorum" and "International Committee on Systematics of Prokaryotes" was used. It was investigated that the sanitary condition of the urbophytocenoses of the "Respublika Park" and "Retroville" shopping centers is characterised by a high degree of weakening of *Acer saccharinum* L. trees and a medium degree for *Ulmus laevis* Pall. It was established that the main cause of weakening of the trees is bacteriosis, the causative agent of which is the bacterium *Lelliottia nimipressurallis* (Carter 1945) Brady *et al*. 2013, which was confirmed by the polymerase chain reaction method. It is noted that the primary signs of damage to the bacteriosis of *Acer saccharinum* and *Ulmus laevis* urbophytocenoses are superficial peeling cracks, swelling of the bark, and the release of exudate. Secondary signs of damage were deep ulcers, necroti sation of wounds, and settlement of wood-destroying fungi. It was shown that the degree of development of bacteriosis on *Acer saccharinum* trees is 2 points and is characterised as rapid, and for *Ulmus laevis* trees – 1 point and is characterised as gradual. Thus, this study allowed to obtain a comprehensive picture of the spread and impact of bacteriosis on woody plants of urban phytocenoses of Kyiv, and also, based on the described features of symptoms – key diagnostic elements to develop measures for timely phytosanitary management of the condition of green spaces of cities to improve the ecological state and improve the quality of life of residents

Keywords: *Acer saccharinum*; *Ulmus laevis*; microbiota; phytopathogens; bacteria; urban plantings

Introduction

The functioning of urbanised phytocenoses occurs under the complex influence of environmental factors (especially anthropogenic and abiotic), such as air and soil pollution due to transport and industrial emissions, radiation and electromagnetic radiation, noise pollution, vandalism, the emergence of "heat islands", insufficient or excessive moisture, temperature fluctuations, disregard for environmental aspects in urban planning, etc. These factors weaken trees, making them vulnerable to the effects of various phytopathogens, which can cause diseases of various etiologies, including bacterial, viral, and fungal infections. Trees weakened by anthropogenic and abiotic stresses lose their natural resistance, contributing to the active spread of pathogenic microorganisms, including bacteria.

Studies of the sanitary condition by M. Matic *et al.* (2023), as well as the causes of weakening of trees that are part of urban phytocenoses, mainly concern factors of abiotic origin, and to a lesser extent – biotic, some gaps are especially noticeable in the identification of the species composition of phytopathogenic organisms, in particular bacteria. However, the availability of literature sources allows us to conduct a comparative analysis of previously obtained results to identify key trends and patterns of the influence of biotic factors, in particular bacterial infections, on the condition of trees in urban conditions. According to M.S. Kolenkina (2020) it was known that urban phytocenoses, especially those that are part of large cities, are constantly exposed to direct or indirect negative impacts of environmental factors, resulting in impaired tree viability.

V.L. Meshkova (2017) emphasised in her works that over the past decades the species composition of pathogens and insects of urban phytocenoses has significantly changed due to aboriginal species that have adapted to exist against the background of technogenic environmental pollution, and adventitious species that, with increasing temperature in cities, have better conditions for increasing the number of generations in the summer to survive in the winter. These studies emphasised the need for an integrated approach to the management of urban green spaces. It is important not only to take into account the resistance of plants to diseases and pests but also to understand how the species composition of potential phytopathogens changes under the influence of urbani sation and climate change. G.P. Nighswander *et al.* (2021) noted that the resistance of woody plants to pathogens and pests is an important ecosystem characteristic of urban stands that should be taken into account since the aggressiveness of phytopathogenic organisms limits the ecosystem services that plants provide in urban ecosystems. According to the authors, to ensure the sustainability of urban stands and maintain their ecosystem services, it is necessary to select resistant species, ensure their proper care, monitor them, and use an integrated approach to combat pests and pathogens, which combines different methods, such as biological control, agrotechnical measures, and chemical treatments. Taking into account all these aspects, it is possible to create more resilient and healthy urban stands that will effectively fulfill their ecological functions and benefit city residents.

Several scientific works are devoted to the study of modern phytosanitary problems caused by biological agents that weaken and damage urban plantings around the world, resulting in the disruption of the various services they usually provide. The study by F. Bălăcenoiu *et al.* (2020) involved a comprehensive study of the role and place of invasive species of pathogens and pests in urban plantings in Europe (in particular, the city of Bucharest, Romania). M. Lisovyy *et al.* (2023) conducted monitoring studies of invasive species of bed bugs in green areas of Kyiv (Ukraine). The studies of T.O. Boyko (2020) concern the factors of deterioration of phytosanitary conditions of green areas of Kherson (Ukraine). M.V. Matusiak (2020) assessed the current state of development of diseases and pests in green areas of Vinnytsia and their impact on the viability of woody plants. present in the region or may spread their, to reveal their distribution, and ecological significance and predict the consequences of impact on the overall biodiversity of urban phytocenoses. At the same time, there is very little information about the spread and impact of phytopathogenic bacteria on woody plants growing within urban stands. Bacteriosis can lead to a significant deterioration in the condition of trees, their dieback, which negatively affects the ecological situation in the city, the aesthetic appearance and the quality of life of residents. The study aimed to comprehensively study the bacteriosis of woody plants in local urban phytocenoses of Kyiv. This included analysing the characteristics of symptoms, identifying pathogens, and understanding the patterns of disease spread. Therefore, research into the features of the symptoms, etiology and spread of phytopathogenic bacteria in urban phytocenoses is an important step for developing effective strategies for protecting green spaces and preserving urban biodiversity.

