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Pseudotsuga Menziesii (Mirb.) Franco on Protected Areas of Ukrainian Polissya

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Abstract. In Europe, including Ukraine, a serious consideration is given to *Pseudotsuga menziesii* (Mirb.) Franco*,* as a prospective species for the creation of various types of plantations. The use of this tree species in plantations looks advantageous. The species composition of rare exotic arboreal plants, including *P. menziesii*, their representation and state of preservation were studied in the protected territories of the Steppe, Forest Steppe, and Ukrainian Polissya. Presently, it is relevant to study the age-class composition, quantitative and qualitative characteristics of *P. menziesii*, species condition and representation in various types of plantings in the protected areas of Ukrainian Polissya. The purpose of this study was to determine the distribution, status, biometric indicators, and age-class distribution of *P. menziesii* in the protected areas of the Ukrainian Polissya. Three research methods were utilized: field (route), analytical, and comparative analysis. In the Ukrainian Polissya, *P. menziesii* was first introduced in Vozdvizhenskyi Garden Art Park Monument (PMLA) in 1903. Mass introduction of the species into reserves in most locations took place in the 1960-70s. Among the areas that accepted introductions, 53.3% were concentrated in Volyn Polissya, 26.7% in Zhytomyr Polissya, and 20% in Novhorod-Siverskyi Polissya. The results of our research revealed that *P. menziesii* grew in 14 protected areas in groups, strip plantations, and as a single tree (a total of 107 specimens were found, of which 17% were *P. menziesii* var. *glauca* (Beissn) Franco). In the Radomska Dacha reserve district, *P. menziesii* plantation was created. In the age-class distribution, 53% of trees fell into 41-60-year-old category, with age categories of 1-40 and 61-80-year-old containing 33% and 7% of trees, respectively. *P. menziesii* produced viable seeds in 14 locations (seed production score varied between 2 and 5 at the maximum score of 5). In one other location trees did not produce seeds because reproductive age was not reached. Three locations were characterized by viable natural regeneration in the amount of 2 specimens per 1 m^2. Among seedlings, 83.2% were in good condition. The obtained results could be used to compare quantitative and qualitative indicators of *P. menziesii* in various types of plantations created in the Forest-Steppe and Steppe, representing the deciduous forests of Ukraine belt

Keywords: Douglas fir, parks-monuments, natural monuments, dendrological parks, tree stand

Introduction

In the coming decades, forestry in the world will be tasked with the goal of restoring ecosystems [1]. In terrestrial ecosystems, forested areas are the main absorber of atmospheric mercury (Hg) [2]. Sustainable forestry may help to increase biodiversity, improve ecosystem services, and restore areas after tree harvest [1]. *Pseudotsuga menziesii* (Mirb.) Franco [3], which has great economic and ecological importance and is one of the five tallest tree species, is suitable for the formation of sustainable multi-species and multipurpose forested areas [4]. *P. menziesii* was introduced to Europe from western North America in the 19th century [3], about 150 years ago [5]. Currently, in Central Europe, preference is given to *P. menziesii*, which considerably surpasses all native forest tree species due to fast growth, effective suppression of competing vegetation, and high drought resistance [1; 3]. In Germany, *P. menziesii* is the most common introduced tree species, occupying about 2% of the forest area [5]. In Central Europe, *P. menziesii* is less affected by pests and pathogens than natural *Picea abies* (L.) Karst. and *Pinus sylvestris* L. *P. menziesii* litter decomposes better in comparison with native coniferous plants [1; 3]. Mixed *P. menziesii* and *Fagus sylvatica* L. as well as *P. menziesii* and *Picea abies* tree stands with sufficient light (after thinning or naturally less dense) are more resistant

