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Current state of ornamental arboreal plants in ordinary street tree stands in Kyiv

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Abstract. An increase in anthropogenic load in urban complexes leads to adverse ecological changes in the environment. Urban tree stands can somewhat smooth out these shortcomings by affecting the microclimate within the local territory. According to statistical data, every year the indicator of the provision of green spaces for the residents of Kyiv decreases, which is caused by the unsatisfactory condition of street tree stands. The main purpose of this paper is to highlight the results of the study on the assortment of arboreal plants, to estimate their general condition on the busiest streets and avenues of Kyiv, and to provide recommendations for creating a perspective list of plants for urban street landscaping. The paper analyses the data of the inventory that was performed within ordinary street tree stands in 2021. It was found that the most common street tree stands include *Tilia cordata*, *Aesculus hippocastanum*, and *Populus nigra*. A comparative analysis of the main assortment of plants in the street tree stands of Kyiv for 2009 and 2021 was conducted, and it was established that the number of *Aesculus hippocastanum* and *Populus nigra* decreased, while the percentage of *Robinia pseudoacacia*, *Fraxinus excelsior* increased. The assessment of the general condition of plants indicates that the largest share of plants is in a satisfactory condition – 50%. The best condition was noted in *Robinia pseudoacacia*, *Acer platanoides*, and *Tilia cordata*. Attention is paid to the general condition of arboreal plants by the percentage of inactive photosynthetic surface. High resistance of *Acer platanoides*, *Fraxinus excelsior*, and *Robinia pseudoacacia* to urban conditions is revealed. The analysis of the experimental data provides grounds for determining the main and supplementary assortment of arboreal plant species recommended for use in street landscaping, with further study of their stress resistance

Keywords: dendroflora, general condition, arboreal plants, assortment, defoliation

Introduction

Urbanization of megacities influences changes in the environment, as well as the increase in anthropogenic load. Urban tree canopies provide various ecological and social benefits for urban spaces by reducing local temperatures, energy consumption, and absorbing rainwater runoff. They are one of the closest and familiar green infrastructures to city dwellers [1; 2]. Scientists indicate the importance of street tree stands because they can create a large amount of green cover, especially within dense buildings [3; 4]. Today, Kyiv has the title of “Green Capital” [5], but considering the recreational and anthropogenic load on green areas, the change in microclimate and the outdated range of ornamental arboreal plants and their general condition, every year the indicator of the city’s population’s provision of green spaces decreases. It is the urban green infrastructure, with a special emphasis on street plantings, that is

a sophisticated engineered ecosystem, which plays an important role in the creation of ecosystem services and, if properly managed, can prevent negative and harmful impacts [6]. Street tree stands in Kyiv play a significant role in landscaping and planning structure of the city, which determines their important landscape-architectural, aesthetic, and recreational role [7]. Empirical results of Japanese researchers indicate that increasing the greening ratio of the street landscape improves the residential environment in terms of both the magnitude and saturation level of the tree stand ratio, while increasing the number of urban parks does not [8].

According to urban planner P. Gartner, who studied satellite images using Normalized Difference Vegetation Index, the city of Kyiv was recognized as the greenest capital in Europe in 2017. But not all city residents agree with

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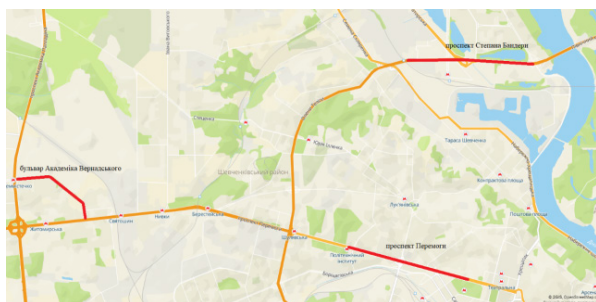
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the result of this study, which is caused, in most cases, by the unsatisfactory state of tree stands within the settlement zone. DC Evolution analysts examined the capital's green zones and noted that the total area of Kyiv is 83.4 thousand hectares, and the area of green zones is 16.2 thousand hectares, which is 19.3% of the total [5]. But a significant area of greenery is growing within recreational zones, forest parks, etc.

