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Assessment of drought resistance in plants of the genus *Aristolochia* L.

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Abstract. The examination of plant resistance to drought is becoming increasingly relevant due to global warming. All species of the genus *Aristolochia* L. possess high decorative qualities and play an important role in natural ecosystems. However, under conditions of temperature imbalance, their ornamental value may decrease due to leaf turgor loss and even leaf shedding. The purpose of the paper is to highlight the results of studies on the drought resistance assessment of *Aristolochia* L. plant species to identify the most promising taxa suitable for cultivation in the city of Kyiv. The study was conducted in 2022 on three species of vines: *Aristolochia macrophylla* Lam., *A. tomentosa* Sims., *A. manshuriensis* Kom., which grow in the M.M. Gryshko National Botanical Garden (Kyiv). The study presented results on leaf hydration parameters, water deficit, water-holding capacity of leaves, electrical conductivity, and specific leaf area conducted in the Plant Physiology and Microbiology Laboratory of the Institute of Horticulture, National Academy of Agrarian Sciences

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of Ukraine. Field assessment of *Aristolochia* L. plant drought resistance was also conducted. It was established that *Aristolochia macrophylla* Lam. is the most drought-resistant species, exhibiting low transpiration rates and high water-holding capacity. *Aristolochia tomentosa* Sims. it is the least drought-resistant species, which therefore needs additional care. In field conditions, significant signs of wilting were not observed, indicating that leaves reduce turgor during the day and recover at night. It is also important to preserve the environment in which these plants grow, as its changes affect the drought tolerance and life cycle of lianas. The results of the drought resistance research on *Aristolochia* L. plants point to the potential of these species. They can be used for selecting plant assortments for creating various types of plantations in urban environments

Keywords: water retention capacity; water deficiency; water content; lianas, electrical conductivity

Introduction

Insufficient moisture and the influence of high temperatures on plants during the summer period often have a negative impact on the state of decorative qualities, the appearance of foliage, flowers, and fruits. Vines can be beneficial for greening in drought conditions as they usually have deep roots and the ability to store water in their stems and leaves. Analysis of the impact of drought on vines is necessary for several reasons: climate change, the importance of lianas for ecosystems, industrial and medicinal uses, and biodiversity conservation.

Due to global climate change and the consequences of war, the state of Ukrainian lands is deteriorating, which pushes its ecosystems almost to the verge of destruction. According to UN forecasts, by 2050, drought could affect more than three-quarters of the world's population (Espinosa, n.d.). According to an all-Ukrainian sociological survey by O. Mar'iuk *et al.* (2021), it was mentioned that since 2000, the number and duration of droughts have increased by 29% compared to previous decades. Forest restoration is the largest natural climate solution that could potentially reverse the biodiversity crisis, especially in tropical countries. H.P. Griscom (2020) claimed that almost half of all inventoried trees in dry tropical forests (44%) have at least one vine crawling on them, with the most common species being *Bauhinia glabra* Jacq. and *Macherium microfolium*.

From the study of S.G. Boychenko & O.G. Zabarna (2019), it can be seen that in recent years, there has been a trend towards increasing average monthly temperatures in the summer in Kyiv. A large number of plantations, especially urban ones, are in areas with limited water supply. In such conditions, the water-holding capacity of leaf tissues and the ability to repair physiological processes after the effects of drought are particularly important, and similar studies in Ukraine were conducted fifteen or more years ago (Kyryliuk 2005).

A.I. Kolesnikov (2018) concluded that species of the genus *Aristolochia* L. are perennial herbaceous plants with smooth upright or twining stems or woody lianas. They are distributed in tropical, and less frequently, temperate zones. The root system consists of short creeping rhizomes. Their size can be larger than that of trees, which has a positive impact on the plant condition during drought. However, as with any plant, prolonged and severe drought can have a negative effect on this plant genus. In particular, *Aristolochia* L. can react to drought by reducing the size and colour of its foliage. In addition, these plants can temporarily reduce the growth rate of new shoots and leaves. Species of the genus *Aristolochia* L. can store water in their roots and stems and use it when needed. Research on *Aristolochia bracteolata* Lam. revealed its ability to survive even in hot dry summer conditions. With moderate to severe water scarcity, the moisture content does not significantly decrease. P. Madhuri *et al.* (2021) established that increased tannin content during drought in plants indicates an oxidative role and protection of tannins in dry conditions. Warming can also affect the interaction of plants with other trophic levels, including herbivores. M. Gonzalez-Teuber *et al.* (2023) found that warming did not considerably affect the productivity of the species *Aristolochia chilensis* Bridges ex Lindl., but it led to changes in leaf nutrient content. Larvae that fed on heat-treated plants demonstrated enhanced growth and efficient food conversion. Furthermore, as asserted by S. Nath *et al.* (2022), some *Aristolochia* L. species are economically important due to the presence of secondary metabolites and wide usage in traditional and modern medicine. Consequently, most recent studies focused on genetic and biotechnological aspects, with little emphasis on the ecological features of these lianas.

The purpose of this study is to evaluate the drought resistance of *Aristolochia* L. plants using laboratory and field methods, with the intention of recommending their use for greening in Kyiv. The research objectives included determining the physical and biochemical parameters of plants under hydrothermal stress conditions, which form the basis for identifying functionally related characteristic complexes with the action of protective mechanisms and exploring the water regime as part of the overall metabolic exchange process to assess the state of introduced species in the urban conditions of Kyiv. Based on the obtained data, the study aimed to recommend the most promising plants capable of adapting to stressful situations created by climatic conditions during the vegetation period.

Materials and Methods

For the study, plants of the genus *Aristolochia* L. were selected (*Aristolochia macrophylla* Lam. – native to North America, *Aristolochia manshuriensis* Kom. – native to Northeast China and Korea, *Aristolochia tomentosa* Sims. – native to North America).

The physiological characteristics of *Aristolochia L.* plants were investigated in the Plant Physiology and Microbiology Laboratory of the Institute of Horticulture, National Academy of Agrarian Sciences of Ukraine. The experiments were conducted in July 2022. Samples were taken early in the morning, placed in sealed bags, and delivered to the laboratory. Three samples were taken for each plant species for the experiment. During the study, the Convention on Biological Diversity (1992) standards were observed.

To identify drought-resistant varieties, the water-holding capacity of leaves, their water deficit, ability to regain turgor, and tissue hydration were determined (Eremin & Gasanova, 1999).

For the determination of the total water content, 5-10 leaves of each variety were placed in metal boxes (with double repetition) and dried in a thermostat at a temperature of 105°C until a stable mass was achieved.

The total amount of water (B) as a percentage of the raw weight of the suspension is determined by the formula:

$$B = \frac{в-c}{в-a} \times 100\%, \qquad (1)$$

where a is the mass of the empty box (g); b is the mass of the box with the fresh weight (g); c is the mass of the box with the dry weight (g).

Water deficit (WD) was studied over time (at 2, 4, 6, and 24 hours). To determine water deficit, leaves (3 each from every species) were weighed and placed in a flask with water for saturation. The flasks were placed in a crystalliser with water and covered with a similar crystalliser to create an air chamber. After 24 hours of saturation, the leaves were blotted with filter paper and weighed.

The water deficit in the leaves (as a percentage of the total water content in a fully saturated state) was calculated using the formula:

$$B = \frac{M2-M1}{M3-M} \times 100\%, \quad (2)$$

where M is the mass of dry weight; M1 is the mass of water before saturation; M2 is the mass of water after complete saturation; M3 is the mass of leaves after full saturation with water.

The drought resistance, particularly water-holding capacity during wilting, was determined over specific time intervals (2, 4, 8, 24 hours). To assess moisture deficit, samples were immersed in room-temperature water for 30 minutes, then blotted with paper towels to remove surface water. The calculation of moisture deficit was performed as a percentage of the mass of water-saturated leaves. In field conditions, the drought resistance of *Aristolochia* L. plants was determined using the S. Piatnytskyi scale (1961). This scale allows the assessment of plant drought resistance on a scale from 0 to 5 based on external signs of their condition: 0 points – the plant dies from drought; 1 point – leaves fall off, tips of shoots dry out; 2 points – more than half of the leaves and some shoots dry out; 3 points – less than half of the leaves are affected; 4 points – leaves lose turgor during the day but regain it overnight; 5 points – the plant is not affected by drought.

Specific leaf surface density (*SLSD*) is a morphological characteristic that significantly influences plant productivity (Sedov & Ogoltsova, 1999). It is measured in g/cm^2 and calculated using the formula:

$$SLSD = LM/LA, \quad (3)$$

where *LM* is the leaf mass and *LA* is the leaf area.

For the determination of electrical conductivity, the E 7-13 conductivity meter (manufacturer – radio measuring equipment factory, Zolochiv, Ukraine) was used with needle-like molybdenum electrodes and a distance of 9 mm between them, following the method of V.V. Torop *et al.* (2002). This device operates by measuring the resistance of the electrolyte in the solution, which is proportional to its electrical conductivity.

Results and Discussion

An important element of assessing the physiological state of plants during water deficit is their ability to maintain an optimal level of leaf tissue hydration. Determining the water-holding capacity of *Aristolochia* L. plants allows for establishing their capacity to retain water after wilting. This feature provides high drought resistance (Krivoshapka *et al.*, 2012). In Table 1, it can be observed that when investigating the total moisture content under laboratory conditions, the level of leaf hydration of the investigated *Aristolochia* L. species ranged from 69.1% (*Aristolochia macrophylla* Lam.) to 72.8% (*Aristolochia manshuriensis* Kom.).

Table 1. Water content of leaves of plants of the genus *Aristolochia* L., %

Species name	Water content, %			
	Sample No.1	Sample No.2	Sample No.3	Average value
Aristolochia macrophylla Lam.	73.9	66.7	66.7	69.1
Aristolochia tomentosa Sims.	69.3	69.7	70.5	69.8
Aristolochia manshuriensis Kom.	74.2	71.8	72.4	72.8

Source: compiled by the authors

Leaf water deficiency shows the stability of water homeostasis during drought. It depends on various factors, such as climatic conditions, seasonal changes, and the environment in which the liana grows. Many *Aristolochia* L. lianas have the ability to survive in water deficit conditions. They can possess large and deep root systems, allowing them to extract moisture from deeper soil layers. The average values of the studied species, according to Table 2, did not exceed 13.99%, indicating high drought resistance of the plants.

Table 2. Water deficiency of plant leaves of *Aristolochia* L., %

Species name	Water deficiency, %			
	Sample No.1	Sample No.2	Sample No.3	Average value
Aristolochia macrophylla Lam.	12.37	12.19	11.11	11.89
Aristolochia tomentosa Sims.	12.97	13.23	15.77	13.99
Aristolochia manshuriensis Kom.	13.10	12.00	11.94	12.35

Source: compiled by the authors

The lowest water deficit was found in *Aristolochia macrophylla* Lam. – 11.89%, and the highest in *Aristolochia tomentosa* Sims. – 13.99%. Moreover, a high water deficit value was observed in *Aristolochia manshuriensis* Kom. – 12.35%. This indicates a lower adaptive potential for drought. Leaf water holding capacity reflects their ability to retain water during drought and can indicate the behavior of plants in extreme conditions.

Some *Aristolochia* L. liana species are specially adapted to collect and retain water. Their leaves can have a fairly large surface that collects dew and precipitation. In addition, some species of *Aristolochia* L. have a robust and spongy leaf structure, which enables them to retain moisture and enhance water holding capacity. Overall, *Aristolochia* L. lianas have the ability to retain a certain amount of moisture, although their exact capacity to do so may vary depending on the species and the environment in which they grow. Studies on water retention capacity during drying revealed that in the first 2 to 4 hours, the leaves of *Aristolochia* L. lianas lost the most water.

The highest water retention capacity was found in *Aristolochia macrophylla* Lam. After 24 hours of air drought, the remaining water content was 72.6%, as can be seen in Figure 1.

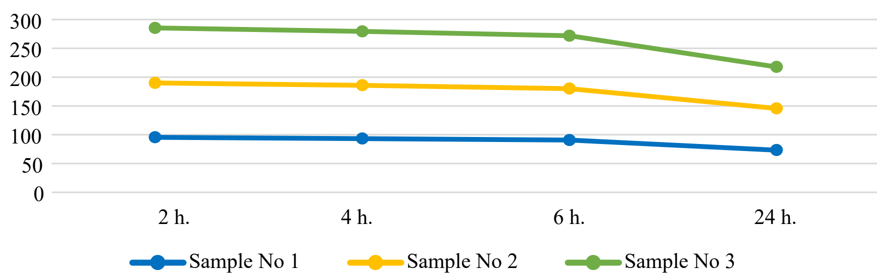

Figure 1. Water retention capacity of the leaves of *Aristolochia macrophylla* Lam

Source: compiled by the author

In the first 2 hours, the remaining water content in the leaves of *Aristolochia macrophylla* Lam. was 95.12%. After 4 hours of water loss, the remaining content was 93.1%, and after 6 hours, it was 90.6%. This indicates that this species is drought-resistant and capable of withstanding dry climatic conditions.

The liana *Aristolochia tomentosa* Sims. possesses large leaves covered with dense hairs. The presence of such dense hairs suggests that they might have adaptations for water conservation. These hairs could also help reduce water loss by creating a barrier that slows down evaporation from the leaf surface and retains moisture nearby. However, our research showed that within the first 2 hours, the remaining water content in *Aristolochia tomentosa* Sims. was 90.08%. Figure 2 illustrates that the critical measure of water loss is the value after 24 hours of dryness exposure.

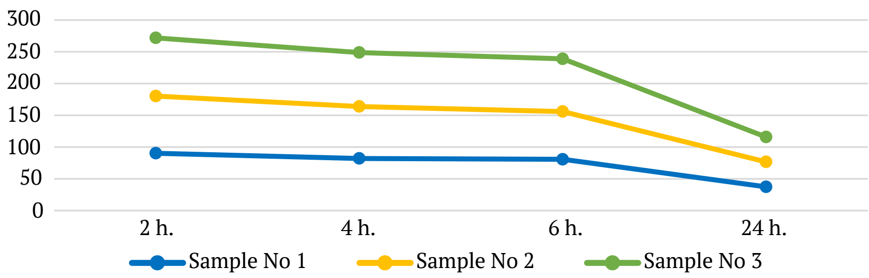

Figure 2. Water retention capacity of the leaves of *Aristolochia tomentosa* Sims
Source: compiled by the author

Therefore, *Aristolochia tomentosa* Sims. has a water retention capacity of 37.36% after 24 hours of air-dry exposure, indicating its lower drought resistance compared to other species. The least water loss in the first 2 hours was observed in *Aristolochia manshuriensis* Kom. – the remaining content was 95.8%. The remaining water content after 24 hours of exposure in *Aristolochia manshuriensis* Kom. was 62.22%, indicating better drought resistance (Fig. 3).

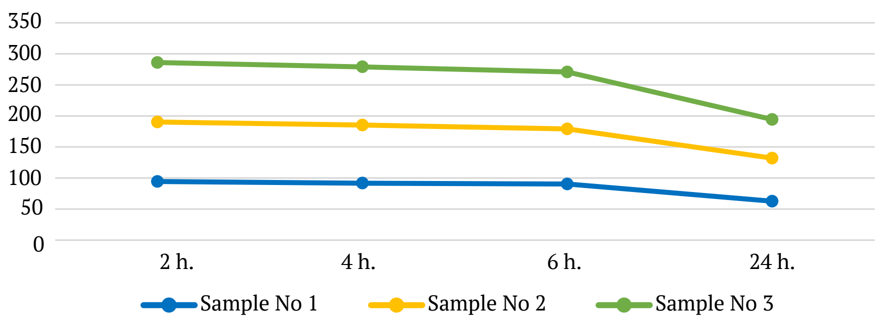

Figure 3. Water retention capacity of the leaves of *Aristolochia manshuriensis* Kom.
Source: compiled by the author

After 24 hours of air-dry exposure, as depicted in Figure 4, it is visually evident that *Aristolochia macrophylla* Lam. possesses the highest water retention capacity, which is also confirmed by laboratory measurements. The leaves of *Aristolochia tomentosa* Sims. experienced the most significant negative impact from dryness, indicating lower drought resistance compared to *Aristolochia manshuriensis* Kom. and *Aristolochia macrophylla* Lam.

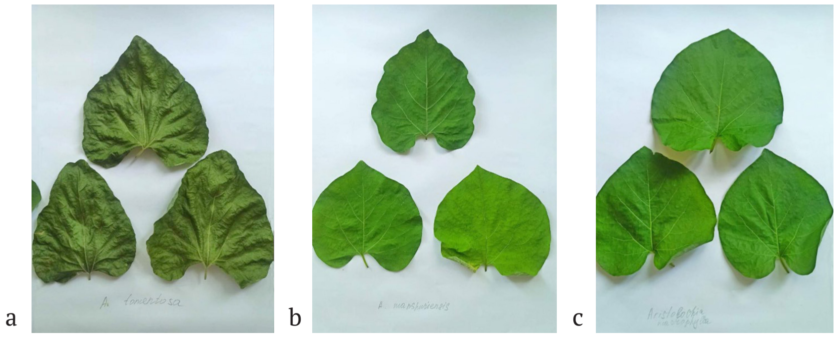

Figure 4. The leaves of *Aristolochia* L. after 24 hours of air drought
Note: a – *Aristolochia tomentosa* Sims., b – *Aristolochia manshuriensis* Kom., c – *Aristolochia macrophylla* Lam
Source: photographed by the authors

The electrical conductivity of plant leaves is closely related to their drought resistance. This process in plants can occur due to the presence of ions that can be transported through plant tissues. Furthermore, the reduced water content in leaves can decrease electrical conductivity since water is a good conductor of electricity. Therefore, plants with high ion content and low leaf moisture may be more drought-tolerant. Upon completing the investigation to assess the leaf electrical conductivity levels in *Aristolochia L.* plants over a 24-hour period, it is evident from Figure 5 that there is an inverse relationship between water depletion and electrical conductivity. As the plant expends more water, the electrical conductivity decreases.

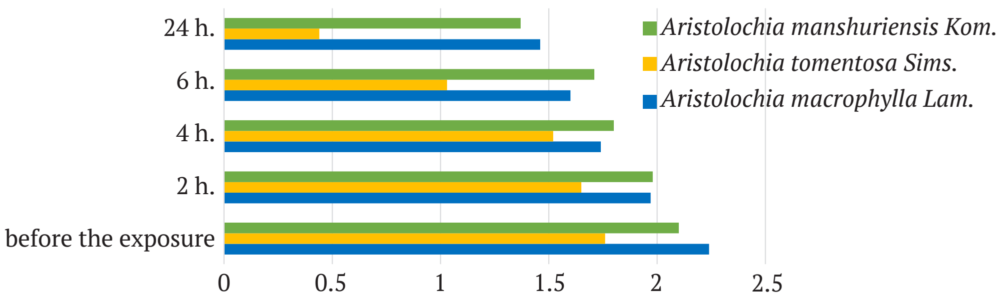

Figure 5. Electrical conductivity level of plant leaves of *Aristolochia* L., mS
Source: compiled by the author

Plant leaves typically consist of various tissues and cells that contain fluids, which can contain certain amounts of electrolytes. However, leaf electrical conductivity often tends to be lower compared to other plant parts like stems or roots. According to the measurement results, *Aristolochia macrophylla* Lam. exhibits the highest level of electrical conductivity among *Aristolochia* L. liana species, indicating its greater drought resistance.

V.V. Makovskyi & N.H. Vakhnovska, (2019) conducted experimental studies on drought resistance in liana species from the *Ampelopsis* Michx. and *Parthenocissus* Planch. genera. They concluded that the higher drought resistance of *Ampelopsis* Michx. species is due to more pronounced xeromorphic features in leaf surface anatomy, higher water retention capacity, and lower leaf water deficit levels, all of which contribute to a higher degree of adaptive potential. A gradual decrease in the electrolytic conductivity of leaves during their wilting indicates a high resistance of the studied introducers to atmospheric drought. This theory is supported by studies on *Aristolochia* L. liana species.

Plants with a more active photosynthetic apparatus tend to accumulate more dry matter per unit leaf area under optimal conditions. Lianas usually grow in dry or hot environments, so they can have leaves with a high surface density, which helps reduce moisture evaporation through the leaf plate. This may be due to the waxy coating of the leaves, a large number of hairs, or the presence of stomata (pores on the leaves) that regulate gas exchange and evaporation (Table 3).

Table 3. Specific leaf surface density of *Aristolochia* L. plants, g/cm²

Species name	SLSD, g/cm²			
	Sample No.1	**Sample No.2**	**Sample No.3**	**Average value**
Aristolochia macrophylla Lam.	1.84	8.59	5.87	5.43
Aristolochia tomentosa Sims.	3.72	2.77	2.35	2.95
Aristolochia manshuriensis Kom.	3.30	5.49	3.57	4.12

Source: compiled by the authors

Research results indicate that *Aristolochia macrophylla* Lam. exhibits the highest SLSD values (5.43 g/cm²), while *Aristolochia tomentosa* Sims. has the lowest (2.95 g/cm²). Furthermore, *Aristolochia manshuriensis* Kom. shows a high SLSD value (4.12 g/cm²). It affects the effectiveness of transpiration. Leaves with high density tend to have reduced evaporation surface area, aiding the plant in water conservation and adaptation to water-limited conditions.

Conversely, the low SLSD of *Aristolochia tomentosa* Sims. leaves suggests that they might evaporate more water through their surface. This can be a problem in arid and hot climates when the plant can quickly lose moisture. High SLSD in *Aristolochia macrophylla* Lam. indicates a greater number of cells and tissues per unit area, potentially an adaptation to optimise photosynthetic surface. Such leaves reduce evaporation through their surface and preserve resources.

A.A. Wright *et al.* (2014) found that lianas are vital components of tropical forests, accounting for up to 35% of tree species diversity. Removing trees improved the survival of planted seedlings compared to liana removal, likely due to reduced competition for light. In contrast, lianas negatively impacted drought-resistant *Dipteryx oleifera* Benth. seedlings during the dry season, potentially due to water competition. On a local scale, lianas and trees have distinct impacts on understory dynamics, with lianas potentially exerting stronger competition during dry seasons, while trees compete more intensely for light.

In the pantropical region, liana density increases with reduced precipitation and heightened seasonality. The findings of I. Maréchaux *et al.* (2017) suggest that this pattern has led to the hypothesis that lianas demonstrate a growth advantage over trees in dry conditions. Liana leaves were less resistant to drought than trees during the wet season, but achieved similar drought resistance during the dry season. Stronger osmotic adjustments in lianas contribute to maintaining turgor pressure, a crucial precondition for carbon uptake, growth, and liana success compared to trees under drier conditions.

Lianas are a significant component of neotropical forests, and their biomass and numbers are increasing. Lianas are particularly abundant in seasonally dry tropical forests, leading to the hypothesis that they are better adapted to drought and possess an advantage in high-light environments in these forests. Lianas have a deeper root system than trees. They primarily capitalise on growth advantages during wet periods, where they are less vulnerable to cavitation and can achieve high conductivity. However, research by M.T. van der Sande *et al.* (2013) indicates that hydraulic characteristics and functional traits studied do not explain differences in the distribution of lianas and trees in seasonal forests.

The average monthly temperature in July in Kyiv is +20.5°C. Absolute maximum is +39.9°C (August 1898). P.A. Kravchuk (2011) established that air temperature in Kyiv is generally a few tenths of a degree higher than in surrounding cities. The average annual precipitation in Kyiv is about 619 mm. Humidity in Kyiv is most often high. Considering actual weather observations in Kyiv and the global trend of rising annual temperatures, O. Mar'iuk *et al.* (2021) concluded that climate change is occurring within the city. The climatic summer arrives in Kyiv in early to mid-May when the average daily temperature rises above +15°C and typically ends in mid to late September, lasting about one month, or two months longer in particularly hot years.

Drought resistance indicates the ability of plants to maintain an optimal water level in leaf tissues under adverse environmental factors. M.D. Kushnirenko *et al.* (1975) noted that examining and determining drought resistance enables the identification of plant species suitable for cultivation under specific climatic conditions. This can improve the condition of plantings and enhance the technology of their cultivation. Tissue hydration of leaves is an indicator that defines the overall water content within a plant's organs. M.D. Kushnirenko (1975) concluded that leaves are typically the primary part of a plant responsible for photosynthesis and playing a crucial role in moisture retention. They contain a significant amount of water, particularly in cells located within the leaf mesophyll. In dry conditions, especially during water deficit, leaves can lose water more rapidly, resulting in reduced tissue hydration.

In his study, A.I. Kolesnikov (2018) asserted that species of the genus *Aristolochia* L. are widespread in tropical, and less commonly in temperate zones. Species within this genus have simple leaves, often with a heart-shaped form, arranged alternately on petioles. Leaf size varies across species, ranging from 10 to 30 cm in diameter.

Based on these findings, the assessment of plant drought resistance under field conditions revealed no significant signs of wilting among *Aristolochia* L. species. According to S. Piatnytskyi's scale (1961), the evaluated plants received a score of 4, indicating that leaves reduce turgor during the day and recover it at night. In wet conditions, when water availability is high, water content may be higher. Leaf hydration within *Aristolochia* L. lianas can vary depending on the plant's growth conditions. O. Bahatska's data (2008) for the years 2003-2007 suggest slightly higher drought resistance scores ranging from 4.6 to 4.8, despite similar temperature indicators.

N.O. Boiko *et al.* (2019) investigated the biological and ecological properties of woody lianas in Ukraine using a drought resistance assessment scale for the city of Kherson, where drought resistance is a critical indicator. According to their study, the highest drought resistance scores were found only in *Fallopia baldshianica* and *Wisteria sinensis*. Most species exhibited lower levels of drought resistance, ranging from moderately to weakly drought resistant.

Aristolochia bracteolata Lam., belonging to the family *Aristolochiaceae Juss*., thrives even under scorching dry summer conditions. The paper by P. Madhuri *et al.* (2021) described in detail that with moderate to severe water scarcity, the moisture content does not decrease significantly and the high moisture content persists even in conditions of water scarcity. The authors found that with increased water stress, moisture content experienced minimal reduction, indicating the plant's ability to sustain water status even under water scarcity. Elevated tannin content during drought suggests an oxidative role and protection of tannins under arid conditions.

Conclusions

Drought resistance is a vital trait for plants used in vertical greening. t indicates the ability of lianas to withstand physical stress and weight when they grow and cling to support structures. Lianas of the genus *Aristolochia* L. possess sturdy and flexible stems that enable them to bear the weight of leaves and fruits as they grow and intertwine. This characteristic allows them to create intriguing compositions in gardens or around buildings. Lianas exhibit certain adaptations that enable them to be drought-resistant and survive in conditions of limited water availability.

Through studies of drought tolerance in *Aristolochia* L. species growing within the territory of the M.M. Gryshko National Botanical Garden (Kyiv), it has been established that *Aristolochia macrophylla* Lam. is the most drought-resistant species. The average drought resistance indicator is observed in *Aristolochia manshuriensis* Kom. Despite having leaf structures with hairs, which should contribute to better drought resistance, *Aristolochia tomentosa* Sims. did not exhibit such resistance, and it showed the lowest drought resistance among these liana species. In general, analysing the impact of drought on *Aristolochia* L. lianas using field methods has determined that all species can withstand brief periods of drought without significant morphological changes and without losing their decorative qualities. Drought-tolerant foliage enhances the plant's decorative appearance and adds interest. The leaves exhibit attractive colour shades, contributing to their uniqueness.

It is worth considering that the drought resistance of *Aristolochia* L. lianas can also depend on factors such as the condition and quality of the support structures they grow on, which warrants further investigation. In the future, there are plans to examine the creation of plantings for various purposes, especially in conditions with limited water access. This would allow recommending *Aristolochia macrophylla* Lam., *Aristolochia manshuriensis* Kom., and *Aristolochia tomentosa* Sims. species for use in the greening of Kyiv.

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None.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Bahatska, O. (2008). *Peculiarities of the growth and development of the introduced species of woody vines and the prospects of their use in landscaping in Kyiv* (PhD thesis, National Agrarian University, Kyiv, Ukraine).

[2] Boiko, T.O., Dementieva, O.I., & Kotovska, Y.S. (2019). Assessment of biological and ecological properties of woody lianas in the conditions of the city of Kherson. *Scientific Bulletin of UNFU*, 29(5), 31-35. doi: 10.15421/40290506.

[3] Boychenko, S.G., & Zabarna, O.G. (2019). Estimation of comfort of weather conditions and trends of their changes for the Kyiv region in the conditions of climate change. *Geofizicheskiy Zhurnal*, 41(6), 128-143. doi: 10.24028/gzh.0203-3100.v41i6.2019.190071.

[4] Convention on Biological Diversity. (1992). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[5] Eremin, G., & Gasanova, T. (1999). The study of heat resistance and drought resistance of varieties. In *Program and methods of variety study of fruit, berry and nut crops* (pp. 80-85). Orel: VNIISPK.

[6] Espinosa, P. (n.d.). *Climate calls for a unity of purpose*. Retrieved from https://www.un.org/en/climatechange/patricia-espinosa-a-unity-of-purpose.

[7] Gonzalez-Teuber, M., Palma-Onetto, V., Aguirre, C., Ibáñez, A.J., & Mithöfer, A. (2023). Climate change-related warming-induced shifts in leaf chemical traits favor nutrition of the specialist herbivore Battus polydamas archidamas. *Frontiers in Ecology and Evolution*, 11, article number 1152489. doi: 10.3389/fevo.2023.1152489.

[8] Griscom, H.P. (2020). The long-term effects of active management and landscape characteristics on carbon accumulation and diversity within a seasonal dry tropical ecosystem. *Forest Ecology and Management*, 473, article number 118296. doi: 10.1016/j.foreco.2020.118296.

[9] Kolesnikov, A.I. (2018). *Decorative dendrology*. Kharkiv: Zolotye stranitsy.

[10] Kravchuk, P.A. (2011). *The book of nature records*. Lutsk: Volyn Regional Printing House PJSC.

[11] Kryvoshapka, V.A., Kytaiev, O.I., Shevel, L.O., & Kondratenko, V.V. (2012). Assessment of drought resistance of Chinese aster varieties and hybrids (*Callistephus chinensis* Nees.). *Sadivnytstvo*, 65, 209-215.

[12] Kushnirenko, M.D. (1975). Quantitative changes in the pigment complex on the leaves of various wheat varieties under the influence of drought stress. In *Physiology of water exchange and drought resistance of fruit plants* (p. 216). Kishinev: Shtiintsa.

[13] Kushnirenko, M.D., Kurchatova, G.P., & Kryukova, E.V. (1975). *Methods for assessing the drought resistance of fruit plants*. Kishinev: Shtiintsa.

[14] Kyryliuk, V. (2005). Study of drought resistance of species of the genus *Lonicera* L. in the conditions of the city of Kyiv. In *Actual problems of research and conservation of phytodiversity* (pp. 160-161). Uman.

[15] Madhuri, P., Shashikant, C., & Chandrashekhar, M. (2021). Response of secondary metabolites in *Aristolochia bracteolata* Lam. under water stress regimes. *Journal of Stress Physiology & Biochemistry*, 17(4), 60-66.

[16] Makovskyi, V.V., & Vakhnovska, N.H. (2019). Drought tolerance of woody vines of the Vitaceae Juss. family under conditions of introduction in the Right-Bank Forest-Steppe of Ukraine. *Plant Varieties Studying and Protection*, 15(1), 51-58. doi: 10.21498/2518-1017.15.1.2019.162482.

[17] Mar'iuk, O., Zhavzharova, T., Tsyhryk, M., Kolishevskyi, Y., Skydaniuk, M., & Fursik, O. (2021). *Climate change and climate adaptation (All-Ukrainian sociological survey and recommended measures for adaptation to climate change)*. Kyiv: Ukrainian Climate Network.
[18] Maréchaux, I., Bartlett, M.K., Iribar, A., Sack, L., & Chave, J. (2017). Stronger seasonal adjustment in leaf turgor loss point in lianas than trees in an Amazonian forest. *Biology Letters*, 13(1), article number 20160819. doi: 10.1098/rsbl.2016.0819.
[19] Nath, S., Ghosh, N., Ansari, T.A., Mundhra, A., Patil, M.P., Mane, A., Gopalakrishnan, A.V., Rahman, M.H., Kumar,M., Radha, Ghorai, M., Paul, S., & Dey, A. (2022). Genetic diversity assessment and biotechnological aspects in *Aristolochia* spp. *Applied Microbiology and Biotechnology,* 106, 6397-6412. doi: 10.1007/s00253-022-12152-1.
[20] Piatnytskyi, S. (1961). *Workshop on forest selection*. moscow: Selkhozyzdat.
[21] Sedov, E.N., & Ogoltsova, T.P. (Eds.). (1999). *Program and methodology for variety study of fruit, berry and nut crops*. Orel: VNIISPK.
[22] Torop, V.V., Yareshchenko, O.M., & Sylaieva, A.M. (2002). The method of determining the drought resistance of berry crops based on the electrical conductivity of the leaves. *Sadivnytstvo*, 54, 237-244.
[23] van der Sande, M.T., Poorter, L., Schnitzer, S.A., & Markesteijn, L. (2013). Are lianas more drought-tolerant than trees? A test for the role of hydraulic architecture and other stem and leaf traits. *Oecologia*, 172(4), 961-972. doi: 10.1007/s00442-012-2563-x.
[24] Wright, A., Tobin, M., Mangan, S., & Schnitzer, S.A. (2014). Unique competitive effects of lianas and trees in a tropical forest understory. *Oecologia*, 177(2), 561-569. doi: 10.1007/s00442-014-3179-0.

Оцінка посухостійкості рослин роду *Aristolochia* L.