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to pests than pure stands of *P. menziesii* [6]. At the same time, as noted by T. Fiala, Ja. Holuša, A. Véle [7], in Central Europe (Western Bohemia), there is a threat of native bark beetles attacking exotic tree species of the genera *Abies, Picea, Pinus, and Pseudotsuga* in resort forests. In 12 localities in the western Czech Republic, 19 native bark beetle species were identified, which affected over 10% of exotic tree species in 1 year. A wide range of epigeal arthropods is preserved in the pure middle-aged *P. menziesii* stands in small areas (Germany, north-western Lower Saxony), so the amount of biodiversity is sufficient. However, afforestation by pure Douglas fir has led to marked changes in epigeal invertebrate communities compared to deciduous forests from autochthons *Quercus petraea* Liebl. of the same age in Western Europe [8]. In north-eastern Spain (Catalonia) in the Montseny Nature Park *P. menziesii* naturalized less than 30 years after the creation of plantations at an altitude of >1000 m and was able to naturally regenerate in adjacent areas within 100 m from the original plantation footprint [9]. In southwestern Germany, based on regional inventory data A. Bindewald, S. Miocic, A. Wedler, J. Bauhus [10] estimated the risk of *P. menziesii* and *Quercus rubra* L. being invasive in protected forests by quantifying natural regeneration and its height. Natural renewal of both plants was observed on 0.3% of the total area of protected biotopes. It was found that in stands with sufficient light in the understory and competitive tree species, there is a risk that *P. menziesii* and *Quercus rubra* L. may cause changes in species composition in the absence of management. Such risks can be minimized in protected areas by establishing buffer zones and regularly removing unwanted regeneration [10]. Researchers note that the invasive potential of *P. menziesii* in Central Europe is very limited and can be controlled at any time if *P. menziesii* plantations are created in combination with the shade-tolerant *F sylvatica* [1; 10]. Based on the inventory of conifers in Orleans (France), J.-P. Rossi, V. Imbault, T. Lamant, J. Rousselet [11], found that in 5 districts of the city, *P. menziesii*, *P. sylvestris*, and various species of the *Cedrus* genus are less common than *Pinus nigra*. In Denmark, based on 50 years of research in 13 sites with 12 species (*F. sylvatica, P. menziesii, Abies grandis, Larix kaempferi, Chamaecyparis lawsoniana, Pinus contorta, Pinus mugo, Abies procera, Picea abies, Quercus robur, Abies alba, and Picea sitchensis*), it was noted that North American coniferous tree species have a considerably higher biomass production potential than other species [12]. Research conducted in Great Britain (North Wales) and a comparative analysis of spruce-fir forests of the Swiss Jura showed the possibility of creating sustainable mixed tree stands with a density of 27.4 m^2 ha^{-1} using *P. menziesii*. Such stands could be created with lower *P. menziesii* tree density that is 85% of that in Norway spruce plantations. However, the volume increment in *P. menziesii* plantations is estimated to be greater than that of common spruce by 15.3 $m^3ha^{-1}year^{-1}$ [13]. Thus, in Europe, considerable attention is paid to epy research of *P. menziesii,* as a prospective species for creating various plantations. Similar studies are being conducted in Ukraine. Yu. Debryniuk emphasizes the advantage of creating tree stands with *P. menziesii* in the western region of Ukraine, where wood reserves could be as high as 700 m^3 ha^{-1} or higher at the age of 50-60 years [14]. Considerable attention is paid to research in the protected areas of Ukraine. For example, on the territory of the State Dendrological park (DP) "Trostianets" of the National Academy of Sciences of Ukraine (Sumy region), *P. menziesii* is resistant to abiotic and biotic factors and has high seed production [15]. On the territory of the National Nature Park (NNP) "Vyzhnytskyi" (Chernivtsi region), invasive plants occupy 3% of the area of the NNP. Among the invasive plants, *P. menziesii* ranks second in terms of area – 35.7 ha (Sukhyi reserve (24.3 ha), Slavets (2.8 ha), Vyzhenka (8.6 ha)), which is 10.9% [16]. In "Roztochchia" reserve (Ivano-Frankivsk region), researchers noted that the artificial restoration of forests involving invasive plants in the past has led to the transformation of forests in the reserved territories [17]. The researchers claim that under the canopy of artificial plantations involving *P. menziesii*, *Pinus strobus* L., *Larix leptolepis* (Sieb. et Zucc.) Gord., there is unsatisfactory or insufficient renewal of native species (*Fágus sylvática* L., *Carpinus betulus* L., *Ácer platanoídes* L., and *Acer pseudoplatanus* L.), and introduced species are not regenerating either, except for *Quercus rubra* L. [17]. V.M. Prokopchuk, M.V. Matusiak, Yu.O. Pankratiev, Yu.A. Yelisavenko [18], having assessed the viability and perspective of the introduction of *P. menziesii* in the area of the "Ladyzhynskyi Hai" dendrological park, note that *P. menziesii* is rare (4 specimens present) and that species is one of the promising decorative species for creating compositions in parks. *P. menziesii* has a remarkably high decorative effect [19]. However, *Pseudotsuga menziessi* var. *glauca* can be attacked by bark beetles (*Ips typographus* and *Pityogenes chalcographus*) [20]. In Ukraine, rare tree species including *P. menziesii* were studied in various natural zones on protected territories: in the Steppe zone [21; 22], in the Forest-Steppe [23; 24], in the zone of deciduous forests [25], in Ukrainian Polissya [26-28]. The authors of the mentioned studies analysed the species composition of dendrosozoexotes, the categorical, regional representativeness of the conservation status of the protected dendrosozoflora, including age-class composition. However, the age-class composition is not covered, the quantitative and qualitative features of the plants are not described, and the state and species representation of *P. menziesii* in tree stands in the protected territories of Ukrainian Polissya were not investigated.

The purpose of this study is to investigate the representation, status, biometric indicators, and age-class distribution of *Pseudotsuga menziesii* (Mirb.) Franco in the protected areas of Ukrainian Polissya.

The objective of this study is to conduct an inventory of *P. menziesii* trees in reserved areas of Ukrainian Polissya, distribute them by age class, to determine the quantitative and qualitative indicators of *P. menziesii*, and to identify the types of *P. menziesii* plantations.