For Kyiv to become a truly “Green Capital”, it is necessary to pay great attention to street landscaping. As A. Ryzhikov, head of the DC Evolution company, says about Kyiv: “Walk through the centre or the neighbourhood – how many trees will you see? They simply do not exist. And it matters not if they got sick and withered, or if they were cut for another kiosk or car park. At the same time, landscapers plant about 10,000 trees every year... A comfortable city starts small” [5].

One of the effective ways to preserve the quality of the environment is to stabilize the quantity and maintain the quality of green spaces, which must be properly maintained. Trees planted along streets tend to require more maintenance and have a shorter lifespan than those growing in more natural settings. Poor tree growth is often associated with insufficient soil volume for the root system, which limits access to water and nutrients. Tree roots in the urban environment often compete for underground space with urban services and infrastructure, and insufficient space for rooting is one of the factors in the unsatisfactory condition and mortality of street trees in cities [9].

Urban greening encompasses a range of incentives, strategies, and initiatives to green urban landscapes, and often includes urban tree planting programs. The increase of green spaces has both advantages and disadvantages,



since the solution to the problem of improving green spaces in an urbanized environment, as well as the increase in green areas, is possible with the use of justifications and scientific recommendations regarding the selection of the assortment of plants and its maintenance, which is based on inventory and assessment of the condition of ornamental tree stands. Only plants in good condition can effectively perform vital functions. Currently, the city of Kyiv does not have comprehensive information on the inventory of street plants, although some plants are already included in the main database of inventory data. Therefore, the purpose of this paper is to establish the main and supplementary assortment of plants for their further use in street landscaping.

Materials and Methods

The study adopted a representative sampling approach. According to the general plan of the city, the experimental area was chosen, where street tree stands are an important green infrastructure with high maintenance needs, namely: Peremohy Avenue, S. Bandery Avenue, Holosiivskyi Avenue, Vernadskyi Boulevard, Velyka Vasylkivska Street, etc. (Fig. 1). For the accuracy of the experiment, the selected streets are located in different parts of Kyiv and differ in the assortment of plants. All trees that grow on the experimental sites are classified as public tree stands, grow in row plantings along the roads, have different ages and composition. From May to November 2021, field research was conducted, 938 trees were examined on 7 streets of the city. To estimate the number of street trees within the selected objects, a preliminary stage of selection took place using Google Earth. The sample survey was designed in such a way as to represent all types of plants under conditions of limitation of more intensive recreational load.

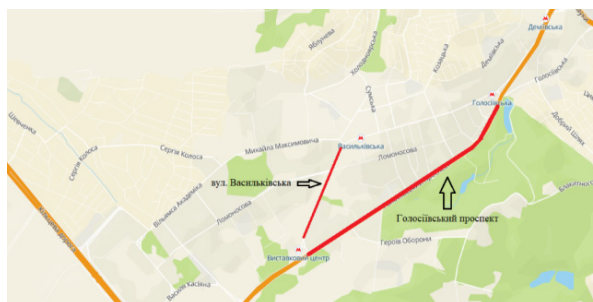


Figure 1. Experimental sites within the districts of Kyiv

To indicate a promising assortment of plants for street tree stands, the main task of the study was to conduct an inventory of tree stands at the experimental sites, to determine and estimate the general condition of the most common arboreal plants. The inventory was carried out according to the “Instructions for the inventory of green spaces in populated areas of Ukraine” [10]. A 5-point scale was also used to detail the assessment of plant condition, according to which the category of plant condition was determined by the percentage of inactive or lost photosynthesizing (leaf) surface. Trees without suppressed growth with a full leaf surface were evaluated at 5 points;

trees with growth that generally meets the norm and has about 20-25% of the inactive surface – 4 points; trees with weakened growth, which have about 50% of inactive leaf surface – 3 points; trees with suppressed growth, the growth of the current year is almost absent, have about 75-80% of inactive leaf surface – 2 points; dead and dying, without current tree growth with 100% inactive leaf surface – 1 point [11].