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Анотація. Дослідження стійкості рослин до посухи стає дедалі більш актуальним питанням у зв'язку з глобальним потеплінням. Усі види роду *Aristolochia* L. мають високі декоративні якості та відіграють важливу роль у природних екосистемах. Але в умовах дисбалансу температурного середовища декоративність може знижуватись внаслідок втрати тургору листя і, навіть, його опадання. Метою статті було висвітлення результатів проведених досліджень з оцінки посухостійкості видів рослин роду *Aristolochia* L. для виявлення найбільш перспективних таксонів, придатних для вирощування в умовах м. Київ. Дослідження проводились 2022 році на 3 видах ліан: *Aristolochia macrophylla* Lam., *A. tomentosa* Sims., *A. manshuriensis* Kom., які зростають у Національному ботанічному саду ім. М. М. Гришка (м. Київ). Представлені результати досліджень параметрів показників оводненості листків рослин, водного дефіциту, водоутримувальна здатність листків, рівень електропровідності та питома поверхнева щільність листків, проведених у лабораторії фізіології рослин і мікробіології Інституту садівництва Національної академії аграрних наук України. Також проведено польову оцінку посухостійкості рослин роду *Aristolochia* L. Встановлено, що *Aristolochia macrophylla* Lam. є найбільш посухостійкою, має низький рівень транспірації та має високу водоутримуючу здатність. *Aristolochia tomentosa* Sims. є найменш посухостійким видом, який унаслідок цього потребує додаткового догляду. У польових умовах спостерігали, що істотних ознак в'янення не було виявлено, тобто листки вдень зменшують тургор, а вночі – відновлюють. Важливим також є збереження середовищ, де зростають ці рослини, оскільки їхня зміна впливає на посухостійкість та життєвий цикл ліан. Результати досліджень посухостійкості рослин роду *Aristolochia* L. вказують на перспективність цих рослин. Вони можуть бути використані при доборі асортименту рослин для створення насаджень різного призначення в урбанізованому середовищі

Ключові слова: водоутримуюча здатність; водний дефіцит; оводненість; ліани; електропровідність

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Shyshatska sand arena: History, current state, and prospects of afforestation

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Abstract. Non-afforested lands in Ukraine are the primary instrument for increasing the forest cover of the territory The issue of sand afforestation is relevant in the context of climate change. Treeless sand arenas are a source of dust storms, and deflationary processes that occur lead to negative consequences that are quite difficult to correct in the future. The purpose of this study was to summarise the experience and achievements of the branch "Myrhorod Forest Enterprise" of the State Specialised Commercial Enterprise "Forests of Ukraine" in afforestation of mobile sands in the conditions of the Forest-Steppe of Ukraine. Forest stands are established using one-year-old Scots pine seedlings on sandy soils to achieve the set goal. Testing is conducted using planting material grown under various conditions – in the open ground and in a greenhouse. Extended periods for establishing forest stands beyond agrotechnical terms are examined during the late spring and summer periods using rejuvenated planting material with partially damaged root systems. The current state of plantings within the Shyshatska sand arena is analysed. It is established that in general, the territory of the arena is represented by the entire range of types of forest conditions ranging from bors to mixed broad-leaved forests. The prevailing types of forest-growing conditions are given, among which dry and fresh forests are distinguished. Subors and su-deciduous forests are

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represented on small areas. Deciduous types of conditions are located mainly in the drained areas of the Psel River floodplain. The main forest-forming species on the territory of the arena is Scots pine, which occupies more than 60% of the territory. Also in the lowlands and floodplains of the Psel River stands of Black Alder and Common Oak grow. In the conditions of bors, Scots pine grows in III – Va bonitet class. In richer conditions, subor and su-deciduous forest cultures have better indicators and have a class I-II bonitet, but there are not many of them. The results of this study can be used in the afforestation of sandy lands in the Forest-Steppe of Ukraine and adjacent regions

Keywords: mobile sands; forest sand cultures; afforestation; planting material; Scots pine

Introduction

The importance of forests on a planetary scale is steadily increasing. This is due to the fact that the forest is a powerful factor in the balanced functioning of natural ecosystems, increases their resistance to anthropogenic impact and climate change. At the global level, mutually agreed decisions are being made on forest conservation and reproduction, namely: United Nations Framework Convention on Climate Change (1992), United Nations Convention to Combat Desertification (1994), etc.

The issues of preserving and increasing the area of forests and implementing the principles of sustainable forestry are also acute in Ukraine. One of the main tasks within the framework of the programme of the President of Ukraine Green Country (n.d.), is an increase in the area of forests and bringing the state's forest cover to an optimal level. The programme provides for an increase in the area of forests by 1 million hectares to achieve optimal forest cover. In addition, when creating new forests, it is important not to violate the natural integrity of all components of the ecosystem – flora, fauna, and microorganisms. Therefore, it is advisable to prioritise attention to non-forested areas where the establishment of new forests will have the maximum positive impact on the ecosystem in general. Thus, it is necessary to conduct research on the afforestation of degraded and sandy lands.

According to Yu.A. Bondarenko & I.V. Ivanyuk (2022), existing sand arenas in Forest-Steppe conditions were also forested, but with better results than in the Steppe zone, due to more precipitation and less evaporation of moisture from the soil. Sand arenas which were formed as a result of intense anthropogenic impact were also forested. One of these territories is the Shyshatska sand arena, which is located on the territory of the Myrhorod district of the Poltava region.

Researchers from China, Y. Rong *et al.* (2022) conducted research in the Tengger Desert using various sandstorm management projects. One of the options was to create a "straw chessboard", in the open cells of which various grasses, bushes and trees were planted and sown for the subsequent fixing of the sands. This method helped to partially fix the sand, and straw shields reduced the heating of sand and evaporation of moisture that came with precipitation.

E.A. Elhadi *et al.* (2016) and M. Moradi *et al.* (2017) investigated that the existing organic residues from precipitation after afforestation of sands, artificially introduced organic fertilisers and plant residues (straw shields) in the upper horizons of sandy lands improve the content of the main elements of mineral nutrition in it. There is also a decrease in the pH of the soil from alkaline to neutral. The introduction of organic waste into desertified sand dune soils has increased the nutrient content and, consequently, the sustainable biological fixation of sand dunes.

Romanian foresters have achieved substantial achievements in reforestation and afforestation. C. Palaghianu & I. Dutca (2017) determined that for the period from 1990 to 2015, the annual volume of reforestation reached the range of 10-15 thousand hectares. Approximately 1% of these territories were occupied by deforested areas with sandy soils. The main species that were planted on sandy lands were Acacia (*Robinia pseudoacacia* L.) and Poplar (*Populus* × *canadensis*).

A study by Z. Vacek *et al.* (2021) in the Czech Republic compared different types of reclamation: areas after coal mining, a former sand pit, and a reclaimed sand dune that was used as pasture. The areas were afforested with Scots pine. (*Pinus sylvestris* L.). Comparing all reclamation options, the highest productivity was determined in the reclaimed coal mine, and the smallest differences between forest and reclaimed areas were documented in the case of a reclaimed sand pit. In terms of climate change, Scots pine has proven to be a very adaptive and suitable tree species, the wood production of which in reclaimed areas after mining is comparable to conventional forest areas. Pine afforestation of reclamation areas brings invaluable environmental and industrial benefits.

Having considered the methods of fixing and afforestation of sands in other regions that were examined by researchers, the purpose of the study was to examine modern approaches and methods of afforestation of sands. The following tasks were considered for this purpose: to examine the survival rate of seedlings in forest plantations depending on their location and agrotechnics of cultivation and analyse the current state of plantations within the Shyshatska sand arena in terms of forest vegetation types, dominant tree species, and stand quality.

Materials and Methods

A work program was developed for the establishment of forest plantations of Scots pine on the Shyshatska Sand Arena by the "Myrhorod Forestry" branch, aimed at investigating the afforestation of mobile sands. The study was conducted from November 2020 to November 2021. According to the work program, the following tasks were envisaged:

- plant seedlings in areas with or without area preparation;
- plant seedlings in extended agrotechnical terms to identify the possibility of extending the planting time (Patent No. 62077. Method for sanitating propagation ..., 2011);
- plant seedlings grown in the open ground, with a closed and partially damaged root system (Maurer & Moiseyets, 2010).
- plant seedlings in spring and autumn agrotechnical terms.

In accordance with the programme of work, experimental crops were created in different agrotechnical terms and using different planting materials (Table 1).

For each research variant, at least 100 Scots pine seedlings were taken. The preparation of seedlings for planting was conducted uniformly to maintain the purity of the experiment. Standard one-year-old Scots pine seedlings of approximately the same size were selected. The root systems were formed to have equal lengths (15-20 cm), and the roots were dipped in a clay-sand slurry without the addition of fertilisers or moisture-retaining agents.

Control was provided by forest plantations created by the employees of the "Myrhorod Forest Enterprise" branch of the State Specialised Enterprise "Forests of Ukraine" within the designated area. Their years of experience in forest cultivation and restoration within the Shyshatska sand arena demonstrated the utility of adding growth stimulants (rooting compounds, amber acid, and others) and water-retaining agents at 50% concentration as recommended by the manufacturer to the planting mixture.

Table 1. Characteristics of the experiment, in the context of the timing of planting seedlings of Scots pine grown in different conditions

No.	Date of planting	Number of seedlings planted	Origin of planting material
1	09.11.2020	276	Lubenske FE (closed ground, greenhouse)
2	16.11.2020	292	
3	28.03.2021	200	Poltava FE (open ground)
4	11.04.2021	300	
5	23.04.2021	200	Lubenske FE (closed ground, greenhouse)
6	20.05.2021	126	Partially injured root system
7	05.06.2021	108	
8	21.06.2021	111	
9	27.06.2021	108	
10	07.11.2021	103	Poltava FE (open ground)
11	21.11.2021	144	Lubenske FE (open ground)

Note: FE – Forest Enterprise
Source: compiled by the authors

Soil preparation for the study was conducted using mechanised methods. Furrows were created using a PKL-70 plough (Republic of Belarus) at a depth of 10-15 centimetres to prevent the planted seedlings from being buried by sand and avoid any displacement. Adjacent areas were left without soil preparation for comparison purposes. The width of the row spacing was 2 meters, with a step of planting seedlings in a row after 0.5 meters.

The study was conducted on the territory where forest cultures were established on the prepared soil using the PKL-70 plough. Furrows were created to a depth of 10-15 cm to prevent the seedlings from being covered by sands and to avoid lodging. The inter-row width is 2 meters, and the furrow depth during cutting was 20-25 cm, considering the filling by winds and erosion during spring rains (Fig. 1).

Figure 1. Soil preparation using a PKL-70 plough

Standard seedlings of Scots pine were planted with a row planting step of 0.5 meters in different agrotechnical terms in accordance with the research programme (Fig. 2). Planting in May – August was conducted considering precipitation, to maximise the use of moisture by plants.

Figure 2. Planting of annual Scots pine seedlings in experimental plots

The condition of plantations within the mobile sand dune arena was analyzed based on the materials of the periodic forest inventory from the database of the production association Ukrderzhlisproekt (n.d.). For analysis, quadrants within the Shyshatska sand arena were selected within the territories of Shyshatske and Velykobahachanske forest districts of the "Myrhorod Forest Enterprise" branch of the State Specialised Enterprise "Forests of Ukraine".

During the study, the requirements of the Convention on Biological Diversity (1992) were met. The historical aspects of afforestation of shifting sands were analysed based on literary and scientific publications, including the information provided in forestry culture books and the experience of enterprise employees documented in reports and forestry management materials.

Results and Discussion

Sand afforestation has been and remains important since the 18th century. The main focus of the researchers V.N. Vynogradov & D.P. Toropogritsky (1963) was devoted to the afforestation of the Prydniprovsk and Lower Dnieper sands in the southern part of Ukraine. The Steppe zone of Ukraine for almost two centuries was an experimental site of afforestation (Kherson region) and reforestation (Luhansk, Kharkiv region) (Dryuchenko, 1964; Vynogradov, 1966) on sands that man in a very short time turned from blackened sandy steppes and woodlands into bare mobile sands with hilly terrain. The first century of creating sand forests was marked by failures and disappointments, which enriched the Ukrainian forestry industry with invaluable experience, which allowed finding several reliable sand afforestation technologies and applying them in practice. Historical aspects and experience of sand afforestation are given in the studies of M.I. Gordienko & V.P. Shlapak (1998), S.V. Zibtsev *et. al.* (2022).

The most well-known in Ukraine are the Lower Dnieper (Oleshkivske) sands and the sands formed on the land areas located between Kharkiv and Luhansk (Moroz & Shlapak, 2000). Samara forests are located on the sands of

Dnipropetrovsk region. Less known are the island forests that grow on both banks of the Dnipro River, from Kaniv to Zolotonosha and Chyhyryn, where the most famous ones are located – Cherkasy and Chyhyryn forests. (Lehmkuhl *et al.*, 2021).

The total area of the Shyshatska sand arena is 3.1 thousand hectares. Previously, the Shyshatska sand arena was used as a military training ground for throwing aerial bombs, where explosions increased the flowability and mobility of sand. The sand dunes reached heights of up to 10-15 meters, and the depth of sand deposition reached up to 30 meters. Work on the afforestation of mobile sands, which were formed on the site of the military aviation training ground, began in 1952. However, they were unsuccessful; all technologies and scientific recommendations were unsuitable for the conditions of the arena. The temperature of the sand could reach up to +60°C, and in some cases, one-year-old seedlings with a height of 4-5 cm were simply buried during dust storms.

Researchers investigated the prevention of wind erosion by creating mechanical protection using pine branches cut during maintenance operations in young stands to control mobile sand and prevent dust storms in the Shyshatska sand arena (Dryuchenko *et al.*, 1975). Protective rows were arranged every 6 meters perpendicular to the prevailing winds. Although this method gave short-term results since the branches quickly dried up and did not perform their functions. For partial consolidation of the sands, forest cultivation work was continued. Pine seedlings were planted in strips of 3-4 rows. The distance between the lanes was 30-40 m. After the reduction of sand deflation due to the influence of the pine seedlings, large-scale afforestation of the arena began (Bondarenko & Ivanyuk, 2021).

Since 1957, decisive attempts to afforestation the arena have yielded the first results. The plantations were established using a planting scheme with planting spots arranged at intervals of 1.5 by 0.5 meters. Each of the approximately 3 million seedlings was planted manually under the guidance of the "Kolesov's sword" technique over a span of 20 years. Protective structures were placed approximately every 6-7 meters, using shields made from hazel, alder, and pine branches. These shields helped restrain the main force of the sand during storms and protected the pine trees from being buried or having their root systems exposed. Shields were placed at an angle to the prevailing winds and covered the sand arena in a north-south direction. At the end of the growing season, the survival rate of created crops was 95%. Care for crops consisted in uncovering seedlings buried with sand. The full afforestation of the arena was completed in 1975 (Yaresko, 2019). Most of the forest planted in the 1970s was destroyed by a large-scale fire in 2005. Then the fire destroyed more than 450 hectares of forest due to human negligence. The technology that helped reforest the inhospitable desert played against foresters. Due to the fact that the crops were planted thickly, the fire spread very quickly (Yaresko, 2019).

According to Myrhorod Forestry (n.d.), during the reforestation of 2007, the planting scheme was changed – 2.0 × 0.7 m. Scots pine, Crimean pine and Acacia were planted. Soil cultivation mainly involved partial furrowing. On flat areas, planting was carried out mechanically using planting machines, while sandy hills were afforested manually. The primary soil cultivation was carried out through deep loosening using mounted cultivators RN-60 and RN-80 (RN stands for mounted loosener), which facilitated deeper root penetration. Then the addition of cultures was conducted for another 5 years. A general view of the wooded arena after the 2005 fire is shown in Figure 3. Due to the fact that the stumps remained after the fire, it was no longer necessary to put up protective structures. Wide fire breaks were created to protect against fires.

Figure 3. The reforested Shyshatska Arena after the 2005 fire
Source: photo by Google maps (2009)

The created Acacia stands, which served as fire barriers at the age of 12-15 years, started to deteriorate, negatively impacting the condition of the stands.

As of 2023, reforestation efforts are still ongoing in the Shyshatska sand arena. There are isolated cases of death of certain areas of forest cultures due to damage by stem pests and partial covering with sand, despite the fact that preventive measures to combat them are conducted regularly. Currently, with almost 50 years of experience in the afforestation of sands, hygrotopes of afforded areas and fire prevention measures are considered. When creating forest cultures, the width of row spacing is from 2.0 to 2.5 m, the planting step in a row is from 0.5 to 0.7 m, which allows to effectively fixing the sands in conditions from AA_0 to A_2.

Afforestation of the territory of the Shyshatska sand arena is conducted annually. This, in turn, is associated with the partial death of forest crops in small areas. Territories that were covered by a fire in 2005. Depending on weather conditions, such as temperature and sufficient rainfall, they substantially influence the survival and preservation of the established forest cultures. The results of the inventory of forest crops on 15.10.2021 and 25.05.2022 at the experimental sites are shown in Table 2. No additions were made at the experimental sites.

Table 2. Survival rate and preservation of crops in experimental plots

No.	Date of planting	Number of seedlings	15.10.2021		25.05.2022	
			Surviving seedlings, pcs	Survival rate, %	Surviving seedlings, pcs	Survival rate, %
1	09.11.2020	276	105	38	104	38
2	16.11.2020	292	110	38	108	37
3	28.03.2021	200	58	29	58	29
4	11.04.2021	300	81	27	80	27
5	23.04.2021	200	25	13	25	13
6	20.05.2021	126	0	0	-	-
7	05.06.2021	108	10	9	9	8

Table 2, Continued

No.	Date of planting	Number of seedlings	15.10.2021		25.05.2022	
			Surviving seedlings, pcs	Survival rate, %	Surviving seedlings, pcs	Survival rate, %
8	21.06.2021	111	0	0	-	-
9	27.06.2021	108	20	20	19	20
10	07.11.2021	103	-	-	84	82
11	21.11.2021	144	-	-	121	84

Source: compiled by the authors

According to the results of the inventory, it is clear that the terms of planting outside the agrotechnical terms starting from the second half of May do not give positive results. Cultures created in the autumn and spring period have a better survival rate, although it is not enough to leave plots without supplements. Although the sufficient amount of moisture in the spring period, survival rates are low. Sands do not retain moisture in the upper layer, which causes low preservation of created crops.

The results of the autumn planting experiment outside of agrotechnical terms under favourable weather conditions showed excellent results due to the substantial amount of precipitation that was in the region in the winter-spring period of 2022. According to the research programme, planting seedlings on a forest-cultivated area without soil preparation did not give a positive result even using growth stimulators and moisture accumulators. This is due to the formation of a dense upper layer of sand formed by deflation processes, and the burying and damaging of the plantings by sand.

It has been determined that the territory of the arena encompasses the full range of forest vegetation types, ranging from bors to deciduous forests (Fig. 4). This is due to the location of Psel River, which surrounds the sand arena from Southeast to Northeast. The main types of forest-growing conditions are dry and fresh bors, which occupy 60% of the area. Transitional types of subors and su-deciduous forests cover an area of less than 10%. This is due to a sharp transition to deciduous forests in the floodplain of the Psel River. Here, rich conditions were formed as a result of lowering the groundwater level and drying up wetlands (12%). A substantial part of deciduous forest conditions D_{4-5} (17%) is located in the floodplain of the river and is partially swampy.

The species composition of plantings (Fig. 5) is represented mainly by Scots pine on the sands. Monocultural plantings pose a certain threat during the fire hazard period and require timely logging and maintenance. Common Oak and Black Alder grow in floodplains and partially swampy areas. Other woody species such as Common Ash, Aspen, White Poplar, and Hanging Birch occupy small areas in the transitional subor and su-deciduous types.

Due to the fact that Scots pine is the main forest-forming species of the Shyshatska sand arena, it occupies 63% of the territory and grows on 94% of the sand. The distribution of Scots pine stands by bonitets was analysed (Fig. 6).

After analysing the data shown in Figure 6, it can be argued that in the conditions of dry and fresh bors, pine grows mainly in 2-5[a] bonitets. Such low bonitets of plantings are fully explained by poor types of forest conditions on the sands, the horizon of which in most areas of the arena is 5-15 m, and sometimes up to 30 meters, and almost no layer of fall-off and litter. A small part of the high-granite plantings was formed along the perimeter of the Shyshatska arena on soils with a less powerful layer of sand up to 1.5 m.

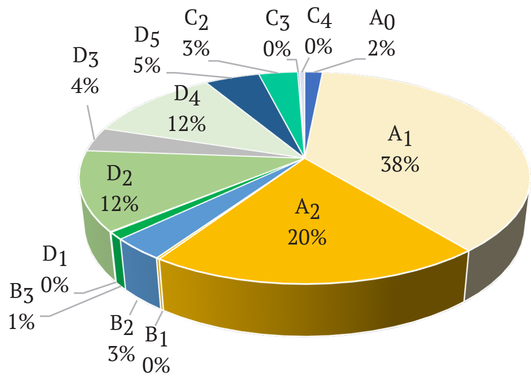

Figure 4. Distribution of areas by type of forest conditions
Source: developed by the authors on the basis of data from the Official website of the Ukrainian State Project Forest Management Industrial Association "Ukrderzhlisproekt" (n.d.)

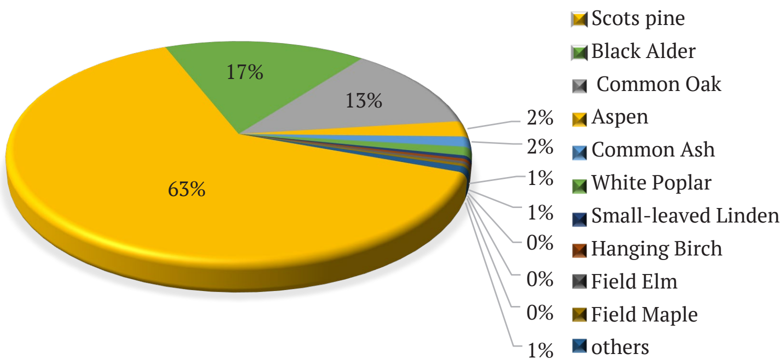

Figure 5. Distribution of areas by forest-forming species
Source: developed by the authors on the basis of data from the Official website of the Ukrainian State Project Forest Management Industrial Association "Ukrderzhlisproekt" (n.d.)

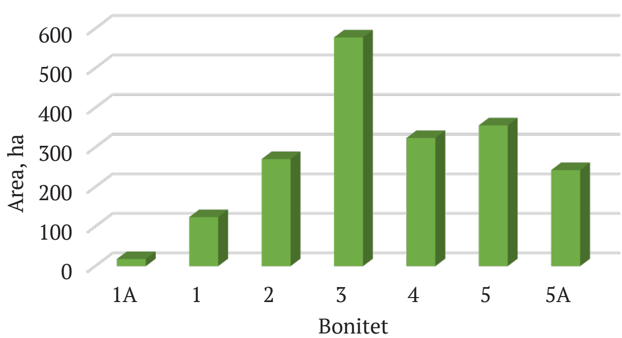

Figure 6. Distribution of the area of Scots pine stands by bonitet
Source: developed by the authors on the basis of data from the Official website of the Ukrainian State Project Forest Management Industrial Association "Ukrderzhlisproekt" (n.d.)

The main goal of sand afforestation in different parts of the world is to improve the ecological situation and reduce dust storms. Ukraine is no exception, and sand afforestation in the south and east of the country is a priority. Atypical plots of land like the Shyshatska sand arena are also found in other regions of the state. In some years, these issues were considered by many researchers and certain results were achieved, on the basis of which this study was based. Thus, the study by M.M. Dryuchenko *et al.* (1975) on afforestation of the sands of the Shyshatska arena with the use and introduction of organic matter in the seating areas was positive. Similar results were recorded by E.A. Elhadi *et al.* (2016) by adding organic residues to sandy soil, it improved its chemical properties and maintained the fixation of sand dunes.

Sand fixing using herbaceous plants in Iran (Moradi *et al.,* 1917) and straw shields in China (Rong *et al.,* 2022) indicates the possibility of partial sand fixation and short-term prevention of deflationary processes. These options are relatively effective and require further afforestation to successfully anchor the sands.

Studies of sandy lands in Europe and their mapping were examined by F. Lehmkuhl *et al.* (2021). The distribution and formation of sands in Europe, considering geomorphological processes, have been examined in detail and provide the opportunity to comprehend the extent of territories that require afforestation. According to Z. Vacek *et al.* (2021), for afforestation of Reclamation lands in the Czech Republic, the best woody species is Scots pine. It is second only by 9-32% in productivity compared to the same plantings on forest soils.

The solution of afforestation of sands on the territory of Ukraine on the lower Dnieper Sands was considered in the papers of V.N. Vynogradov (1963), V.N. Vynogradov (1966), afforestation in the steppe in different years was examined by T.T. Govorova (1970), M.I. Gordienko *et al.* (2002), Prydniprovsk sand formations – P.I. Moroz & V.P. Shlapak (2000). All of them chose Scots pine when selecting tree species for the afforestation of sands. It has one of the largest distribution areas in Europe and a flexible adaptive property to various growing conditions. Considering the different climatic zones of sandy land placement, researchers recommended planting seedlings during periods with maximum accumulation of moisture in the sands, which contributes to better survival and preservation of forest cultures.

The use of different planting dates with improved planting material in Polissya conditions on sod-podzolic sandy loam soils was tested by V.M. Maurer & P.Ya. Moiseyets (2010). Healthy Scots pine seedlings planted in the summer had better preservation in the range of 20-30% compared to similar planting material grown in a nursery in the open ground.

Due to climate changes and possible forecasts of changes in the range boundaries of the main forest-forming species of the Forest-Steppe of Ukraine, Scots pine and Common Oak may shift to the North and Northwest, according to A. Shvidenko *et al.* (2017). Therefore, according to the authors, afforestation of all possible sandy lands is an urgent issue to prevent and mitigate potential negative and unforeseen consequences in the future.

According to the results of this study, for afforestation of sand arenas, it is worth recommending the use of branches from care logging and the formation of a protective fence with a height of 60-80 cm, every 6 meters, perpendicular to the direction of prevailing winds

Considering the prospects of afforestation and stabilizing the shifting sands of the Shyshatska Arena, the “Myrhorod Forest Enterprise” branch possesses substantial expertise. Scots pine stands will form a sufficient layer of litter with time and in the future, the quality indicators will increase proportionally.

Conclusions

Studies have established that the survival rate and safety of forest crops primarily depends on high-quality tillage and moisture reserves after the winter period. The best way to prepare the soil on sand is to cut furrows with a PKL-70 plough using an RN-60 or RN-80 soil loosener. Preparation should be conducted in the autumn period, for maximum accumulation of moisture in the soil.

Planting seedlings outside the agrotechnical deadlines did not give positive results, although the planting of seedlings occurred after precipitation. The best results of seedling preservation were obtained in crops planted in the late autumn period. By that time, a sufficient amount of moisture accumulates in sandy lands, which contributes to better survival. However, it is worth remembering that late plantings can suffer from squeezing seedlings out of the soil by frosts. Due to the fact that the predominant types of forest conditions on the territory of the arena are dry and fresh bors – 58% of the area, pure Pine cultures were formed on sandy soils, mainly of the II-V bonitet classes.

Richer types of forest conditions were formed along the floodplains of the Psel River. Alder trees grow here, which periodically experience short-term flooding during spring floods. A small portion of Common Oak (13%) has developed in drained swamps and wetlands, as well as in low-lying areas and depressions of the sandy arena. Additionally, stands of Aspen have formed in the lowlands of the sandy arena, mostly confined within their boundaries.

Afforestation of mobile sands is necessary in the context of climate change and considers the possible challenges of the present time and the possible negative consequences that have been prevented. Further research on afforestation in the Shyshatska arena encourages a more detailed examination of the structure and composition of the sands. Of particular interest are the features of growth and formation of root systems in the first years. Investigating the growth rate of Scots pine stands on the sands and comparing the results with similar plantings in the region is promising for subsequent research.

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None.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Bondarenko, Yu.A., & Ivanyuk, I.V. (2021). To the history of the afforestation of the Shishak sand arena. In *International scientific and practical conference "Present and future forests of the middle latitudes ecotone"* (pp. 35-36). Kyiv: National University of Life and Environmental Sciences of Ukraine.

[2] Bondarenko, Yu.A., & Ivanyuk, I.V. (2022). Peculiarities of afforestation and the state of forest plantations in the Shishak sand arena. In *International scientific and practical conference "Forests and urban ecosystems of Ukraine in conditions of war: State, preservation and restoration"* (pp. 19-20). Kyiv: National University of Life and Environmental Sciences of Ukraine.

[3] Convention on Biological Diversity. (1992). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[4] Dryuchenko, M.M. (1964). *New agrotechnics for afforestation of sands*. Kyiv: Urozhay.

[5] Dryuchenko, M.M., Govorova, T.T., & Korobov, I.A. (1975). Influence of tillage and fertilizers on the safety and growth of pine crops on the sands of the Shishak forestry. *Forestry and Agroforestry,* 42, 39-43.

[6] Elhadi, E.A., Mubarak, A.R., & Rezig, F.A.M. (2016). Effects of organic amendments on sand dune fixation. *International Journal of Recycling of Organic Waste in Agriculture*, 5, 1-8. doi: 10.1007/s40093-015-0111-5.

[7] Gael, A.G. (1952). *Afforestation of hilly sands of arid regions*. moscow: Geografgiz.

[8] Gordienko, M.I., & Shlapak, V.P. (1998). *Steppe forests of Ukraine*. Lviv: Prestige Inform.

[9] Gordienko, M.I., Shlapak, V.P., Hoychuk, A.F., Rybak, V.O., Maurer, V.M., Gordienko, N.M., & Kovalevskyi, S.B. (2002). *Scots pine cultures in Ukraine*. Kyiv: Institute of Agrarian Economics of the Ukrainian Academy of Sciences.

[10] Govorova T.T. (1970). *Methods for creating pine cultures on the sands of the steppe and southern forest-steppe of the Ukrainian SSR* (Doctoral thesis, Agricultural Institute named after V.V. Dokuchaeva, Kharkov, Ukraine).

[11] Green Country. (n.d.). Retrieved from https://zelenakraina.gov.ua.

[12] Lehmkuhl, F., Nett, J.J., Pötter, S., Schulte, P., Sprafke, T., Jary, Z., Antoine, P., Wacha, L., Wolf, D., Zerboni, A., Hošek, J., Marković, S.B., Obreht, I., Sümegi, P., Veres, D., Zeeden, C., Boemke, B., Schaubert, V., Viehweger, J., & Hambach, U. (2021). Loess landscapes of Europe – Mapping, geomorphology, and zonal differentiation. *Earth-Science Reviews*, 215, article number 103496. doi: 10.1016/j.earscirev.2020.103496.

[13] Maurer, V.M., & Moiseyets, P.Ya. (2010). Extension of planting dates of pine forest crops due to the use of seedlings with optimized root-leaf correlation. *Scientific Bulletin of NUBiP of Ukraine,* 152, 247-252.

[14] Mirgorod Forestry. (n.d.). Retrieved from https://mirglisgos.com.ua/.

[15] Moradi, M., Imani, F., Naji, H.R., Moradi Behbahani, S., & Ahmadi, M.T. (2017). Variation in soil carbon stock and nutrient content in sand dunes after afforestation by *Prosopis juliflora* in the Khuzestan province (Iran). *iForest*, 10, 585-589. doi: 10.3832/ifor2137-010.

[16] Moroz, P.I., & Shlapak, V.P. (2000). *Integrated development of the Middle Dnieper sandy massifs*. Lviv: Prestige Inform.

[17] Official website of the Ukrainian State Project Forest Management Industrial Association “Ukrderzhlisproekt”. (n.d.). Retrieved from https://www.lisproekt.gov.ua.

[18] Palaghianu, C., & Dutca, I. (2017). Afforestation and reforestation in Romania: History, current practice and future. *REFORESTA*, 4, 54-68. doi: 10.21750/REFOR.4.05.44.

[19] Patent No. 62077 “Method for sanitating propagation material with open root system and raising acceptance of forest cultures due to optimizing root and leaf correlation of seedlings of needle tree species”. (2011, August). Retrieved from https://sis.ukrpatent.org/en/search/detail/243377.

[20] Pogrebnyak, P.S. (1971). *New ways of afforestation of hilly sands*. moscow: Kolos.

[21] Rong, Y., Yan, Y., Zhao, C., Wang, C., Shang, X., Zhu, J., Li, K., Yang, S., Lu, H., Zheng, T., & Zheng, L. (2022). Straw checkboard or Afforestation? – Assessment and comparison of combined benefits of two typical sand fixing models. *Journal of Cleaner Production*, 358, article number 131924. doi: 10.1016/j.jclepro.2022.131924.

[22] Shvidenko, A., Buksha, I., Krakovska, S., & Lakyda, P. (2017). Vulnerability of Ukrainian forests to climate change. *Sustainability*, 9(7), article number 1152. doi: 10.3390/su9071152.

[23] United Nations Convention to Combat Desertification. (1994, June). Retrieved from https://www.unccd.int/sites/default/files/2022-02/UNCCD_Convention_ENG_0_0.pdf.

[24] United Nations Framework Convention on Climate Change. (1992, June). Retrieved from https://unfccc.int/sites/default/files/convention_text_with_annexes_english_for_posting.pdf.

[25] Vacek, Z., Linda, R., Cukor, J., Vacek, S., Šimůnek, V., Gallo, J., & Vančura, K. (2021). Scots pine (*Pinus sylvestris* L.), the suitable pioneer species for afforestation of reclamation sites? *Forest Ecology and Management*, 485, article number 118951. doi: 10.1016/j.foreco.2021.118951.