Materials and Methods

The study was conducted during 2014-2021 in park-monuments of landscape art, dendrological parks, a botanical garden, and natural monuments of the Hamarnia landscape reserve, and Shatskyi National Nature Park. During field research, the status of *P. menziesii* was assessed and ranked (good – trees are healthy, normally developed, needles are dense, evenly distributed on the branches, normal size and colour, no signs of disease and pests, wounds, damage to the trunk and skeletal branches, as well as hollows; satisfactory – the trees are healthy, but with signs of slow growth, with an unevenly developed crown, few needles on branches, minor mechanical damages and small hollows; unsatisfactory – the trees are weakened, the trunks are twisted, the crowns are poorly developed, dry branches are present, the one-year shoot growth is insignificant, mechanically damaged trunks, hollows) [29]. The diameter at breast height (1.3 m) was measured with a tree calliper, and the height was measured with a Suunto PM-5/1250 altimeter. Seed production was assessed visually according to the unified scale of O.A. Kalinichenko [30], where 0 points meant the plant does not produce seeds; 1 point – the crown contains very few flowers covering 0-20% of crown area; 2 points – the crown contains few flowers covering 21-40% of crown area; 3 points – the crown contains an average amount of flowers covering 41-60% of crown area; 4 points – the crown contains a large amount of flowers covering 61-80% of crown area; 5 points – the crown contains very large amount of flowers covering 81–100% of crown area. The age-class distribution was assessed according to the inventory description with trees assigned to the following age classes: 1-20 years and 21-40 years (young), 41-60 years (middle-aged), 61-80 years (semi-mature), 81 to 100 years (mature), from 100 to 200 years (over-mature). *P. menziesii* was checked for a presence on The International Union for Conservation of Nature (IUCN) Red List of Threatened Species [31].

Results and Discussion

70 reserved areas of Ukrainian Polissya were studied. These areas included 54 park-monuments of landscape art (PMLA), three dendrological parks (DP), Shatskyi National Nature Park (arboretum), Hamarnia landscape reserve (LR) (arboretum), botanical garden (BG) of the Polissia National University, 10 natural monuments (NM), reserved area (RA) Radomska Dacha. *P. menziesii* was detected in 15 nature reserve areas, which contains 21% of the total number of experimental plots. *P. menziesii* is mesophyte, mesotroph, heliophyte, microtherm [26], belongs to the Least Concern category of the IUCN Red List [31]. In Ukraine, *P. menziesii* was first introduced to the Bantyshevskyi Park in the Donbas region in 1864 [32]. In Ukrainian Polissya, *P. menziesii* was first planted in the Vozdvizhenskyi PMLA in the early 1900s [33]. The largest representation of *P. menziesii* in reserved territories of the Forest Steppe is in 46 localities, including PMLAs – 32, BGs – 5, and DPs – 7 [23]. In the Steppe, *P. menziesii* grows in 16 localities (Fig. 1), mainly in man-made reserved areas, namely in five BGs and seven PMLAs, two DPs [21]. In Ukrainian Polissya, the number of localities and categories varied in 2017 (13 localities, seven categories) and in 2019 (11 localities, six categories) [26; 18]. Having conducted field research using the route method, the author of this study specified the number of reserved plots (15), belonging to nine categories. Among them are PMLAs (4), NMs (4), DPs (3), BG (1), LR (arboretum), NNP Shatskyi (arboretum), and Radomska dacha RA (Fig. 1), where *P. menziesii* is growing. *P. menziesii* var. *glauca* (Beissn) Franco was also found in our research plots.

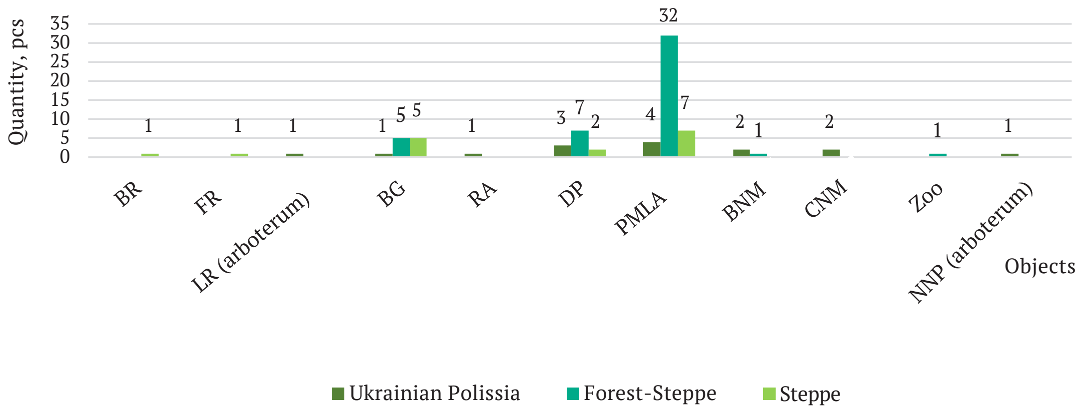

Figure 1. Representation of *P. menziesii* in the reserved areas of Ukrainian Polissya, Forest-Steppe, Steppe (BR – Biosphere Reserve; FR – forest reserve)

In the Rivne region, five protected areas were detected, where *P. menziesii* and *P. menziesii* var. *glauca* grow: botanical nature monument (BNM) Psevdotsuha tysolysta (Fig. 2a), a complex natural monument (CNM) Sarnenskyi dendrological park (Fig. 2b), CNM Rokytnivskyi dendrological park, PMLA Novostavskyi dendrological park, Bereznivskyi DP (Fig. 2c). BNM Psevdotsuha tysolysta covers an area of 0.1 ha. On the territory of the natural monument, *P. menziesii* var. *glauca* grows in a strip plantation of five plants along the road (planted 2 m apart) and five specimens – in a mixed group with *Quercus robur* L., *Acer platanoides* L., and *Betula pendula* Roth. The average diameter is 40.8 ± 2.3 cm, the average height is 23.1±1.1 m (Table 1), the largest specimen has a diameter of 49.0 cm and a height of 27.5 m. The condition of the plants is good (spreading crown 12 m wide) and satisfactory (crown raised high, unevenly developed, one-sided, inclined to the west). Regeneration was found along the road – a 3-year-old specimen 30 cm high and a 6-year-old specimen – 60 cm high (Fig. 3). Seed production was ranked as 3 and the plants were in good condition.