Results and Discussion

The examined 938 trees include 17 species belonging to 13 genera and 11 families (Fig. 2).



Figure 2. The most common types of arboreal plants at experimental sites

According to the inventory data, it was found that the most common species in street tree stands are as follows: small-leaved linden (*Tilia cordata* Mill.), which is 35.8%, horse chestnut (*Aesculus hippocastanum* L.) – 20.3%, and black poplar (*Populus nigra* L.) – 18.9%, which in total makes up 75% of the surveyed tree stands. Black locust (*Robinia pseudoacacia* L.) and Norway maple (*Acer platanoides* L.) have slightly lower figures – 10.4% and 9.6%, respectively, as well as other types of arboreal plants, such as common ash (*Fraxinus excelsior* L.), common oak (*Quercus*

robur L.), sugar maple (*Acer saccharum* Marsh.), hybrid plane (*Platanus×hispanica* Mill.), mountain-ash (*Sorbus aucuparia* L.), etc. Comparing the data with the studies of 2008-2009 [12], the percentage of *Aesculus hippocastanum* L. within street tree stands decreased by about 20%, and *Populus nigra* L. by approximately 27% (Fig. 3). Therewith, the number of *Robinia pseudoacacia* L., *Fraxinus excelsior* L. plants is increasing, and the frequency of occurrence of *Platanus×hispanica* Mill. and *Catalpa bignonioides* Walter has increased within the avenues and streets of Kyiv.

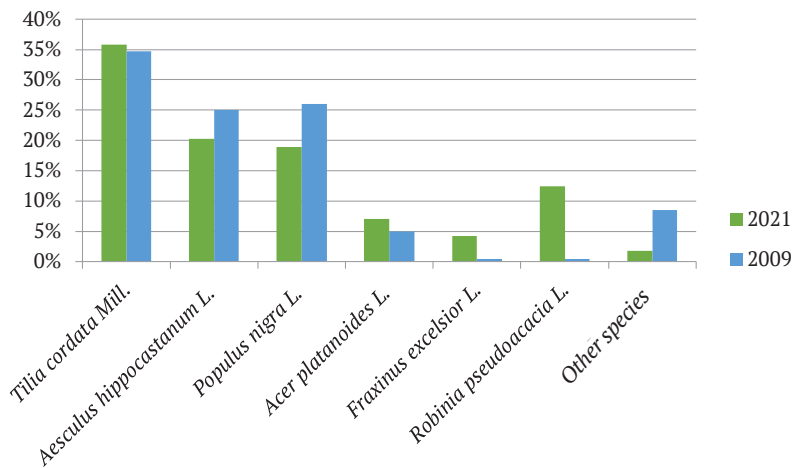


Figure 3. Species composition of street tree stands in Kyiv for 2009 and 2021

The decrease in the number of specimens of *Aesculus hippocastanum* L. is primarily related to the annual damage to the plants by the horse-chestnut leaf miner, which adversely affects the general condition of the plants, starting from June [13]. Moth larvae feed on leaves, which causes their defoliation, and depending on environmental conditions, there can be up to five

generations of this pest per year [14]. Combined with anthropogenic load, the weakening of plants is accelerated, the canopy and branches die back, trunk frostbite cracks appear, re-flowering is found in many specimens, etc. (Fig. 4). All the factors listed above have a detrimental effect on the condition of plants, which in the future leads to their death.



Figure 4. *Aesculus hippocastanum* L. in street tree stands in Kyiv: a) canopy defoliation; b) frost cracks; c) repeated flowering; d) defoliation of leaves

The decrease in the percentage of *Populus nigra* L. plants in street tree stands is caused by several factors, namely: short-lived species and the downing of plants during flowering, which causes allergic reactions among the city residents [6]. Furthermore, reaching a critical age barrier and having brittle wood, small gusts of wind lead to branch breaks and falling poplar trees.