[26] Vynogradov, V.N. (1966). Agrotechnics of creating forest plantations on the Nizhny Dnieper sands. *Bulletin of Rural Science,* 4, 65-69.

[27] Vynogradov, V.N., & Toropogritsky, D.P. (1963). *Advanced experience of afforestation of the Nizhnedneprovsky forests*. moscow: Goslesbumizdat.

[28] Yaresko, O. (2019). *Myrhorod forest farm historical essay*. Kyiv: LLC "VB "Avanpost-Prim".

[29] Zibtsev, S.V., Savushchik, M.P., Maurer, V.M., Balabukh, V.O., Myronyuk, V.V., Pinchuk, A.P., Ivanyuk, I.V., Lobchenko, G.O., Soshenskyi, O.M., Humenyuk, V.V., & Tarnopilskyi, P.B. (2022). *Restoration of Luhansk region's forests on wildfires under conditions of climate change*. Kyiv: RVC NUBiP of Ukraine.

Шишацька піщана арена: історія, сучасний стан та перспективи заліснення

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Анотація. Незаліснені землі в України є основним інструментом підвищення лісистості території. Питання заліснення пісків є актуальним в умовах змін клімату. Безлісі піщані арени є джерелом пилових бур, та дефляційні процеси які відбуваються призводять до негативних наслідків які в подальшому виправити досить складно. Метою даної роботи було узагальнити досвід та напрацювання філії «Миргородське лісове господарство» Державного спеціалізованого господарського підприємства «Ліси України» у залісненні рухомих пісків в умовах Лісостепу України. Для досягнення поставленої мети були створені лісові культури однорічними сіянцями сосни звичайної на пісках. Проведено апробацію із використанням садивного матеріалу вирощеного за різних умов – у відкритому ґрунті та теплиці. Досліджено розширені терміни створення лісових культур поза межами агротехнічних термінів у пізньо-весняний та літній період з використанням оздоровленого садивного матеріалу з частково травмованою кореневою системою. Проаналізовано сучасний стан насаджень в межах Шишацької піщаної арени. Встановлено, що загалом територія арени представлена всією амплітудою типів лісорослинних умов від борів до дібров. Наведено переважаючі типи лісорослинних умов, серед яких виділені сухі та свіжі бори. Субори та судіброви представлені на незначних площах. Дібровні типи умов розміщені переважно на осушених територіях заплави річки Псел. Основним лісоутворюючим видом на території арени є сосна звичайна, яка займає понад 60 % території. Також у низинах і заплавах річки Псел зростають насадження вільхи чорної та дуба звичайного. В умовах борів сосна звичайна зростає за III – Va класом бонітету. У багатших умовах суборів та судібров культури мають кращі показники і мають I – II клас бонітету але їх не багато. Результати даної роботи можуть бути використані при залісненні піщаних земель в умовах лісостепу України та суміжних регіонів

Ключові слова: рухомі піски; лісові культури; лісорозведення; садивний матеріал; сосна звичайна

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Prospects for the use of Walnut and Poplar in agroforestry of Polissya and Forest-Steppe of Ukraine

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Abstract. Climate changes actualise the need for the transition of Ukraine's agricultural business to agroforestry systems not only in the steppe but also in the northern regions of the country. The purpose of the study is to examine the features of creating protective stands of Walnut (*Juglans regia* L.) and Poplars (Populus × euramericana) in Polissya and in the Forest-Steppe of Ukraine. Experimental plantings of Walnut were created by one-year-old seedlings on sod-podzolic sandy loam soils of Zhytomyr Polissya and on carbonate soils of the Western Forest-Steppe, and the analysis of the survival rate of Poplar plantings was conducted on chernozems of the Right-Bank Forest-Steppe. It was established that on sod-podzolic soils, five-year-old plants of Walnut had an average height of 91.8 cm. At the age of 4, some of them bore fruit. The fruit-bearing trees had higher indicators of average height of 13.4% and a diameter of 71.5% compared to the rest. On carbonate soils, the trees showed substantially better growth in height, which is explained by the calciphile nature of the nut. It is determined that an effective way to increase the survival

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rate of one-year-old seedlings of Poplar varieties Dorskamp, Robusta and I-45/51 is to plant them without trunks. In all the examined varieties, during the first two years, the highest survival rate of seedlings was in the variant without a trunk – from 57.0 to 68.9%, while in seedlings with a trunk – from 50.3% to 68.1%. In 2022, due to irrigation, the survival rate ranged from 74.4% to 88.9%. The average height was mostly also higher in plants that grew from seedlings without a trunk. It was the largest in plants of the Dorskamp clone – 188.6 to 209.3 cm. In uncut plants of this variety, it ranged from 174.0 to 197.2 cm. The practical importance of the study lies in the possibility of developing new forms of Walnut and Poplar and improving technologies for creating forest lands with their involvement, which can be used in Polissya and Forest-Steppe conditions.

Keywords: forest-field lands; *Juglans regia* L.; Populus × euramericana; seedlings; plantings; survival rate; average height; fruiting

Introduction

At the present stage of development of world agricultural production, it becomes clear that the existing management systems in agriculture are not viable in the long term, and excessive use of chemicals to increase the yield of field crops and protect them from weeds, pests, and diseases creates a serious danger to the environment. Food and Agriculture Organisation (FAO) (n.d.) recognises that complex, multifaceted issues, including sustainable land use, require cross-sectoral approaches. The agenda in the field of sustainable development for the period up to 2030 not only defines the goals in sustainable development but also proposes the means to achieve them (Burgess & Rosati, 2018; Moreno *et al.*, 2018). In the context of increasing global competition, uncertainty and increasing risk of crisis factors both at the national and global levels, special emphasis in the process of land management is placed on the issues of their effective use. The complexity and lack of a unified approach to solving this problem has led to the need to develop scientific foundations for determining effective land use areas and modelling agri- and economic processes (Rigueiro-Rodrìguez *et al.*, 2009; Smith *et al.*, 2013).

V.Yu. Yukhnovsky *et al.* (2019), I.D. Ivaniuk *et al.* (2022) argue that an extremely high risk to European farming systems in the coming years is climate change, with steady warming, and an increase in the occurrence of unpredictable weather events, which negatively affects the development of the global economy. G. Moreno *et al*. (2018) note that optimising agricultural production is essential for obtaining the necessary amount of food and improving the resilience of European agricultural systems to current challenges.

An alternative area for the development of sustainable and rational use of land resources can be agroforestry – simultaneous cultivation of conventional crops and woody plants on agricultural land. Research M.L. Augère-Granier (2020) indicates the ability of larger or smaller groups of woody plants to improve, stabilise the environment, and control the negative impact of adverse natural phenomena and anthropogenic impacts. The authors note that agroforestry is a type of environmentally oriented agriculture that combines woody vegetation with objects of agricultural activity (agricultural crops or animals) to increase the economic and ecological efficiency of agricultural landscapes.

It can provide an increase in biomass production per hectare by an average of 40%, due to an increase in the leaf surface area per 1 ha, which provides higher efficiency in the use of solar energy, compared to areas without trees (Mosquera-Losada *et al.*, 2012a; 2012b).

According to K. Kovács & A. Vityi (2019) and S. Fahad *et al.* (2022), one of the main types of agroforestry is silvoarable – growing agricultural (garden) crops in the aisles of tree alleys of a certain width. Therewith, wood and tree fruits are additional products that increase economic indicators, without substantially reducing the main crop yield.

The stable trend towards climate warming in Ukraine actualises the need to switch to agroforestry systems of agricultural business not only in the steppe but also in the Forest-Steppe regions of the country and in Polissya. The results of the studies by Ya.D. Fuchylo *et al*. (2022; 2023), and data from the State register of plant varieties suitable for dissemination in Ukraine (2022) confirm that under these conditions, woodlands using Walnut (*Juglans regia* L.) can be effective – mainly for the production of fruits and Euro-American hybrids of the Black Poplar section (Populus × euramericana) for the production of wood and energy biomass.

The purpose of the study was to examine the features of creating field-protected Walnut stands (*Juglans regia* L.) and Poplars (Populus × euramericana) in Polissya and in the Forest-Steppe of Ukraine.

The objectives of the study were to evaluate the effectiveness of the creation of agroforestry facilities in the Forest-Steppe and Polissya of Ukraine, using the two most effective systems of forest land (silvoarable): 1 – growing woody plants for the purpose of obtaining fruit and 2 – for growing high-quality wood.

Materials and Methods

The objects of the study were Walnut plantings created by one-year-old seedlings grown from seeds of fast-fruited, lateral, low-growing forms, which can be considered the third generation of selection by L.S. Shugin (Skrypchuk, 2020; Shugins hazelnuts, n.d.). In the Rivne region, Walnut seedlings were planted in the fall of 2019 in pits with the addition of 9 litres of vermicompost, and on the grounds of the Malyn Vocational College – in the spring of 2020 using a similar technology. Due to the low moisture capacity of sandy loam sod-podzolic Polissya soils, drip irrigation and careful soil care were conducted during the first two years. After the end of each growing season, studies were conducted on the survival rate of seedlings, their growth, and fruit yield. The study of 4-year-old Walnut plantations were conducted in 2022 (Ivaniuk *et al.*, 2022). This study presents 5-year examination of these plants. During the study, the Convention on Biological Diversity (1992) standards were observed.

The study of the features of creating agroforestry objects using one-year-old seedlings of Poplar was conducted at the Experimental Field of the Institute of Bioenergy Crops and Sugar Beets of the National Academy of Agrarian Sciences of Ukraine. Three Poplar varieties were used in the studies: Dorskamp, Robusta and I-45/51. Seedlings of these varieties were grown from one-year-old seedlings and planted in the spring of 2020, 2021, and 2022. Rooting of plants, their safety, and growth were determined according to conventional methods in crop production (Fuchylo *et al.*, 2018).

Results and Discussion

Considering that after the completion of the first vegetative period, the seedling survival rate at Malyn Vocational College was 100%, and no plant losses were observed during the subsequent years. The height of the aboveground part of the seedlings at the time of their planting was 10.4 ± 0.64 cm, after the end of the fourth growing season (plant age – 5 years), their average height increased to 91.8 ± 6.49 cm (Table 1).

Table 1. Morphometric characteristics of Walnut seedlings

Morphometric indicators	one-year-old seedlings	Age of Walnut plants / calendar year			
		2/2020	3/2021	4/2022	5/2023
Height, cm	10.4 ± 0.64	25.4 ± 2.39	47.6 ± 3.77	65.5 ± 5.36	91.8 ± 6.49
Height inrease, cm	10.4	15.0	22.2	17.9	26.3
Root neck diameter, cm	0.8	1.2	1.8	2.3	2.9
Increase in the diameter of the root neck, cm	0.8	0.4	0.6	0.5	0.6

Source: compiled by the authors

The diameter of the root neck grew almost synchronously with the height, reaching 2.3 cm in four-year-old plants and 2.9 – in five-year-old ones. After the first year, the average increase in diameter was 0.4 cm, after the second – 0.6 cm, and after the fifth – 0.6 cm, that is, it was approximately the same in recent years. The relatively cold winter of 2020-2021 and spring with strong late frosts led to the complete freezing of the aboveground part of 56.3% of plants. Over the next two years, the nut trees were not damaged by low temperatures. Studies have shown that the average height of three-year-old seedlings affected by frost was 50.4 ± 4.68 cm, and resistant to cold – only 44.0 ± 6.31 cm (Table 2).

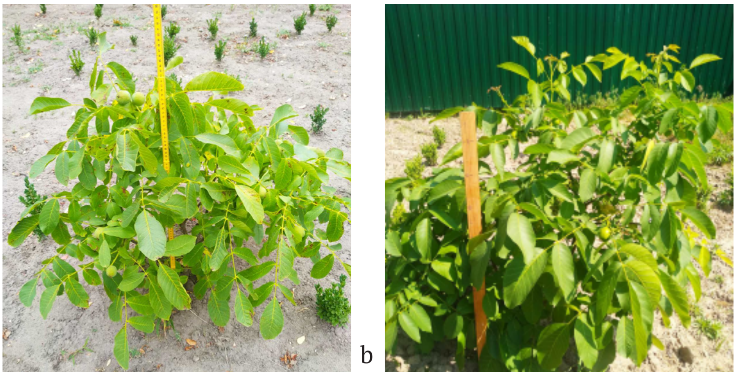
Table 2. Morphometric characteristics of groups of four-year-old Walnut seedlings that differ in cold resistance

Cold resistance	Morphometric parameters of seedlings	
	average height, cm	average diameter of the root neck, mm
2021 (three-year-old plants)		
Non-cold resistant	50.4 ± 2.39	21.4 ± 1.63
Cold-resistant	44.0 ± 2.31	14.1 ± 1.44
Difference, %	14.5	51.8
2022 (four-year-old plants)		
Non-cold resistant	59.6 ± 2.90	26.0 ± 2.71
Cold-resistant	83.3 ± 8.94	23.1 ± 2.82
Difference, %	-39.6	12.6
2023 (five-year-old plans)		
Non-cold resistant	78.7 ± 6.48	31.0 ± 3.64
Cold-resistant	109.4 ± 12.45	26.1 ± 2.91
Difference, %	-39.0	18.8

Source: compiled by the authors

Over the next 2 years, cold-resistant forms grew much more intensively and after the growing season of 2023 exceeded the indicators in non-cold-resistant plants by 39.0%. Seedlings exposed to frosts had a larger diameter of the root neck during the study period. In 2021 – by 51.8%, in 2022 – by 12.6%, and in 2023 – by 18.8%. During the growing season of 2022, 22.7% of plants formed fruits in the amount of 3 to 17 pcs., or 6.6 pcs. on average, on one plant (Fig. 1a).

During the spring season of 2023, in the period of the flowering and pollination of nuts (in April), there was cold and rainy weather, which negatively affected the fruit set. Fruiting was observed on the same trees where it was in the previous year, but not on all – the number of plants with fruits decreased to 18.2%. The average number of fruits was 5.0 pcs. per plant (Fig. 1b).



a b

Figure 1. Fruiting of a Walnut in the conditions of Zhytomyr Polissya

Note: a – 2022; b – 2023

Comparison of morphometric indicators of trees that entered the fruiting stage and other trees (Table 3) showed that plants with fruits had higher indicators of average height (by 27.4% at 4 years of age and by 13.4% at five years of age) and diameter – by 61.4% and 71.5%, respectively. The obtained data indicate that one of the markers of early fruitfulness of Walnut plants can be a larger diameter of the root neck and partially – a larger height.

Table 3. Morphometric characteristics of Walnut seedlings that differ in the beginning of fruiting

Fruit availability	Morphometric indicators	
	average height, cm	average diameter of the root neck, mm
Four-year-old plants		
With fruits	78.6 ± 4.51	32.6 ± 2.50
Without fruits	61.7 ± 5.22	20.2 ± 1.51
Difference, %	27.4	61.4
Five-year-old plants		
With fruits	101.0 ± 12.97	42.2 ± 4.85
Without fruits	89.1 ± 7.56	24.6 ± 1.78
Difference, %	13.4	71.5

Source: compiled by the authors

In the western Forest-Steppe zone, Walnut plantations grew and developed much more intensively. The growth of trees in 2020 ranged from 0.4 to 0.90 m. Some individuals had fruit ovaries (0.5% of trees). In 2022, the growth of shoots ranged from 0.7 to 1.1 m. 48.5% of trees entered the fruiting stage (Fig. 2).

Figure 2. Fruiting of a four-year-old Walnut in the conditions of the Western Forest-Steppe
Source: photographed by the P. Skrypchuk (2020)

About 9% of the fruit had a cluster shape and a second flowering. According to the stage of development, about 15% of trees had later signs of development (budding, leaf colour, fruit development). Trees are characterised by different crown shapes: conventional (45%), cup-shaped and low-growing (up to 2%), and vertical (18%). The remaining trees are not structured and need to be formed in subsequent years.

P. Skrypchuk (2020), I.D. Ivaniuk *et al.* (2022), selected and analysed the morphological features of more than 80 varieties of Walnut in Rivne, Volyn, Khmelnytsky, Vinnytsia, Lviv, Kyiv, Kherson, Poltava, and other regions of Ukraine in recent years. The variety Soyka has been created and introduced into the State register of plant varieties suitable for dissemination in Ukraine (2022). It provides high indicators of stability and yield of trees in the northern and western parts of Ukraine.

There is a large difference in the size and reproductive characteristics of nuts selected by L. Shugin, which were grown in the Forest-Steppe and Polissya, is largely determined by soil conditions because Walnut needs calcium, and on the soils of Zhytomyr Polissya that are poor in calcium compounds, it grows and develops worse, which should be considered when creating its plantings in this region.

Due to the lowering of the groundwater level on the territory of Ukraine, the use of Walnuts in the agroforestry system will increase due to its deep root system. In particular, a study of Chinese researchers W. Wu *et al.* (2022), showed that Walnut trees growing on the semi-arid Loess Plateau of China, compared to peach and apple trees, are characterised by a more stable response to dry periods due to their deep root system, which makes their use in these conditions more cost-effective.

It is advisable to continue research in the area of investigating morphometric and other characteristics of plants of fast-fruiting forms of Walnut to identify new promising forms suitable for obtaining fruits and performing agroforestry functions.

European researchers K. Kovács & A. Vityi (2019), V.-N. Nicolescu *et al.* (2020), M. Báder *et al.* (2023) considering the agroforestry systems of different European countries, the types of trees used, the quality of wood produced in these systems, and analysing the current goals of support and practices of the European Union for agroforestry, indicate that agroforestry projects are important and can lead to the spread of agroforestry systems in Europe. They play an important role in reducing wood scarcity. Therewith, Black Walnut and Poplar are considered among the most important tree species in the European agroforestry.

Unlike Walnut, Poplar plantings are practically not created by seedlings since most Poplars reproduce well vegetatively, and the planting material for creating their plantings is most often stem plantings and cuttings. The latter, as a rule, are grown for one year, while the average height of varieties taken for the study on leached chernozems of the Right-Bank Forest-Steppe is from 144 to 181 cm (Fuchylo *et al.*, 2022; 2023). The advantage of such planting material is that it already exceeds the height of adjacent agricultural crops at the stage of creating forest lands. In particular, Indian researchers N. Sharma & R. Singh (2012) emphasise this, investigating wheat woodlands with American Black Poplar (*Populus deltoides* Marsh.).

The watering is usually used to increase the survival rate of cuttings, although this does not always contribute to the high survival rate of plants due to the substantial xerification of climatic conditions in recent years. In this regard, it has become necessary to search for new ways to ensure the high survival of one-year-old seedlings, in particular, the use of seedlings with the trunk removed as planting material. Studies have shown that such seedlings take root better and form trunks in one year that are taller than seedlings with an undivided trunk (Table 4).

Table 3. Survival rate of Poplar seedlings depending on varietal characteristics and type of planting material, %

Cultivar name	One-year-old seedlings	Years of the study		
		2020	2021	2022
Dorskamp	with a trunk	60.3 ± 2.40	68.1 ± 2.71	81.1 ± 4.15
	without a trunk	63.3 ± 2.92	71.5 ± 3.30	82.2 ± 4.05
Robusta	with a trunk	50.3 ± 2.40	56.8 ± 2.71	88.9 ± 3.33
	without a trunk	57.0 ± 3.01	64.4 ± 3.40	74.4 ± 4.62
I-45/51	with a trunk	57.1 ± 2.12	64.5 ± 2.39	77.8 ± 4.41
	without a trunk	61.0 ± 2.57	68.9 ± 2.90	75.6 ± 4.55

Source: compiled by the authors according to Ya.D. Fuchylo *et al.* (2023)

As can be seen from the above data, all the examined varieties during the first two years had higher survival rates of one-year-old seedlings in the variant with the cut aboveground part – from 57.0 ± 3.01 to 68.9 ± 2.90%.

In seedlings with an aboveground part, the survival rate ranged from 50.3 ± 2.40% to 68.1 ± 2.71%. During the growing season of 2022, due to irrigation, the highest survival rates of seedlings were obtained – from 74.4 ± 4.62% for the Robusta variety with removed trunks to 88.9 ± 3.33% for the same variety with trunks. Therewith, in the remaining clones examined, the survival rate of both variants of planting material was approximately the same. In plants of the Dorskamp variety, it was 81.1 ± 4.15 and 82.2 ± 4.05%, respectively, and in I-45/51 – 77.8 ± 4.41 and 75.6 ± 4.55.

It was also established that in 2020, the average height was mostly higher in plants grown from seedlings without a trunk. The plants of the Dorskamp clone had the highest height – 189.5 ± 3.45 cm. In uncut plants of this variety, it was 174.0 ± 7.69 cm. Therewith, the height increase in seedlings with a trunk was very small and ranged from 4.6 to 17.7 cm.

The results of similar studies that were conducted during the growing season of 2021 showed that the indicators of preservation and height were slightly higher, but in general, the overall trend observed in 2020 continued. The growth of seedlings with trunks in 2021 was higher compared to 2020 – from 17.8 cm for the variety Robusta to 31.1 cm for Dorskamp. Accordingly, their average heights were also higher. Therewith, in the case of the Dorskamp variety, seedlings with trunks were slightly higher – 190.4 ± 7.93 cm against 188.6 ± 4.15 cm for using seedlings with the trunk removed.

The 2022 study generally confirmed the conclusions made in previous years. The highest height indicators at the end of the growing season in 2022, as in previous years, were established in plants of the Dorskamp variety. When using seedlings with trunks, the height was 197.2 ± 6.61 cm, and without trunks – 209.3 ± 5.62 cm.

The weather conditions of 2022 were the least favourable for the growth of plants of the I-45/51 variety. Their average height at the end of the growing season was 134.1 ± 4.31 cm when using seedlings with trunks, and 135.9 ± 4.94 cm without trunks.

In plants of the Robusta variety, the average height of plants from seedlings with trunks in 2022 for the first time in years of research was slightly higher than that of seedlings without trunks (160.1 ± 5.09 and 155.6 ± 5.91 cm, respectively), which is associated using irrigation.

In conclusion, it is important to highlight some positive aspects of the forest component of agroforestry, which are emphasised by a number of researchers investigating this problem. In particular, most of them (Szigeti & Vityi, 2019; Bayala & Prieto, 2020; Nicolescu *et al.*, 2020) indicate its high efficiency in terms of improving conditions for successful agricultural crops growth. Especially important is the role of tree stands in stabilising the moisture content of territories and reducing the temperature of the environment during the hottest parts of the growing season. A study by North American researchers J. Ansari *et al.* (2023) showed high efficiency of absorption of inorganic nitrogen introduced with fertilisers from the soil by tree roots in agroforestry systems (forest pastures, field protection strips and alleys), which substantially reduces emissions of N_2O in the atmosphere. In this way, agroforestry maximises the efficiency of using N and simultaneously minimises nitrate pollution of air and drainage of water.

S. Fahad *et al.* (2022) indicate that planting trees on arable land substantially increases the content of organic carbon and nutrients in the soil, including nitrogen, phosphorus, metabolic potassium, etc. This reduces the need for fertilisers.

Thus, the conducted studies indicate a generally higher efficiency of using seedlings without trunks when creating forest fields and other Poplar plantings, compared to seedlings that were planted with trunks. In addition to higher survival rates of plantings and higher average plant height, this option releases a substantial number of one-year-old trunks, which can be used for harvesting high-quality seedlings to create other plantings, or growing cuttings.

Conclusions

The trend towards xerification of the climate of Ukraine actualises the need to switch to agroforestry systems of agricultural business not only in the Steppe, but also in the Forest-Steppe regions of the country and in Polissya. Under these conditions, wooded areas using Walnut can be effective (*Juglans regia* L.) – mainly for the production of fruits and hybrid Poplars – for the production of high-quality wood and energy biomass.

In the conditions of Zhytomyr Polissya, short-fruited five-year-old plants of Walnut of the selection by L. Shugin had an average height of 91.8 cm and a root neck diameter of 2.9 cm. Some of the trees entered the reproductive stage at the age of 4 years. Comparison of morphometric parameters of fruit-bearing trees and other trees showed that plants with fruits had a higher average height (by 27.4% at 4 years of age and by 13.4% at five years of age) and diameter – by 61.4% and 71.5%, respectively. The obtained data indicate that one of the markers of early fruitfulness of Walnut plants can be a larger diameter of the root neck and partially – a larger height.

In the Western Forest-Steppe zone, the examined Walnut forms had substantially higher growth rates. In the fourth year, their height increase ranged from 0.7 to 1.1 m. 48.5% of the trees entered the fruiting stage. A substantial difference in the size and reproductive characteristics of Walnuts selected by L. Shugin, which were grown in the Forest-Steppe and in Polissya, is largely determined by soil conditions because Walnut needs calcium and on the soils of Zhytomyr Polissya that are poor in calcium compounds, it grows and develops worse, which should be considered when creating its plantings in this region.

There were no studies of the features of creating Poplar stands with one-year-old seedlings in the Forest-Steppe in recent decades, so the results obtained have elements of scientific originality and practical importance.

The results of the study have shown that an effective way to increase the survival rate of one-year-old Poplar seedlings when creating agroforestry fields and other plantings is to plant them without an aboveground part. In addition to higher survival rates and higher average plant height, this option releases a substantial number of one-year-old shoots, which can be used as planting material for creating other Poplar plantings or growing seedlings. The research towards using various storage options, other planting dates, the use of superabsorbents, etc. should be continued to increase the survival rate of cuttings seedlings.

It is advisable to continue research in the area of investigating morphometric and other characteristics of plants of fast-fruiting forms of Walnut to identify new promising forms suitable for obtaining fruits and performing agroforestry functions.

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None.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Ansari, J., Udawatta, R.P., & Anderson, S.H. (2023). Soil nitrous oxide emission from agroforestry, rowcrop, grassland and forests in North America: A review. *Agroforest Systems*. doi: 10.1007/s10457-023-00870-y.

[2] Augère-Granier, M.L. (2020). *Agroforestry in the European Union*. Retrieved from https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/651982/EPRS_BRI(2020)651982_EN.pdf.

[3] Báder, M., Németh, R., Vörös, Á., Tóth, Z., & Novotni, A. (2023). The effect of agroforestry farming on wood quality and timber industry and its supportation by Horizon 2020. *Agroforestry Systems*. 97, 587-603. doi: 10.1007/s10457-023-00812-8.

[4] Bayala, J., & Prieto, I. (2020). Water acquisition, sharing and redistribution by roots: Applications to agroforestry systems. *Plant Soil*, 453, 17-28. doi: 10.1007/s11104-019-04173-z.

[5] Burgess, P.J., & Rosati, A. (2018). Advances in European agroforestry: Results from the AGFORWARD project. *Agroforestry Systems*, 92, 801-810. doi: 10.1007/s10457-018-0261-3.

[6] Convention on Biological Diversity. (1992). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[7] Fahad, S., *et al.* (2022). Agroforestry systems for soil health improvement and maintenance. *Sustainability*, 14, article number 14877. doi: 10.3390/su142214877.

[8] Food and Agriculture Organization (FAO). (n.d.). Retrieved from https://www.fao.org/about/en/.

[9] Fuchylo, Ya.D., Bordus, O.O., & Kyrylko, Ya.O. (2023). The influence of the technology of growing one-year-old poplar cutting seedlings on their morphometric indicators. *Modern Engineering and Innovative Technologies*, 26(4), 100-109. doi: 10.30890/2567-5273.2023-26-04-050.

[10] Fuchylo, Ya.D., Ivaniuk, I.D., & Bordus, O.O. (2022). Some peculiarities of planting of poplar cutting seedlings growing on leached chernozem of the Right-Bank Forest-Steppe of Ukraine. *Scientific Bulletin of UNFU*, 32(3), 20-25. doi: 10.36930/40320303.

[11] Fuchylo, Ya.D., Sinchenko, V.M., Hanzenko, O.M., Gumentik, M.Y., Pirkin, V.I. (2018). *Methodology for studying of energy plantations of willow and poplar*. Kyiv: Komprynt.

[12] Ivaniuk, I.D., Fuchylo, Y.D., Skrypchuk, P.M., & Yakymenko, O.H. (2022). Growth and development of quick-fruiting forms of walnut of L.S. Shugin selection in the North-Western part of Ukraine. *Bulletin of the Malyn Vocational College*, 1, 74-82.

[13] Kovács, K., & Vityi, A. (2019). How can agroforestry improve the success of afforestation and contribute to meeting the growing demand of wood? In *Proceedings of the 52nd international symposium on forestry mechanization* (pp. 606-612). Sopron: University of Sopron Press.

[14] Moreno, G., Aviron, S., Berg, S., Crous-Duran, J., Franca, A., García de Jalón, S., Hartel, T., Mirck, J., Pantera, A., Palma, J.H.N., Paulo, J.A., Re, G.A., Sanna, F., Thenail, C., Varga, A., Viaud, V., & Burgess, P.J. (2018). Agroforestry systems of high nature and cultural value in Europe: Provision of commercial goods and other ecosystem services. *Agroforestry Systems*, 92, 877-891. doi: 10.1007/s10457-017-0126-1.

[15] Mosquera-Losada, M., Moreno, G., Pardini L., Mcadam, J., Papanastasis, V., Burgess, P., Lamersdorf, N., Castro, M., Fabien, L., & Rigueiro-Rodríguez, A. (2012a). Past, present and future of agroforestry systems in Europe. In *Agroforestry – the future of global land use* (pp. 285-312). Dordrecht: Springer. doi: 10.1007/978-94-007-4676-3_16.

[16] Mosquera-Losada, M-R., Pantera, A., Rosati, A., Amaral, J., Smith, J., Rigueiro-Rodríguez, A., Watté, J., & Dupraz, C. (Eds.). (2012b). *What priorities for European Agroforestry?* Santiago Compostela: USC.

[17] Nicolescu, V.-N., Rédei, K., Vor, T., Bastien, J.-C., Brus, R., Benčať, T., Dodan, M., Cvjetkovic, B., Andrašev, S., La Porta, N., Lavnyy, V., Petkova, K., Perić, S., Bartlett, D., Hernea, C., Pástor, M., Mataruga, M., Podrázský, V., Sfeclă, V., & Štefančik, I. (2020). A review of black walnut (*Juglans nigra* L.) ecology and management in Europe. *Trees*, 34, 1087-1112. doi: 10.1007/s00468-020-01988-7

[18] Rigueiro-Rodrìguez, A., McAdam, J.H., & Mosquera-Losada, M.R. (Eds.). (2009). *Agroforestry in Europe. Current status and future*. Dordrecht: Springer.

[19] Sharma, N., & Singh, R. (2012). Dry matter accumulation and nutrient uptake by wheat (*Triticum aestivum* L.) under Poplar (*Populus deltoides*) based agroforestry system. *Agronomy*, 2012, article number 359673. doi: 10.5402/2012/359673.

[20] Shugin's hazelnuts. (n.d.). Retrieved from https://bokoplidni.blogspot.com/.

[21] Skrypchuk, P. (2020). Creation of an industrial walnut garden on the example of a united territorial community. *Horishnyk. Technologies and Innovations*, 4(9), 94-100.

[22] Smith, J., Pearce, B.D., & Wolfe, M.S. (2013). Reconciling productivity with protection of the environment: Is temperate agroforestry the answer? *Renewable Agriculture and Food Systems,* 28(1), 80-92. doi: 10.1017/S1742170511000585.

[23] State register of plant varieties suitable for dissemination in Ukraine. Retrieved from https://minagro.gov.ua/file-storage/reyestr-sortiv-roslin.

[24] Szigeti, N., & Vityi, A. (2019). Soil moisture and temperature characteristics in a young silvoarable agroforestry system. *Regional and Business Studies*, 11(1), 21-27. doi: 10.33568/rbs.2399.

[25] Wu, W., Tao, Z., Chen, G., Meng, T. Li, Y., Feng, H., Si, B., Manevski, K., Andersen, M.N., & Siddique, K.H.M. (2022). Phenology determines water use strategies of three economic tree species in the semi-arid Loess Plateau of China. *Agricultural and Forest Meteorology*, 312, article number 108716. doi: 10.1016/j.agrformet.2021.108716.

[26] Yukhnovsky, V.Yu., Gladun, G.B., Sovakov, O.V., & Lobchenko, H.O. (2019). The current state, problems and prospects for the development of agroforestry in Ukraine. In *Forest reproduction and forest reclamation in Ukraine: Origins, current state, current challenges and prospects in the conditions of the Anthropocene* (pp. 269-283). Kyiv: Lira-K.

Перспективи використання горіха волоського та тополі в агролісівництві Полісся та Лісостепу України

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Анотація. Кліматичні зміни актуалізують необхідність переходу аграрного бізнесу України до агролісівничих систем не тільки у степових, а й у північних регіонах країни. Мета досліджень – вивчення особливостей створення полезахисних насаджень волоського горіха (*Juglans regia* L.) та тополі (Populus × euramericana) на Поліссі та в Лісостепу України. Дослідні насадження швидкоплідного горіха створені однорічними сіянцями на дерново-підзолистих супіщаних ґрунтах Житомирського Полісся та на карбонатних ґрунтах Західного Лісостепу, а дослідження приживлюваності живцевих саджанців тополі виконувались на чорноземах Правобережного Лісостепу. Встановлено, що на дерново-підзолистих ґрунтах п'ятирічні рослини скороплідного гріха волоського мали середню висоту 91,8 см. У віці 4 роки деякі з них заплодоносили. Плодоносні деревця мали на 13,4 % більшу середню висоту і на 71,5 % більший діаметр, порівняно з рештою. На карбонатних ґрунтах горіхи відзначалися значно кращим ростом за висотою, що пояснюється кальцієфільністю горіха. Визначено, що ефективним способом підвищення показників приживлюваності однорічних живцевих саджанців сортів тополі 'Dorskamp', 'Robusta' та 'I-45/51' є їх висаджування без стовбурів. У всіх досліджуваних сортів протягом перших двох років вища приживлюваність саджанців була у варіанті без стовбура – від 57,0 до 68,9 %, тоді як у саджанців зі стовбуром – від 50,3 % до 68,1 %. У 2022 р., завдяки проведеному поливу, приживлюваність становила від 74, 4 % до 88,9 %. Середня висота переважно теж була вищою у рослин, що виросли із саджанців без стовбура. Найбільшою вона виявилася у рослин клону 'Dorskamp' – 188,6 до 209,3 см. У необрізаних рослин цього сорту вона становила від 174,0 до197,2 см. Практичне значення дослідження полягає в можливості виведення нових форм горіха і тополі та удосконалення технологій створення лісопольових угідь за їх участі, які можуть бути використані в умовах Полісся і Лісостепу.