Materials and Methods

The study of the symptoms, etiology and spread of bacteriosis of woody plants was conducted in the urban phytocenoses of Kyiv using the example of green spaces in the territory of the "Respublika Park" and "Retroville" shopping and entertainment complexes. In the surveyed territories, plantings of woody plants were mainly presented in a linear form along streets, boulevards or along the perimeter of areas bounded by fences. As part of the study, a total of 375 woody plants from two species were examined in the territories of shopping and entertainment centres in Kyiv. These included 200 *A. saccharinum* and 50 *U. laevis* specimens at "Respublika Park" shopping center, and 100 *A. saccharinum* and 25 *U. laevis* specimens at "Retroville shopping centre. The sampling was carried out using a complete enumeration method, covering all available and representative individuals of the respective species at each location. As such, the variability in the number of trees across diameter classes reflects the actual structure of the plantings rather than a result of selective sampling. Despite the relatively narrow interval between diameter classes (2 cm), the chosen grouping allowed for the identification of potential trends in the spread of the bacterial pathogen, even with minor differences in morphometric parameters. The diameter at breast height (DBH) of each tree was measured at 1.3 metres using a measuring tape, and trees were grouped into diameter classes with a 2 cm interval (16, 18, 20 cm).

The general assessment of the sanitary condition of the plantations was carried out by the method of phytosanitary inspection during the growing season of 2024 with a division into sanitary condition categories (I-VI) (Resolution of the Cabinet of Ministers of Ukraine No. 756, 2016). During the monitoring, stands were inspected by route and list methods in order to identify typical signs of infection by the bacteriosis pathogen, as well as identify foci of infection. The development of bacteriosis was evaluated using a four-stage scale developed by the authors: 0 – absence of visible symptoms; 1 – initial manifestation of infection; 2 – active pathological development; 3 – reduction of pathological activity. Identification of pathogens of bacterial diseases of woody plants was carried out by the polymerase chain reaction method based on the private laboratory and production complex Farmer.ua. The object of the study was the plant material of *A. saccharinum* and *U. laevis*.

The procedure for identifying bacterial pathogens consisted of the following stages: sampling, DNA isolation (which included both plant and bacterial DNA), and PCR analysis. Sampling was carried out on trees that were potentially affected or exhibited visible signs of bacteriosis infection. A total of 24 plant material samples were analysed, comprising 12 samples of *A. saccharinum* vegetative organs (shoots (3), leaves (3), bark (3), and wood (3)) and 12 similar samples from *U. laevis* trees. The samples were taken under sterile conditions and stored refrigerated until further analysis. For DNA extraction, a modified method based on the J.J. Doyle & J.L. Doyle (1987) protocol for plant material was used. A feature of this method is the use of cetyltrimethylammonium bromide (cetavlon, CTAB) as a detergent for DNA extraction and subsequent precipitation with alcohol. PCR (polymerase chain reaction) analysis was performed using specific primers complementary to unique DNA regions of potentially pathogenic bacteria. Primers targeting the following bacterial species were used: *Xylella fastidiosa* (Wells *et al.*), *Pseudomonas syringae* (Van Hall), *Erwinia amylovora* (Burrill) Winslow *et al.*, and *L. nimipressurallis*. PCR products were analysed by electrophoresis in a 1.5-2% agarose gel for 5 hours in 1 × SB buffer (5 mM Na2B4O7, pH 8.5). The presence of a specific DNA fragment, visualised by staining with ethidium bromide and photographed under UV light, indicated the presence of a disease-causing bacterium in the sample. Additionally, two controls were used for each pathogen in PCR: a positive control (containing the pathogen's genetic sequences) and a negative control (lacking biomaterial to check for contamination or nonspecific reactions).

Each sample also contained an internal control, an amplification of the plant genomic sequence, to verify successful nucleic acid isolation. DNA Marker 100 bp (100 bp + 1.5 Kbp; SibEnzyme) was used as a standard for determining the size of DNA fragments.

Latin names of higher plant species were given by: World Flora Online (n.d.), fungi by: Index Fungorum (n.d.), bacteria by: International Committee on Systematics of Prokaryotes (n.d.). Certain conclusions were obtained based on data that were established during the processing of herbarium specimens, as well as during the analysis of special literature. The study was conducted in accordance with the ethical standards specified in the Convention on Biological Diversity (1992).