a) BNM Psevdotsuha tysolysta (Rivne region)

b) Sarnenskyi dendrological park CNM (Rivne region)

c) Bereznivskyi DP (Rivne region)

Figure 2. *P. menziesii* in the reserved areas of Ukrainian Polissya (author's photographs)

Table 1. Characteristics of *Pseudotsuga menziesii* (Mirb.) Franco and *P. menziesii* var. *glauca* (Beissn) Franco in the reserves of Ukrainian Polissya

Protected area	Number of specimens, pcs	Age, years	Height, m	Diameter, cm	Condition
Dubechnenskyi PMLA	1	60	25.0	28.0	s
Bairak PMLA	1	45	25.0	31.0	s
Vozdvyzhenskyi PMLA	9	120	24.1 ± 0.6	30.2 ± 2.3	g, s
Novostavsky dendrological park PMLA	10	58	25.9 ± 0.9	42.8 ± 4.8	g
NNP Shatskyi (arboretum)	3	50	19.0; 18.5; 21.5	45.0; 50.0; 63.0	g
Hamarnia LR (arboretum)	12	38	14.7 ± 1.4	26.7 ± 1.8	g, s
Rokytnivskyi dendrological park BNM	1(3)*	59	23.5; 23.5; 24.0; 24.5	35.0; 39.0; 49.0; 53.0	g, s
Sarnenskyi dendrological park CNM	8	57	26.6 ± 0.4	38.0 ± 3.6	g
Bereznivskyi DP	10(3)*	44	25.4 ± 0.4	48.4 ± 4.3	g, s
Hladkovetskyi DP	29(2)*	63	23.1 ± 1.1	30.8 ± 1.6	g
Elita DP	2	36	14.0; 14.0	28.0; 30.0	g
Psevdotsuha tysolysta BNM	(10)*	55	23.1 ± 1.1	40.8 ± 2.3	g, s
Forest arboretum BNM	2	12	1.5; 2.7	4.0; 5.0	g, s

Note: ()* *P. menziesii* var. *glauca*; g – good condition; s – satisfactory condition

Figure 3. Natural regeneration of *P. menziesii* var. *glauca* in Psevdotsuha tysolysta BNM (Rivne region)

Three 59-year-old specimens of *P. menziesii* var. *glauca* were measured, their diameter ranged between 35.0 cm and 49.0 cm (average diameter 41.0 ± 4.1 cm), height ranged between 23.5 and 24.0 m (Table 1) (average height 23.7 ± 0.2 m) and *P. menziesii*, which was 24.5 m tall and 53.0 cm in diameter. One specimen each of *P. menziesii* and *P. menziesii* var. *glauca* growing near the pond were in good condition, two specimens of *P. menziesii* var. *glauca* were in satisfactory condition (½ crown in the lower part has no needles). Plants produced t, with seed production rating of 3. A group of 8 *P. menziesii* specimens was growing at the CNM Sarnenskyi dendrological park CNM (Fig. 2b). The average diameter was 38.0 ± 3.6 cm, average height was 26.6 ± 0.4 m (Table 1), the maximum diameter was 56.0 cm, the maximum height was 27.5 m. Trees were in good condition, the crown was raised high, almost symmetrical, the diameter from west to east – 9 m, from north to south – 8 m. They produce seeds, the seed production rating of 3. Seeds are similar. At the age of 40-50 years, the trees produced natural regeneration, which was planted in the nearby stands. Currently, natural regeneration is absent.

In PMLA Novostavsky dendrological park, *P. menziesii* grew in a group along the path in the central part of the park in the quantity of 10 trees, aged 58 years. The average diameter was 42.8 ± 4.8 cm, the average height was 25.9 ± 0.9 m, the maximum diameter was 63.0 cm, the maximum height was 28.5 m, with seed production rating of 2s, in good condition. In the Bereznivskyi DP, 10 specimens of 44-year-old *P. menziesii* plants were detected. Seven plants grew in a group with a spacing from 3 to 9 m. The lighting was sufficient, crowns were equilateral, lowered. The average diameter was 48.4 ± 4.3 cm, the average height was 25.4 ± 0.4 m, the maximum diameter was 67.0 cm, the maximum height was 26.0 m, in good condition. In the north-western part of the experimental plot, on an area of 70 m^2, there were 17 specimens of self-seeded trees aged 3-6 years old and 15-35 cm tall. The seed production rating was 3. Two specimens of *P. menziesii* grew in the "modular garden" area (height – 22.0 m; 20.0 m, diameter – 67.0 cm; 54.0 cm), another one – near the seed storage (height – 23.0 m, diameter – 63.0 cm) in good condition. *P. menziesii* var. *glauca* was represented by three specimens planted in 1979. The seedlings were imported from a nursery in Estonia. Two *P. menziesii* var. *glauca* grew in a group with *Thuja occidentalis* L. and *Fagus sylvatica subsp. Purpurea*, with the spacing of 3.5 m. *P. menziesii* var. *glauca*, which has sufficient lighting from the eastern and north-eastern parts, had a diameter of 49.0 cm, a height of 19.0 m, the crown was lowered, the condition was good. The second one, which grew in the middle of the group, had a high-raised crown, the lower branches were dead from suppression, the needles were not dense and unevenly spaced on the branches. Diameter was 39.0 cm, height was 18.0 m, in satisfactory condition, with seeding rating of 5. Three specimens of self-seeded 1-2-year-old trees were found. They were located at a distance of 13.0 m from the mother trees, the age of 5 years and 20 cm high. The third tree had sufficient lighting, diameter was 42.0 cm, height was14.0 m, in satisfactory condition. Dead branches were present. Needles were unevenly distributed on the branches, in satisfactory condition, with seeding rating of 3.