Ключові слова: лісопольові угіддя; *Juglans regia* L.; Populus × euramericana; сіянці; саджанці; приживлюваність; середня висота; плодоношення

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Peculiarities of natural regeneration in oak forests after different methods of regeneration fellings

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Abstract. An important task for Ukrainian foresters is to adapt forests to climate change and ensure sustainable forest management. One key measure for achieving this goal is the natural regeneration of tree species, which contributes to the biological resilience of forest stands. The purpose of this study is to assess the impact of different methods of main use fellings on the natural regeneration process of tree species in oak forests. The study was conducted within the territory of the Stradch Forestry Educational and Production Complex of the Ukrainian National Forestry University. Data on the quantity and height of oak seedlings and saplings, and other tree species, were collected through observation after various methods of main use fellings were applied in oak forests. An

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analytical method was applied to detect patterns and differences in quantitative and qualitative indicators of young trees of different species in sample plots. Statistical data analysis was employed to establish relationships and draw conclusions based on numerical data. Different success rates of natural regeneration of tree species were identified on plots subjected to various methods of main use fellings. Positive dynamics in the quantity of seedlings and saplings were observed due to first intervention of the uniform shelterwood felling, ranging from unsatisfactory to good levels. It is recognised that the distribution of seedlings and saplings of all tree species was uneven across the area. Hornbeam has the highest frequency of occurrence – 75.6%. Tree species like Scots pine, European birch, and goat willow exhibited occurrence frequencies ranging from 30.8% to 39.7%. In general, in all the studied areas, the undergrowth of tree species was dominated by a small fraction up to 20 cm of height. To ensure the prevalence of pedunculate oak in naturally formed young stands, silvicultural care for its saplings is necessary on all plots. The obtained results provide a basis for developing scientifically grounded forest management measures aimed at increasing the quantity and quality of valuable tree species' saplings, particularly pedunculate oak

Keywords: self-seeding; undergrowth; species composition; hight structure; frequency of occurrence; hornbeam-pine-oak forest on fresh relatively rich soils

Introduction

The natural regeneration of tree species in the forest-steppe region of Ukraine holds significant importance in terms of forest adaptation to climate change and the pursuit of sustainable forest management. The implementation of seed-based natural regeneration is a crucial step towards enhancing the quality of forest stands and ensuring the sustainable development of the forestry sector. However, to effectively utilise natural regeneration, comprehensive research and a scientifically grounded system of forestry measures are required to improve its efficacy.

Researchers pay attention to the problems that remained unresolved in previous studies. For example, M.G. Rumyantsev *et al.* (2016) and O.G. Krynytska (2019) concluded that by employing the uniform shelterwood felling with improved and progressive techniques, successful natural regeneration of pedunculate oak can be achieved. This contributes to the formation of natural oak forests, enhancing their resilience and ecological protection functions.

Numerous works in this field have been conducted in the Vinnytsia region. Specifically, O. Vasylevskyi *et al.* (2018; 2021) examined the impact of reconstructive cutting on forest regeneration under the canopy of middle-aged oak stands. They found that increased illumination of trees after cutting leads to better crown development. V.V. Levchenko (2019) established that release cutting should be performed in areas with dense natural oak seedling undergrowth, ensuring better illumination and preservation of the young oak generation.

The main forest-forming tree species of the Ukrainian Roztochya region, including the pedunculate oak, exhibit high reproductive potential. According to O.G. Krynytska (2019), under favorable conditions, they regenerate successfully both in clear-cuts and under the canopy of parent stands (with satisfactory and good regeneration rates at 80-100% occurrence frequency). However, O.B. Bondar *et al.* (2020) reflected on the question of unsatisfactory natural oak regeneration. The authors consider the widespread implementation of selective and gradual clearcutting in operational forests, along with reforestation measures excluded from primary use, including actions to support natural oak regeneration, to be crucial. Overall, the success of natural seed-based regeneration of tree species is a complex process influenced by various factors. G.P. Ishchuk (2017) distinguished the following factors: the presence of seed sources, seed crop size, the regenerative maturity of the soil (with the condition of the forest floor being a criterion), and the conditions for the further development and growth of seedlings and saplings.

Results from M. Dillen *et al.* (2017) suggest a potentially significant positive impact of mixing certain tree species. Mixing species on an individual basis is recommended. Therewith, it is necessary to consider differences in the growth rate of young trees, as this variation can negatively affect pedunculate oak growth due to shading. Despite numerous studies on forest vegetation in general and oak stands in particular in the Ukrainian Roztochya, specifics of the natural regeneration of tree species in oak forests after different regeneration felling methods remain unexplored.

Studies on the natural regeneration of tree species remain relevant and vital for forest adaptation to climate change and sustainable forest management.

The purpose of the study is to assess the influence of different methods of regeneration in oak forests on natural regeneration of tree species.

Materials and Methods

The examination of natural regeneration of pedunculate oak and other tree species was conducted within the territory of the Stradch Forestry Educational and Production Complex (SFEPC) of the Ukrainian National Forestry University, which falls within the geographical region of the Ukrainian Roztochya.

The Ukrainian Roztochya is a physiogeographical region situated between the basins of the Dniester, Syan, and Western Bug rivers, starting from the outskirts of Lviv and extending approximately 70 km northwestward to the border with Poland.

The investigation of the natural regeneration of tree species was conducted both in forest plots under the canopy of oak stands after uniform shelterwood felling and in continuous clearcut areas. To determine the quantity of tree seedlings and saplings, monitoring plots of 2 m^2 or 4 m^2 were established on each plot, and the number of tree plants was counted. The number of these plots ranged from 26 to 50 on each site. In addition, measurements of the height of seedlings and saplings were taken, and then they were categorised by height groups: less than 20 cm, 21-50 cm, 51-130 cm, and over 130 cm. The assessment of tree seedlings and saplings was conducted three times: at the beginning of the vegetation period in 2020, at the end of the vegetation period in 2020, and at the end of the vegetation period in 2021.

The examination of the natural regeneration of tree species after the first intervention of the uniform shelterwood felling was conducted in a 138-year-old hornbeam-pine-oak forest on fresh, relatively rich soils within the Lelekhivka Forest District of the SFEPC (Lviv Region) in section 17, compartment 5. The stand composition is 88% pedunculate oak, 9% common hornbeam, 2% Scots pine, and 1% silver birch. Pedunculate oak in the stand is represented by two generations, old and middle-aged trees. The first intervention in this section was performed in February-March 2020 over an area of 1.0 ha with an intensity of 31.7% (103 m^3 removed).

In the same forest type, to compare the success of natural regeneration of tree species, the assessment of tree seedlings and saplings was also performed in two clearcut areas in the compartments 8 and 9 of the Lelekhivka Forest District of the SFEPC. The stand composition was 69% pedunculate oak, 10% Scots pine, 18% common hornbeam, and 3% silver birch, and the age was also 138 years. In compartment 8.1, the average diameter of oak trees was 40 cm, and in compartment 9.1 it was 36 cm. Clearcutting of the entire stand area was conducted in both compartments in February-March 2020 over an area of 1.0 ha.

Correlation analysis was used in the study to establish the relationship between the quantity of saplings and their occurrence frequency in the oak stand of the Lelekhivka Forest District after the regeneration fellings.

Results and Discussion

The obtained data indicate successful natural regeneration of tree species in all investigated areas within the conditions of a hornbeam-pine-oak forest on fresh relatively rich soils. After the the first intervention of the uniform shelterwood felling, the total quantity of tree seedlings and saplings changes from unsatisfactory at the beginning of the 2020 growing season (10,480 trees per hectare) to good at the end of the same period (41,825 trees per hectare). A year later, at the end of the 2021 growing season, the quantity of tree seedlings and saplings slightly increased and reached 42,693 trees per hectare (Table 1).

Table 1. Species composition and quantity of tree seedlings and saplings per experimental area after the first intervention of the uniform shelterwood felling, categorised by height groups, units per hectare

Tree species	Height groups, cm	Accounting period		
		spring 2020	autumn 2020	autumn 2021
Common hornbeam	≤ 20	8173	11635	5577
	21-50	1442	1538	7212
	51-130	481	481	5000
	> 130			1346
Scots pine	≤ 20		2019	5385
	21-50			96
	51-130			
	> 130			
Silver birch	≤ 20		4423	1827
	21-50		96	3077
	51-130			2500
	> 130			
Pedunculate oak	≤ 20	192	288	385
	21-50		192	385
	51-130		96	
	> 130			
Red oak	≤ 20			
	21-50			96
	51-130			
	> 130			
Goat willow	≤ 20		6154	192
	21-50		10192	4712
	51-130		4327	3558
	> 130			

Table 1, Continued

Tree species	Height groups, cm	Accounting period		
		spring 2020	autumn 2020	autumn 2021
White willow	⩽ 20			
	21-50			96
	51-130			
	> 130			
Sycamore maple	⩽ 20	192	96	
	21-50		96	673
	51-130			192
	> 130			
Rowan	⩽ 20			
	21-50		192	96
	51-130			96
	> 130			192
Total growth per 1 ha		10480	41825	42693

Source: compiled by the authors

The findings indicate an increase in the quantity of pedunculate oak seedlings and saplings under the canopy of the mother oak stand after the first intervention of the uniform shelterwood felling. During the 2020 growing season, its quantity increased from 192 trees per hectare to 576 trees per hectare, and a year later (in autumn 2021) it increased to 770 units per hectare, even though specific support for natural regeneration of pedunculate oak was not conducted on the site.

An analysis of the species composition of the saplings revealed that common hornbeam and goat willow dominate among the tree species, accounting for 57.9% and 23.1% of the total quantity, respectively. Pedunculate oak accounts for only 1.7% of the total amount of undergrowth (Table 1). There is also natural regeneration of species such as Scots pine (5.9%), silver birch (9.4%), sycamore maple (1.4%), and others, the proportion of which in the sapling composition does not exceed 0.5% (Table 1, Fig. 1).

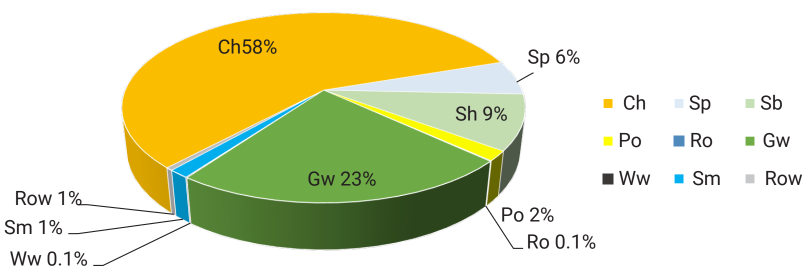


Figure 1. Proportion of tree species in the composition of seedlings and saplings under the canopy of the oak stand after the first intervention of the uniform shelterwood felling

Note: Ch – common hornbeam, Sp – Scots pine, Sb – silver birch, Po – pedunculate oak, Ro – red oak, Gw – goat willow, Ww – white willow, Sm – sycamore maple, Row – rowan

Source: compiled by the authors

An analysis of the height structure of the saplings revealed that after the first intervention of the uniform shelterwood felling within the oak stand, small (≤20 cm) and medium (21-50 cm) size fractions dominate in the pedunculate oak seedlings. Seedlings and one-year-old saplings constitute the major part of the regeneration, whereas large saplings taller than 130 cm are mainly observed among common hornbeam and common rowan (Table 1, Fig. 2).

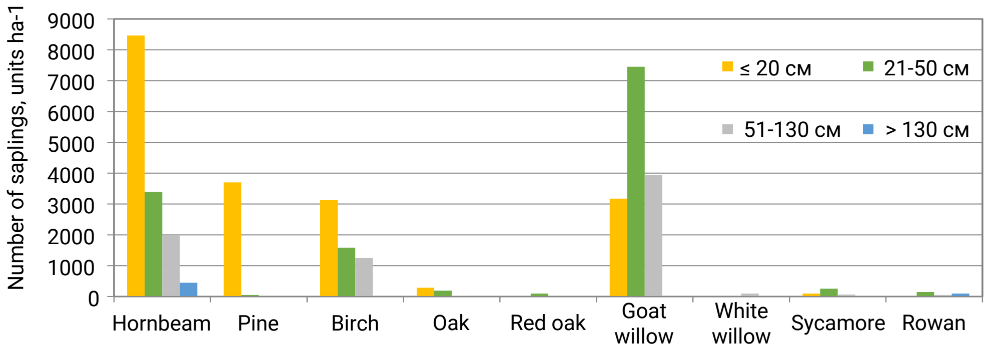


Figure 2. Distribution of understory by height groups under the canopy of an oak stand after the first intervention of the uniform shelterwood felling

Source: compiled by the authors

The spatial distribution of understory within the plot represents the frequency of occurrence, expressed as a percentage ratio of the number of sample plots with presence of certain tree seedlings and saplings to the total number of established sample plots within the plot area. Under the canopy of the oak stand, the natural regeneration of all tree species is characterised by an uneven distribution across the area. The highest frequency of occurrence is observed in common hornbeam – 75.6 %. Other species such as Scots pine, silver birch, and goat willow have occurrence frequencies ranging from 30.8% to 39.7%. All other tree species, including pedunculate oak, are encountered much less frequently (from 1.3% to 12.8%) (Fig. 3).

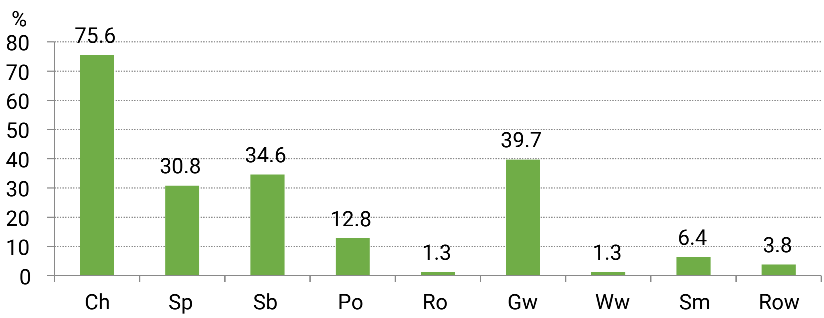


Figure 3. Occurrence frequency of tree seedlings and saplings (%) under the canopy of the oak stand

Note: Ch – common hornbeam, Sp – Scots pine, Sb – silver birch, Po – pedunculate oak, Ro – red oak, Gw – goat willow, Ww – white willow, Sm – sycamore maple, Row – rowan

Source: compiled by the authors

A strong correlation was found between the number of tree seedlings and saplings and their occurrence frequency in the oak forest of Lelekhivka Forest District after the first intervention of the uniform shelterwood felling ($R^2 = 0.9$):

$$N = 0.881 \cdot Z^2 + 133.82 \cdot Z - 494.65, \quad (1)$$

where N – number of undergrowth, units; Z – occurrence rate, %.

The prediction of the future participation of tree species in the forest structure can be performed based on the occurrence frequency of the respective species in the understory. The quantity and species composition of the understory are largely influenced by the development of the ground cover and undergrowth, the presence of forest fauna, crown closure of the mother trees, and other factors. Suppression by herbaceous vegetation is one of the main reasons for the mortality of the understory. The indices of the projective cover of the herbaceous layer on the sample plots varied greatly (from 1% to 100%), and its height ranged from 3 cm to 120 cm. Optimal natural regeneration of tree species was observed in places with low closure of the herbaceous cover, and in situations where low-growing plants predominated in its structure.

The composition of the ground cover on the sample plots was quite uniform. It was dominated by European dewberry (*Rubus caesius* L.), reed bent grass (*Calamagrostis epigejos* (L.) Roth), and brown sedge (*Carex brizoides* L.), while white bedstraw (*Galium album* Mill.) and male fern (*Dryopteris filix-mas* (L.) Schott) were less common. The thickness of the forest litter averaged 2 cm.

In contrast to the plot subjected to the first intervention of the uniform shelterwood felling, the two areas that underwent clearcut logging of a mature 138-year-old oak stand exhibited a notably higher abundance of young tree seedlings and saplings. The collective count of understory vegetation on these clear-cut areas ranged from 175.6 to 275.3 thousand specimens per hectare at the commencement of the 2020 growing season, rising to 299.4 thousand specimens per hectare by the conclusion of the same growing season, and further increasing to 461.2 thousand specimens per hectare during the autumn of 2021 (Table 2). It should be noted that the predominant proportion of tree seedlings and saplings on these clear-cut areas comprises youthful common hornbeam entities, forming dense clusters across certain sample plots.

Table 2. Species composition and quantity of tree seedlings and saplings on clear-cut areas by height groups, units per hectare

Tree species	Height groups, cm	Lelekhivka Forest District, compartment 25, subcompartment 8.1			Lelekhivka Forest District, compartment 25, subcompartment 8.1		
		Accounting period			Accounting period		
		VI 2020	X 2020	X 2021	VI 2020	X 2020	X 2021
Common hornbeam	⩽ 20	239500	226400	154900	164861	178750	53472
	21-50	100	1700	147700	278	1806	211250
	51-130	100	200	11100	139	139	25556
	> 130					278	
Scots pine	⩽ 20		4600	3200		4861	2500
	21-50	300		1600			1389
	51-130						

Table 2, Continued

Tree species	Height groups, cm	Lelekhivka Forest District, compartment 25, subcompartment 8.1			Lelekhivka Forest District, compartment 25, subcompartment 8.1		
		Accounting period			Accounting period		
		VI 2020	X 2020	X 2021	VI 2020	X 2020	X 2021
Silver birch	⩽ 20		19100	7600		5417	1250
	21-50		4300	36500		1389	9444
	51-130			28800			10833
	> 130			1100			
Pedunculate oak	⩽ 20	30700	35700	19000	5417	4861	2639
	21-50	1800	3200	19400		972	4444
	51-130			100			139
	> 130						
Small-leaved linden	⩽ 20		1800	1800			139
	21-50		800	5700			139
	51-130			2100			278
Goat willow	⩽ 20			1300			694
	21-50			8700			6389
	51-130			5900			3194
	> 130			100			
White willow	⩽ 20			800			
	21-50			200			
	51-130						278
	21-50			200			
	51-130						139
Norway maple	⩽ 20	1900	1100	900	1528	694	556
	21-50	600	400	300	139	556	556
	51-130	100	100	200			
Common beech	⩽ 20				139		139
	21-50				278	278	139
	51-130			100	2361	2361	2917
	> 130				417	278	139
Scots elm	⩽ 20	200					
	21-50			300			
	51-130			200			
	21-50			1200			139
	51-130			200			556
Total growth per 1 ha		275300	299400	461200	175557	202640	339307

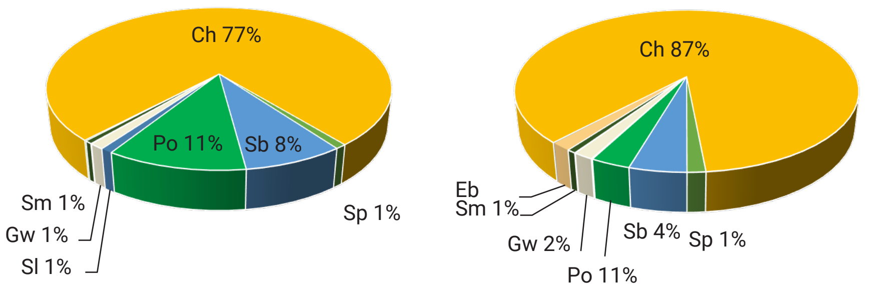
Source: compiled by the authors

Unlike the abundant presence of common hornbeam saplings on the clear-cut areas, the number of pedunculate oak saplings was significantly lower and remained relatively consistent throughout the study period. For instance, in compartment 25, subcompartment 8.1

of the Lelekhivka Forest District, the number of pedunculate oak saplings was 32,500 units per hectare in the spring of 2020, 38,900 units per hectare at the end of the 2020 growing season, and slightly decreased over the following year to reach 38,500 units per hectare in the fall of 2021.

Due to the recent implementation of clearcut logging, it is logical that both clear-cut areas predominantly feature a small fraction of young tree seedlings and saplings. The growth of species such as beech, birch, and various types of maple with a height of 51 cm and above is primarily attributed to their vegetative regeneration.

To gain a more comprehensive understanding of the natural regeneration process on the clear-cut areas within the context of the hornbeam-pine-oak forest on fresh relatively rich soils, the collected data has been summarized in Figure 4.



a) Lelekhivka Forest District, compartment 25, subcompartment 8.1

b) Lelekhivka Forest District, compartment 25, subcompartment 9.1

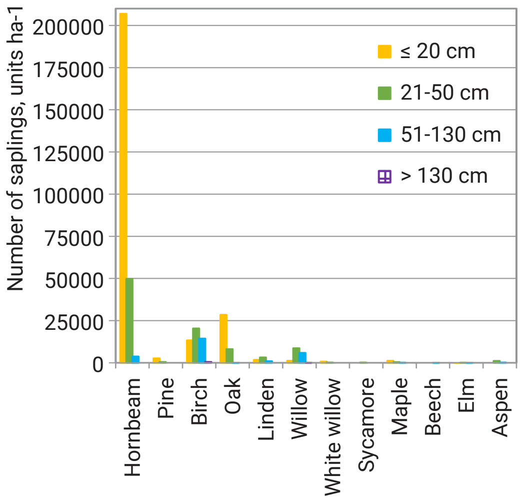
Figure 4. Distribution of tree species in the composition of tree seedlings and saplings on clear-cut areas

Note: Ch – common hornbeam, Sp – Scots pine, Sb – silver birch, Po – pedunculate oak, Gw – goat willow, Sb – silver birch, Eb – European beech, Sm – sycamore maple, Sl – small-leaved linden

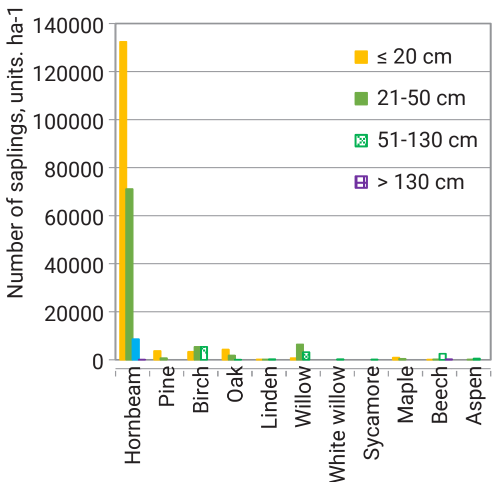
Source: compiled by the authors

The analysis of the sapling composition on the investigated clear-cut areas indicates the dominance of common hornbeam among other tree species. The average proportion of common hornbeam, based on three counts, ranges from 77% to 87% of the total number of young individuals, while the proportion of pedunculate oak accounts for only 3% to 11%. Occasional occurrences of other accompanying species like Scots pine, silver birch, goat willow, white willow, sycamore maple, Norway maple, small-leaved linden, common rowan, European beech, rough-leaved elm, red oak, and European aspen are observed (Table 2, Fig. 4). Thus, natural regeneration of all representative tree species is present on the clear-cut areas, allowing forest management methods to establish a stable stand of native trees.

An analysis of the height structure of the saplings on the clear-cut areas reveals that the dominance of small sapling fractions (up to 20 cm in height) is prevalent for both pedunculate oak and other tree species (Fig. 5). However, a substantial portion of these saplings later succumbs to damage caused by forest animals, lack of light, intense competition from the forest floor vegetation, and other unfavourable factors.



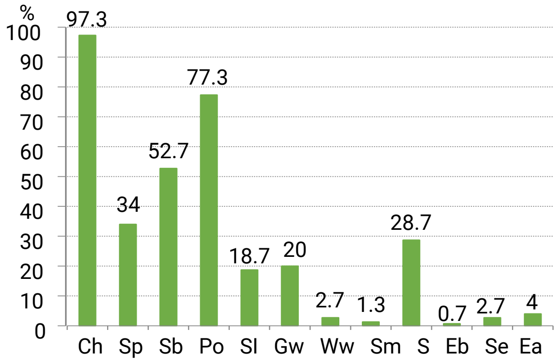
a) Lelekhivka Forest District, comp. 25, subcomp. 8.1



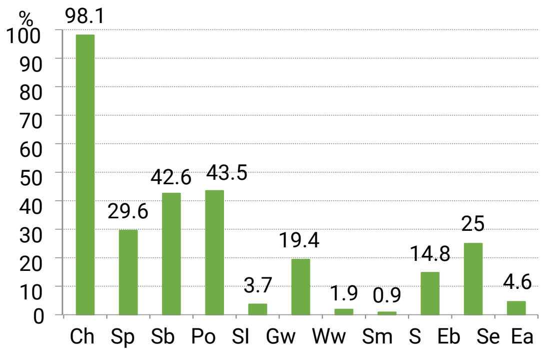
b) Lelekhivka Forest District, comp. 25, subcomp. 9.1

Figure 5. Distribution of tree saplings on clear-cut areas by height groups
Source: compiled by the authors

The distribution pattern of saplings across the area indicates that the natural regeneration of all tree species is characterised by uneven spread on the clear-cut areas. The highest frequency is observed for common hornbeam, ranging from 97.3% to 98.1%. Less frequent occurrences include pedunculate oak (43.5% to 77.3%), silver birch (42.6% to 52.7%), and Scots pine (29.6% to 34.0%). Other tree species such as small-leaved linden, willow, white willow, sycamore maple, sycamore, European beech, rough-leaved elm, and European aspen account for 0.7% to 20% (Fig. 6).



a) Lelekhivka Forest District, comp. 25, subcomp. 8.1



b) Lelekhivka Forest District, comp. 25, subcomp. 9.1

Figure 6. Frequency of tree sapling occurrence (%) on clear-cut areas

Note: Ch – common hornbeam, Sp – Scots pine, Sb – silver birch, Po – pedunculate oak, Sl – small-leaved linden, Gw – goat willow, Ww – white willow, Sm – sycamore maple, S – sycamore, Eb – European beech, Se – Scots elm, Ea – European aspen

Source: compiled by the authors

Very close correlations were established between the number of undergrowth in the test areas and the frequency of its occurrence:

$$N = 39{,}712 \cdot Z^2 - 1719{,}5 \cdot Z + 10643 \quad (R^2 = 0.9) \text{ (25 comp., subcomp. 8.1)}; \qquad (2)$$

$$N = 24{,}574 \cdot Z^2 - 787{,}67 \cdot Z + 4556{,}1 \quad (R^2 = 1{,}0) \text{ (25 comp., subcomp. 9.1)}, \qquad (3)$$

where N – number of undergrowth, units; Z – frequency of occurrence, %.

The extent of the projected ground cover of the herbaceous layer on the clear-cut areas varied from 10% at the beginning of the 2020 growing season (the first year after clearcut logging) to over 70% by the end of the 2021 growing season. The average height of this herbaceous layer was 6 cm and 70 cm, respectively. The most successful natural regeneration process occurred in areas with low plants and a sparse herbaceous cover. The herbaceous layer composition on the clear-cut areas was dominated by wood anemone (*Anemone* *sylvestris* L.), common reed (*Calamagrostis epigejos* (L.) Roth.), tawny sedge (*Carex brizoides* L.), wood spurge (*Euphorbia amygdaloides* L.), lily of the valley (*Convallaria majalis* L.), lungwort (*Pulmonaria officinalis* L.) and greater stitchwort (*Stellaria holostea* L.). The average thickness of the forest litter was 1.0 cm.

The results obtained from this study confirm the importance of issues related to the preservation and effective management of forest ecosystems, particularly within the unique natural complex of the Ukrainian Roztochya region, which holds significance as part of the Main European Watershed (Soroka, 2008). In general, the study of natural oak regeneration was conducted under diverse edaphoclimatic conditions and across multiple geographical regions of Ukraine: from Zakarpattska Oblast (Agiy *et al.*, 2016) to Sumy Oblast (Rumyantsev, 2016; Bondar *et al.*, 2020).

The findings share common features with the results of other researchers. Similar key factors for successful and high-quality oak forest regeneration in northwestern Germany were described by the German researchers A. Mölder *et al.* (2019). They recommend natural oak regeneration to be performed in close proximity to old oak stands or directly within them. Similar conclusions were drawn by English researchers. R. Harmer *et al.* (2005) asserted that in southern England, the number of oak seedlings is closely linked to the quantity and distance from parent trees, decreasing by 40-50% each year. Likewise, Dobrowolska (2006), who conducted studies in floodplain oak forests of Lower Silesia (Poland), arrived at similar conclusions.

M.M. Vedmid (2008), R. Crouzeilles *et al.* (2016), L.I. Kopiy *et al.* (2017) have found that naturally regenerated oak forest stands are more viable and advantageous compared to artificially established forests. These naturally regenerated stands grow faster, exhibit higher competitive ability against other tree species, and demonstrate greater resilience to negative natural influences. Harnessing the potential of natural oak regeneration not only reduces the costs of reforestation but also significantly shortens the time required for oak wood production and enhances the productivity of oak forest stands. This approach also contributes to the formation of more resilient oak-dominated stands that can better withstand adverse natural phenomena. These conclusions are supported by O. Vasylevskyi *et al.* (2018; 2021), who conducted extensive studies on natural oak forests in Vinnytsia. They assert that the main reason for the decline in the proportion of natural oak forests in Vinnytsia is the establishment of forest plantations and the low utilisation of natural oak regeneration.

Moreover, apart from the described and studied factors influencing the success of natural seedling regeneration of tree species, P. Annighöfer *et al.* (2015), J. Leonardsson *et al.* (2015), and M.V. Matusyak *et al.* (2019) indicate the following factors as relevant: the presence of seed sources, abundant fruiting, regenerative soil maturity, which is indicated by the state of forest litter, and the conditions for the further development and growth of seedlings and saplings. However, the most considerable factors in the natural regeneration of oak stands are illumination and competition of oak seedlings with associated tree species and herbaceous vegetation (Didenko & Polyankov, 2019; Mölder *et al.*, 2019). Polish researchers concluded that to achieve the best stem quality, it is necessary to ensure full canopy illumination for oak as soon as possible, but no later than 20 years from the start of pedunculate oak regeneration (Skrzyszewski & Pach, 2015).

T.P. Fedonyuk *et al.* (2017) demonstrated that five years is the ultimate deadline when oak can withstand inadequate illumination in coppice and understorey conditions. The vertical structure of the stand, understory, and the undergrowth of older generations directly influence the solar radiation reaching the oak seedlings. Therefore, to ensure successful natural seed regeneration of oak on relatively rich soils and to ensure its participation in future stands, it is proposed to maintain a relative stand density of no more than 0.7. Similar views are also upheld by O.G. Krynytska (2019). For successful regeneration and formation of natural oak stands, she recommends implementing measures that promote natural regeneration and appropriate forest management to preserve oak seedlings and undergrowth. Among these, the main ones include thinning the parent stands to a relative density of 0.6-0.7, reducing competition from herbaceous cover and understory, and timely canopy openings.

In addition to illumination, the success of pedunculate oak regeneration also significantly depends on the acorn yield and the population size of wildlife. To mitigate the impact of ungulates, R. Solymos (1993) from Hungary and J. Leonardsson *et al.* (2015) from Sweden suggest establishing enclosures to protect oak seedlings or saplings.

Another important factor influencing the intensity and quality of natural regeneration of key forest-forming species, including pedunculate oak, is the development of competing understorey and herbaceous vegetation (Leonardsson *et al.*, 2015; Lavnyy, 2021). The research conducted by C.J. Schweitzer *et al.* (2016) pertains to factors affecting fruiting and survival of young oak trees. They identify two main factors for successful natural regeneration: ensuring previous oak regeneration under the canopy of advancing stands and subsequent promotion of its undergrowth by thinning the upper canopy of the stand and removing parts of trees from the second canopy layer.

Similar to this study, in the conditions of fresh oak-pine coppice in Volyn region, M. Shevchuk *et al.* (2021) found that the highest number of pine and oak saplings is present in areas with low to moderate herbaceous cover density. The optimal environment for the emergence and preservation of seedlings is in low-lying and plain microrelief areas, where the oak sapling density is highest. The modelling systems of German researchers A. Mölder *et al.* (2019) yielded similar results. Competition from secondary tree species and herbaceous vegetation is the most decisive factor in the success of pedunculate oak regeneration.

Therefore, to increase the number of oak seedlings and undergrowth, V.V. Levchenko (2019), M. Shevchuk *et al.* (2021) recommend implementing forestry measures to promote natural regeneration. One of the most effective measures for increasing oak participation in the undergrowth is the proper selection of cutting methods (selective, gradual, transformation), which will improve oak tree fruiting and its quality natural regeneration.