Results and Discussion

Symptoms. The general sanitary condition of woody plants is an important indicator of the "health" of the urban environment and its ability to fulfill its functional purpose fully. After all, cities' trees create aesthetic appeal provide shade, and play a key role in regulating the microclimate, purifying the air from pollution, reducing noise levels, and creating favorable conditions for people's lives. The results of phytosanitary monitoring of woody plants of urban phytocenoses in Kyiv showed signs of a violation of the normal physiological state of trees, which is visually manifested in the form of growth retardation, a decrease in the size of the leaf, openwork crown, ulcers on woody organs, and dieback (Fig. 1).

a *b* *c*

Figure 1. General phytosanitary condition of the surveyed stands of the urban phytocenoses of Kyiv

Note: a – trees without visible signs of damage; b – ulcer on the trunk of *Acer saccharinum*; c – a tree that dieback

Source: compiled by the authors

Signs of weakening have been recorded on *Acer saccharinum, Acer platanoides, Ulmus laevis* and *Tilia cordata*. However, the particularly dangerous symptoms characteristic of the known bacteriosis have only been detected on *Acer saccharinum* and *Ulmus laevis*, so further research is focused on these tree species. The spread of bacteriosis symptoms occurs from the bottom up, i.e., from the root system to the crown of the tree. The first signs of infection are swelling of the bark and the formation of longitudinal peeling cracks (Fig. 1a), the bark on which changes color to dark (black). Over time, the swellings begin to actively crack (peel), fall off in large pieces, exposing the cambium. A characteristic sign of infection is the formation of longitudinal necrotic lesions of the phloem in the basal zone of the trunk. Also, over time, relatively short (from 0.5 to 10 cm) transverse cracks form, which ring the affected organ – the trunk or branch, partly resembling transverse oak cancer or stepped cancer in the early stages of pathogenesis. Also, a typical sign is the leakage of exudate. Usually, it is a viscous liquid of dark color with an unpleasant odor, which is localised within the ulcer (Fig. 2b). The intensity of the leakage of exudate depends significantly on weather conditions and the condition of the affected tree. At the end of the growing season, the leakage process stops, but on the trunks for a long time you can notice weeping wounds or dirty streams.

a *b* *c*

Figure 2. Typical symptoms of bacteriosis development on maple trunks
Note: a – peeling cracks; b – open longitudinal wound with exudate leakage; c – development of wood-destroying fungi on the surface of the ulcer
Source: compiled by the authors

The pathogen actively multiplies in the tissues of the tree, affecting the bark, phloem and cambium. In one growing season, it is able to form significant lesions in terms of area, which leads to serious consequences for the tree. Tangential spread of necrotic lesions of the phloem with longitudinal connection into continuous strips of ulcers covering the phloem and cambium was detected during a detailed examination of the trees. The lesion covered a significant part of the tree, starting from young branches in the upper part of the crown and reaching the base of the trunk. Tangential spread of necrotic lesions of the phloem on the tree trunk was often localised in the areas of branch attachment, where increased ribbing of the bark was observed. Local necrosis of the cambium was observed in the affected area. This is indicated by the radial growth of the xylem beyond the necrotic lesions, where the cambium retained its functional activity, and the formation of a "traumatic ring" in the xylem of the branches, which are morphological signs of local death of the cambium within the pathological changes. Despite the lesions, the parenchyma cells under the wood remained alive, their death was not detected. Problems with wood growth were observed only where the cambium was already dieback.

The final stage of the development of bacteriosis is the coloni sation of the affected wood tissues by wood-destroying and wood-staining fungi (Fig. 2c). This process can last for years, gradually destroying the structure of the wood and weakening its mechanical strength. Wood-destroying fungi feed on cellulose and lignin, which form the basis of wood. They secrete enzymes that break down these substances, converting them into nutrients available to them. This process is accompanied by the decomposition of wood, its softening and loss of strength. Wood-staining fungi, in turn, do not destroy the structure of the wood, but can change its color, causing the appearance of spots, stripes or other visual defects. This occurs due to the fact that the fungi penetrate the cells of the wood and secrete pigments that color it in different colors. The combination of bacterial damage with fungal coloni sation significantly accelerates the process of wood destruction and leads to its rapid decay. This is especially dangerous for trees growing in urban environments, where they are already under significant stress from air pollution, lack of moisture, and other negative factors.

Etiology. Analysis of symptoms of pathologies registered during phytosanitary monitoring of woody plants of urban phytocenoses of Kyiv allowed us to state that the detected diseases have an infectious origin (Table 1).