During the inventory of tree stands within the streets of Kyiv, the current state of the plants was determined. According to the “Instructions for the inventory of green spaces in populated areas of Ukraine”, the examined plants were assigned to three categories according to their

general condition: good, satisfactory, and unsatisfactory. As indicated in Fig. 5, the largest share of plants is in satisfactory condition – about 50% of the examined plants, in good condition – within 40%, and in unsatisfactory condition – 10%. Among the most common types of street tree stands, the best condition was noted in *Robinia pseudoacacia* L., *Acer platanoides* L. and *Tilia cordata* Mill., although the percentage of plants in an unsatisfactory condition in these representatives reaches more than 10%. Therefore, it is necessary to analyse the current state of experimental plants and the specific features of their growth in more detail to explain the unsatisfactory state of numerous specimens.

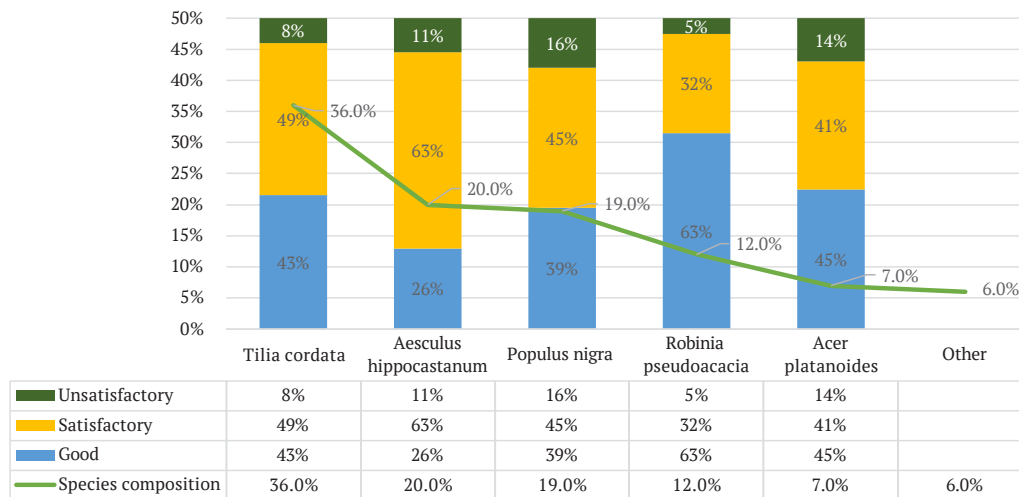


Figure 5. General condition of street tree stands in Kyiv

To estimate the detailed state of street tree stands, several methods were analysed, which included various aspects of plant growth, their condition, appearance, presence of pests and diseases, etc. [7; 4]. The following was highlighted from these methods: during the visual inspection of street tree stands, the researcher pays special attention to the general condition of the plants and the condition of the leaf blade. Therefore, the next step in the research was to determine the category of plant condition based on the percentage of inactive or lost photosynthetic (leaf) surface. It is this indicator that is key in the rating of tree

mortality, which is conducted by the Japanese Centre for Research and Development of Greenery and is widely used in scientific research institutions and expert companies in Japan [15]. This method includes 12 parameters, which include plant growth energy, density of branches and leaves, leaf colour, damage to the lower and upper parts of the leaf, damage or rotting of the tree bark, leaf size, presence or absence of sprouts, etc. Therefore, during field surveys, the state of plants was estimated according to the state of the leaf blade in the most common types of street tree stands during May-June 2021 (Table 1).