Conclusions

The findings indicate that there is successful natural regeneration of tree species in the oak forests of the Stradch Educational and Production Forest Enterprise of the Ukrainian National Forestry University. This regeneration occurs both under the canopy of mature oak stands after the implementation of the first intervention of the uniform shelterwood felling and on clearcuts after the implementation of clearcutting in mature oak stands. Among the regenerating plants, common hornbeam was the most frequently observed species on the studied plots, comprising an average proportion ranging from 58% to 87% of the total regenerating population. The study showed that the proportion of pedunculate oak among the regenerating and undergrowth plants is relatively low: only 2% after the first intervention of the uniform shelterwood fellingg and 3-11% on clearcuts. This emphasises the necessity of implementing silvicultural measures across all areas to support the natural regeneration of pedunculate oak, ensuring its dominance within the naturally formed young stand. It was established that the natural regeneration of tree species in the studied areas depends on a complex of abiotic, biotic, and anthropogenic factors. Key among them are climatic indicators, species composition, and density of the understory, forest fauna, organisation of forestry operations, and proper execution of clearcut site preparation.

Analysis of the height structure of the undergrowth on sample plots showed that the dominant fraction is the small one (up to 20 cm). The frequency of occurrence of young pedunculate oak plants on the sample plots varies, accounting for 12.8% after the first intervention of the uniform shelterwood felling and 43.5-77.3% on clearcuts. A very strong correlation was found between the amount of undergrowth on sample plots and its frequency, confirmed by the coefficient of determination R^2 ranging from 0.9 to 1.0.

Based on the obtained results and the aforementioned conclusions, an important area for further studies is a deeper understanding of the mechanisms of natural regeneration of oak forests and the impact of various factors on this process. Further studies may involve analysing a wider spectrum of abiotic, biotic, and anthropogenic factors, the dynamics of the height structure of the undergrowth, and establishing further relationships between its quantity and frequency. In addition, these studies can be extended to other forest ecosystems to obtain more generalised and representative data on the natural regeneration of tree species, which will contribute to sustainable forest management and the preservation of natural biodiversity.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Agiy, V.O., Kopiy, S.L., Fizyk, I.V., & Kopiy, L.I. (2016). Influence of forestry measures on the redistribution of organic matter and chemical elements of the soil in the oak forests of Transcarpathia. *Scientific Bulletin of UNFU,* 26(5), 5-22. doi: 10.15421/40260502.

[2] Annighöfer, P., Beckschäfer, P., Vor, T., & Ammer, C. (2015). Regeneration patterns of European oak species (*Quercus petraea* (Matt.) Liebl., *Quercus robur* L.) in dependence of environment and neighborhood. *PLoS*, 10(8), article number e0134935. doi: 10.1371/journal.pone.0134935.

[3] Bondar, O.B., Rumyantsev, M.G., Kobets, O.V., Sidorenko, S.V., & Yushchik, V.S. (2020). The current state of oak plantations on the tributaries of the Vorskla within the Sumy region and the peculiarities of their natural regeneration. *Scientific Bulletin of UNFU*, 30(4),19-24. doi: 10.36930/40300403.

[4] Convention on Biological Diversity. (1992). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text

[5] Crouzeilles, R., Curran, M., Ferreira, M.S., Lindenmayer, D.B., Grelle, C.E.V., & Benayas, J.M.R. (2016). A global meta-analysis on the ecological drivers of forest restoration success. *Nature Communications*, 7, article number 11666. doi: 10.1038/ncomms11666.

[6] Didenko, M.M., & Polyankov, O.K. (2018). The state of natural regeneration of the common oak under the forest canopy in the Left-Bank Forest-Steppe. *Forestry and Agroforestry*, 132, 25-34. doi: 10.33220/1026-3365.132.2018.25.

[7] Dillen, M., Smit, C., & Verheyen, K. (2017). How does neighbourhood tree species composition affect growth characteristics of oak saplings? *Forest Ecology and Management,* 401, 177-186. doi: 10.1016/j.foreco.2017.07.016.

[8] Dobrowolska, D. (2006). Oak natural regeneration and conversion processes in mixed Scots pine stands. *Forestry,* 79, 503-513. doi: 10.1093/forestry/cpl034.

[9] Fedonyuk, T.P., Fedonyuk, R.G., Zinchuk, Y.V., & Pastushchyk, V.V. (2017). Success of natural seed regeneration of the common oak in Zhytomyr region. In *Ukrainian scientific-practical conference "Sustainable development of the country in within the framework of European integration"* (pp. 78-80). Zhytomyr: Zhytomyr State Technological University.

[10] Harmer, R., Boswell, R., & Robertson, M. (2005). Survival and growth of tree seedlings in relation to changes in the ground flora during natural regeneration of an oak shelterwood. *Forestry*, 78, 21-32. doi: 10.1093/forestry/cpi003.

[11] Ishchuk, G.P. (2017). Natural regeneration of oak and hornbeam under the tent of plantings and on clear cut areas in Korsun-Shevchenkivske Forestry State Enterprise. *Scientific Bulletin of UNFU*, 27(1), 15-18. doi: 10.15421/40270102.

[12] Kopiy, L.I., Fizyk, I.V., Baran, S., Lavnyy, V.V., Kopiy, S.L., Presner, R.B., & Agij, V.O. (2017). Natural seed reproduction of oak plantations as an element of close to nature forestry. *Scientific Bulletin of UNFU*, 27(9), 9-13. doi: 10.15421/40270901.

[13] Krynytska, O.G. (2019). *Forestry and ecological principles of natural reproduction and formation of pine and oak stands in the conditions of Lviv Roztoczia* (Doctoral dissertation, National Forestry University of Ukraine, Lviv, Ukraine).

[14] Lavnyy, V.V. (2021). *Silvicultural and ecological principles of restoration of primary stands on windthrow areas in the Ukrainian Carpathians*. Lviv: Galician Publishing Union.

[15] Leonardsson, J., Löf, M., & Götmark, F. (2015). Exclosures can favour natural regeneration of oak after conservation-oriented thinning in mixed forests in Sweden: A 10-year study. *Forest Ecology and Management,* 354, 1-9. doi: 10.1016/j.foreco.2015.07.004.

[16] Levchenko, V.V. (2019). Cutting to promote the natural regeneration of pedunculate oak. *Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine,* 16, 10-18.

[17] Matusyak, M.V., Neiko, I.S., & Yelisavenko, Y.A. (2019). Characteristics of structure and reforestation processes of natural oak stands of Khmilnyk Forestry State Enterprise. *Collection of scientific works of VNAU*, 12, 131-141.

[18] Mölder, A., Sennhenn-Reulen, H., Fischer, C., Rumpf, H., Schönfelder, E., Stockmann, J., & Nagel, R.V. (2019). Success factors for high-quality oak forest (*Quercus robur, Q. petraea*) regeneration. *Forest Ecosystems,* 6(1), article number 49. doi: 10.1186/s40663-019-0206-y.

[19] Rumyantsev, M.G., Solodovnik, V.A., Chigrinets, V.P., Lunachevsky, L.S., & Kobets, O.V. (2016). Peculiarities of formation and reproduction of natural oak stands of the Left-Bank Forest-Steppe of Ukraine. *Forestry and Agroforestry*, 128, 63-73.

[20] Schweitzer, C.J., Janzen, G., & Dey, D. (2016). Regenerating oak stands the "natural" way. In P.D. Keyser, T. Fearer, C.A. Harper (Eds.). *Managing oak forests in the eastern United States* (pp. 75-84). Boca Raton, FL: CRC Press.

[21] Shevchuk, M., Myroniuk, V., & Kurchyk, O. (2021). Reforestation process of fresh oak-pine forest in the State Enterprise "Kolkivske lisove hospodarstvo". *Notes in Current Biology*, 1, 38-41. doi: 10.29038/NCBio.21.1.38-41.

[22] Skrzyszewski, J., & Pach, M. (2015). Crookedness of pedunculate oak (*Quercus robur* L.) growing under a canopy of Scots pine (*Pinus sylvestris* L.). *Scandinavian Journal of Forest Research,* 30, 688-698. doi: 10.1080/02827581.2015.1048713.
[23] Solymos, R. (1993). Improvement and silviculture of oaks in Hungary. *Annals of Forest Science*, 50, 607-614. doi: 10.1051/forest:19930609.
[24] Soroka, M.I. (2008). *Vegetation of Ukrainian Roztochchya*. Lviv: Svit Publishing House.
[25] Vasylevskyi, O., Neyko, I., Yelisavenko, Yu., & Matusiak, M. (2021). Characteristics of natural oak forests of in SE "Khmilnytske lisove hospodarstvo" and implementation of measures for their regeneration. *Scientific Horizons*, 24(2), 37-46. doi: 10.48077/scihor.24(2).2021.37-46.
[26] Vasylevskyi, O.G., Yelisavenko, Y.A., Zlenko, O.P., & Monarch, V.V. (2018). Regeneration processes in natural oak forests of State Enterprise "Vinnytsia Forestry". *Agrobiology*, 138(1), 201-209.
[27] Vedmid, M.M. (2008). Preliminary renewal in the forests of fresh oak stands of the Left Bank of Ukraine. *Forestry and Agroforestry*, 112, 48-56.

Особливості природного поновлення в дубових лісах після різних способів рубок головного користування

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Анотація. Важливим завданням лісівників України є адаптація лісів до змін клімату та забезпечення сталого лісового господарства. Одним із ключових заходів для цього є природне поновлення деревних видів, яке сприяє підвищенню біологічної стійкості деревостанів. Метою дослідження була оцінка впливу способів рубок головного користування у дубових лісах на процес природного поновлення деревних видів. Дослідження проводилося на території

Страдчівського навчально-виробничого лісокомбінату Національного лісотехнічного університету України. За допомогою методу спостереження було проведено збір даних щодо кількості та висоти самосіву і підросту дуба звичайного та інших деревних видів після різних способів рубок головного користування в дубових лісах. Метод аналізу був застосований для виявлення залежностей та відмінностей між кількісними та якісними показниками молодих особин різних деревних видів на пробних площах. За допомогою статистичної обробки даних було встановлено зв'язки та зроблені висновки на основі числових даних. На ділянках з різними способами рубок головного користування було виявлено різну успішність природного поновлення деревних видів. Внаслідок першого прийому рівномірно-поступової рубки спостерігалася позитивна динаміка кількості самосіву та підросту від незадовільного до доброго рівня. Встановлено, що самосів і підріст всіх деревних видів характеризувався нерівномірним поширенням на площі. Найбільшу частоту трапляння має граб звичайний – 75,6 %. Такі види як сосна звичайна, береза повисла та верба козяча мають частоту трапляння в межах від 30,8 % до 39,7 %. Загалом на всіх досліджених ділянках у складі підросту деревних видів переважала дрібна фракція висотою до 20 см. Для забезпечення переваги дуба звичайного в складі природно сформованого молодого деревостану на всіх ділянках потрібно провести лісівничий догляд за його підростом. Результати дослідження дають підстави для розробки науково обґрунтованих лісогосподарських заходів з метою підвищення кількості та якості підросту цінних деревних видів, зокрема дуба звичайного

Ключові слова: самосів; підріст; видовий склад; висотна структура; частота трапляння; свіжа грабово-соснова судіброва

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Dominant pests and pathogens of urban plantings in Kyiv: Species composition and prevalence

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Abstract. Impact of pests and pathogens on trees, along with air pollution, are one of the most important factors that determine tree health in parks, squares, boulevards and streets of Kyiv. The purpose of the study was to monitor populations of dominant pests and foci of pathogens of tree ornamental plantings in Kyiv from 2020 to 2022. The objects of the study were horse chestnut leaf miner *Cameraria ohridella* Deschka & Dimic., leaf blotch miner moth *Acrocercops brongniardella* F., Linden gall mite *Eriophyes tiliae* Nal., and powdery mildew of Common Oak *Erysiphe alphitoides* Griffon & Maubl. U. Braun&S. Takam. Using the route method and the E.E. Geschele scale, population indicators were evaluated for *Cameraria ohridella, Acrocercops brongniardella* and *Eriophyes tiliae*. It is found that the number of these species is increasing. It

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is showed that these pests are common on tree species *Aesculus hippocastanum* L., *Quercus robur* L., and *Tilia cordata* Mill., in street and urban plantings under the intense influence of abiotic and anthropogenic factors. In 2021, compared to 2020, the prevalence of *Cameraria ohridella* increased by 7 times, the distribution of *Acrocercops brongniardella* ranged from 76-78%, and powdery mildew damage to Common Oak, on average, is 3.41. According to the results of the study, it is identified that the populations of *Acrocercops brongniardella* and *Eriophyes tiliae* are in a stable condition and do not have substantial deviations by year, while the invasive species *Cameraria ohridella* is characterised by a substantial increase in prevalence and abundance, which means that it causes an intense weakening and decrease in the decorative effect of Chestnut in the city's street plantings. Annual intensive powdery mildew *Erysiphe alphitoides* damage was noted at young ordinary plantings of Common Oak along the main roads of the metropolis. The potential reproduction opportunities of phytophagous insect populations are analysed. In practice, the obtained results can be used for pest management and further monitoring of tree health in street and urban plantings in Kyiv

Keywords: phytophage insects; accounting; *Cameraria ohridella; Acrocercops brongniardella; Eriophyes tiliae; Erysiphe alphitoides*

Introduction

Green spaces of Kyiv perform a variety of functions and are important for the city. They not only provide opportunities for recreation but also act as natural treatment complexes and urban compensation zones. Green areas of Kyiv include various types of green spaces that are characteristic of urbanised ecosystems of megacities. These include parks, including meadow parks, sports parks, and waterfront parks, squares, boulevards, botanical and dendrological gardens, zoos, street and avenue plantings, inner courtyard plantings, plantings near educational, cultural, and healthcare institutions, memorial complexes and cemeteries, as well as urban forests. According to V.V. Rodinkova *et al.* (2020), among the species composition of street plantings, linden (29.7%), maple (26.2%), common and red Horse Chestnut (14.8%), poplar (10.8%), black locust (7.8%), oak and ash (each at 1.1%), hawthorn (0.7%) are most commonly represented. Less frequently found on the city streets are birch, catalpa, elm, cherry, bird cherry, and other species, together accounting for about 8%. The taxonomic composition of Kyiv's dendroflora is quite rich. In the composition of street green spaces of the city, the leading share belongs to representatives of the genus *Tilia* L. which are generally characterised as resistant to urban conditions, but vulnerable to damage by *Eriophyes tiliae* Nal. with the formation of galls (erineums).

According to U. Braun *et al.* (2022), *Microsphaera alphitoides* (*Erysiphe alphitoides*) the most Common Oak leaf disease in Europe, numerous studies confirm the harmful effects of the pathogen on plants due to the absorption of nutrients from leaf tissues and reduced assimilation (Takamatsu *at al.*, 2015). P. Pap *et al.* (2013) note that it is particularly important to identify the influence of environmental factors on the complex relationships that exist between a plant and a pathogen.

L. Guedes *et al*. (2023) note that the bright colours of galls caused by *Eriophyes tiliae* on heart-shaped linden trees, due to the accumulation of pigment in their tissues, these newly formed organs develop for protection and nutrition. At the structural level, the most common changes caused by halo-forming organisms are homogenisation, hyperplasia, and cell hypertrophy.

L. Volter *et al.* (2022) established that an increase in the number of invasive species indicates an aggravation of the problem of degradation of local ecosystems. Therefore, in the studies of A. Cedro & G. Nowak (2022), N. Olenici *et al.* (2022), it is stated that the dynamic propagation *Cameraria ohridella* leads to a substantial weakening of Chestnuts in European countries. A study by A.F. Lihanov *et al.* (2016) of common bitter Chestnut plants indicate that the viability of Chestnut leafminer caterpillars depends on the viscosity of cell sap and has little to do with the content of phenols in the leaves. In late summer, on trees damaged by *Cameraria ohridella,* the development of dormant leaf buds begins, which should normally be in the next spring. Defoliation for a long time can lead to a substantial weakening of the tree, and, as a result, its death.

The purpose of the study is to examine populations of dominant pests (*Cameraria ohridella*, *Acrocercops brongniardella, Eriophyes tiliae, Erysiphe alphitoides*) and foci of pathogens of urban plantings in Kyiv.

Materials and Methods

The object of the study is tree species *Aesculus hippocastanum* L., *Quercus robur* L., *Tilia cordata* Mill. on the territory of the city of Kyiv in the period 2020-2022. The subject of the study is street and urban plantings in the zone of intense influence of abiotic and anthropogenic factors.

Monitoring of populations of dominant pests and foci of pathogens of urban plantings in Kyiv was conducted by the route method, 100 model trees were determined and 100 leaf plates were randomly selected, which were collected and numbered. The score of powdery mildew infestation of Common Oak with *Microsphaera alphitoides* (*Erysiphe alphitoides*) (Braun *et al.*, 2022) was determined by the E.E. Geschele scale visually on each leaf (Fig. 1).

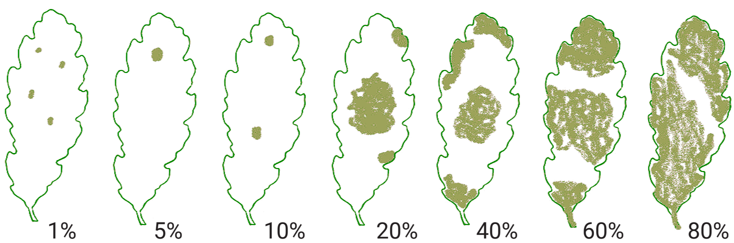

Figure 1. E.E. Geschele scale for investigating the distribution of powdery mildew fungi
Note: 0 points – healthy, 1 point – less than 10% of plants affected (weak degree), 2 points – 11-25% of plants affected (moderate degree), 3 points – up to 50% of plants affected (strong degree), 4 points – more than 50% of plants affected (very strong degree), 5 points – dying or dead plants
Source: A.F. Goychuk *et al.* (2012)

Disease prevalence – the number of affected plants or organs, expressed as a percentage, was determined by the formula (1):

$$P = \frac{n}{N} \cdot 100, \quad (1)$$

where P – prevalence of the disease, %, N – total number of plants on the test area, pcs., n – number of affected plants on the test area, pcs.

The intensity of disease development is a qualitative indicator of the process of disease development, calculated by Formula (2) to assess the general condition of woody plants in points:

$$R = \frac{\Sigma(a \cdot b)}{n}, \qquad (2)$$

where *R* – the intensity of disease development, score, *Σ (a · b)* – the sum of products of the number of plants (organs) and the corresponding lesion score, *n* – total number of plants or organs in accounting (Goychuk *et al.*, 2012; Puzrina *at al.*, 2021).

Inspection of the street and urban plantings for damage by *Cameraria ohridella* and *Acrocercops brongniardella* was conducted in the following periods: during the mass migration of adults and their egg laying, after the birth of the first generation of caterpillars, in the first and second decades of September. During the mass flight of butterflies and egg-laying of *Cameraria ohridella,* the approximate number of butterflies attaching to the bark of Common Horse Chestnut trees was determined (Meshkova, 2020). The counting of mines was conducted in the first and second decades of September using a hand lens. Calculated data regarding the area of the leaf blade and the area of mines for all 100 randomly selected leaf blades were recorded in an inventory sheet (Fig. 2).

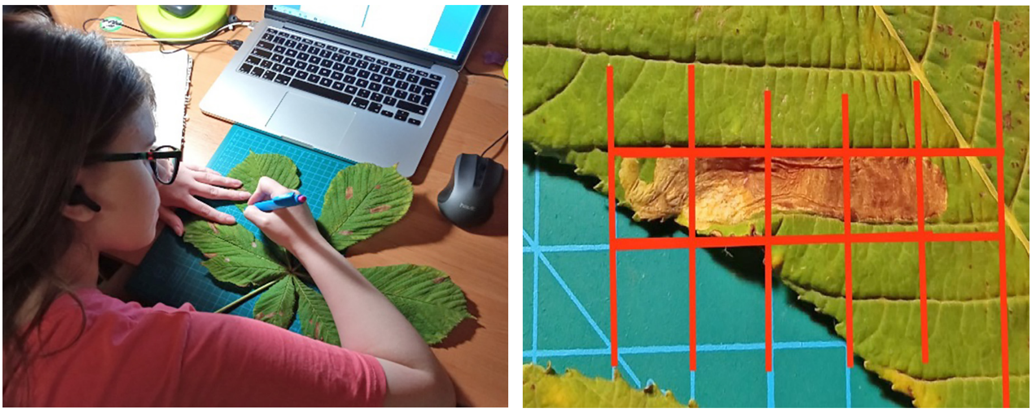

Figure 2. Process for calculating the area of mines on a leaf blade *Aesculus hippocastanum* L
Source: photographed by the authors

Moth generation and age were determined by identifying mines and comparing caterpillars by well-known morphological features (Zavada, 2017; Shvidenko *et al.*, 2020). On one sheet, the number of caterpillars was counted, their age and the number of dead caterpillars were determined.

Monitoring of *Acrocercops brongniardella* F. was conducted in July on damaged leaf plates, on which the area of mines and the number of caterpillars were determined. Leaf blades of Common Oak were selected randomly, the area of damage was determined using a palette in the field, then the average value of the lesion of leaf blades was calculated. Monitoring the spread of Linden gall mite *Eriophyes tiliae* was conducted by the route method, where the leaves of the lower tiers of *Tilia cordata* Mill. were randomly selected, on which the area of the leaf blade and the number of gall were calculated (Fig. 3).

Figure 3. The process of calculating the number of gall and leaf blade area, 2020
Source: photographed by the authors

In the laboratory, work was reduced to processing the collected materials and analysing the results obtained. The study met all the requirements of the Convention on Biological Diversity (1992).

Results and Discussion

In Ukraine, the rate of spread of invasive species and the scale of damage to green spaces in gardens, parks, and squares of cities are becoming more noticeable (Maksymchuk, 2009; Pihalo, 2010). Colonisation by atypical species for the region leads to a decrease in the energy of plant growth and their longevity, loss of decorative properties and yield, and ultimately leads to the gradual death of the plant. According to monitoring and accounting data for *Cameraria ohridella*, information was obtained on the number of species generations in Kyiv (Table 1).

Table 1. Generation of horse chestnut leaf miner in the conditions of Kyiv

Year	Month	Average monthly temperature, °C	Generation
2020	April	9.9	I
	May	12.4	I
	June	21.7	I, 2 dec.* II
	July	21.9	II
	August	21.4	II, 1 dec. III
	September	18.4	III, 1 dec. VI
	October	12.5	VI-fr.**
2021	April	8.0	I
	May	14.4	I
	June	21.3	I, 2 dec. II
	July	24.6	II
	August	21.1	II, 1 dec. III
	September	13.5	III, 1 dec. VI
	October	8.4	fr.

Table 1, Continued

Year	Month	Average monthly temperature, °C	Generation
2022	April	8.1	I
	May	14.6	I
	June	21.7	I, 2 dec. II
	July	20.8	II
	August	22.3	II, 1 dec. III
	September	12.7	III, 1 dec. VI
	October	10.6	VI – fr.

Note: *dec. – decade, **fr. – frosts
Source: compiled by the authors

During accounting, the number of caterpillars on one leaf, their age, and the number of dead caterpillars were determined, for example, on a leaf with an area of 122.8 mm^2 (model tree No, 2) in 2022, 7 caterpillars were identified at different stages of development: 2 of them were in IV-V age, 2 in the pupal stage, and 3 more died at different stages of development (Fig. 4).

a b

Figure 4. Comparison of the size of a caterpillar of stage IV and the tip of a mechanical pencil that has a size of 0.4 mm (a) and the number of caterpillars on the leaf (b)
Source: photographed by the authors

Invasive species are species that have a high ability to spread and pose a substantial threat to natural ecosystems, including flora and fauna. They can spread naturally or with the help of humans. These species have a high potential for expansion, as they have a wide ecological amplitude, resistance to stress, a high rate of reproduction and the ability to take root in new environments, can use resources inaccessible to native species, and substantially affect the balance of the ecosystem by changing its structure (Meshkova *et al.*, 2014). Monitoring of insect populations is essential to optimise pest control with appropriate protection periods and avoid unnecessary use of insecticides (Florian *et al.*, 2023). Accounting results that demonstrate the dynamics of the distribution of *Cameraria ohridella* on the Horse Chestnut are shown in Figure 5.

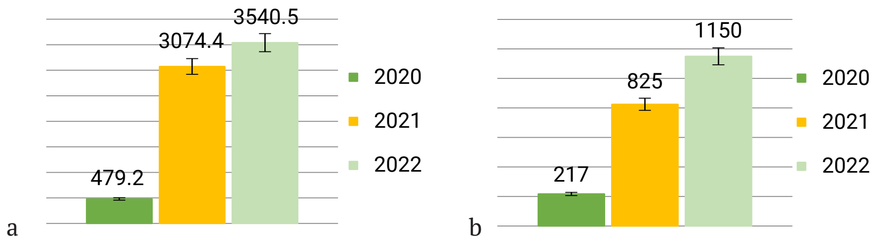

Figure 5. Total area, cm^2 (*a*) and quantity (*b*) of mines on model trees of *Aesculus hippocastanum* L. in the period of 2020-2022

Source: compiled by the authors

Sharp increase in the number of mines and their area in 2021 can be explained by several factors: an increase in the number of caterpillar generations due to rising temperatures and daylight hours. In September 2020, the average monthly temperature was 18.5°C, which led to an extension of the moth's summer period and the formation of the VI generation, therefore, this led to the fact that by the time it left for wintering, the population was dominated by caterpillars, most of which did not have time to pupate and died after frost in the thaw. During the 2021 period, the moth prevalence was much higher than in the 2020 period, due to constant temperatures above 15°C during the summer and favourable conditions for the butterflies to fly and better survival of the first two generations. 2022 was characterised by a very hot August, where the air temperature on some days exceeded 30°C, which led to more favourable conditions for the summer of the third generation of moths, an increase in the number of the fourth generation and the continuation of its activity in October. According to the authors' forecasts for 2023, the prevalence of moths will be 30-50% higher than in previous years under favourable climatic conditions. Early defoliation of Chestnuts (in climatic conditions of Kyiv this usually occurs in August), is a consequence of the colonisation of the leaf plate by moths not even of the third generation, but of the complete settlement by the first and second generations (Fig. 6).

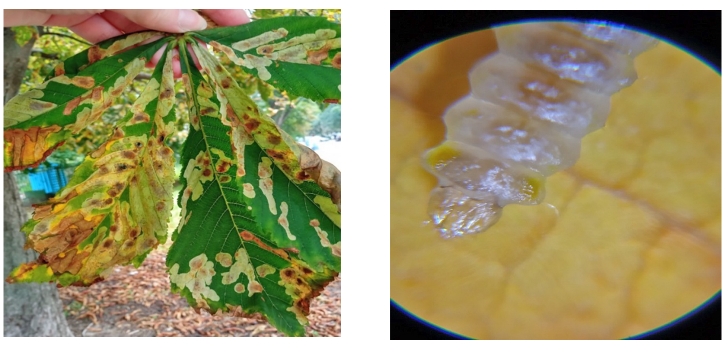

Figure 6. Intensive damage to the leaf blade (a) and V-age larva with a pronounced gnawing oral apparatus (b)

Source: photographed by the authors

Thus, according to the results of monitoring 2020-2022, a substantial spread of *Cameraria ohridella* was identified during this period, the prevalence increased seven-fold, which indicates clear favourable conditions, the absence of natural enemies in the examined conditions, and the rapid reproduction and viability of caterpillars of the first three generations, which, in turn, under favourable temperature conditions in September can produce a fourth generation. This trend towards an increase in the population size under favourable conditions will continue to be relevant in the following years. Accounting results that demonstrate the dynamics of the prevalence of *Acrocercops brongniardella* on Common Oak are shown in Figure 7.

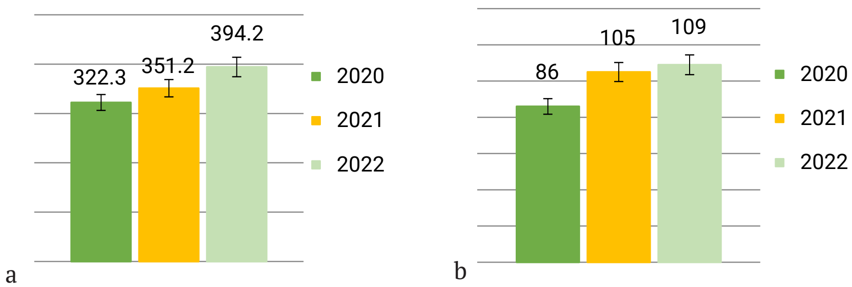

Figure 7. Total area, cm² (*a*) and quantity (*b*) of mines on model trees of *Quercus robur*. in the period of 2020-2022

Source: compiled by the authors

It was established that the number and area of mines on the leaf blades of Common Oak in the period from 2020-2022 fluctuated slightly. The Oak broadly leaf-mining moth is an aboriginal species for Ukraine, which means that in the conditions of Kyiv, the moth has natural entomophages among various representatives of the fauna, which regulates the number of species from uncontrolled outbreaks.

According to the phenogram of moth development in the conditions of the forest park zone of Kyiv, it can have two generations within 1 year (Grigoryuk *et al.*, 2014), the first generation of butterflies and the period of mass egg laying begins in April and ends in May. In May 2021 and 2022, the average monthly temperature was 14.4°C and 14.6°C, respectively, which contributed to the stretching of the flight period of *Acrocercops brongniardella* and during the survey period, the development of one generation per year. When examining urban plantings with a predominance of Common Oak for the presence of *Acrocercops brongniardella* it is established that the distribution of the population is 77-79%, and practically does not change over the years.

In addition, during the monitoring period, powdery mildew of Oak developed quite rapidly on the leaves of *Erysiphe alphitoides* (Griffon & Maubl.) U. Braun & S. Takam. According to the E.E. Geshele scale (Fig. 8), powdery mildew damage of Common Oak averages 3.41, that is, the disease has a strong degree of prevalence. Therefore, it can be assumed that young oak plantings are greatly weakened, considering their location opposite the main road where continuous emissions of toxic substances and heavy metals are observed around the clock. The complex of the above factors substantially hndeers the growth and development of young plantings, which can lead to their fall off.

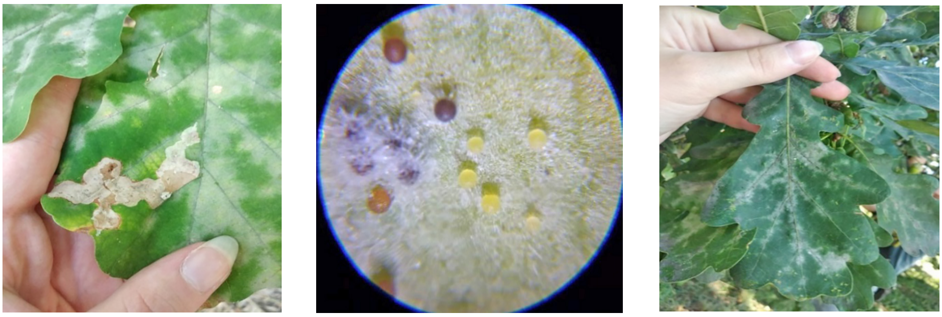

Figure 8. Powdery mildew of Oak *Erysiphe alphitoides*
(in the centre – cleistothecia on the underside of the leaf under the microscope)
Source: photographed by the authors

Based on the results of monitoring the number of galls in outdoor plantings dominated by heart-leaved Linden, the dynamics of distribution of *Eriophyes tiliae* was established (Fig. 9).

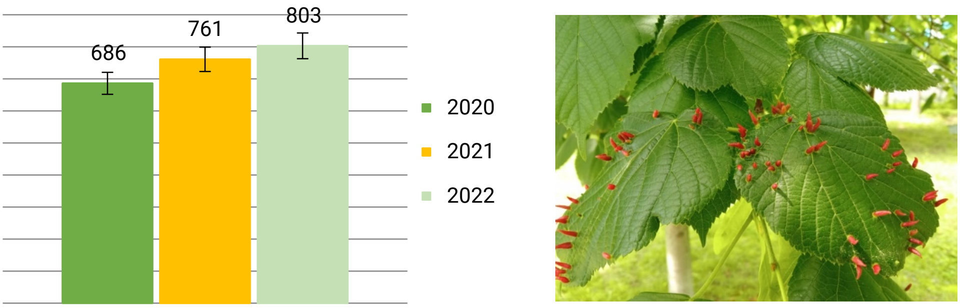

Figure 9. Total number of galls on model trees *Tilia cordata* for the period of 2020-2022
Source: compiled by the authors, photographed by the authors

The number of galls in the period of 2021-2022 on a single leaf blade ranges from 4 to 22, and within the model tree from 50-89 (2021) and 74-103 (2022), respectively. According to the results of observations and accounting, the distribution of the species was established in the range of 76-78%. It was established that the Linden gall mite primarily inhabits the lower part of the crown of the heart-leaved Linden and exhibits a focal pattern of colonisation. Firstly, the harm that *Eriophyes tiliae* Nal. causes consists in deformation of the leaf blade and a decrease in decorative effect, but with mass development, the species causes a disruption of the functions of the assimilation apparatus and the transfer of pathogens.

On trees of the species *Aesculus hippocastanum* the population of *Cameraria ohridella* was identified, the prevalence of which increased 7-times from 2020 to 2022. This clearly indicates favourable conditions, the absence of natural enemies, and rapid reproduction and viability of caterpillars of the first three generations, which under favourable temperature conditions in September can produce a fourth generation. Under such conditions, the flight of the first generation is predicted to be in mid-April 2023. Although the estimates of the rate of spread of *Cameraria ohridella* have been well investigated over the past few decades, particularly in the conditions of Kyiv (Serova *et al.*, 2007) and are consistent with data obtained by I. Shvidenko *et al.* (2020), K. Holoborodko *et al.* (2022), the data obtained will complement the study of population distribution dynamics and identify factors that affect the spread of the population of invasive species in a megapolises (Tobin & Robinet, 2022; Tokarieva *et al.*, 2022).