Table 1. Results of PCR analysis of plant material of trees of urban phytocenoses in Kyiv

Type of bacteria	Plant material for research	
	Acer saccharinum	*Ulmus laevis*
Xylella fastidiosa	–	–
Pseudomonas syringae	–	–
Erwinia amylovora	–	–
Lelliottia nimipressurallis	+	+

Note: + detected, – not detected
Source: compiled by the authors

PCR analysis revealed the presence of the bacterium *Lelliottia nimipressurallis* in plant material of both *Acer saccharinum* and *Ulmus laevis*. As is known, this bacterium is a dangerous phytopathogen that causes the disease bacterial wetwood. This disease is currently registered in Ukraine, both on deciduous (*Betula pendula* Roth., *Quercus robur* L.) and coniferous (*Abies alba* Mill.) species of woody plants, which was experimentally confirmed by research. The bacteria *Xylella fastidiosa, Pseudomonas syringae*, and *Erwinia amylovora* were not detected in the tested samples, indicating their absence or presence in quantities below the sensitivity limit of the PCR method. Thus, the etiology of the disease of *Acer saccharinum* and *Ulmus laevis* trees was associated with the dangerous phytopathogenic bacterium *Lelliottia nimipressurallis*, which is dynamically spreading in Ukraine, characterised by the rapid development of pathogenesis, the final stage of which is the dieback of affected trees. Therefore, in the absence of early diagnosis and accurate identification of the pathogen, it is practically impossible to choose an effective plant protection scheme.

Distribution. Woody plants have an important role in creating a comfortable microclimate, purifying the air and aesthetic design of urban space. Maintaining the health, and therefore the possibility of normal functioning, of green spaces is important for ensuring ecological stability and quality of life in cities. Currently, *Acer saccharinum* and *Ulmus laevis*, due to their unpretentiousness to growing conditions and decorativeness, are often used in urban landscaping. Both types of trees can be planted to create shady alleys, which is important in hot climates.

At the same time, a large number of these trees in a limited area in specific conditions of urban phytocoenoses creates favorable conditions for the rapid spread of dangerous types of phytopathogens, including pathogens of bacteriosis. A detailed analysis of the phytosanitary inspection of woody plants on the territory of the "Respublika Park" and "Retroville" shopping malls allowed us to obtain an objective picture of the spread of bacteriosis (Tabl. 2).

Table 2. Results of phytosanitary inspection of woody plants with signs of bacteriosis, which is part of the urban phytocenoses of Kyiv

Species name	Number of surveyed trees, pcs.	Sanitary condition category											
		I		II		III		IV		V		VI	
		pcs.	%	pcs.	%	pcs.	%	pcs.	%	pcs.	%	pcs.	%
Territory of the "Respublika Park" shopping mall													
A. saccharinum	200	89	44.5	6	3.0	51	25.5	44	22.0	10	5.0	0	0.0
U. laevis	50	19	38.0	7	14.0	18	36.0	6	12.0	0	0.0	0	0.0
Territory of the "Retroville" shopping mall													
A. saccharinum	100	50	50.0	25	25.0	14	14.0	9	9.0	2	2.0	0	0.0
U. laevis	25	16	64.0	5	20.0	2	8.0	2	8.0	0	0.0	0	0.0

Source: compiled by the authors

On the territory of the "Respublika Park" shopping mall, a significant part of *Acer saccharinum* trees (47.5%) has visible signs of weakening (trees are classified as III–V sanitary condition), which indicates the need to implement sanitary measures, including treatment or removal of individual specimens. At the same time, the majority (over 50.0%) of the surveyed *Ulmus laevis* trees are in satisfactory condition, but are characterised by a medium or high level of infection by infectious agents (including the causative agent of bacteriosis), which requires monitoring and measures for their recovery.

A somewhat better, but also alarming, phytosanitary situation is observed with the trees of the urban phytocenoses of the "Retroville" shopping center: a quarter of *Acer saccharinum* trees have minor signs of weakening, and 3/4 of the trees can be considered viable. However, 14.0% of the trees have an average level of weakening, 9.0% – severe weakening, and 2.0% of the trees are currently in a critical condition, which requires their urgent removal. The general condition of elms is better than that of maples: 64.0% of the trees are healthy, 20.0% have minor signs of weakening, 16.0% are classified as III–IV categories of sanitary condition, which indicates the need for care and regular monitoring.

Analysis of the spread of bacteriosis on *Acer saccharinum* shows that the largest proportion (55.0%) of affected specimens is observed among trees with a thickness of 16 cm (Table 3, Fig. 3). The largest number of lesions (259 pieces) was recorded on trees with a trunk diameter of 18 cm, and the bacterium spread to practically every second tree (the proportion of affected trees is 49.0%). In trees with a diameter of 20 cm, the proportion of infected specimens is slightly lower (42.6%), while type II lesions prevail (76.9%), which indicates a progressive stage of the disease. In all groups of examined trees, type II lesions prevail over type I, which means an aggressive disease development.