a) Shatskyi NNP (arboretum) b) Hladkovetskyi DP (Zhytomyr region) c) Forest arboretum BNM (Chernihiv region) d) Vozdvizhenskyi PMLA (Sumy region)

Figure 4. *P. menziesii* in the reserved areas of Ukrainian Polissya (author's photographs)

In the Volyn region, three 50-year-old specimens of *P. menziesii* grew in the Shatskyi (arboretum) NNP, their diameter was 45.0, 50.0, and 63.0 cm, height was 19.0, 18.5, and 21.5 m (Table 1). They were in good condition (Fig. 4a) and seeding rating of 3. They formed dissimilar seeds. One 50-year-old specimen of *P. menziesii* was found in the Dubechnenskyi PMLA. The tree had a diameter of 28.0 cm, and a height of 25.0 m. It grew in a group with *Picea pungens* Engelm. The crown was raised high, the trunk was poorly cleaned, the condition was satisfactory and seeding rating of 2. Natural regeneration was absent.

In the Zhytomyr region, *P. menziesii* was found in two dendrological parks, one arboretum Hamarnia LR, and a botanical garden. Their numbers ranged between 1 and 17 specimens. Two 36-year-old *P. menziesii* trees were growing in the Elita DP, their height was 14.0 m each, their diameter was 30.0 cm and 28.0 cm (Table 1). They were in good condition. The crowns were lowered, symmetrical. Seeding rating was 2. In the Hladkovetskyi DP, a 63-year-old *P. menziesii* grew in 20×25 m^2 area in a group of 29 specimens (the crown was raised high, the trunk was poorly cleaned of branches that started at a height of 2.5-3.0 m, the condition was good) (Fig. 4b). Their average diameter w 30.8 ± 1.6 cm, the average height was 23.1 ± 1.1 m, the maximum diameter was 50.0 cm, and the maximum height was 24.5 m. The seeding rating was 2. Two specimens of *P. menziesii* var. *glauca* (diameter – 49.0; 36.0 cm, height – 24.0; 23.5 m) grew in the group with *Picea abies* Karst in good condition, with seeding rating of 2. Natural regeneration was absent. One 35-year-old specimen of *P. menziesii* grew at the entrance of the botanical garden of the Polissya National University. The height was 19.0 m, the diameter was 28 cm, in good condition. In Hamarnia (arboretum) LR, 12 specimens of *P. menziesii* were located, aged 38 years old. The average diameter was 26.7 ± 1.8 cm, height – 14.7 ± 1.4 m, the maximum diameter was 36.0 cm, the maximum height was 23.0 m. *P. menziesii* grew in a group with *Pinus sylvestris* L. and *Picea abies* Karst. Plants that were growing in sufficient light had better biometric indicators (good condition, seeding rating of 4) than those that were suppressed (diameter ranges within 16-24 cm, height – 8.5-15 m, satisfactory condition, seeding rating of 2).

In the Chernihiv region, two 12-year-old specimens of *P. menziesii* grew in the Forest arboretum BNM, the condition of one plant was satisfactory (height – 1.5 m, diameter – 4 cm, seeding rating of 1) (Fig. 4c), the second one was in good condition (height – 2.7 m, diameter – 4 cm, did not bear seeds) (Table 1). In 2014, in the Radomska Dacha reserved area (Radom Forestry Enterprise, quartal 88, stand 5), a 1.9-acre plantation was created using 2-year-old seedlings using the following mixing arrangement: 5 rows of Pinus sylvestris L., 5 rows of P. menziesii, and 1 row of Querqus robur L. In this plantation, *P. menziesii* accounted for 45% of all trees. Thomas, Rzepecki, Werner [3] noted that mixed tree stands including *P. menziesii* and native tree species could be effective in sequestering carbon and nitrogen. Most environmental organizations recommend limiting the share of *P. menziesii* in plantations containing natural species at up to 30% ratio and to avoid *P. menziesii* monocultures.