Diagnostics of urban plantings with a predominance of Common Oak for damage have showed that most of the plants are damaged by *Acrocercops brongniardella*, the distribution of the species is 77-79%. This is confirmed by the study conducted by I.P. Grigoryuk *et al.* (2014), according to which in urban plantings of Kyiv, the favourable natural and climatic conditions for the development of *Acrocercops brongniardella* are formed, which leads to the rapid spread of the population, but according to the observations of this study, the population had a one-year generation and an extended period of flight and reproduction during the study period. In the examined plantings, a strong lesion of powdery mildew was noted (3.4 points on the scale of E.E. Geschele), so the plants of Common Oak are greatly weakened.

Stable population indicators of the species *Eriophyes tiliae* indicate good adaptability of ticks to environmental conditions, in particular, this is consistent with the study by G. Soika & M. Kozak (2013), who noted that red galls have high levels of anthocyanins and perform various physiological functions, such as antioxidant and UV protection. Distribution of the Linden gall mite *Eriophyes tiliae* population ranges from 76-78%, mainly affecting the foliage from the lower part of the crown.

Notably, the city's garden and park landscapes are located in a dense circle of enterprises and highways, so comprehensive monitoring of the ecological and sanitary condition of the territory is relevant (Ogorodniychuk, 2009; Pihalo, 2010; Polyakov *et al.*, 2012). Monitoring and investigating the dynamics of the number of phytophagous insects and pathogens in urban conditions provides accurate information about their species composition, and harmfulness and allows allows to predict their number and potential reproduction (Grigoryuk *et al.*, 2014; Branco *et al.*, 2019; Holoborodko, 2022). Therefore, monitoring of insect populations is important both in the field of ecology and practical pest control, and is an integral part of integrated control and a primary approach to reducing environmental loads.

Monitoring studies in the period 2020-2022 indicate an increase in damage to urban plantings in Kyiv. This is due to the influence of abiotic (climatic conditions), biotic (growth in the number of phytophagous insects and the spread of pathogens), and anthropogenic (light load, noise, dust, emissions of toxic substances and heavy metals) factors on selected woody plant species.

Conclusions

Based on the results of an examination of model trees, the settlement of Horse Chestnut leaves with *Cameraria ohridella* and the area of mines increased from 217 mines (2020) to 1,150 mines (2022) and from 479.2 cm^2 up to 3540.5 cm^2 accordingly. Such an intensive increase in these indicators is indicative of favourable conditions for the reproduction and viability of *Cameraria ohridella* due to the formation of the fourth generation of insects.

In urban plantings with a predominance of Common Oak, the distribution of *Acrocercops brongniardella* was observed in the range of 77-79% and almost did not change from year to year. The total area of mines ranged from 322.3 cm^2 (2020) up to 394.2 cm^2 (2022), the number of mines was from 86 to 109, respectively. In addition, the rapid development of powdery mildew of Oak *Erysiphe alphitoides* was recorded annually, which is characterised by a high degree of damage (3,41).

Heart-leaved Linden trees have been established to have a focal nature of Linden gall mite *Eriophyes tiliae* colonisation, which caused deformation of the leaf blade and a decrease in decorative effect. Studies have shown that the number of galls on a single leaf blade varies from 4 to 22 during the period of 2021-2022. Within the model tree, the number of galls ranged from 50 to 89 in 2021 and from 74 to 103 in 2022.

Thus, the populations of *Cameraria ohridella, Acrocercops brongniardella, Eriophyes tiliae* and the pathogen *Erysiphe alphitoides* are the most common in street and urban plantings of the metropolis. Further investigation into the biology of the mentioned phytophagous insect species and associated disease pathogens will allow for the identification of patterns in their interactions within complex habitats and ecosystems and the level of threat to the green spaces of Kyiv.

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None.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Branco, M., Nunes, P., Roques, A., Fernandes, M.R., Orazio, C., & Jactel, H. (2019). Urban trees facilitate the establishment of non-native forest insects. *Neo-Biota*, 52, 25-46. doi: 10.3897/neobiota.52.36358.

[2] Braun, U., Bradshaw, M., & Pfister, D.H. (2022). (2864) Proposal to conserve the name *Microsphaera alphitoides* (*Erysiphe alphitoides*) (*Ascomycota: Erysiphaceae*) with a conserved type. *Taxon,* 71(2), 460-460. doi: 10.1002/tax.12693.

[3] Cedro, A., & Nowak, G. (2022). Influence of horse-chestnut leaf miner invasion on the growth-climate relationship of common horse-chestnut trees from north-western Poland. *Sylwan,* 166(2), 101-113. doi: 10.26202/sylwan.2021107.

[4] Convention on Biological Diversity. (1992). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[5] Florian, N., Josvai, J.K., Toth, Z., Gergocs, V., Sipocz, L., Toth, M., & Dombos, M. (2023). Automatic detection of moths (*Lepidoptera*) with a funnel trap prototype. *Insects*, 14(4), article number 381. doi: 10.3390/insects14040381.

[6] Goychuk, A.F., Reshetnyk, L.L., & Maksymchuk, N.V. (2012). *Methods of forest pathology examinations*. Zhytomyr: Polissya.

[7] Grigoryuk, I.P., Yavorovsky, P.P., & Stefanovskaya, T.R. (2014). Monitoring and regulation of abundance of the oak broad-mining moth (*Coriscium=Acrocercops*) *brongniardella* F.) in the forest park zone of Kyiv. *Scientific Notes of the Ternopil National Pedagogical Uni*versity, 61(4), 101-105.

[8] Guedes, L.M., Sanhueza, C., Torres, S., Figueroa, C., Gavilan, E., Perez, C.I., & Aguilera, N., (2023). Gall-inducing eriophyes tiliae stimulates the metabolism of tilia platyphyllos leaves towards oxidative protection. *Plant Physiology and Biochemistry,* 195, 25-36. doi: 10.1016/j.plaphy.2022.12.014.

[9] Holoborodko, K., Seliutina, O., Alexeyeva, A., Brygadyrenko, V., Ivanko, I., Shulman, M., & Bandura, L. (2022). The impact of *Cameraria ohridella* (Lepidoptera, Gracillariidae) on the state of aesculus hippocastanum photosynthetic apparatus in the urban environment. *International Journal of Plant Biology,* 13(3), 223-234. doi: 10.3390/ijpb13030019.

[10] Lihanov, A.F., Pentelyuk, O.S., Grigoryuk, I.P., & Kostenko, S.M. (2016). Spatial specificity of accumulation of phenols in leaves of plants of bitter-chestnut common (Aesculus hippocastanum L.). *Bioresursy i Pryrodokorystuvannya*, 8(3-4), 5-13. doi: 10.31548/bio2016.03.001.

[11] Maksymchuk, N.V. (2009). Peculiarities of development of the chestnut miner moth Cameraria ohridella Desch. & Dem. in the conditions of the Nikitsky Botanical Garden. *Fruit Growing, Seed Growing, Introduction of Woody Plants,* 12, 55-58.

[12] Meshkova, V.L. (Ed.). (2020). *Methodological guidelines for monitoring, recording and forecasting the spread of forest pests and diseases for the flat part of Ukraine*. Kharkiv: Planeta-print.

[13] Meshkova, V.L., Turenko, V.P., & Baidyk, G.V. (2014). Adventitious harmful organisms in the forests of Ukraine. *KHNAU Bulletin. Phytopathology and Entomology Series*, 1-2, 112-121.

[14] Ogorodniychuk, Yu.O. (2009). The dynamics of the state of stands of chestnut (*Aesculus hippocastanum* L.) in Kyiv. *Scientific Bulletin of the National University of Life and Environmental Science of Ukraine*, 134(3), 311-315.

[15] Olenici, N., Balacenoiu, F., Tomescu, R., Nețoiu, C., Buzatu, A., & Alexandru, A. (2022). Invasive alien forest insect species in south-eastern romania. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca,* 50(1), article number 12618. doi: 10.15835/nbha50112618.

[16] Pap, P., Rankovic, B., & Masirevic, S. (2013). Effect of temperature, relative humidity and light on conidial germination of oak powdery mildew (*Microsphaera alphitoides* Griff. et Maubl.) under controlled conditions. *Archives of Biological Sciences,* 65(3), 1069-1078. doi: 10.2298/ABS1303069P.

[17] Pihalo, O.V. (2010). The current state of the chestnut (*Aesculus hippocas*tanum L.) in the ornamental plantations of the historical part of Kyiv. *Scientific Bulletin of the National University of Life and Environmental Science of Ukraine*, 152(1), 136-140.

[18] Polyakov, O.K., Suslova, O.P., Netsvetov, M.V., Datsko, O.M., & Lykhatska, O.M. (2012). Viability of woody plants in urban street plantings in the Southeast of Ukraine. *Industrial Botany,* 12, 12-18.

[19] Puzrina, N.V., Meshkova, V.L., Myronyuk, V.V., Bondar, A.O., Tokarieva, O.V., & Boiko, H.O. (2021). *Monitoring of harmful organisms of forest ecosystems*. Kyiv: NULESU Editorial and Publishing Department.

[20] Rodinkova, V.V., Kremenska, L.V., Kryklyva, S.D., Bobrovska, O.A., & Shcherba, I.K. (2020). Aspects of feasibility of planting species of the genus Tilia L. in the urban zone of Vinnytsia. *Ukrainian Journal of Medicine, Biology and Sports*, 5(2), 192-197. doi: 10.26693/jmbs05.02.192.

[21] Shvidenko, I., Kardash, E., & Kolienkina, M. (2020). Peculiarities of mine density dynamics and phenology of the chestnut transient moth (*Cameraria ohridella* Deschka and Dimic, 1986) in the green areas of Kharkiv. *Biodiversity, Ecology and Experimental Biology*, 22(2), 60-70. doi: 10.34142/2708-5848.2020.22.2.07.

[22] Soika, G., & Kozak, M. (2013). Eriophyes species (acari: *Eriophyoidea*) inhabiting lime trees (Tilia spp.: Tiliaceae) – supplementary description and morphological variability related to host plants and female forms. *Zootaxa,* 3646(4), 349-385. doi: 10.11646/zootaxa.3646.4.3.
[23] Takamatsu, S., Ito, H., Shiroya, Y., Kiss, L., & Heluta, V. (2015). First comprehensive phylogenetic analysis of the genus *Erysiphe* (Erysiphales, Erysiphaceae) I the *Microsphaera* lineage. *Mycologia,* 107(3), 475-489. doi: 10.3852/15-007.
[24] Tobin, P.C., & Robinet, C. (2022). Advances in understanding and predicting the spread of invading insect populations. *Current Opinion in Insect Science,* 54, article number 100985. doi: 10.1016/j.cois.2022.100985.
[25] Tokarieva, O.V., Puzrina, N.V., & Lakyda, M.O. (2022). *Pest management in Forests of Eastern Europe*. Kyiv: NULESU Editorial and Publishing Department.
[26] Volter, L., Prenerova, E., Weyda, F., & Zemek, R. (2022). Changes in the parasitism rate and parasitoid community structure of the horse chestnut leafminer*, Cameraria ohridella* (Lepidoptera: Gracillariidae), in the Czech Republic. *Forests,* 13(6), article number 885. doi: 10.3390/f1306088.
[27] Zavada, M.M. (2017). *Forest entomology*. Kyiv: Vinnichenko.
[28] Zerova, M.D., Nikitenko, G.M., Narolsky, N.B., Gershenzon, Z.S., Sviridov, S.V., Lukash, O.V., & Babydorych, M.M. (2007). *Chestnut Mining Moth in Ukraine*. Kyiv: National Academy of Sciences of Ukraine Schmalhausen Institute of Zoology.

Домінантні шкідники і збудники хвороб міських насаджень м. Київ: видовий склад та розповсюдженість

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Анотація. Однією з важливих проблем, які стосуються мережі парків, скверів, бульварів, озеленених вулиць та площ м. Києва залишається поширення шкідників та збудників хвороб деревних насаджень. Мета дослідження полягала у моніторингу популяцій домінуючих шкідників та осередків збудників хвороб деревних декоративних насаджень м. Київа з 2020 по 2022 роки. Об'єктами дослідження були каштанова мінуюча міль *Cameraria ohridella* Deschka & Dimic., дубова широкомінуюча міль *Acrocercops brongniardella* F., липовий галовий кліщ *Eriophyes tiliae* Nal. та борошниста роса дуба звичайного *Erysiphe alphitoides* Griffon & Maubl. U. Braun & S. Takam. За допомогою маршрутного методу та шкали Е. Е. Гешеле проведено оцінку показників популяції *Cameraria ohridella, Acrocercops brongniardella* та *Eriophyes tiliae*. Встановлено, що чисельність зазначених видів зростає. Констатовано, що зазначені шкідники поширені на деревних видах *Aesculus hippocastanum* L., *Quercus robur* L. та *Tilia cordata* Mill., у вуличних та міських насадженнях за інтенсивного впливу абіотичних та антропогенних чинників. У 2021 році порівняно з показниками 2020 року, розповсюдженість *Cameraria ohridella* збільшилася у 7 разів, поширення *Acrocercops brongniardella* коливалося в межах 76-78 %, а ураження борошнистою росою дуба звичайного, в середньому, становить 3,41. За результатами досліджень виявлено, що популяції *Acrocercops brongniardella* та *Eriophyes tiliae* перебувають в стабільному стані і не мають суттєвих відхилень по рокам, тоді як інвазивний вид *Cameraria ohridella* відрізняється значним збільшенням розповсюдженості та чисельності, а відтак, спричиняє інтенсивне ослаблення та зниження декоративності гіркокаштана у вуличних насадженнях міста. Відмічено щорічне інтенсивне ураження борошнистою росою *Erysiphe alphitoides* молодих рядових посадок дуба звичайного вздовж магістральних шляхів мегаполісу. Проаналізовано потенційні можливості розмноження популяцій комах-фітофагів. На практиці отримані облікові дані, можна використовувати для подальших моніторингових спостережень у вуличних та міських насадженнях м. Києва

Ключові слова: комахи-фітофаги; облік; *Cameraria ohridella*; *Acrocercops brongniardella*; *Eriophyes tiliae*; *Erysiphe alphitoides*

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Effect of magnesium nanoparticles on formaldehyde emissions from wood composite materials

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Abstract. For the production of wood composite materials, adhesives based on cheap and affordable, but harmful urea-formaldehyde resins are mainly used. Given the substantial production volumes of such materials, it is important to find environmental solutions to reduce formaldehyde emissions during their pressing and subsequent operation. The purpose of the study was to present the results of a study on the use of magnesium oxide nanoparticles to bind unreacted formaldehyde in wood composite materials. Analysis of methods for manufacturing metal nanoparticles allowed determining a priority method that allows obtaining ultrafine structures with a size not exceeding 100 nm, namely, the method of volumetric electric spark dispersion of metals in a liquid.

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Investigating the morphology of magnesium nanoparticles allowed determining that they have an almost crystalline form formed from the vapour phase, with an average particle length not exceeding 100 nm. The results of spectral analysis of the element composition in the nanophase, specifically magnesium and oxygen, demonstrated that the magnesium content does not exceed 32.2%, while oxygen constitutes 67.78%. This indicates that divalent magnesium oxide does not have a pronounced metallic phase, which would interfere with the sorption processes of formaldehyde. The conducted examinations of formaldehyde emission of samples of particle boards with modified magnesium oxide nanoparticles in concentrations of 2% and 8% glue based on urea-formaldehyde resin showed mixed results. Compared to the control samples, the formaldehyde level remained almost unchanged on the second day of follow-up, and for a concentration of 2%, it even increased by 6%. However, by the sixteenth and ninetieth day, a reduction in the level of free formaldehyde emissions was observed at 19% and 22% respectively. The results obtained can be used to improve the production of non-harmful particle boards with improved properties

Keywords: ultrafine structures; metal oxide; production method; samples; harmfuly reduction

Introduction

With the development of nanotechnologies, a substantial body of findings has been accumulated regarding the usage of metal nanoparticles across various fields, ranging from medicine to agricultural production. The usage of nanometals as fillers in adhesives contributes to the enhancement of physical and mechanical properties of medium-density fiberboard (MDF) wood composite panels. A. Pizzi *et al*. (2020) noted that a special feature of the technology of manufacturing wood composite materials is the combination of crushed wood particles with a binder, followed by pressing under the influence of elevated temperature. O. Bekhta & T. Krystofiak (2023) indicated that urea-formaldehyde (UF) resins are predominantly used as binders, which are harmful to human health both during the manufacturing process of MDF and particleboard (PB) panels and their subsequent use. There is experience in reducing unreacted formaldehyde emissions by adsorbing it with nanoscale metals.

In the nanoscale state, there are a large number of atoms with uncompensated bonds on the metal surface, which leads to increased surface energy and their intense interaction with the environment (Lopatko *et al.*, 2020; Murmantsev *et al.,* 2022). The effectiveness of the use of nanomaterials is associated with the appropriate form of preparation and the possibility of long-term storage of chemical and biological activity (Aftandilyants & Lopatko, 2019).

Metals such as iron, zinc, and aluminium are most commonly used. H. Alabduljabbar *et al.* (2020) established that iron nanoparticles are able to bind free formaldehyde and react with it, with the release of CO_2, water on low valence iron. The ability of aluminium to improve the physical and mechanical properties of UF resin to adsorb free formaldehyde contributed to the use of aluminium oxide (Al_2O_3) in various thermosetting polymers. According to X. Tian *et al.* (2017), ZnO is quite sensitive to formaldehyde molecules and is used as part of analysers to detect free formaldehyde in the air.

There are several methods for producing metal nanoparticles: explosion of conductors, electron beam and gas-thermal, mechanical or chemical dispersion, and evaporation-condensation of materials. K.V. Vynarchuk *et al.* (2021) proved that the method of volumetric electric spark dispersion of metals in a liquid has an advantage in obtaining an ultrafine structure not exceeding one hundred nanometers with the specified characteristics. The experience of using this method for processing aluminium granules in organic matter has shown that 92.81% of aluminium nanoparticles with a length of 36.6 nm and a width of 35 nm were formed. Notably, by reducing the grains of metallic materials in the nanoscale range, more effective strengthening of the particle structure is observed (Aftandilyants & Lopatko, 2018). Therewith, the average temperature of the working fluid may be low, but in microplasma volumes of short-term sparks, ultra-high temperatures from 10,000 °C to 12,000 °C occur during 10-100 microseconds. Such flares allow obtaining particles from materials with substantially different melting points. High cooling rates in the liquid of dispersed spark-erosion particles lead to a substantial modification of their structure and the formation of materials with unique properties.

Magnesium oxide MgO, which has a high specific surface area and high absorption efficiency of toxic heavy metal ions and organic pollutants, was examined in a study by Z. Fusheng *et al.* (2022). Experience of using MgO nanoparticles for the destruction of organochlorine compounds, adsorption of large amounts of SO_2, CO_2 HCl, HBr, and other gases allows expecting the binding of unreacted formaldehyde in wood composite materials. This issue could be addressed by incorporating magnesium nanoparticles obtained through the electrospark method into the adhesive.

The purpose of the study was to investigate the use of magnesium nanoparticles as a potential adsorbent of unreacted formaldehyde in wood composite materials.

Materials and Methods

For the study, crushed pine wood with a humidity of 6%, an adhesive based on urea-formaldehyde resin Unicol RESIN 474 (Italy) were used. As a filler, magnesium nanoparticles were used, which were added to the resin solution in the amount of 2% and 8%. For comparison, control samples were made without a nanofiller.

A total of 9 samples with a thickness of 10 mm and a diameter of 41 mm were produced. The Temtop M2000 device (China) was used to measure free formaldehyde values. Measurements were conducted on the second, sixteenth, and ninetieth days after the production of prototypes. To determine the formaldehyde emission experimentally, obtained as a result of measurement (mg/$m^{3)}$ converted to ppm by the formula (Villanueva *et al.*, 2021):

$$C_{ppm} = \frac{C_{mg/m^3} \times 24.45}{M.W.}, \quad (1)$$

where C_{ppm} – the concentration of free formaldehyde is expressed in ppm (mln^{-1}, or $a \times 10^6$); $C_{mg/m}{}^3$ – concentration of free formaldehyde in mg/m^3; *M.W.* – molecular weight of the pollutant (g/mol); 24.45 – molar volume of any gas or vapour under normal conditions.

Magnesium nanoparticles were obtained using the method of volumetric spark dispersion (VSD) of metals in liquid (Patent No. 130939..., 2018). The essence of the VSD method is as follows: metal magnesium granules are placed in an aqueous medium in a special reaction chamber, where a voltage pulse passes through a freely enclosed layer of granules, causing current switching in the electrically conductive layer of granules. As a result of this process, there is electrical erosion of the surface of metal granules and the formation of a nanodispersed fraction of magnesium through the condensation of the vapour phase. When all parameters of the discharge circuit are properly coordinated, this nanodispersed fraction constitutes a significant portion of the erosion products. By adjusting the parameters of the discharge circuit (charging voltage of the capacitor and its capacitance), the frequency of pulse passage, their duration, and the initial resistance of the reaction chamber, it is possible to obtain suspensions with varying concentrations of magnesium nanoparticles.

A layer of conductive magnesium granules (5-10 mm) was used in the discharge chamber (Fig. 1) to ensure spark-erosion dispersion, made of a dielectric. For the volumetric electrospark dispersion of metal in liquid, discharge pulses (DP) were generated with currents ranging from 1 to 10 kA, which is 5 to 500 times greater than the average current of the power grid. The electrical resistance of the granule layer (0.1-1 Ohm) depends on the voltage and frequency of the discharge pulses and can stochastically vary within the range of 0.01-10 Ohms with an increase in discharge current by 1.5-5 times (without sparks between the granules), or a decrease by 2-100 times (with a corresponding increase in the duration of the discharge pulses, also without electrical sparks between the granule layer). The parameters of the discharge circuit are subject to changes within the following limits: working capacitor capacity C = 25-200 uF, capacitor charge voltage U_C = 50 - 250 V, and the inductance of the discharge circuit L did not exceed 1 μH. The dispersion process was conducted in a discharge chamber filled with deionised water.

Figure 1. Device for producing metal nanoparticles
Note: 1 – electric spark generator; 2 – discharge chambers; 3 – discharge pulse control unit

The morphology of the dispersed phase was determined using a Zeiss SUPRA 40VP electron microscope (SEM) (Germany).

A colloidal metal solution dried in a Labexpert thermal chamber (Ukraine) and ground to a powdery form was dispersed in distillate to 2% and 8% concentrations to examine the effect of nanomagnum oxide on formaldehyde emission. Adhesive mass according to recipe of A. Kumar *et al.* (2018) was introduced into pre-prepared chips in a ratio of 1:2, respectively. The adhesive weight was 10% of the wood chip weight.

Tarred chips were pressed in a laboratory press in one cycle for 180 seconds, under the schedule: temperature t = 130°C, pressure p = 2.9 MPA. The compressed samples were left under the press to cool to a temperature of t = 40°C. After that, they were kept for 48 hours in a room at an air temperature of t = 20°C and a relative humidity of φ = 60 ± 5% (Fig. 2). The density of the pressed samples was 780 kg/m^3 ± 10% (Mantau, 2012).

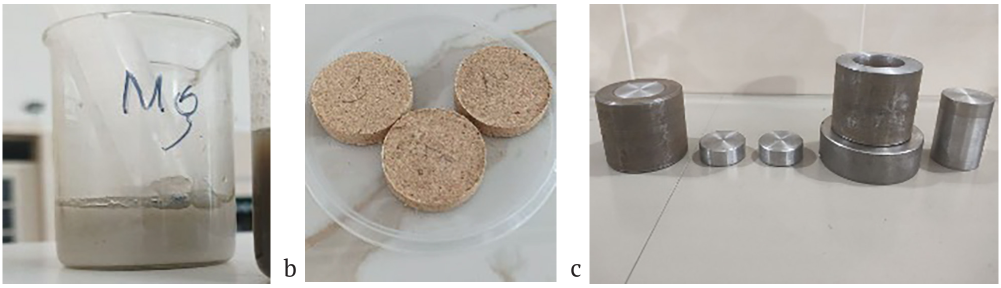

Figure 2. Visualisation of components and accessories for sample production
Note: a – colloidal magnesium solution; b – finished samples using an 8% UF resin-based adhesive modified with Mg nanoparticles in three repetitions; c – moulds for manufacturing samples with an internal diameter of d = 41 mm

The samples together with the Temtop M2000 device (China) were placed under a sealed transparent cap with a volume of 12 litres and the indicators were taken after 15 minutes on the second, sixteenth and ninety days to determine the free formaldehyde emission index. Determination of the formaldehyde emission value was calculated using formula (1).

Results and Discussion

The result of determining the morphology of the dispersed phase is shown in Figure 3.

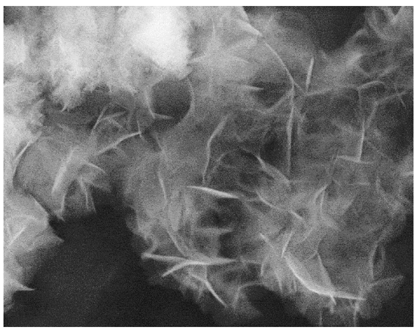

Figure 3. View of magnesium nanoparticles through a Zeiss SUPRA 40VP electron microscope (SEM)
Source: compiled by the authors

Particles that approach the crystalline shape were formed from the vapour phase. The presence of spherical particles in the total mass is the result of spraying the liquid phase. It was established that the average particle size in cross-section does not exceed 10 nm when they are about 60-100 nm long. Therewith, spectral measurements of the quantitative composition of the elements that formed the Nanophase were performed (Fig. 4).

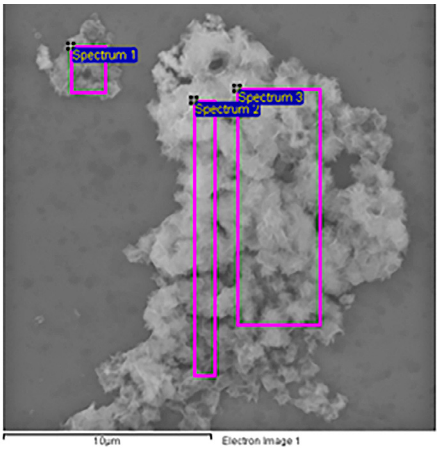

Figure 4. Result of spectral studies of the composition of nanophase elements
Source: compiled by the authors

The general structure of metal nanoparticles obtained by electric spark dispersion in water implies the presence of an oxide layer on the surface and a metal core. According to the results of microrentgenospectral analysis (Table 1), it can be seen that the amount of magnesium in the total mass of the particle varies from 14.5% to 32.2%, the rest is oxygen. Considering the atomic mass of magnesium and its total amount in the examined phase, it can be assumed that almost all magnesium forms a MgO compound, and magnesium nanoparticles do not have a pronounced metallic phase. Thus, two-valence magnesium oxide MgO is mainly involved in sorption and other processes of interaction between the Nanophase and the medium.

The results of experimental studies are shown in Figure 5 and Figure 6.

Table 1. Results of microrentgenospectral analysis of magnesium nanoparticles

Spectrum	**In stats.**	**O**	**Mg**	**Total**
Spectrum 1	Yes	85.55	14.45	100
Spectrum 2	Yes	70.73	29.27	100
Spectrum 3	Yes	67.78	32.22	100
Spectrum	**O**	**Mg**		
Max.	85.55	14.45		
Min.	67.78	32.22		

Source: compiled by the authors

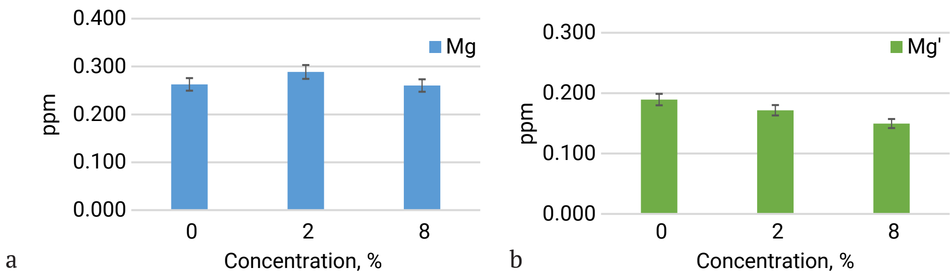

Figure 5. The level of free formaldehyde emission when using an adhesive based on UF resin modified with magnesium nanoparticles in various concentrations

Note: a – on the second; b – on the sixteenth day after pressing

Source: compiled by the authors

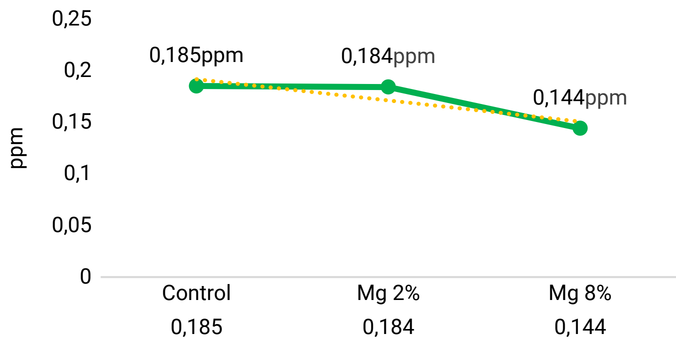

Figure 6. Emission of free formaldehyde when using an adhesive based on UF resin modified with magnesium nanoparticles in various concentrations of 2% and 8% on the ninetieth day

Source: compiled by the authors

On the second day, when using magnesium, the value of the isolated formaldehyde was on average 0.263 ppm for samples modified with a 2% solution and 0.260 ppm for 8%, while the control indicators were 0.188 ppm. On the sixteenth day, the control remained at a constant level of 0.186 ppm, while Mg 2% was 0.189 ppm and 0.150 ppm for 8%, which is 19% lower than the control.

On the ninetieth day, repeated measurements were made to understand the effect of nanoscale magnesium on the formaldehyde binding process in the long-term use of chipboard. The following results were obtained: for samples modified with a 2% colloidal solution of magnesium nanoparticles – 0.184 ppm, for 8% – 0.144 ppm, which is a 22% reduction in the emission of the test gas relative to the control. In turn, the level of formaldehyde emission in samples not modified with a nanofiller fluctuated within the standard error and amounted to 0.185 ppm.

Similar research results were obtained by G. Paul *et al.* (2021) when using magnesium lignosulfonate in the adhesive formulation. However, an increase in the content of lignosulfonate solution in the adhesive formulation, according to the authors, can lead to an increase in moisture and the content of the combined-cycle gas mixture during the pressing process, and an increase in the brittleness of the plates (Hu *et al.,* 2015; Bekhta *et al.*, 2021). Studies by E. Athanassiadou *et. al.* (2009), A. Pizzi (2013), and S. Costa *et al.* (2019) showed a reduction in formaldehyde emissions (up to the production of panel class – E1) when using magnesium lignosulfonates in the case of wood composite boards such as MDF or plywood, using a filler content of more than 20% (Alonso *et.al.*, 2005).

The results obtained show that magnesium has the ability to act as an adsorbent due to the fact that a strong four-membered ring involving a carbonyl group (CO) is formed on its surface links. This results in the weakening of the carbonyl bond to nearly a single bond. Nanoscale magnesium can be considered as a stoichiometric chemical reagent. Its high surface area means that 30-40% of magnesium fragments are located on the surface, which allows adsorption reactions to occur in the stoichiometric range, and its electronic structure involves only s-p electrons.

According to M. Nagpal & R. Kakkar (2020), there are several ways to adsorb formaldehyde onto MgO nanostructures. Depending on the coordination and type of defect site, different adsorption products are formed, and all reactions are exothermic. Low-coordination magnesium centres have high reactivity and adsorb the formaldehyde molecule. Oxygen from the carbonyl group coordinates with the surface centre of magnesium, which leads to the formation of a four-coordinate complex, in which the carbonyl bond is substantially weakened, which leads to the destruction of formaldehyde.

In the works of researchers P. Cademartori *et al.* (2018), W. Gul *et al.* (2021), it is established that the experience of using magnesium oxide for formaldehyde adsorption is still insubstantial, but there is interest in using nanoparticles of other metals to reduce the toxicity of particle boards. The positive effect of aluminium, iron, and zinc oxide nanoparticles on the binding of free formaldehyde when the latter were introduced into the UF resin solution was observed in the studies by M. Salem *et al*. (2013), S. Dinesh Ram *et al*. (2022).

Considering the surface feature of magnesium nanoparticles, P. Gabriela *et al.* (2022), A.E. Elsayed *et al.* (2023) consider it appropriate to use them for binding unreacted formaldehyde in the manufacture of wood composite materials, which will contribute to the environmental friendliness of both the technological process and products during operation. This modification of wood-composite materials makes it possible to obtain materials with additional characteristics and added value (M. Shvets *et al.*, 2020). Moreover, the issue of reducing the toxicity of finished products made of wood composite materials is a priority for the furniture industry (Pinchevska & Šmidriaková, 2016).

Conclusions

Analysis of studies on the use of metal nanoparticles – iron, zinc, and aluminium as a modifier of UF resin to reduce formaldehyde emissions showed the possibility of reducing free formaldehyde emissions into the air during the long-term operation of wood composites. The experience of using magnesium oxide, which has a high specific surface area and high absorption efficiency of hamful heavy metal ions and organic pollutants, allowed determining the possibility of using nanomagnet as an adsorbent for binding unreacted formaldehyde in wood composite materials. The scientific originality lies in the production of magnesium oxide nanoparticles using the electric spark method, which made it possible to achieve average particle sizes in the range of 5-60 nm. Experimental studies of the production of magnesium nanoparticles by the electric spark method and their subsequent use as a binder filler for the production of chipboard samples confirmed the hypothesis of reducing formaldehyde emission. Further research is necessary to determine the optimal concentration of nanometals in the adhesive used for the manufacture of wood composite materials.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Aftandilyants, Ye., & Lopatko, K. (2019). Influence of modified iron nanoparticles on the microstructure of low-alloyed steel. In *XV International scientific and practical conference Lithuania 2019* (pp. 19-23). Zaporizhzhia: Tandem

[2] Aftandilyants, Ye.G., & Lopatko, K.G. (2018) Effect of grain size on mechanical properties of nanomaterials. In *XIV International scientific and practical conference Lithuania 2018* (pp. 19-21). Zaporizhzhia: Tandem.