Table 3. Distribution and types of symptomatic signs of bacteriosis on Acer saccharinum and Ulmus laevis trees

Thickness level, cm	Total number of trees counted, pcs.	Including infected trees, pcs.	Number of visible lesions by type				Total lesions, pcs.	Disease prevalence, %
			Type I		Type II			
			pcs.	%	pcs.	%		
Acer saccharinum								
16	20	11	10	23.8	32	76.2	42	55.0
18	151	74	107	41.3	152	58.7	259	49.0
20	129	55	45	23.1	150	76.9	195	42.6
Total	300	140	162	-	334	-	496	-
Ulmus laevis								
16	15	7	9	69.2	4	30.8	13	46.6
18	35	16	19	67.9	9	32.1	28	45.7
20	25	8	6	54.5	5	45.5	11	32.0
Total	75	31	34	-	18	-	52	-

Note: *affected – all plants that had visible symptoms of infection with the bacteriosis pathogen were considered affected; **type I (primary symptoms – swelling of the bark, peeling cracks, exudate secretion), type II (secondary symptoms – deep longitudinal ulcers, necroti sation of the wound surface, settlement of xylotrophic fungi)
Source: compiled by the authors

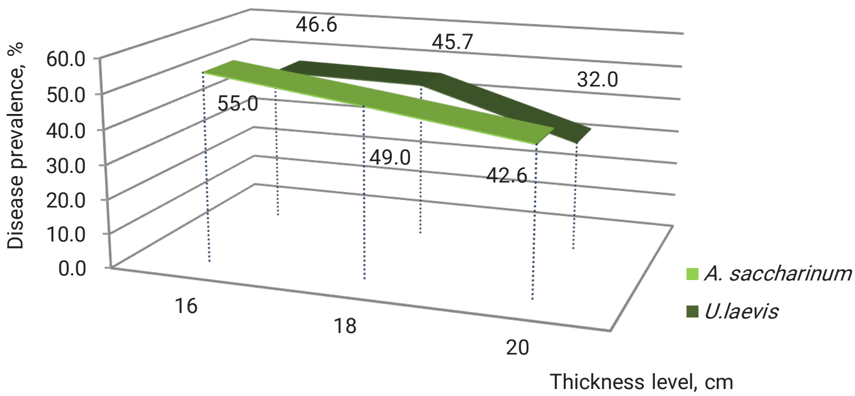

Figure 3. The dependence of the spread of *L. nimipressuralis* on *A. saccharinum* and *U. laevis* of different degrees of thickness
Source: compiled by the authors

The total proportion of infected *Ulmus laevis* trees is 41.3%, which is slightly lower than that of *Acer saccharinum*. Within the surveyed trees, a certain trend is observed: with increasing trunk diameter, the proportion of infected specimens decreases (for trees with a diameter of 16 cm, the infection rate was 46.6%, and for trees with a diameter of 20 cm – 32.0%), which may indicate an increased vulnerability of trees with a smaller diameter to damage by phytopathogens, although this trend requires additional verification taking into account age indicators. The type of lesions dominates in all examined plants, which indicates a less aggressive development of the disease compared to *Acer saccharinum*. The largest total number of lesions (28 pieces) was recorded on trees with a diameter of 18 cm, which may indicate a high vulnerability of trees that are in the phase of active growth, which weakens protective plant barriers.

The key characteristics of bacteriosis development and spread by location are summarised in Table 4.

Table 4. The main characteristics of the development and spread of bacteriosis

Location of experimental plots	Average number of ulcers, pcs.		Degree of bacteriosis development, score		The nature of the spread of bacteriosis (according to the authors' method)	
	A. saccharinum	*U. laevis*	*A. saccharinum*	*U. laevis*	*A. saccharinum*	*U. laevis*
Territory of the "Respublika Park" shopping mall	4	1	2	1	Rapid	Gradual
Territory of the "Retroville" shopping mall	3	1	2	1	Rapid	Gradual

Note: the analysis presented in this table is based on data collected from all 375 surveyed trees
Source: researched by the authors

It has been established that the visible signs of infection of *A. saccharinum* and *U. laevis* trees are the formation of longitudinal necrotic ulcers on the woody parts of the plant (branches and trunk). The length of the ulcers varies from 1.0 cm to 150 cm. Their number is also variable – from 1 to 10 pcs./m^2 and occupies from 5.0 to 100% of the branch circumference. When assessing the degree of bacteriosis development, the following criteria were taken into account: the area of tissue damage, the depth of pathogen penetration, the presence of secondary infections, and the general condition of the tree. The highest score for bacteriosis development was assigned to *A. saccharinum* trees since the pathogenesis of the disease is characterised by very active visual manifestations of the disease, and as a result, an already noticeable impact on the physiological state of the trees. *U. laevis* trees were assigned a score of 1 for bacteriosis development (according to the authors' method), i.e. initial signs of infection are recorded, macro signs of the lesion are barely noticeable, and the intensity of development is weak.