Table 1. Estimation of the general condition of plants by the percentage of inactive or lost photosynthetic surface

Plant name	Number of trees of each type (pcs/%)					Total, points	Total number of trees, %
	By status categories, points						
	1	2	3	4	5		
1	2	3	4	5	6	7	8
<i>Tilia cordata</i> Mill.	11	19	43	142	122	337	36
	3.3	5.6	12.7	42.1	36.2	100	
<i>Aesculus hippocastanum</i> L.	8	12	42	62	63	187	20
	4.3	6.4	22.4	33.2	33.7	100	
<i>Populus nigra</i> L.	8	9	38	67	56	178	19
	4.5	5	21.3	37.6	31.5	100	
<i>Robinia pseudoacacia</i> L.	2	4	7	29	70	112	12
	1.8	3.6	6.2	26	62.4	100	
<i>Acer platanoides</i> L.	4	5	11	15	30	65	7
	6.1	7.7	16.9	23	46.2	100	
<i>Fraxinus excelsior</i> L.	1	1	3	7	25	37	4
	2.7	2.7	8.1	18.9	67.6	100	
<i>Catalpa bignonioides</i> Walter.	0	0	0	3	8	11	1
	0	0	0	27.3	72.7	100	
<i>Platanus×hispanica</i> Mill. ex Münchh	0	0	1	4	5	10	1
	0	0	10	40	50	100	
Total	34	50	145	329	379	937	100
	3.6	5.3	15.5	35.1	40.4	100	

Estimating the general condition of arboreal plants by the percentage of inactive photosynthetic surface, it was established that a considerable part of the experimental plants is in excellent and good condition precisely in this period of the growing season. However, *Aesculus hippocastanum* L. and *Tilia cordata* Mill. have signs of leaf defoliation for 60% and 45%, respectively, already at the beginning of summer, which further adversely affects the general condition of the plants. *Catalpa bignonioides* Walter. and *Platanus×hispanica* Mill. are represented by a small percentage in street tree stands, but according to the results of research, they have the best rating – over 90% of specimens are in good and excellent condition. Notably, during field surveys in dry weather, the leaves of *Catalpa bignonioides* were flabby, and at that time the decorativeness and general condition of the plants became significantly lower, but when moisture entered the soil, the leaves again had turgor and good condition. According to research data, *Acer platanoides* L., *Fraxinus excelsior* L., and *Robinia pseudoacacia* L. are highly resistant to urban conditions.

Having conducted a detailed inventory of street tree stands and assessing their general condition using two methods, considering the information in literary sources, a description of arboreal plants was compiled, considering their ecological, dendrological, and other features.

Acer L. Three distinct species of the genus *Acer* are found at the experimental sites in Kyiv: the sharp-leaved maple (*A. platanoides*), the silver maple (*A. saccharinum*), and the ash-leaved maple (*A. negundo*). Maple, in the conditions of Kyiv, has a height of up to 25 m (*A. saccharinum*), 30 m (*A. platanoides*), and 20 m (*A. negundo*). According

to the literature, different *Acer* species have different soil requirements [16]: *A. platanoides* grows well on all soils except peat, *A. saccharinum* needs fertile, moist, acidified, and drained soil, while *A. negundo* is the most undemanding. Compared to other species, *A. negundo* has lower frost resistance, a shorter lifespan, is an invasive species, but is characterized by high resistance to air pollution and some decorative forms. *A. saccharinum* can grow in the shade and tolerates soil salinity, which is vital in street tree stands. However, it has many developed superficial lateral roots, which need a large open surface, which cannot always be provided in urban conditions. But considering all the ecological “pros” and decorativeness, *A. platanoides* is more universal, as it can tolerate almost all adverse factors of urban conditions.

Aesculus L. *A. hippocastanum* and its hybrid *Aesculus×carnea* are among the most common trees in street tree stands, dominating due to their crown habit and decorativeness during flowering. *Aesculus×carnea* has better indicators of frost resistance, drought resistance and is less affected by *Cameraria ohridella*, which makes it much more hardy in urban environments [17].

Tilia Mill. In street tree stands, lindens are of immense importance as static plants that create a lot of shade, alley, and park trees. Due to their high regenerative capacity and durability, they are well suited for all types of urban plantings.

T. cordata and *T. platyphyllos* are two species of the genus *Tilia*, which are most often found in the street tree stands of the city of Kyiv, and at the same time differ from each other in their features. *T. cordata* easily adapts and

grows well on poor soils, requires less air humidity and nutrients, is wind resistant, less damaged by *Aphidoidea Latreille* compared to *T. platyphyllos*.