[3] Alabduljabbar, H., Alyousef, R., Gul, W., Shah, S., Khan, A., Khan, R., & Alaskar, A. (2020). Effect of alumina nano-particles on physical and mechanical properties of medium density fiberboard. *Materials*, 13(18), article number 4207. doi: 10.3390/ma13184207.

[4] Alonso, M.V., Oliet, M., Rodriguez, F., Garcia, J., Gilarranz, M.A., & Rodriguez, J.J. (2005). Modification of ammonium lignosulfonate by phenolation for use in phenolic resins. *Bioresource Technology*, 96, 1013-1018. doi: 10.1016/j.biortech.2004.09.009.

[5] Athanassiadou, E., Tsiantzi, S., & Markessini, C. (2009). *Producing panels with formaldehyde emission at wood levels*. Retrieved from https://chimarhellas.com/wp-content/uploads/2021/06/athanassiadou-tsiantzi-markessini-paper-2.pdf.

[6] Bekhta, O., & Krystofiak, T. (2023). Performance and modification of wood and wood-based materials author to whom correspondence should be addressed. *Forests,* 14(5), article number 963. doi: 10.3390/f14050963.

[7] Bekhta, P., Noshchenko, G., Réh, R., Kristak, L., Sedliacik, J., Antov, P., Mirski, R., & Savov, V. (2021). Properties of eco-friendly particleboards bonded with lignosulfonate-urea-formaldehyde adhesives and pMDI as a crosslinker. *Materials*, 14, article number 4875. doi: 10.3390/ma14174875.

[8] Cademartori, P., Henrique, J., Luiz, B., Pierre, M., & Washington, M. (2018). The use of low-pressure plasma on enhancing the attachment of Al_2O_3 nanoparticles to wood-plastic composites. *Journal of Wood Chemistry and Technology*, 38(2), 71-83. doi: 10.1080/02773813.2017.1372477.

[9] Costa, S., Costa, C., Madureira, J., Valdiglesias, V., Teixeira-Gomes, A., de Pinho, P.G., Laffon, B., & Teixeira, J.P. (2019). Occupational exposure to formaldehyde and early biomarkers of cancer risk, immunotoxicity and susceptibility. *Environmental Research*, 179A, article number 108740. doi: 10.1016/j.envres.2019.108740.

[10] Dinesh Ram, S., Shukla, D., & Gupta, A. (2022). Fatigue strength of copper and mild steel single lap joints bonded with epoxy-alumina nanocomposite adhesive. *IOP Conference Series*: *Materials Science and Engineering*, 1248, article number 012091. doi: 10.1088/1757-899X/1248/1/012091.

[11] Elsayed, A.E., Mohamed, L.M., Ahmed, F.S., & Farida, A.A. (2023). Using nano-magnesium oxide/bentonite composite for cadmium removal from industrial wastewater. *Environmental Engineering Research,* 28(2), article number 210545. doi: 10.4491/eer.2021.545.

[12] Fusheng, Z., Shaogeng, C., Bo, K., Long, X., Yinbin, S., & Runkai, W. (2022). Synergistic solidification of lead-contaminated soil by magnesium oxide and microorganisms. *Chemosphere*, 308, article number 136422. doi: 10.1016/j.chemosphere.2022.136422.

[13] Gabriela, P., Aurel, L., Zeleniuc, O., & Cosereanu, C. (2022). Three adhesive recipes based on magnesium lignosulfonate, used to manufacture particleboards with low formaldehyde emissions and good mechanical properties. *Forests*, 13(5), article number 737. doi: 10.3390/f13050737.

[14] Gul, W., Shah, S., Khan, A., & Pruncu, C. (2021). Characterization of zinc oxide-urea formaldehyde nano resin and its impact on the physical performance of medium-density fiberboard. *Polymers,* 13(3), article number 371. doi: 10.3390/polym13030371.

[15] Gupta, A., Kumar, A., Sharma, K., & Gupta, R. (2018). Application of high conductive nanoparticles to enhance the thermal and mechanical properties of wood composite. *Materials Today: Proceedings*, 5(1), 3143-3149. doi: 10.1016/j.matpr.2018.01.121.

[16] Hu, J.-P., & Guo, M.-H. (2015). Influence of ammonium lignosulfonate on the mechanical and dimensional properties of wood fiber biocomposites reinforced with polylactic acid. *Industrial Crops and Products*, 78, 48-57. doi: 10.1016/j.indcrop.2015.09.075.

[17] Lopatko, K., Zakharchenko, S., Shydlovska, N., Perekos, A., & Savluk, O. (2020). Features of obtaining of plasma-erosion nanodispersed silver hydrosols and their bactericidal and fungicidal properties. *Metallofizika i Noveishie Tekhnologii,* 42(6), 829-851. doi: 10.15407/mfint.42.06.0829.

[18] Mantau, U. (2012). Wood flows in Europe (EU27). Project report. Brussels: CEPI Confederation of European Paper Industries.

[19] Murmantsev, A., Veklich, A., Boretskij, V., & Lopatko, K. (2022). Hydrogen Balmer spectral lines in spectroscopy of underwater electric spark discharge plasma. *Contributions of the Astronomical Observatory Skalnate Pleso*, 50, 96-104. doi: 10.31577/caosp.2020.50.1.96.

[20] Nagpal, M., & Kakkar, R. (2020). Facile synthesis of mesoporous magnesium oxide-graphene oxide composite for efficient and highly selective adsorption of hazardous anionic dyes. *Research on Chemical Intermediates*, 46, 2497-2521. doi: 10.1007/s11164-020-04103-0.

[21] Patent No. 130939 "Device for producing a metal colloid". (2018). Retrieved from https://dspace.nuft.edu.ua/jspui/handle/123456789/30082.

[22] Paul, G., Lunguleasa, A., Zeleniuc, O., & Cosereanu, C. (2022). Three adhesive recipes based on magnesium lignosulfonate, used to manufacture particleboards with low formaldehyde emissions and good mechanical properties. *Forests*, 13(5), article number 737. doi: 10.3390/f13050737.

[23] Pinchevska, O., & Šmidriaková, M. (2016). Wood particleboard covered with slices made of pine tree branches. *Acta Facultatis Xylologiae Zvolen*, 58(1), 67-74. doi: 10.17423/afx.2016.58.1.08.

[24] Pizzi, A. (2013). Bioadhesives for wood and fibres. *Reviews of Adhesion and Adhesives*, 1, 88-113. doi: 10.7569/RAA.2013.097303.

[25] Pizzi, A., Papadopoulos, A., & Policardi, F. (2020). Wood composites and their polymer binders. *Polymers,* 12(5), article number 1115. doi: 10.3390/polym12051115.

[26] Salem, M.Z.M., Zeidler, A., Böhm, M., & Srba, J. (2013). Norway spruce (*Picea abies* [L.] Karst.) as a bioresource: Evaluation of solid wood, particleboard, and MDF technological properties and formaldehyde emission. *BioResources*, 8(1), 1199-1221. doi: 10.15376/biores.8.1.1199-1221.

[27] Shvets, M., Markov, F., Fitisov, A., & Didenko, P. (2020). Analysis of financial and economic activity of state forest enterprises in the conditions of economic and ecological crisis. *Scientific Horizons,* 06(91), 92-100. doi: 10.33249/2663-2144-2020-91-6-92-100.

[28] Tian, X., Li, Y., Wan, S., Wu, Z., & Wang, Z. (2017). Functional surface coating on cellulosic flexible substrates with improved water-resistant and antimicrobial properties by use of ZnO nanoparticles. *Journal of Nanomaterials,* 2017, article number 9689035. doi: 10.1155/2017/9689035.

[29] Villanueva, F., Ródenas, M., Ruus, A., Saffell, J., & Gabriel, M. (2021). Sampling and analysis techniques for inorganic air pollutants in indoor air. *Applied Spectroscopy Reviews,* 57, 1-49. doi: 10.1080/05704928.2021.2020807.

[30] Vynarchuk, K.V., Zazymko, O.V., & Lopatko, K.G. (2021). Electrospark synthesis of nanoorganometallic complexes of biogenic metals. In *International scientific and practical online conference "Modern problems and prospects for the development of mechanical engineering of Ukraine»* (pp. 184-185). Kyiv: NULES of Ukraine.

Вплив наночастинок магнію на показники викидів формальдегіду з деревино композиційних матеріалів

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Анотація. Для виробництва деревних композиційних матеріалів переважно використовують клеї на основі дешевих та доступних, проте токсичних карбамідоформальдегідних смол. Враховуючи значні обсяги виробництва таких матеріалів, актуальним є пошук екологічних рішень щодо зменшення викидів формальдегіду під час їх пресування та подальшої експлуатації. Метою статті було представити результати дослідження з використання наночастинок оксиду магнію для зв'язування непрореагованого формальдегіду у деревинокомпозиційних матеріалах. Аналіз способів виготовлення наночастинок металів дозволив визначити пріоритетний метод, що дозволяє отримати ультрадисперсні структури, розмір яких не перевищує 100 нм, а саме метод об'ємного електроіскрового диспергування металів у рідині. Вивчення морфології наночастинок магнію дозволило визначити, що вони мають майже кристалічну форм яка утворилася з парової фази, та середня довжина частинок не перевершує 100 нм. Результати спектральних досліджень складу елементів у нанофазі а саме магнію і кисню, показали, що кількість магнію не перевищує 32,2 %, а 67,78 % займає кисень. Це свідчить про те, що двохвалентний оксид магнію не має вираженої металевої фази, яка б заважала процесам сорбції формальдегіду. Проведені дослідження емісії формальдегіду зразків деревностружкових плит із модифікованим наночастинками оксиду магнію в концентраціях 2 % і 8 % клеєм на основі карбамідоформальдегідної смоли показали неоднозначні результати. У порівнянні з контрольними зразками на другу добу спостереження рівень формальдегіду майже не змінився, а для концентрації 2 % навіть збільшився на 6 % . Проте, вже на шістнадцяту і дев'яносту добу спостерігалося зниження рівня виділення вільного формальдегіду на 19 % та 22 % відповідно. Отримані результати можуть бути використані у вдосконаленні виробництва нетоксичних деревностружкових плит з покращеними властивостями

Ключові слова: ультрадисперсні структури; оксид металів; спосіб отримання; зразки; зниження токсичності

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The spread of alien vascular plant species in the biotopes of the Moshnohirsky Ridge (Cherkasy region, Ukraine)

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Abstract. Invasion of organisms pose a potential threat to the existence of natural habitats and lead to impoverishment of biological diversity. Particularly pronounced is the negative impact within the boundaries of the Middle Dnieper region, where approximately a quarter of vascular plant species are of alien origin. The purpose of the study was to identify the current species composition of alien vascular plant species, the specific features of their distribution outside the culture, naturalisation, and involvement in plant communities of Moshnohirsky Ridge biotopes. The species composition of plants was recorded by transects and releves in the habitats of representatives of alien plant species were conducted to achieve this goal. It was determined that the vegetation cover of forest and related biotopes in the research area is significantly contaminated with alien vascular plant species, amounting to 48 species from 45 genera and 29 families. Substantial involvement of alien species is noted in Forest biotopes of hornbeam-oak forests – 35.4%, and oak and pine-oak forests – 29.2%. Among the alien species that have a substantial impact on the structure of plant communities of these broad-leaved forest biotopes are *Impatiens parviflora* DC., *Robinia pseudoacacia* L.,

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Acer negundo L. Over time, the majority of introduced species are considered neophytes (81.3%), with a significant portion originating from North America (43.8%), the Mediterranean region (16.7%), and East Asia (8.3%). In terms of their penetration into natural ecosystems, species that are capable of actively integrating into natural communities, namely agriophytes and agriocoenophytes, hold high positions (a total of 30.2%). In contrast to these groups, limited alien species without active distribution – ephemerophytes and colonophytes are substantially represented in the groupings of the research area (30.6%). The identified patterns of distribution and cenotic distribution of alien species are the primary basis for the formation of optimal measures to counteract new invasions in forest communities and restrain the process of population compaction for species that already have a wide distribution within the research area

Keywords: adventitious fraction; phytoinvasions; Middle Dnieper region; kenophytes; agriophytes; naturalisation

Introduction

Increased anthropogenic impact on the environment leads to ecosystem transformation, reduced species diversity, and invasion of alien species into natural phytocenoses. Invasion of alien species, according to the degree of risk to the conservation of biological diversity, is recognised as a highly dangerous phenomenon that causes long-term negative consequences and poses a threat to the existence of natural habitats (Czechowska *et al.*, 2022). Biodiversity is inextricably linked to ecosystem services and human well-being, but in recent decades, the threat from alien plant species to native biodiversity, habitats, ecosystem services, and human health has tended to increase, as reflected in they study by R.L. Macêdo *et al.* (2022). High economic activity in the modern world, in particular, the extensive network of transport routes, population migration, and trade continue to contribute to the spread of an increasing number of alien organisms, through previously insurmountable spatial and ecological barriers, such as freshwater and marine aquatic ecosystems, mountain ranges, and unfavourable climatic zones (Kueffer, 2017). According to P.K. Rai & J.S. Singh (2020), plant invasions, anthropogenic disturbances, climate change, biodiversity, and social and economic well-being can often have complex and confusing links.

Researchers M. Kourantidou *et al.* (2022) separately raised the global problem of increasing the impact on the economic situation from the spread and naturalisation of alien species in new regions and the invasive activity of their individual representatives.

V.V. Konishchuk *et al.* (2020), L.V. Zavialova *et al.* (2021) proved that the problem of the distribution of alien species is particularly acute for reference territories. These territories hold a protected status and have a specific management regime, encompassing a range of natural vegetation types, primarily forests, steppes, and wetlands. These habitats are essential for the conservation and restoration of indigenous phytocoenotic and cenotic diversity, including within the boundaries of Ukraine's nature reserve objects.

According to V. Wagner *et al.* (2017), for the forest areas of Europe, 53 invasive alien plant species distributed in broad-leaved forests of the temperate zone are indicated, the invasion of which as part of native groups can have a direct or indirect impact on their recovery. Since invasive plant species pose a challenge in terms of managing the recovery of native tree species, according to the results of the study by M. Langmaier & K. Lapin (2020), the inventory of alien species in forest fund areas and early detection of potentially invasive ones is gaining extraordinary weight to avoid or reduce the negative environmental and economic impact of phytoinvasias.

Preventing the spread of invasive alien species and controlling the introduction of such species into natural ecosystems, including marine ones, is one of the tasks of the main principles (strategy) of the state environmental policy of Ukraine for the period up to 2030, approved by the Law of Ukraine "On the Main Principles (strategy) of the state Environmental Policy of Ukraine for the Period up to 2030" (2019).

In the paper by V.V. Konishchuk *et al.* (2020), it is noted that in the territory of Ukraine, there are approximately 1000 plant species that are considered alien, 85 of which are highly invasive. The Law "On the Approval of the List of Invasive Tree Species with a substantial Capacity for Uncontrolled Spread, Prohibited for Use in the Process of Reforestation" (2023) was put into force to reduce the substantial negative impact of phytoinvasion on the environment and forest resources of Ukraine.

Considering the above, in view of on the one hand, the high economic development of the Forest-Steppe of Ukraine, on the other hand, the substantial environmental value of the Moshnohirsky Ridge, as an important protected area with various natural settlements, the assessment of biological pollution of its vegetation cover and the spread of alien species by settlements still remains relevant.

Thus, considering the high environmental value of the research area, the purpose of this study was to identify the species composition of alien vascular plant species, the features of their distribution outside the culture and naturalisation by biotopes of the Moshnohirsky Ridge.

Materials and Methods

The study was conducted during the vegetation seasons of 2018-2021 within the territories of Moshnivske and Zakrevske forestry subdivisions of the Cherkasy Forestry Enterprise of the State Enterprise "Forests of Ukraine". The study utilised approaches described in the "Handbook for collecting vegetation plot data in Minnesota". The relevé method (2013) and R.I. Burda & O.A. Ignatyuk (2011), considering the available taxonomic, cartographic materials, published information (Chopyk *et al.*, 1998; Gaiova, 2013), herbarium materials (KW), and the results of the authors' own observations (Churilov, 2018, 2019). Biotopes are identified according to the National Catalogue of Biotopes of Ukraine (Kuzemko *et al.*, 2018).

Identification of higher vascular plants was conducted according to the key to determination of vascular plant species of Ukraine (Dobrochaeva *et al.*, 1987), the nomenclature was consistent with the lists of the Catalogue of Life (n.d.) and Plants of the World Online (POWO) (n.d.). Plants were classified as alien species considering published reports on the occurrence of alien species within Ukraine (Protopopova & Shevera, 2014; Onyshchenko, 2019; Burda & Koniakin, 2019) and the research area (Protopopova *et al.*, 2010, Protopopova & Shevera, 2019; Fedoronchuk *et al.*, 2020). The quantitative involvement of plants in biotope communities is shown in accordance with the values of projective coverage on the Tensley scale, considering recommendations for field mapping of habitats (Kuzemko *et al.*, 2018). During the study, the requirements of the Convention on Biological Diversity (1992) were met.

The Moshnohirsky Ridge is a geomorphological formation of glacial origin, separated from the southern part of the Kaniv dislocations by the valley of the Vilshanka River (Fig. 1). This includes wet alder forests along the floodplain of the river Irdynka.

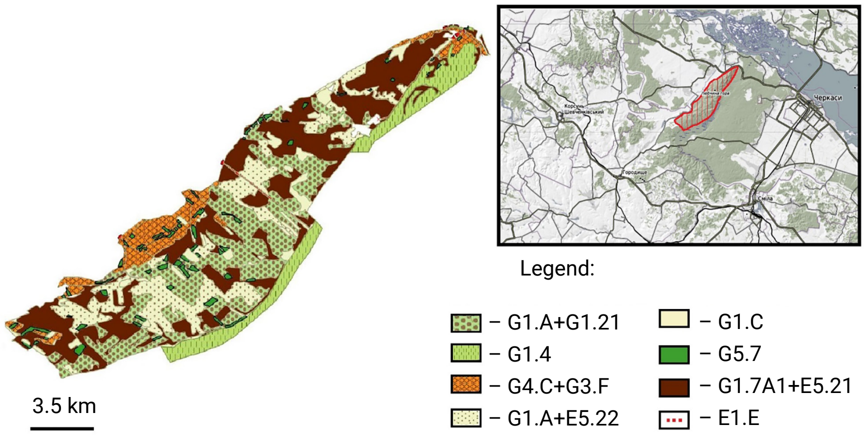

Figure 1. Scheme of the spatial distribution of biotopes on the territory of the Moshnohirsky Ridge

Source: developed by the authors in the QGIS environment (v. 2.8) based on taxonomical materials of the Cherkasy Forestry branch of the State Enterprise "Forests of Ukraine"

In addition, anthropically transformed edges and roadsides of forest roads with ruderal vegetation are hotbeds of synanthropisation and subsequent invasion of alien species into the natural vegetation cover of the Moshnohirsky Ridge. Therefore, to investigate the invasion of alien species into forest communities, the biotopes with recently disturbed tree layers was investigated. These biotopes included clearings, young stands before canopy closure, as well as glades and understory areas along forest paths. These forest paths play a crucial role as primary habitats for alien plant species, facilitating their entry into forest communities.

Results and Discussion

Forest and related biotopes present within the Moshnohirsky Ridge are shown in Table 1.

Table 1. Moshnohirsky Ridge biotopes

No.	Biotopes according to European University Information Systems (EUNIS)	Biotopes in accordance with the National Habitat Catalogue of Ukraine
1	G1.A Meso- and eutrophic Quercus, Carpinus, Fraxinus, Acer, Tilia, Ulmus and related woodland	Central European oak-hornbeam forests (G1.A1 Quercus – Fraxinus – Carpinus betulus woodland on eutrophic and mesotrophic soils)*
2	G4.C Mixed Pinus sylvestris-thermophilous Quercus woodland	Subacidophilous species-rich oak and pine-oak forests (G1.7 Thermophilous deciduous woodland)*
3	G1.7A1 Euro-Siberian steppe Quercus woods	Continental termophilous oak forests (G1.7 Thermophilous deciduous woodland)*
4	G1.21 Riverine Fraxinus-Alnus woodland, wet at high but not at low water	Ash-alder alluvial forests (G1.21 Riverine Fraxinus-Alnus woodland, wet at high but not at low wate)*
5	G1.4 Broadleaved swamp woodland not on acid peat	Eutrophic swamps with layer of black alder or birch (G1.41 Alnus Swamp Woods not on acid peat)*

Table 1, Continued

No.	Biotopes according to European University Information Systems (EUNIS)	Biotopes in accordance with the National Habitat Catalogue of Ukraine
6	G1.C Highly artificial broadleaved deciduous forestry plantations	Anthropogenic broad-leaved forests
7	G3.F Highly artificial coniferous plantations	Anthropogenic coniferous forests
8	G5.7 Coppice and early-stage plantations	Areas with recently removed tree layer
9	E5. 21 Xero-thermophile fringes	Thermo-xerophilous fringes
10	E5. 22 Mesophile fringes	Mesophilous fringes and glades on neutral and base-rich soils
11	E1.E Trampled xeric grasslands with annuals	Trampled habitats

Note: * – localisations included in Resolution No. 4. “Listing Endangered Natural Habitats Requiring Specific Conservation Measures” (1996) to Convention on the Conservation of European Wildlife and Natural Habitats (1979)
Source: compiled by the authors according to A. Kuzemko *et al.* (2018)

Overall, 5 of the 11 available biotopes within the ridge are important for conservation and are protected in accordance with Resolution No. 4. “Listing Endangered Natural Habitats Requiring Specific Conservation Measures” (1996).

Previous studies have confirmed the botanical uniqueness and conservation value of the Moshnogirya area (Udra, 1983; Didukh *et al.*, 1987; Gaiova, 2008). Within the territory, a number of objects of the nature reserve fund have been established, including two local landscape reserves (“Moshnohirsky” and “Moshnivsky”), a nationally significant natural monument “Moshenska Dibrova”, three botanical monuments (“Velvet Amur Plantation”, “Group of Mature Firs”, “Alder Tree with Oak”), a local zoological reserve “Moshnivsky Conservation Zone”, and two hydrological monuments (“Cascade of Forest Lakes”, “Subterranean Spring”). Since 2016, the territory of the Moshnohirsky Ridge has been included in the Cherkaskyi Bir (UA0000254) (Emerald Network – General Viewer, n.d.).

Information about alien plant species was first found in the descriptions of the Moshnohirsky English-style park by Michal Grabovsky in 1853, where the distribution was noted *Robinia pseudoacacia* L., a representative of the genus *Parthenocissus* Planch., *Pinus nigra* subsp. *pallasiana* (Lamb.) Holmboe. O. Spryagailo (2010) indicates that among the introduced plants, there were *Larix gmelinii* (Rupr.) Rupr. and *Picea abies* (L.) H. Karst. However, to this day there are no records of the full range of introducing plants that were cultivated on the territory of park of Knyaz M.S. Vorontsov. In the 80s of the 20th century, the territory of the Moshnohirsky Ridge in part of the cultivated area of the sanatorium “Moshnohirsky” was replenished with introducents, hybrids, and cultivars – *Cercidiphyllum japonicum* Siebold et Zucc., *Yucca filamentosa* L., *Tamarix ramosissima* Ledeb., *Robinia viscosa* Vent., *Campsis radicans* (L.) Seem., *Spiraea* × *vanhouttei* (Briot) Zabel, *Thuja occidentalis* ‘Ericoides’ (Spryagailo, 2015), whose spontaneous spread outside the culture has not been observed by this study.

In the current stage of research on alien species in the Middle Dnieper region, particularly regarding the question of synanthropization of the meadow floristic complex, it has been noted that 109 species of vascular plants from the category of adventives are widespread (Protopopova *et al.*, 2010). For forest and shrub flora complexes V.V. Protopopova *et al.* (2014), M.M. Fedoronchuk *et al.* (2020) established the distribution of 162 adventitious species, of which the following have a substantial negative impact on native phytodiversity: *Bidens frondosa* L., *Erigeron annuus* (L.) Desf., *Echinocystis lobata* (Michx.) Torr. et A. Gray, a *Acer negundo* L., *Impatiens parviflora* DC., *Robinia pseudoacacia* L., *Amorpha fruticosa* L., in addition, are transformer species that actively and massively compact the distribution area.

Regarding phytoinvasias within the Forest-Steppe, was the study by N.A. Pashkevych & R.I. Burda (2017), which also relate to the territories adjacent to Moshnohirsky Rigde, given there are 172 alien species (about 15% of the floral composition) in Feofaniia Park, Golosiivsky National Nature Park (NPP). A study by O.I. Shynder *et al.* (2021) determined the synanthropic fraction of the flora of the biostationary "Hluboki Balyky" (Rzhishchivska City United Territorial Community, Obukhiv District of the Kyiv region), identified 241 species of alien vascular plants (27% of the total floristic composition), among which the most dangerous invasive species are identified: *Asclepias syriaca* L., *Acer negundo* L., *Amorpha fruticosa, Elaeagnus angustifolia* L., *Robinia pseudoacacia, Parthenocissus inserta* (A.Kern.) Fritsch, *Impatiens parviflora*. V.V. Protopopova & M.V. Shevera (2019), M.M. Fedoronchuk *et al.* (2020) concluded that the adventisation of the flora of the Middle Dnieper region is increasing, in particular, the fraction of kenophytes listed in the 20th century is substantial. Results obtained by N.A. Pashkevych & R.I. Burda (2017), for floral complexes within the objects of the nature reserve fund in the Forest-Steppe of Ukraine, a high degree of colonisation by alien species of meadow, forest, and shrub floral complexes is indicated.

In the course of the study, the distribution of 48 alien vascular plant species belonging to 45 genera and 29 families by biotopes of the research area was established (Table 2).

Table 2. Annotated list of alien vascular plant species of the Moshnohirsky Ridge

No.	Species name (family)	Characteristics of species	Biotopes of the research area
1	*Acer negundo* L. (Sapindaceae)	p, nam, kn, ae	G1.A, G1.4 (1), G4.C, E1.E (2), G1.21, G1.C, G5.7 (3)
2	*Acer saccharinum* L.* (Sapindaceae)	p, nam, kn, ef	G1.C (1)
3	*Aesculus hippocastanum* L.* (Sapindaceae)	p, mter, kn, ef	G1.A, G4.C, G1.7A1 (1), G1.C (2)
4	*Amaranthus retroflexus* L. (Amaranthaceae)	t, nam, kn, ep	G1.C (1), G5.7, E1.E (2)
5	*Ambrosia artemisiifolia* L. (Asteraceae)	t, nam, kn, ae	G3.F (1), G5.7 (3), G1.C (1), E1.E (3)
6	*Amelanchier ovalis* Medikus (Rosaceae)	p, mter, kn, kl	G4.C (1)
7	*Amorpha fruticosa* L. (Fabaceae)	p, nam, kn, ae	G1.A, G4.C, G1.21 (2), G1.4 (1)
8	*Asclepias syriaca* L. (Asclepiadaceae)	he, nam, kn, ep	G1.C (1), G5.7, E1.E (2)
9	*Ballota nigra* subsp. *ruderalis* (Sw.) Briq. (Lamiaceae)	he, mtasm, ah, ep	G1.A, G1.C, E1.E (2), G5.7 (3)
10	*Berberis vulgaris* L. (Berberidaceae)	p, eas, kn, kl	G4.C, G1.7A1 (1)
11	*Bidens frondosa* L. (Asteraceae)	t, nam, kn, ep	G1.C (1), G4.C, E1.E (2), G1.21, G1.4 (3)
12	*Capsella bursa-pastoris* (L.) Medikus (Brassicaceae)	t, un, ah, ep	G3.F (2), G5.7, E1.E (3)
13	*Celtis occidentalis* L.* (Cannabaceae)	p, nam, kn, ef	G1.A (1)
14	*Cichorium intybus* L. (Asteraceae)	he, mter, ah, gp	G3.F (1), G5.7, E1.E (2)
15	*Cotinus coggygria* Scop. (Anacardiaceae)	p, mter, kn, kl	G1.7A1 (2)
16	*Descurainia sophia* (L.) Webb ex Prantl (Brassicaceae)	t, cas, ah, ep	G5.7, E1.E (2)

Table 2, Continued

No.	Species name (family)	Characteristics of species	Biotopes of the research area
17	*Echinochloa crus-galli* (L.) Beauv. (Poaceae)	t, as, ah, ep	G5.7 (1), E1.E (2)
18	*Echinocystis lobata* (Michx.) Torr. et A. Gray (Cucurbitaceae)	t, nam, kn, ae	G1.21, G1.4 (2)
19	*Erigeron annuus* (L.) Desf. (Asteraceae)	t, nam, kn, ag	G3.F (1), G1.A, G4.C, G1.C, E5.21, E5.22, E1.E (2), G5.7 (3)
20	*Erigeron canadensis* L. (Asteraceae)	t, nam, kn, ep	G4.C, G1.C (1), G3.F, E1.E (2), G5.7 (3)
21	*Erysimum cheiranthoides* L. (Brassicaceae)	t, un, ah, ep	G5.7, E1.E (2)
22	*Galinsoga parviflora* Cav. (Asteraceae)	t, sam, kn, ep	G1.A, G4.C (1), G1.C, G5.7, E1.E (2)
23	*Gleditsia triacanthos* L.* (Fabaceae)	p, nam, kn, ef	G1.A, G1.7A1 (1), G1.C (3)
24	*Heracleum sosnowskyi* Manden. (Apiaceae)	he, ccs, kn, ae	E5.21, G5.7, E1.E (1)
25	*Impatiens parviflora* DC. (Balsaminaceae)	t, cas, kn, ae	G1.21, E1.E (2), G1.A, G4.C, G1.C, G5.7 (3)
26	*Juglans regia* L.* (Juglandaceae)	p, bcas, kn, ef	E5. 21, G1.A, G1.7A1, G1.C (1)
27	*Lepidium densiflorum* Schrad. (Brassicaceae)	t, nam, kn, ep	G3.F (1), G1.C, E1.E (2), G5.7 (3)
28	*Morus alba* L.* (Moraceae)	p, eas, kn, ef	E5. 22, G1.C, G5.7, E1.E (1)
29	*Oenothera biennis* L. (Onagraceae)	he, nam, kn, ag	G3.F, G1.C, E1.E (1), G5.7 (2)
30	*Oxalis stricta* L. (Oxalidaceae)	t, nam, kn, ep	E1.E (1), G5.7 (2), G1.C (3)
31	*Oxybaphus nyctagineus* (Michx.) Sweet* (Nyctaginaceae)	he, nam, kn, ep	G1.21, E1.E (1)
32	*Parthenocissus inserta* (A.Kern.) Fritsch (Vitaceae)	p, nam, kn, ae	G1.A, G4.C (1), G1.C (2)
33	*Phellodendron amurense* Rupr. (Rutaceae)	p, eas, kn, kl	G5.7 (1), G1.C (3)
34	*Pinus nigra* subsp. *pallasiana* (Lamb.) Holmboe* (Pinaceae)	p, crm, kn, ef	G1.A (2)
35	*Prunus armeniaca* L.* (Rosaceae)	p, eas, kn, ef	G1.C (1)
36	*Prunus cerasifera* Ehrh. (Rosaceae)	p, mter, kn, ef	G3.F, G1.7a1, E5.22 (1), G1.C (2)
37	*Pyrus communis* L. (Rosaceae)	p, un, kn, ag	E5.21 (1), E5.22, G1.A, G4.C, G1.7A1, G1.C, G5.7 (2)
38	*Quercus rubra* L. (Fagaceae)	p, nam, kn, ag	E5.21, E5.22 (1), G1.7a1 (2), G1.A, G4.C, G1.C, G5.7 (3)
39	*Robinia pseudoacacia* L. (Fabaceae)	p, nam, kn, ep	E1.E (1), E5.21, E5.22, G4.C, G1.7A1 (2), G1.A, G1.C, G5.7 (3)
40	*Rudbeckia laciniata* L. (Asteraceae)	he, nam, kn, ae	E1.E (2)
41	*Salix* × *fragilis* L. (Salicaceae)	p, asm, ah, ag	G1.21, G1.4 (2)
42	*Saponaria officinalis* L. (Caryophyllaceae)	he, mter, kn, ae	E1.E (1), E5.21, E5.22 (2), G5.7 (3)
43	*Setaria viridis* (L.) Beauv. (Poaceae)	t, mter, ah, ep	G5.7, E1.E (2)
44	*Solanum nigrum* L. (Solanaceae)	t, seu, ah, ep	G1.C (1), E1.E (2), G5.7 (3)
45	*Solidago canadensis* L. (Asteraceae)	he, nam, kn, ae	E5.21, E5.22 (1), E1.E (2), G5.7 (3)

Table 2, Continued

No.	Species name (family)	Characteristics of species	Biotopes of the research area
46	*Syringa vulgaris* L.* (Oleaceae)	p, seu, kn, kl	G1.A (1), G1.C (2)
47	*Vinca minor* L. (Apocynaceae)	ha, mter, kn, ef	E1.E (1), G1.C (2), G1.A (3)
48	*Vitis vinifera* L.* (Vitaceae)	p, un, kn, ef	G1.C (1)

Note: * – species for which there is no active natural renewal and distribution to adjacent areas. In Column 3: *Life form* (Raunkiaer, 1937): p (phanerophyte), ha (hamefite), he (hemicryptophyte), t (terophyte). *Geographical origin of species* (Protopopova & Shevera, 2019): as (Asian), asm (Asia Minor), bcas (Balkan-Central Asian), cas (Central Asian), ccs (Caucasian), ceu (Central European), crm (Crimean), eas (East Asian), mter (Mediterranean), mtasm (Mediterranean-Asia Minor), nam (North American), sam (South American), sas (South Asian); seu (South European), un (unknown), weu (West European). *Groups of species by the time of introduction* (Protopopova & Shevera, 2019): kn (kenophyte), ah (archaeophyte). *Groups of species by degree of naturalisation* (Protopopova & Shevera, 2019): ag (agriophytes), ae (agriophytes), ep (epecophytes), gp (hemiepecophytes), ef (ephemerophytes), kl (colonophytes
Source: compiled by the authors

According to the data provided by Yu. Gaiova (2008), Yu. Gaiova (2013), the species richness of the ridge flora includes about 170 species of vascular plants. Thus, alien plants make up 28.2% of the species richness of broad-leaved forests of the Moshnohirsky Ridge. There are only three genera in the structure of the generic spectrum – *Acer* L., *Erigeron* L. and *Prunus* L. have two species each, while the remaining 42 genera are represented by one species each (Table 3).