Two types of bacteriosis spread were identified during the analysis: rapid and gradual. The rapid nature of bacteriosis spread was found to be characteristic of *A. saccharinum* trees growing in the surveyed areas. This means that there is a high probability that in a short time, a significant number of trees growing next to the infected ones may be affected, which will lead to significant losses of green spaces. The development of the rapid nature of the spread of the disease may be due to or enhanced by various environmental factors, such as favorable weather conditions for the development of the pathogen; the presence of susceptible tree species; the presence and activity of pathogen vectors; insufficient plant care, etc. The gradual nature of the development of bacteriosis is inherent in the surveyed *U. laevis* trees. This means that the disease can develop imperceptibly for a long time, and only later manifest itself in the form of visible symptoms. That is why it is important to remember that the health of urban plantings is the key to the environmental safety and comfort of city residents.

According to data from C. Copeland *et al.* (2023), *Ulmus* spp. (elms) in urban environments are currently threatened by complex biotic pressures. Specifically, the phytopathogenic fungi *Ophiostoma ulmi* (Buism.) Nannf. and *O. novo-ulmi* Brasier cause Dutch Elm Disease (DED), which is one of the most dangerous elm diseases in the Northern Hemisphere. Simultaneously, these trees are significantly damaged by the leaf-eating pest *Aproceros leucopoda* (Takeuchi, 1939), whose larvae cause extensive leaf gnawing, premature leaf fall, and reduced photosynthesis. The simultaneous action of these factors, in combination with the bacterial pathogen *Lelliottia nimipressuralis* identified in the present study, may result in a cumulative weakening of *Ulmus* spp. in urban conditions. Even when bacterial symptoms begin as superficial lesions (Type I), their interaction with fungal infections and insect damage may amplify the overall decline of trees. This observation highlights the importance of a holistic view of tree health that integrates multiple stressors rather than treating them in isolation.

A. Scattolini Rimada *et al.* (2023) emphasise that trees of the genus *Platanus* spp., especially in Europe and North America, are significantly negatively affected by phytopathogenic microorganisms, in particular, the fungus *Ceratocystis platani* (J.M. Walter) Engelbr. & T.C. Harr., which causes sycamore canker (canker stain disease). Studies by M. Lisovyy *et al.* (2023) confirmed the spread of the invasive species of the bug *Corythucha ciliata* (Say, 1832) in Europe (including Ukraine), where it actively infects *Platanus* spp., sucking sap from the leaves, which leads to a weakening of photosynthetic activity, premature yellowing, and leaf fall, as well as general inhibition of tree growth. The current study contributes to this broader context by documenting the presence of *L. nimipressuralis* in *Acer saccharinum* and *Ulmus laevis* in Kyiv's urban phytocenoses. The observed symptoms – ranging from bark cracking and exudate production to secondary fungal colonisation – are consistent with chronic, system-wide physiological stress. Taken together, these findings illustrate how urban tree populations are exposed to an escalating array of biotic stressors, which, under the compounded pressure of climate change, pollution, and anthropogenic disturbance, may act synergistically to compromise tree vitality. The diversity of pathogenic organisms (bacteria, fungi, and insects) in these ecosystems points to the need for integrated plant health monitoring systems in urban forestry.

Quercus spp. trees, as noted by researchers J. Meunier *et al.* (2019), and C. Pintos *et al.* (2023), are significantly weakened by the fungi *Biscogniauxia mediterranea* (De Not.) Kuntze, *Phytophthora ramorum* Werres, De Cock & Man, *Cronartium quercuum* (Berkeley), *Ceratocystis fagacearum* (Bretz) Hunt. A particularly dangerous disease for oak is bacterial wetwood (the causative agent is the bacterium *Lelliottia nimipressuralis* (Carter 1945), also identified in study on *Acer saccharinum* and *Ulmus laevis*). As demonstrated in I.M. Kulbanska *et al.* (2021), this bacterium is capable of causing not only chronic weakening but also rapid death of oaks, including trees of older age groups, which emphasises its high pathogenic potential. This makes *L. nimipressuralis* a universal and particularly dangerous phytopathogen for a wide range of deciduous trees in cities. Thorough studies of the species composition of phytopathogens of *Acer* spp. trees belong to T. Jung *et al.* (2018), which concern the history, dynamics of distribution, features of symptoms, and etiology of cancer diseases caused by representatives of the genus of oomycetes Phytophthora in forests and natural ecosystems of Europe, Australia, and America. The impact of the fungus *Phytophthora acerina* on maples is described in particular detail by T. Jung *et al.* (2018). Symptoms of the lesion include necrotic lesions of the bark and cambium, which often lead to the formation of deep cracks and ulcers; the appearance of wet, dark spots on the bark; wilting of leaves and partial drying of the crown; rotting of the tree's root system. These symptoms share many similarities with the clinical picture of bacterial infection described for Acer saccharinum, highlighting the difficulty of differential diagnosis in urban environments where multiple pathogens, both bacterial and fungal, may be present. Known phytopathogens of trees of the genus *Fraxinus* spp. are the fungus *Hymenoscyphus fraxineus* (T. Kowalski) Baral *et al.* (2014) (Volke *et al.*, 2019), the bacterium *Pseudomonas syringae* pv. *savastanoi* (Smith, 1908) Young *et al.* 1978 (Goychuk *et al.*, 2020; 2022) and the pest *Agrilus planipennis* Fairmaire (Subburayalu & Sydnor, 2018). Each of these pathogens has specific mechanisms of damage and leads to significant losses among ash populations, particularly in urbanised areas.