T. platyphyllos is light-demanding, frost-resistant, heat-demanding, does not tolerate dryness of the air and soil, creates shade, is sensitive to air pollution and salinity, is damaged by *Panonychus ulmi*, and therefore *T. cordata* has the advantage in outdoor tree stands.

Populus L. The genus *Populus* includes three deciduous tree species within the surveyed area, characterized by rapid growth, growing to massive and large trees. It is often used in street landscaping, but it is worth paying attention to the short lifespan and fragility of poplar with age. Their roots are aggressive, spread widely, raising the road surface, and causing damage to underground communications. *Populus nigra* L. and its subspecies *Populus nigra* var. *pyramidalis* Spach are the most common in landscaping in Kyiv. The main difference between them is the crown shape and the life span since it is much greater in *P. nigra*. Both plants are light-demanding, frost-resistant, wind-resistant, and heat-demanding, but *P. nigra* var. *pyramidalis* tends to be damaged by diseases and fungal infections, at the age of 40 the tree becomes brittle.

Robinia L. *R. pseudoacacia* is very heat-demanding, tolerates heat, drought and salinity well, is undemanding to soils and is well suited for landscaping extreme inner-city facilities. This species is promising in the street tree stands of megacities.

Fraxinus L. For landscaping, ash trees are important

as a fast-growing and long-lived plant that is used for street landscaping. *F. excelsior* is light-demanding, tolerates light shade and partial shade. Prefers fairly fresh, moist, fertile and well-drained soils, dislikes compacted and too wet soils. Young trees are damaged by late frosts, it is wind-resistant, has a high regenerative capacity, and the top dries up when the groundwater level drops.

Platanus L. *Platanus* × *hispanica* Mill. ex Münchh. is a deciduous tree that grows up to 20-30 m in height, and in recent years has often been planted on the streets of Kyiv. Prefers growth in the sun or light shade. Undemanding to the soil, it grows well on very dry soils if they are not too poor. Features: frost-resistant, heat-loving, smoke- and gas-resistant plant, grows well after shaping and rejuvenating cutting [18].

Catalpa Scop. *Catalpa bignonioides* Walter in urban conditions grows to a height of 10-15 m. It has a tap root system and thick, fleshy roots. Prefers the sunny side and a place protected from the wind. It is unpretentious to soils, tolerates dryness well. On dry, not very fertile soils, shoots ripen better, are less damaged by frost, resistant to urban and industrial environments [16].

Based on the study of the current state, ecological and physiological features of the growth of arboreal plants in ordinary street tree stands, it is possible to single out the species that are the main ones, and which can be used as supplementary ones. Some species from the main category will eventually be included in supplementary ones and vice versa (Table 2).

Table 2. Distribution of the assortment of arboreal plants in the street tree stands of Kyiv

Item No.	Plant name	Assortment	
		main	supplementary
1	<i>Acer negundo</i>		+
2	<i>Acer platanoides</i>	+	
3	<i>Acer saccharinum</i>		+
4	<i>Aesculus hippocastanum</i>	+	→
5	<i>Aesculus</i> × <i>carnea</i>		←
6	<i>Catalpa bignonioides</i>		←
7	<i>Fraxinus excelsior</i>		←
8	<i>Platanus</i> × <i>hispanica</i>		←
9	<i>Populus nigra</i>	+	→
10	<i>Populus nigra</i> var. <i>pyramidalis</i>	+	→
11	<i>Quercus robur</i>		+
12	<i>Robinia pseudoacacia</i>		←
13	<i>Sorbus aucuparia</i>		+
14	<i>Tilia cordata</i>	+	
15	<i>Tilia platyphyllos</i>		+

Tree species *Aesculus hippocastanum*, *Populus nigra*, and *Populus nigra* var. *Pyramidalis* will eventually be used as a supplementary assortment of plants for greening row plantings along the streets, while *Aesculus*×*carnea*, *Catalpa bignonioides*, *Fraxinus excelsior*, *Platanus*×*hispanica*, and *Robinia pseudoacacia* are included in the main assortment. The recommended assortment of tree plants for street tree stands in Kyiv will be supplemented as a result of further

research among rare species and analysis of the general condition of plants within the entire growing season.