In the Ukrainian Polissya, the oldest specimens of *P. menziesii*, aged 120 years, grew in the Vozdvyzhenskyi PMLA in the group near the pond (Fig. 4d), which was drained at the time of this study. Their average diameter was 30.2 ± 2.3 cm, height – 24.1 ± 0.6 m (Table 1), the maximum diameter was 43.0 cm, the maximum height was 29.0 m. The condition of the trees was good and satisfactory (crown was raised high, started at a height of 8 m, the trunks were poorly cleaned of branches, no needles in the lower part of the branches). Seeding rating was 3. There was one over-mature *P. menziesii* in one plot in Ukrainian Polissya. In other natural zones of Ukraine, over-mature trees grew in one or two localities, in the Forest-Steppe – in the Trostianets DP (120-year-old specimens of *P. menziesii*) [24; 34], a zone of deciduous forests in the Kremenetskyi BG (200-year-old *P. menziesii),* Mykhailivskyi PMLA (100-year-old *P. menziesii*) [25].

Having analysed the age-class distribution of *P. menziesii* and *P. menziesii* var. *glauca* in 15 areas of Ukrainian Polissya, the author found that trees aged 41-60 years (57%) predominated, with almost half of that (33%) in 1-40 years category, and 61-80 years and 7% in the age category of above 100 years (Fig. 5).

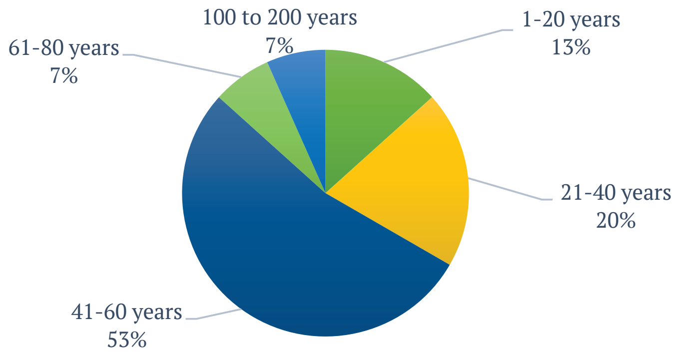

Figure 5. Age-class distribution of *P. menziesii* in reserved areas of Ukrainian Polissya

Tarabun [34] noted that one of the reasons for the insignificant distribution of *P. menziesii* is an insufficient amount of planting material due to the weak seed base. It was founded that in 93% of plots *P. menziesii* and *P. menziesii* var. *glauca* trees produce seeds; in one plot, *P. menziesii* did not produce seeds because the tree has not reached reproductive age. The seeding rating ranged from 2 (Hamarnia LR arboretum, *P. menziesii*) to 5 (Bereznivskyi DP, *P. menziesii* var. *glauca*). In three plots (Sarnenskyi dendrological park CNM, Psevdotsuha tysolysta BNM, Bereznivskyi DP) *P. menziesii* and *P. menziesii* var. *glauca* were able to regenerate naturally. In Shatskyi (arboretum) NNP, *P. menziesii* did not form similar seeds, which may be due to a negative correlation between population size and genetic diversity [5]. As J. Wojacki, P. Eusemann, D. Ahnert, B. Pakull, H. Liesebach [5] stated, an elevated level of self-pollination (1-13%) correlates with an increased inbreeding effect, resulting in a high percentage of empty seeds. Therefore, at least 100 mature trees are needed to create elite wind-pollinated stands of *P. menziesii*.

We conclude that *P. menziesii* and *P. menziesii* var. *glauca* have a high potential for use in plantations in the geographic and climatic conditions of the Ukrainian Polissya, therefore it is advantageous to continue to create such types of stands as single trees, groups, strip stands, alleys, groves, and other forested areas. The same opinion was expressed by M.O. Tarabun, who investigated the conditions of the Left-Bank Forest-Steppe [34]. However, the recommendations of M. Méndez-López, A. Gómez-Armesto [2] should be considered as well. They noted that in forest stands, forest vegetation plays a key role in the transfer of atmospheric mercury to soil horizons, the accumulation of mercury in organic horizons is inherent in coniferous species and can increase the risk of mobilising mercury due to forest fires. For afforestation, it is desirable to give preference to tree species that minimize the adverse environmental impacts caused by changes in the biogeochemical cycle of pollutants such as Hg. The research has showed that in the areas dominated by *P. menziesii*, soil concentration of Hg_{Res} is 2.5 times higher than in areas dominated by *Quercus pyrenaica*.

Conclusions

We determined that in nature conservation areas of Ukrainian Polissya, *P. menziesii* and *P. menziesii* var. *glauca* grew in 15 areas. In 14 localities, it grew in groups, strip plantations, and as a single tree (mainly in PMLAs, DPs, NMs) with a total of 107 specimens found. The plantation of *P. menziesii*, *Pinus sylvestris* L., and *Quercus robur* L. was created on one of the sites in the Radomska Dacha reserved area. The largest number of localities with *P. menziesii* and *P. menziesii* var. *glauca* as a component in plantations was concentrated in Volyn Polissya (8 localities), Zhytomyr Polissya (4 localities), and Novhorod-Siverskyi Polissya (3 localities). The introduction of trees into reserved areas in 53.3% of localities took place in the 1960-70s. The oldest trees in Ukrainian Polissya were 120-year-old specimens of *P. menziesii* growing in the Vozdvyzhensky PMLA. The age distribution showed the dominance of 41-60-year-old trees (53%). The highest biometric indicators determined for *P. menziesii* and *P. menziesii* var. *glauca* in Bereznivskyi DP were height – 25.4 ± 0.4 m and diameter – 48.4 ± 4.3 cm. In 93.3% of localities, *P. menziesii* and *P. menziesii* var. *glauca* produced seeds, with the estimated seedling rating ranging between 2 (Hamarnia arboretum LR) and 5 (Bereznivskyi DP).