Such findings reflect the general tendency of increasing vulnerability of urban tree species due to multifactorial stress, including climate change, pollution, and anthropogenic disturbances, which may facilitate the establishment and spread of invasive or opportunistic pathogens. In this regard, the bacterial species described in the current study should be viewed not only as isolated agents of infection but as part of a complex phytopathogenic consortium that influences tree health and survival. The fact that many of these microorganisms have been identified in both local and international studies points to their high ecological plasticity and adaptability to a wide range of hosts. This underscores the importance of applying integrative phytopathological monitoring approaches that combine molecular diagnostics, symptom analysis, and spatial mapping of infection foci in urban green infrastructure. Consequently, the findings of the current research contribute to the broader understanding of urban tree health and demonstrate the practical value of targeted diagnostics in forming evidence-based strategies for maintaining biodiversity and ecosystem services in cities.

The study by P. Romon-Ochoa *et al.* (2024) on the susceptibility of trees of the genus *Castanea* spp. to the fungus *Cryphonectria parasitica* (Murrill) Barr is an important contribution to the study of early symptoms of damage, monitoring, and development of measures to protect trees from mycoses. The authors paid special attention to the identification of early symptoms of the lesion, such as local ulcers, changes in bark color, the formation of necrotic areas, and impaired sap flow. Comparing these results, it should be noted that the presence of common pathogenetic features with the bacterial wetwood detected on *Acer saccharinum* and *Ulmus laevis* is observed. In particular, both types of lesions are accompanied by the formation of ulcers, cambium necrosis and impaired sap flow, which ultimately leads to the weakening and degradation of trees. As in the case of chestnut cancer, bacterial lesions in urbanised plantations remain latent in the early stages, which complicates their timely detection without the use of molecular genetic diagnostic methods. This observation aligns with the challenges P. Romon-Ochoa *et al.* (2024) faced in identifying early symptoms of *Cryphonectria parasitica* infection. Findings in current research also show parallels with research on *Pinus* spp., where trees are significantly weakened by various threats.

For instance, *Pinus* spp. are weakened by the fungi *Heterobasidion irregulare* Garbel. & Otrosina (Gonthier, & Garbelotto, 2023), the nematode *Bursaphelenchus xylophilus*, Nickle, 1970 (Faria *et al.*, 2021), the pests *Leptoglossus occidentalis* Heidemann, 1910 (Muntean & Grozea, 2021) and *Matsucoccus feytaudi* Ducasse, 1941 (Panzavolta *et al.*, 2021). These phytopathogens affect the condition of pine both individually and in combination, reinforcing the negative impact of each other, therefore the complex combination of these threats can have a cumulative effect. The results also indicate a significant weakening of tree stands in urban phytocenoses, in particular due to the spread of bacteriosis, which confirms the tendency towards multifactorial damage to trees in urban ecosystems. As in the case of *Pinus* spp., where pathogens act in a complex manner, bacterial wetwood caused by *Lelliottia nimipressuralis* is accompanied by a combination of primary and secondary symptoms, which complicates early detection and control. This shared characteristic of complex and often synergistic pathogen interactions highlights a broader ecological principle of vulnerability in urban tree populations, irrespective of the specific pathogen or tree species.

While P. Romon-Ochoa *et al.* (2024) primarily focused on fungal pathogenesis in *Castanea* spp. and its early detection, our study, by demonstrating commonalities in symptomology and the challenges of early detection across different tree species and pathogen types (fungal, bacterial, and invertebrate), contributes to a more comprehensive understanding of tree health in urban environments. The work of T. Panzavolta *et al.* (2021) on alien invasive pathogens and pests also echoes the multifactorial threats observed in our study, emphasising pathways, global consequences, and management strategies.

Thus, phytopathogens that weaken trees in urban stands pose a serious threat to the health of green spaces. They destroy tree tissues, disrupt water and nutrient metabolism, reduce stress resistance, and increase vulnerability to other negative environmental factors. The combination of the effects of various pathogens and pests has a cumulative effect, enhancing the overall negative impact on trees. This leads to significant environmental and economic losses, so it is important to carry out phytosanitary monitoring and timely implement control measures to preserve the health of trees in urban phytocenoses.