Table 3. Families spectrum of alien vascular plant species

Families by number of species	Names of families and the number of species in each (units)	Number of families, units. (%)	Number of species in families, units. (%)
four or more species each	(8 types) *Asteraceae*, (4) *Brassicaceae*, *Rosaceae*	3 (10.3)	16 (33.3)
from two to three	(3) *Fabaceae*, *Sapindaceae*, (2) *Poaceae*, *Vitaceae*	4 (13.8)	10 (20.8)
one species	*Amaranthaceae*, *Anacardiaceae*, *Apiaceae*, *Apocynaceae*, *Asclepiadaceae*, *Balsaminaceae*, *Berberidaceae*, *Cannabaceae*, *Caryophyllaceae*, *Cucurbitaceae*, *Fagaceae*, *Juglandaceae*, *Lamiaceae*, *Moraceae*, *Nyctaginaceae*, *Oleaceae*, *Onagraceae*, *Oxalidaceae*, *Pinaceae*, *Rutaceae*, *Salicaceae*, *Solanaceae*	22 (75.9)	22 (45.8)
Total		29 (100)	48 (100)

Note: (%)- share of the total number
Source: compiled by the authors

The detected number of alien species is 29.6% of the total amount of adventitious fraction in the structure of tree and shrub biotopes of the Middle Dnieper region, which is represented by 162 species (Fedoronchuk *et al.*, 2020).

Comparing the level of adventization of floristic complexes within the studied territory to similar indicators for the "Holosiivskyi" National Natural Park and the Kaniv Nature Reserve, both located in the Middle Dnieper region and characterized by a significant presence of broad-leaved forests in their vegetation cover, it has been established that for the Moshnohirsky Ridge, the ratio of alien species to native species is 1:3.5 (28.2% of alien species), similarly for the "Holosiivskyi" National Natural Park, the ratio is 1:3.5 (28.9% of alien species) (Onyshchenko *et al.*, 2016), and for Kanevsky nature reserve 1:4.1 (24.1%) (Nechitaylo *et al.*, 2002).

Such indicators can be explained by significant anthropogenic factors, primarily recreational pressures on the floristic complexes and the introduction of alien plant species. This is especially relevant for the "Holosiivskyi" National Natural Park, which is situated within the urban environment of Kyiv, where recreational activities and human influence are intensified. Similarly, for the Moshnohirsky Ridge, its historical past as an English-style park might have contributed to the presence of alien species in the vegetation cover. Phanerophytes predominate in the spectrum of climamorphs (Raunkiaer, 1937) among alien vascular plant species (45.8%), and therophytes are substantially involved (33.3%). Hemicryptophytes are slightly less involved (21.4%), only one species – *Vinca minor* belongs to the hamefits.

In the spectrum of life forms (Didukh *et al.,* 2000), trees of 16 species (33.3%) and annuals (33.3%), less polycarpics (16.8%) and shrubs (8.4%), the rest of biomorphs are lianas (*Parthenocissus inserta*, *Vitis vinifera*), and biennials (*Heracleum sosnowskyi*, *Oenothera biennis*) account for 4.2% of the total number of identified alien plant species (Table 4).

Table 4. Spectrum of biomorphs of alien plants distributed by broad-leaved and derived biotopes of the Moshnohirsky Ridge

Biomorph (according to Raunquier)	Number of species, units (%)	Biomorph (according to Serebriakov)	Number of species, units (%)
1. Phanerophytes	22 (45.8)	1. Annuals	16 (33.3)
2. Therophytes	16 (33.3)	2. Trees	16 (33.3)
3. Hemicryptophytes	9 (18.8)	3. Polycarpics	8 (16.8)
4. Hamephytes	1 (2.1)	4. Shrubs	4 (8.4)
–	–	5. Lianas	2 (4.2)
–	–	6. Biennials	2 (4.2)
Total: 4	48 (100)	6	48 (100)

Source: compiled by the authors according to K. Raunkiaer (1937), Ya. Didukh *et al.* (2000)

The detected distribution of biomorphs is consistent with the ecological conditions of the habitats of the investigated biotopes and is largely similar to the indicators for the Middle Dnieper region (Fedoronchuk *et al.*, 2020), indicating, simultaneously, their anthropic disturbance (Goncharenko, 2017).

Important indicators for alien plant species are the time of introduction and the degree of naturalisation by natural and disturbed plant communities, which allows understanding their invasive potential and the nature of relationships with native species in recipient ecosystems (Richardson *et al.*, 2000, Burda *et al.*, 2015).

It was established that among the alien species distributed by broad-leaved forest biotopes of the Moshnohirsky Ridge, only 16.1% (nine species) are archaeophytes, mostly distributed in areas with recently removed tree layer – *Ballota nigra* subsp. *ruderalis*, *Capsella bursa-pastoris*, *Cichorium intybus*, *Descurainia* *sophia*, *Echinochloa crus-galli*, *Erysimum cheiranthoides*, *Setaria viridis*, *Solanum nigrum*, less commonly in anthropogenic broad-left forests – *B. nigra* subsp. *ruderalis, S. nigrum*. In the forest-covered areas the following species can be located – *Salix* × *fragilis* (Eutrophic swamps with layer of black alder or birch, Ash-alder alluvial forests) (Table 5).

Table 5. Distribution of alien species of vascular plants of broad-leaved forests of the Moshnohirsky Ridge by time, method of introduction, and degree of naturalisation

Groups of species, units(%)		**acolutophytes 18 (37,5)**	**ergasiophytes 25 (52,1)**	**ergasiophytes-xenophytes 5 (10,5)**
kenophytes 39 (81,3)	agriophytes 4 (8,3)	2 (4.2)	1 (2.1)	1 (2.1)
	agrio-epecophytes 10 (20,8)	2 (4.2)	4 (8.4)	4 (8.4)
	epecophytes 9 (18,8)	6 (12.5)	3 (6.3)	–
	ephemerophytes 11 (29,2)	–	11 (29.2)	–
	colonophytes 5 (10,4)	–	5 (10.4)	–
archaeophytes 9 (18,8)	agriophytes 1 (2,1)	–	1 (2.1)	–
	hemiepecophytes 1 (2,1)	1 (2.1)	–	–
	epecophytes 7 (14,6)	7 (14.6)	–	–

Source: compiled by the authors based on the classification of alien species by time, method of introduction, and degree of naturalisation of V. Protopopova & M. Shevera (2014), V. Protopopova & M. Shevera (2019)

According to the degree of naturalisation, only *S. fragilis* is an agriophyte that has naturalised in the natural ecosystems of the territory of Ukraine, with stands competition with local species and hybridises with *Salix alba* L. (Fedoronchuk *et al.*, 2020).

The vast majority of alien species (83.9%) are kenophytes, among them species that entered the territory of Ukraine in the early 20th century – *Ambrosia artemisiifolia*, *Echinocystis lobata*, *Bidens frondosa*, *Impatiens parviflora*, they have a high invasive capacity (Protopopova & Shevera, 2014) and are widely distributed by ecologically relevant biotopes of the Moshnohirsky Ridge.

In addition to these, species with substantial invasive capacity are *Acer negundo*, *Amorpha fruticosa*, *Heracleum sosnowskyi*, *Solidago canadensis*, are assigned to the group of transformer plants that can have a substantial impact on native biodiversity by changing the parameters of the recipient ecosystem (Burda *et al.*, 2015).

An important component of the characterisation of alien species is information about their origin, which helps to better understand the reasons for adaptation and the success of passing barriers to naturalisation by alien species in the recipient ecosystem in the new distribution region (Richardson *et al.*, 2000; Protopopova & Shevera, 2019).

As a result of the analysis, 13 horologic groups by origin for alien species of the research area were identified. It was established that 43.8% (21) of alien species in the research area are of North American origin, and by the time of introduction, they are exclusively kenophytes. Species from the Mediterranean Region (8 species or 16.7%) are substantially involved, which is associated with the location of the regions of origin and the Moshnohirsky Ridge in similar climatic conditions of temperate latitudes of the Northern Hemisphere. Species of East Asian and unknown origin – archaeophytes (*Capsella bursa-pastoris, Erysimum cheiranthoides*) and kenophytes*Pyrus communis*, *Vitis vinifera*) (Protopopova & Shevera, 2014) account for 8.3% each (4 species). Two species each have groups of southern European and Central Asian origin. The remaining seven species (14.6%) are distributed among seven centres of origin (Table 6).

Table 6. Distribution of alien vascular plant species of broad-leaved forests of the Moshnohirsky Ridge by time of introduction and origin

Alien species by the time of introduction / By Origin	**Archaeophytes**	**Kenophytes**	**Total**
1. North American	–	21	21 (43,8%)
2. Mediterranean	2	6	8 (16,7)
3. East Asian	1	3	4 (8,3)
4. The Unknown	2	2	4
5. Southern European	1	1	2 (4,2)
6. Central Asian	1	1	2
7. Mediterranean-Asia Minor	1	–	1 (2,1)
8. Balkan-Central Asian	–	1	1
9. Caucasian	–	1	1
10. Crimean	–	1	1
11. Asia Minor	1	–	1
12. Asian	1	–	1
13. South American	–	1	1
Total	**10**	**38**	**48**

Source: compiled by the authors based on groups of species by origin according to V. Protopopova & M. Shevera (2014), V. Protopopova & M. Shevera (2019)

In general, the dominance of native species for North America and the Mediterranean in the biotopes of the Moshnohirsky Ridge corresponds to the structure of the adventitious fraction of the forest and shrub flora complexes of the Middle Dnieper region (Fedoronchuk *et al.*, 2020). A special feature of the adventitious phytobiota is the same involvement of species of East Asian and unknown origin of 8.3% each, which is associated with introduction tests within the specified territory during the 19th-20th centuries.

Analysis of the distribution of species by the investigated biotopes naturally showed the highest representation of species in Anthropogenic broad-leaved forests (29 species or 60.4% of the detected number of alien species), Trampled habitats (28 species or 58.3%), and Areas with recently removed tree layer (27 species or 56.3%) (Fig. 2).

Substantial involvement of alien species is noted in the forest biotopes Central European oak-hornbeam forests (17 species or 35.4%) and Subacidophilic species-rich oak and pine-oak forests (14 species or 29.2%), which indicates a violation of the structure of their groups and is explained in particular, by the presence of alien species that have a limited occurrence in their composition, for example, *Aesculus hippocastanum, Celtis occidentalis, Gleditsia triacanthos, Juglans regia, Syringa vulgaris.*

A small number of alien plant species were established in the structure of optimal plant communities (Ash-alder alluvial forests) and excessively moistened (Eutrophic swamps with layer of black alder or birch) fore st-type biotopes. In particular, the most common species for Chornovil forests and eutrophic swamps are the floodplain of the river Irdynka within the Moshnohirsky Ridge is *Bidens frondosa*, *Acer negundo*, *Echinocystis lobata*, *Amorpha fruticosa*, have a lower prevalence of *Salix × fragilis*, *Impatiens parviflora*, *Parthenocissus inserta*, and single plants of the species *Oxybaphus nyctagineus* detected only in one locality.

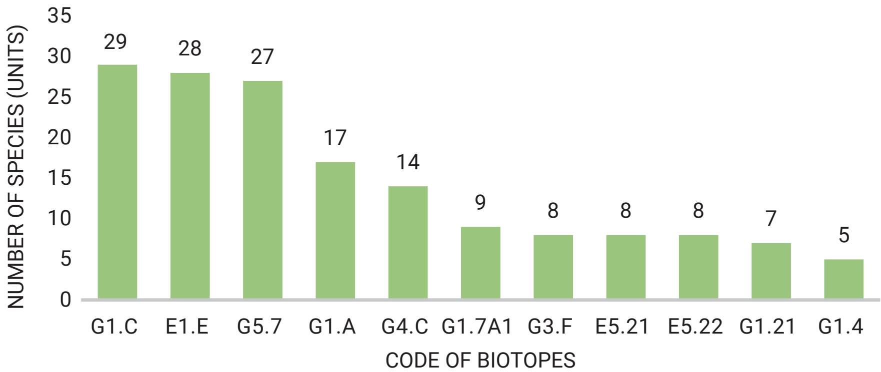

Figure 2. Distribution of alien species by biotopes of the research area
Source: compiled by the authors

With involvement in the composition of groups and occurrence of the investigated biotopes, it was established that a widespread species with a substantial projective coating is *Impatiens parviflora*, which is distributed by six biotopes.

According to the studies of B. Jarcuska *et al.* (2016), A. Florianová & Z. Münzbergová (2017), this species is one of the most common invasive plants established in temperate and northern regions of Europe, characterised by ecological plasticity, high seed productivity and long fruiting during the growing season, now within Ukraine it is classified as a transformer species (Golivets, 2014, Burda *et al.*, 2015), recent studies by V.V. Protopopova & M.V. Shevera (2019) show that it tends to continue compacting its almost formed range. The high degree of projective coverage *I. parviflora* is inherent in nutrient-rich substrates (Burda, 2012, Jarcuska *et al.*, 2016). Coenotically, the species acts as a diagnostic tool for groups of the Epilobietea angustifolii R classes.Tx. et Prsg 1950, Alno glutinosae-Populetea albae P. Fukarek et Fabijanić 1968 (Mucina *et al.,* 2016) and Robinietea Jurko ex Hadač et Sofron 1980 (Davydov, 2019). A substantial development of this species serves as a marker of anthropic disturbance of forest phytocenoses and occurs in conditions of reduced occurrence and abundance for spring ephemeroids (Burda, 2012, Goncharenko, 2017).

In the research area, the coverage of this species sometimes reaches from 10 to 60% as part of the shrub-grass layer of forest communities with the involvement of *Quercus robur* L., *Carpinus betulus* L., with an admixture of *Fraxinus excelsior* L. and *Acer platanoides* L. Together with *Impatiens parviflora* as part of the shrub-grass tier with a coating of 3-5%, there are *Alliaria petiolate* (M. Bieb.) Cavara & Grande, *Lamium galeobdolon* (L.) L., *Mercurialis perennis* L., *Lamium maculatum* (L.) L., *Glechoma hederacea* L., *Aegopodium podagraria* L., coated 1-3%: *Poa nemoralis* L., *Asarum europaeum* L., *Viola odorata* L., *Polygonatum multiflorum* (L.) All., *Brachypodium sylvaticum* (Huds.) P.

Beauv., *Stachys sylvatica* L., *Chelidonium majus* L., singly, having about 1% – *Mycelis muralis* (L.) Dumort., *Geum urbanum* L., *Scrophularia nodosa* L. and some other species (Fig. 3).

Figure 3. Areas of broad-leaved forests of the Moshnohirsky Ridge dominated by the transformer species *Impatiens parviflora* in the shrub-grass layer
Source: photos by Andrii Churilov ©

Accordig to M. Hejda (2012), a minimal degree of negative impact of *I. parviflora* for native mixed grasses of living ground cover of forests is indicated due to a poorly developed root system and features of the phenology of annual populations. Shoots and active vegetation of *I. parviflora* is during the period of completion of flowering of ephemeroids, which allowed researchers to assume a slight effect on their ability to grow and develop within forest communities (Burda, 2012; Hejda, 2012).

Results obtained by A. Florianová & Z. Münzbergová (2017) show that the negative impact that has *I. parviflora* on the native representatives in the vegetation cover of the recipient group can be levelled on a local scale by mechanically removing this transformer species from the plant group, which contributes to the restoration of the native grass tier for several years. However, physical withdrawal of *I. parviflora* from large plots is unrealistic in practice due to its intensive distribution, high seed productivity, and substantial economic costs.

In addition to the above example, other species that have substantial involvement in groupings (sometimes up to 20%) are *Erigeron annuus* (distributed in 8 biotopes), a widespread species with up to 10% coverage are *Quercus rubra* (distributed in 7 biotopes)*, Robinia pseudoacacia* (distributed in 8 biotopes), *Acer negundo* (in 7 biotopes).

The data obtained coincide with those given for forest areas in Europe in general (Wagner *et al.*, 2017), and for natural zones of Ukraine (Onyshchenko, 2019), where a substantial frequency of occurrence is noted for species that are widely distributed in the research area (*Impatiens parviflora, Robinia pseudoacacia, Quercus rubra, Bidens frondosa, Acer negundo, Erigeron annuus*), however, for such a species as *Prunus serotina* Ehrh., no distribution was observed within the research area.

The group, representatives of which are established locally includes *Acer saccharinum*, *Helianthus tuberosus*, *Juglans regia*, *Morus alba*, *Prunus cerasifera*, *Rudbeckia laciniata*, *Syringa vulgaris*, meanwhile, the ability to actively spread and form stable populations for *Pinus nigra* subsp. *pallasiana, Celtis occidentalis*, *Prunus armeniaca*, *Vitis vinifera*.

The results show a weakening of the possibility of natural restoration of forest vegetation areas, which requires balanced approaches, both at the stage of reforestation, contributing to natural renewal for native species, and maintaining existing plantings with gradual removal, primarily of species that are listed as invasive with a substantial ability to spread uncontrollably (Order of the Ministry of Environmental Protection and Natural Resources of Ukraine No. 184..., 2023).

Considering the substantial distribution areas and the involvement of a number of alien species in the forest plant communities of the research area, a substantial violation of the structure of broad-leaved forest biotopes of the Moshnohirsky Ridge was identified.

Conclusions

It was established that the Moshnohirsky Ridge, as an area of high conservation value, which has substantial areas of broad-leaved and mixed forests, meadow and swamp biotopes, has substantially biologically polluted vegetation cover with alien vascular plant species – 48 species or about a third of the floral composition of broad-leaved forests.

A substantial potential threat to the native phytodiversity of the research area are kenophytes of the North American (*Echinocystis lobata*, *Amorpha fruticosa*, *Quercus rubra, Robinia pseudoacacia*) and Asian (*Impatiens parviflora*) origin, which successfully adapted to existence in the broad-leaved forests of the Moshnohirsky Ridge. Based on the analysis of species distribution in the studied habitats, it was consistently observed that the highest number of alien species occurred in anthropogenically disturbed biotopes (Anthropogenic broad-leaved forests – 60.4%, Trampled habitats – 58.3%, Areas with recently removed tree layer – 56.2%). However, it is significant to note that these alien species are also present in natural forest biotopes (Central European oak-hornbeam forests – 35.4%, Subacidophilous species-rich oak and pine-oak forests – 29.2%), indicating disturbances in the structural integrity of their communities and providing conditions for their further transformation.

It was established that a numerical group is a group of plants whose representatives occur locally and do not show an active ability to spread further, for example, *Acer saccharinum*, *Celtis occidentalis, Gleditsia triacanthos, Oxybaphus nyctagineus*, which, with timely measures taken to remove them from the natural environment, will reduce the invasive activity of alien vascular plants in the region.

Further research in the region should be directed towards understanding the population structure of alien species, their impact on trophic and topical interactions within recipient ecosystems, as well as the development of methods to control their spread and weaken their ability to expand their range.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Burda, R.I., & Koniakin, S.N. (2019). The non-native woody species of the flora of Ukraine: Introduction, naturalization and invasion. *Biosystems Diversity*, 27(3), 276-290. doi: 10.15421/011937.

[2] Burda, R.I. (2012). The alien species Impatiens parviflora DC. (Balsaminaceae) in the municipal forests of Kyiv. *Ukrainian Botanical Journal*, 69(3), 352-362.

[3] Burda, R.I., & Ignatyuk, O.A. (2011). *Methodology of the research of adaptive strategy of alien plant species in the urban environment*. Kyiv: Vipol.

[4] Burda, R.I., Pashkevych, N.A., Boiko, G.V., & Fitsailo, T.V. (2015). *Alien species of the protect floras of Forest-Steppe of Ukraine*. Kyiv: Naukova Dumka.

[5] Catalogue of life. Retrieved from https://www.catalogueoflife.org/

[6] Chopyk, V.I., Bortniak, M.M., & Voytiuk, Yu.O. (1998). *Synopsis of the flora of the Middle Dnieper region. Vascular plants*. Kyiv: Phytosociocenter.

[7] Churilov, A. (2018-2019). *iNaturalist Research-grade Observations*. Retrieved from https://www.gbif.org/occurrence/download/0028390-230530130749713.

[8] Convention on Biological Diversity. (1992). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[9] Convention on the Conservation of European Wildlife and Natural Habitats. (1979). Retrieved from https://rm.coe.int/1680078aff.

[10] Czechowska, K., Cardoso, A.C., Magliozzi, C., & Gervasini, E. (2022). *Oriented analysis to enable prioritization of Invasive Alien Species (EU Regulation 1143/2014)*. Retrieved from https://data.europa.eu/doi/10.2760/104047.

[11] Davydov, D.A. (2019). Class Robinietea Jurko ex Hadač et Sofron 1980. In *Prodrome of the Vegetation of Ukraine* (pp. 482-487). Kyiv: Naukova Dumka.

[12] Didukh, Ya., Plyuta, P., Protopopova, V., Ermolenko, V., Korotchenko, I., Karkutsiev, G., & Burda, R. (2000). *Ecoflora of Ukraine* (Vol. 1). Kyiv: Phytosociocentre.

[13] Didukh, Ya.P., Volvach, F.B., & Temchenko, A.M. (1987). Patterns of forest formation in the Moshnogirsky ridge depending on ecological conditions. *Ukrainian Botanical Journal*, 43(1), 11-16.

[14] Dobrochaeva, D.N., *et al*. (1987). *Key to higher plants of Ukraine*. Kyiv: Naukova Dumka.

[15] Emerald Network – General Viewer. (n.d.). Retrieved from https://emerald.eea.europa.eu/.

[16] Fedoronchuk, M., Protopopova, V., Shevera, M., Shevchyk B., Juran B., Kretsul, H., & Yarova, O. (2020). Synanthropization of forest and shrub florocomplexesof the Middle Cis-Dnipro region (Ukraine). *Biological Systems*, 12(2), 263-278. doi: 10.31861/biosystems2020.02.263.

[17] Florianová, A., & Münzbergová, Z. (2017). Invasive *Impatiens parviflora* has negative impact on native vegetation in oak-hornbeam forests. *Flora*, 226, 10-16. doi: 10.1016/j.flora.2016.11.006.

[18] Gaiova, Yu.Yu. (2008). *The differentiation of vegetation Cherkassko-Chyhyrynsky geobotany district* (PhD. thesis, M.H. Kholodny Institute of Botany of the National Academy of Sciences of Ukraine, Kyiv, Ukraine).

[19] Gaiova, Yu.Yu. (2013). Spreading association Aegopodio-Parietarietum Officinalis on territory Moshnogorsky mountain. *Scientific Bulletin of UNFU*, 23.2, 46-52.

[20] Golivets, M.O. (2014). Adaptive strategy of Impatiens parviflora (Balsaminaceae) in the secondary range. I. Patterns of population organization along the environmental gradient. *Ukrainian Botanical Journal*, 71(2), 161-172.

[21] Goncharenko, I.V. (2017). *Phytoindication of anthropogenic factor*. Dnipro: PE T. Seredniak.

[22] Handbook for collecting vegetation plot data in Minnesota. The relevé method. (2013). Retrieved from https://files.dnr.state.mn.us/eco/mcbs/releve/releve_singlepage.pdf.

[23] Hejda, M. (2012). What is the impact of impatiens parviflora on diversity and composition of herbal layer communities of temperate forests? *PLoS ONE*, 7(6), article number e39571. doi: 10.1371/journal.pone.0039571.

[24] Jarcuska, B., Slezák, M., Hrivnákc, R., & Senko, D. (2016). Invasibility of alien *Impatiens parviflora* in temperate forest understories. *Flora*, 224, 14-23. doi: 10.1016/j.flora.2016.06.005.

[25] Konishchuk, V.V., Solomakha, I.V., Mudrak, O.V., Mudrak, H.V., & Khodyn, O.B. (2020). Ecological impact of phytoinvasions in Ukraine. *Ukrainian Journal of Ecology*, 10(3), 69-75. doi: 10.15421/2020_135.

[26] Kourantidou, M., *et al*. (2022). The economic costs, management and regulation of biological invasions in the Nordic countries. Journal of *Environmental Management*, 324, article number 116374. doi: 10.1016/j.jenvman.2022.116374.

[27] Kueffer, C. (2017). Plant invasions in the Anthropocene. *Science*, 358, 724-725. doi: 10.1126/science.aao6371.

[28] Kuzemko A., *et al*. (2018). National habitat catalogue of Ukraine. Kyiv: PE Yu. Klymenko. [29] Langmaier, M., & Lapin, K. (2020). A Systematic review of the impact of invasive alien plants on forest regeneration in European temperate forests. *Frontiers in Plant Science*, 11, article number 524969. doi: 10.3389/fpls.2020.524969.

[30] Macêdo, R.L., Franco, A.C.S., Kozlowsky-Suzuki, B., Mammola, S., Dalu, T., & Rocha, O. (2022). The global social-economic dimension of biological invasions by plankton: Grossly underestimated costs but a rising concern for water quality benefits? *Water Research*, 222, article number 118918. doi: 10.1016/j.watres.2022.118918.

[31] Mucina *et al*. (2016). Vegetation of Europe: Hierarchical floristic classification of vascular plant, bryophyte, lichen, and algal communities. *Applied Vegetation Science*, 19(1), 3-264. doi: 10.1111/avsc.12257.

[32] Nechitaylo, V.A., Pogrebennyk, V.P., & Hrytsenko, V.V. (2002). *Vascular plants of the Kaniv Reserve and its surroundings*. Kyiv: Phytosociocenter.

[33] Onyshchenko, V., Pryadko, O., Virchenko, V., Arap, R., Orlov, O., & Daciuk, V. (2016). *Vascular plants and bryophytes of Holosiivskyi National Nature Park*. Kyiv: Alterpress.

[34] Onyshchenko, V.A. (2019). Kenophytes in different forest types of Ukraine. *Hacquetia*, 18/2: 289-312. doi: 10.2478/hacq-2018-0013.

[35] Order of the Ministry of Environmental Protection and Natural Resources of Ukraine No. 184 “On the Approval of the List of Invasive Tree Species with a Significant Capacity for Uncontrolled Spread, Prohibited for Use in the Process of Reforestation”. (2023, April). Retrieved from https://zakon.rada.gov.ua/laws/show/z0641-23#Text.

[36] Pashkevych, N.A., & Burda, R.I. (2017). Spread of alien plant species in the habitats of the Ukrainian Forest Steppe. *Ekológia (Bratislava)*, 36(2), 121-129. doi: 10.1515/eko-2017-0011.

[37] Plants of the World Online (POWO). (n.d.). Retrieved from http://www.plantsoftheworldonline.org/.

[38] Protopopova, V.V., & Shevera, M.V. (2014b). Ergasiophytes of the Ukrainian flora. *Biodiversity Research and Conservation*, 35, 31-46. doi: 10.2478/biorc-2014-0018.

[39] Protopopova, V.V., & Shevera, M.V. (2019). Invasive species in the flora of Ukraine. I. The group of highly active species. *GEO&BIO*, 17, 116-135. doi: 10.15407/gb.2019.17.116.
[40] Protopopova, V.V., Fedoronchuk, M.M., Shevera, M.V., Dzhuran, V.M., & Kretsul, N.I. (2010). Synanthropization of meadow florocomplex of Middle Dnipro region. *Biologycal Systems*, 2(3), 52-57.
[41] Protopopova, V.V., Shevera, M.V., Fedoronchuk, M.M., & Shevchyk, V.L. (2014a). Transformer species in the flora of the Middle Dnipro region. *Ukrainian Botanical Journal*. 71(5), 563-572. doi: 10.15407/ukrbotj71.05.563.
[42] Rai, P.K., & Singh, J.S. (2020). Invasive alien plant species: Their impact on environment, ecosystem services and human health. *Ecological Indicators*, 111, article number 106020. doi: 10.1016/j.ecolind.2019.106020.
[43] Raunkiaer, C. (1937). *Plant life forms*. Oxford: Clarendon Press.
[44] Resolution No. 4. "Listing Endangered Natural Habitats Requiring Specific Conservation Measures". (1996). Retrieved from https://search.coe.int/bern-convention/Pages/result_details.aspx?ObjectId=09000016807469e7.
[45] Richardson, D., Pyšhek, P., Rejmanek, M., Barbour, M., Paneta, F., & West, C. (2000). Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distribution*, 6(2), 93-107. doi: 10.1046/j.1472-4642.2000.00083.x.
[46] Shynder, O.I., Bezsmertna, O.O., & Kucher, O.O. (2021). Flora of Rzhyshchiv city amalgamated territorial community: Structure, regional features, synanthropic and rare species. In *Biodiversity Studies of "Hlyboki Balyky" Ecological research station of Rzhyshchiv city amalgamated territorial community* (Issue 1, pp. 15-100). Kyiv: Fund for the Protection of Biodiversity of Ukraine.
[47] Spryagailo, O.V. (2010). The formation and development of Forest-Steppe Dnieper region's cultivated dendroflora. *Plant Introduction*, 2, 69-75.
[48] Spryagailo, O.V. (2015). The taxonomic variety of major greenery sites of the Middle Dnieper Area. *Scientific Bulletin of UNFU*, 25.6, 96-102.
[49] The Law of Ukraine "On the Main Principles (strategy) of the State Environmental Policy of Ukraine for the Period up to 2030". (February, 2019). Retrieved from https://zakon.rada.gov.ua/laws/show/2697-19#Text.
[50] Udra, I.Kh. (1983). Finding of Cotinus coggygria Scop. on the Moshnohorsky ridge. *Ukrainian Botanical Journal,* 40(1), 98-101.
[51] Wagner, V., *et al*. (2017). Alien plant invasions across European woodlands. *Diversity and Distributions*. 23(9), 969-981. doi: 10.1111/ddi.12592.
[52] Zavialova, L.V., Protopopova, V.V., Kucher, O.O., Ryff, L.E., & Shevera, M.V. (2021). Plant invasions in Ukraine. *Environmental & Socio-Economic Studies*, 9(4), 1-13. doi: 10.2478/environ-2021-0020.

Поширення чужорідних видів судинних рослин біотопами Мошногірського кряжу (Черкаська область, Україна)

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Анотація. Інвазії організмів несуть потенційну загрозу існуванню природних оселищ та призводять до збіднення біологічного різноманіття. Особливо негативний вплив помітно у межах Середнього Подніпров'я, де близько чверті представників судинних рослин належать до чужорідних видів. Метою дослідження було з'ясування сучасного видового складу чужорідних видів судинних рослин, особливості їхнього поширення за межами культури, натуралізація та участь у рослинних угрупованнях біотопів Мошногірського кряжу. Для досягнення мети проведено реєстрацію видового складу рослин за трансектами, а також здійснено геоботанічні описи місцезростань представників чужорідних видів рослин. Установлено, що рослинний покрив лісових та супутніх їм біотопів дослідженої території істотно забруднені чужорідними видами судинних рослин, які належать до 48 видів з 45 родів та 29 родин. *Значимою участю чужорідних видів відзначаються лісові біотопи грабово-*дубових лісів – 35,4 %, дубових і *сосново*-дубових лісів – 29,2 %. *Серед чужорідних видів, які мають суттєвий вплив на структуру рослинних угруповань вказаних біотопів широколистяних лісів є Impatiens parviflora* DC.*, Robinia pseudoacacia* L.*, Acer negundo* L. За часом занесення переважають кенофіти (81,3 %), значима кількість яких мають північноамериканське (43,8 %), середземноморське (16,7 %) та східноазійське походження (8,3 %). За показником проникнення до природних екосистем високі позиції посідають види, здатні активно проникати до складу природних угруповань – агріо- та агріо-епекофіти (сумарно 30,2 %). На противагу вказаним групам, в угрупованнях дослідженого регіону значимо представлено обмежено поширені чужорідні види без проявів активного розповсюдження – ефемерофіти і колонофіти (30,6 %). Виявлені закономірності щодо розповсюдження та ценотичного розподілу чужорідних видів є первинною основою для формування оптимальних заходів протидії новим інвазіям до лісових угруповань та стримування процесу ущільнення популяцій для видів, які вже мають широке розповсюдження досліджуваним регіоном

Ключові слова: адвентивна фракція; фітоінвазії; Середнє Подніпров'я; кенофіти; агріофіти; натуралізація

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