The results of this study enable the comparison of quantitative and qualitative indicators of *P. menziesii*, to assess the success of introduction and tree condition in diverse natural zones of Ukraine. Using the obtained qualitative indicators of *P. menziesii*, it will be possible to select the best specimens, considering the presence of native regeneration, to obtain high-quality planting material with subsequent introduction into various types of plantations.

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Pseudotsuga Menziesii (Mirb.) Franco на заповідних територіях Українського Полісся

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Анотація. У Європі, у тому числі і в Україні, приділяється значна увага дослідженням *Pseudotsuga menziesii* (Mirb.) Franco, як перспективного виду для створення різних видів насаджень. Відзначено доцільність плантаційного вирощування. На заповідних територіях Степу, Лісостепу, Українського Полісся досліджено видовий склад рідкісних екзотичних деревних рослин, серед яких і *Pseudotsuga menziesii* (Mirb.) Franco, їхня представленість, стан збереження. Наразі є актуальним дослідити вікову структуру, кількісну та якісну характеристики *Pseudotsuga menziesii* (Mirb.) Franco, їхній стан та представленість у різних видах насаджень на охоронних територіях Українського Полісся. Метою дослідження було виявити поширення, стан, біометричні показники та вікову структуру *Pseudotsuga menziesii* (Mirb.) Franco на заповідних територіях Українського Полісся. Застосовано методи дослідження: польові (маршрутний), аналітичні, порівняльного аналізу. На Українському Поліссі *Pseudotsuga menziesii* (Mirb.) Franco. була вперше інтродукована у ППСПМ Воздвиженський, у 1903 р. Масове впровадження рослин у заповідні насадження у більшості об'єктів відбулось у 60–70-х роках XX ст. 53,3 % об'єктів зосереджені на Волинському Поліссі, 26,7 % – на Житомирському Поліссі, 20 % – на Новгород-Сіверському Поліссі. У ході проведених досліджень виявлено, що *Pseudotsuga menziesii* (Mirb.) Franco зростає на 14 заповідних об'єктах у групах, рядовій посадці, як солітер (всього виявлено 107 екземплярів із них 17 % *P. menziesii* var. *glauca* (Beissn) Franco). У заповідному урочищі Радомська дача створено масив з P. menziesii. У віковій структурі малопоширені 61-80-річні та вікові рослини (по 7 %), *P. menziesii* віком від 1до 40 років та 41-60 років складають відповідно по 33 % та 53 %. *P. menziesii* плодоносять на 14 об'єктах (оцінка плодоношення становить від 2 до 5 балів), на одному об'єкті не плодоносять із-за не досягнення репродуктивного віку. У трьох об'єктах є самосів у кількості 2 екземпляри на 1м^2. 83,2 % рослин мають добрий стан. Отримані результати можуть бути застосовані для порівняння кількісних і якісних показників *Pseudotsuga menziesii* (Mirb.) Franco. у різних видах насаджень Лісостепу, Степу, зони широколистяних лісів України

Ключові слова: псевдотцуга, парки-пам'ятки, пам'ятки природи, дендропарки, стан

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Etiology of Bacterial Wetwood of *Quercus robur* L.

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Abstract. Phytopathogenic bacteria in the plant organism form an integral part of the accompanying microflora, as well as pathogens of pathological processes that do not just weaken the plant, but shortly (with acute pathogenesis) lead to degradation and complete dieback. Notably, bacteriosis is described by typical macroscopic signs of the course of the disease, but the exact aetiology of the pathological process can be reliably established only based on bacteriological analysis with the identification of morphological, cultural, and biochemical properties of isolates. The purpose of this study is to experimentally confirm the direct causes of oak degradation caused by bacterial wetwood in the tree stands under study, as well as to investigate the morphological and biochemical properties of the pathogen. This study employed classical microbiological, phytopathological, and biochemical methods that establish the aetiology of the disease, analyse typical symptoms, include microscopy of the affected parts of the oak, isolation, and identification of the pathogen. The properties of bacterial isolates were figured out according to generally accepted methods and using the API 20E test system and the NEFERMtest24 MikroLaTEST®, ErbaLachema a test system. It was experimentally confirmed that by all macroscopic signs (crown openness, exudate discharge from bark cracks, presence of depressed (sunken) necrotic wet wounds in certain areas of cracks, development of a wet pathological core, presence of epicormic sprouts, etc.) the identified disease is a systemic, vascular-parenchymal bacteriosis, known as bacterial wetwood of common oak. The isolated bacterial isolates were identified by morphological, physiological, and biochemical properties as *Lelliottia nimipressuralis* – the causative agent of bacterial wetwood of common oak. This suggests that the aetiology of degradation of common oak in Ukraine is closely related to bacteriosis, and the results of this study allow for early phytosanitary diagnostics of the state of common oak in natural conditions based on typical symptomatic signs

Keywords: common oak, phytopathogenic bacteria, pathogen, pathogenesis, bacteriosis, *Lelliottia nimipressuralis*, sudden dieback