Conclusions

Dangerous symptoms of bacteriosis were found on *Acer saccharinum* and *Ulmus laevis* trees that are part of the urban phytocenoses of Kyiv and grow on the territory of the "Respublika Park" and "Retroville" shopping and entertainment complexes. The primary signs of damage (type I) include the following symptoms: swelling of the bark surface, superficial peeling cracks, and the release of bacterial exudate during the growing season. Secondary signs (type II), which indicate the aggressive and rapid nature of the development of bacteriosis, are deep longitudinal ulcers (length from 1.0 cm to 150 cm), necroti sation of the wound surface, and the settlement of wood-destroying and wood-staining fungi on the affected surface. Analysis of the sanitary condition of green stands on the territory of the "Respublika Park" shopping mall showed a high degree of weakening of *A. saccharinum* and *U. laevis* trees. Half of the surveyed trees are classified as III–V categories of sanitary condition, which indicates the need to implement sanitary measures, including treatment or removal of individual specimens. The phytosanitary situation of the urbophytocenoses of the "Retroville" shopping mall is better: 25.0% of *A. saccharinum* trees have minor signs of weakening, and 75.0% of the trees can be considered viable. Minor signs of weakening are also noted on *U. laevis* trees, which indicates the need for care and regular monitoring.

A tendency to decrease the proportion of *Acer saccharinum* trees affected by L. nimipressuralis with increasing trunk diameter was found (at a diameter of 16 cm, 55.0%, at 18 cm, 49.0%, at 20 cm, 42.6%). However, due to the absence of a statistically significant difference between the indicators, and also taking into account that the diameter is not a direct indicator of the age of the trees, such a dependence should be considered as a preliminary observation that requires further confirmation. In all examined tree thickness levels, type II lesions predominate, which may indicate the aggressive nature of the development of the infectious process. Similar dynamics are observed among *Ulmus laevis* trees: the spread of bacteriosis decreases from 46.6% (at a diameter of 16 cm) to 32.0% (at 20 cm). In trees of this species, type I of the lesion dominates, which probably indicates a less aggressive course of the disease compared to *Acer saccharinum*.

When assessing the degree of development of bacteriosis, the average number of ulcers per tree and the prevailing type of lesion were taken into account. That is why it is important not only to monitor the condition of urban plantings but also to carry out preventive measures because their health directly affects the ecological balance, air quality, and comfort of city residents. Further research should focus on identifying the specific conditions that trigger the aggressive "Type II" symptoms observed in *Acer saccharinum* and investigating the long-term ecological impact of *Lelliottia nimipressuralis* on the overall health and resilience of urban tree populations in Kyiv.

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Бактеріози деревних рослин у локальних урбофітоценозах Києва: симптоми, етіологія та поширення

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Анотація. Урбоекосистеми сучасних міст характеризуються високим рівнем антропогенного навантаження, що негативно впливає на стан зелених насаджень. Особливо вразливими до негативного впливу є деревні рослини, які відіграють ключову роль у забезпеченні екологічної стабільності міського середовища. Фітосанітарний стан дерев є важливим індикатором здоров'я екосистеми міста, тому його моніторинг та аналіз є актуальним завданням сучасної екології. Метою дослідження було комплексне вивчення бактеріозів деревних рослин в локальних урбофітоценозах м. Києва, включаючи аналіз особливостей симптомів, ідентифікацію збудників та закономірностей поширення захворювання. Дослідження проводили впродовж вегетаційного періоду 2024 року у межах зелених насаджень на територіях торгово-розважальних комплексів "Respublika Park" та "Retroville". У роботі використано сучасні мікробіологічні методи ідентифікації збудників бактеріозів, а також класичні прийоми фітосанітарного обстеження. Для уточнення сучасного систематичного положення та актуальної назви таксонів використано інформацію із інтерактивних баз даних "Index Fungorum" та "International Committee on Systematics of Prokaryotes". Досліджено, що санітарний стан урбофітоценозів торгово-розважальних комплексів "Respublika Park" і "Retroville" характеризується високим ступенем ослаблення дерев *Acer saccharinum* L. та середнім ступенем для *Ulmus laevis* Pall. Встановлено, що головною причиною ослаблення дерев є бактеріоз, збудником якого є бактерія *Lelliottia nimipressurallis* (Carter 1945) Brady *et al*. 2013, що підтверджено методом полімеразної ланцюгової реакції. Зазначено, що первинними ознаками ураження бактеріозу дерев *Acer saccharinum* та *Ulmus laevis* урбофітоценозів є поверхневі відлупні тріщини, вздуття кори та виділення ексудату. Вторинними ознаками ураження є глибокі виразки, некротизація ран та оселення грибів-дестукторів. Показано, що ступінь розвитку бактеріозу на деревах Acer saccharinum складає 2 бали і характеризується як стрімкий, а для дерев *Ulmus laevis* – 1 бал і характеризується як поступовий. Таким чином, дане дослідження дозволило отримати комплексну картину поширення та впливу бактеріозів на деревні рослини урбофітоценозів м. Київ, а також, базуючись на описаних особливостях симптоматики, ключових діагностичних елементах – розробити заходи для своєчасного фітосанітарного управління станом зелених насаджень міст для покращення екологічного стану та підвищення якості життя мешканців

Ключові слова: *Acer saccharinum*; *Ulmus laevis*; мікробоценоз; фітопатогени; бактерія; міські насадження

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