Conclusions

The species composition of street tree stands in Kyiv is represented by about 20 species of arboreal plants, although the most common are five: *Tilia cordata*, *Aesculus hippocastanum*, *Populus nigra*, *Acer platanoides*, *Robinia pseudoacacia*.

On the streets of the city, over the past decades, there has been a tendency to change the species composition of arboreal plants in ordinary street tree stands. Thus, compared to 2009, the number of *Fraxinus excelsior*, *Robinia pseudoacacia*, *Catalpa bignonioides*, *Platanus hispanica* increased on the streets under study. The analysis of the general state of the plants gives reasons to substantiate the replacement of *Aesculus hippocastanum*, *Populus nigra* with the above-mentioned species.

Characterization of the general state of plants according to the lost photosynthetic surface indicates early defoliation of the leaf surface in *Aesculus hippocastanum* and *Tilia cordata* and points to high positive indicators in *Robinia pseudoacacia*, *Acer platanoides*.

Based on the results of research, it can be stated that representatives of the family *Robinia* L., *Fraxinus* L., *Platanus* L., *Catalpa* Scop. are those plants that can withstand the urban and anthropogenic load in street tree stands, although without proper agrotechnical measures the plants have fewer opportunities.

A limited number of species of arboreal plants grow in street tree stands, which is associated with special requirements for them, namely: a straight trunk, a high raised dense crown, the possibility of formative pruning, resistance to urbanogenic factors. It is these plants that should form the basis for street tree stands, and the rest of the species should be used for addition and accentuation. In the future, it is planned to investigate the stress resistance of street arboreal plants.

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Сучасний стан декоративних деревних рослин у рядових вуличних насадженнях м. Києва

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Анотація. Підвищення рівня антропогенного навантаження в урбокомплексах призводить до негативних екологічних змін середовища. Міські насадження здатні дещо згладжувати ці недоліки шляхом їх впливу на мікроклімат в межах локальної території. Згідно статистичних даних, щороку показник забезпеченості жителів міста Києва зеленими насадженнями знижується, що, зокрема, викликано незадовільним станом вуличних насаджень. Основною метою публікації є висвітлення результатів дослідження щодо асортименту деревних рослин, оцінки їх загального стану на найбільш навантажених вулицях та проспектах м. Києва та надання рекомендацій щодо створення перспективного списку рослин для міського вуличного озеленення. У статті проаналізовані дані інвентаризації, яка проводилася в межах рядових вуличних насаджень у 2021 році. Визначено, що найбільш поширеними вуличними насадженнями є *Tilia cordata*, *Aesculus hippocastanum* та *Populus nigra*. Проведений порівняльний аналіз щодо основного асортименту рослин у вуличних насадженнях м. Києва за 2009 та 2021 роки та встановлено, що зменшилася кількість *Aesculus hippocastanum* та *Populus nigra* та збільшився відсоток *Robinia pseudoacacia*, *Fraxinus excelsior*. Оцінка загального стану рослин вказує на те, що найбільша частка рослин знаходиться у задовільному стані – 50 %. Найкращий стан відмічено у *Robinia pseudoacacia*, *Acer platanoides* та *Tilia cordata*. Звертається увага на загальний стан деревних рослин за відсотком недіючої фотосинтезуючої поверхні та виявлена висока стійкість до міських умов *Acer platanoides*, *Fraxinus excelsior* та *Robinia pseudoacacia*. Аналіз дослідних даних дає підстави визначити основний та додатковий асортимент деревних видів рослин, які рекомендовані для використання в озелененні вулиць з подальшим вивченням їх стресостійкості

Ключові слова: дендрофлора, загальний стан, деревні рослини, асортимент, дефоліація