Introduction

In recent decades, trees of the Oak genus (*Quercus*) L., especially *Quercus robur*, are described by reduced competitiveness and resistance, as well as the phenomenon of unregulated accelerated dieback, even in those that grow under optimal conditions [1-3]. Every day, researchers register new reports of an alarming situation within the common oak growing area, associated with the degradation of both individual plants and entire stands of an unknown aetiology [4; 5]. It is known that the life cycle of common oak stands alternates between periods of stabilisation of the sanitary condition and periods of accelerated dieback [2]. Researchers note the cyclicity and established the chronology of this phenomenon [1; 6]. In general, over the past century, there are three recorded waves (periods) of extreme exacerbation of the pathological condition of common oak, which was accompanied by its mass dieback: 1982-1911, 1927-1946, and 1964-1983 [2]. Concerned practitioners and scientists of the forest industry are currently searching for prerequisites for weakening and direct causes of pathological processes in common oak cenoses. The leading role in the mass and dynamic spread of pathological phenomena of common oak is played by synoptic and climatic anomalies (hydrothermal stress) [7], the presence of invasive pests [8-10] and infectious agents [3; 11; 12], etc.

Among the researchers of the causes of oak tree dieback, it is advisable to single out the adherents of infectious aetiology, namely mycotic [13; 14] and bacterial [3; 11; 15]. It is known that common oak is characterised by impaired

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resistance and reduced competitiveness, which leads to the dieback of individual oak trees, as well as entire tree stands. Apart from climatic anomalies and invasive pests, phytopathogenic bacteria play a leading role in the degradation of oak stands. A dangerous feature of phytopathogenic bacteria is the ability to cause diseases that reach the size of an epiphytoties.

Currently, in European countries (Germany, the Netherlands, the United Kingdom, etc.) [16] and in the United States, the phenomenon of "Sudden oak death" [4] is widespread, the aetiology of which is associated with the fungus *Phytophthora ramorum* [14; 17]. The pathogen causes typical symptoms of infection (bleeding wounds, ulcers, and necrosis) on branches and trunks of *Quercus robur*, *Quercus falcata* and *Quercus rubra* [17]. In addition, the scientific literature related to the aetiology of mass dieback of Oak cenoses refers to oak wilt, which is caused by a fungus *Bretziella fagacearum* (Bretz) [13]. There is confirmed information on the mycological analysis of common oak wood with blackened vessels, in which the fungus was isolated *Ophiostoma roboris* [6].

As for the pathogens of bacteriosis, researchers [3; 5; 18] isolated and experimentally confirmed the involvement of phytopathogenic bacteria in the mass dieback of oak trees. One of the first information concerning bacteriosis of common oak belongs to A.L. Shcherbyn-Parfenenko, which specifically refers to bacterial dieback caused by *Plasmopara nigro-quercina* sp. n., *Xanthomonas quercus* sp. n., *Erwinia lignifilla* sp. n. and *Erwinia multivora* sp. n. [15; 19]. Bacterial cancer of common oak trunks and branches is also known to be caused by a polymorphic type of bacteria *Pseudomonas syringae* von Hall. [20], with bacteria *Lonsdalea quercina* subsp. *britannica*, and *Lonsdalea quercina* subsp. *populi* also involved [21]. Similar pathological symptoms (peptic ulcer disease) are caused by *Pseudomonas fluorescens* Migula 1895 and *Pseudomonas* sp. [1]. Brown mucus and other symptoms on common oak are caused by *Micrococcus dendroporthos* Ludw, *Pseudomonas syringae* von Hall, *Erwinia valachica* Georg et Bod, *Erwinia valachica* f. *onaca*, *Erwinia gueieicola* Georg, et Bod. [20].

Currently, there is evidence of a wide spread of bacteria involved in Acute Oak Decay (AOD) in British forests [22], which is generally characterised as a complex syndrome affecting key oak species (namely, *Quercus robur* L. and *Quercus petraea* L. (Matt.) Liebl.), in some cases causing mortality within five years of the development of primary symptoms. The most noticeable symptom is damage to the tree trunk, from which four types of bacteria are isolated: *Brenneria goodwinii*, *Gibbsiella quercinecans*, *Lonsdalea britannica*, and *Rahnella victoriana* [18; 22]. In the northern and mountain forests of Zagros (Iran), symptoms of common oak disease are recorded [23], which are observed in several native species of arboreal plants, including *Quercus castaneifolia* C.A. Mey., *Quercus brantii* Lindl., and *Carpinus betulus* L. There are parallels between the disease in Iran and the AOD reported in the UK, specifically the presence of wet ulcers, which have been associated with a polybacterial complex where *Brenneria goodwinii* is considered a key necrogen [23; 24].

There are also isolated reports of bacterial leaf scorch (BLS) of common oak caused by the bacterium *Xylella fastidiosa*, lives which in xylem vessels (water supply elements) and restricts the flow of water. *Xylella fastidiosa* is transmitted from tree to tree by xylem-feeding insects, such as cicadas and leafhoppers [25].

The Drippy Nut of Oak disease has been spreading in the world (pathogen – *Lonsdalea quercina*) [21], with currently recorded separate data from Spain [26] and Colorado [5]. The symptoms of this disease include loss of colour of acorns and discharge of a viscous brown liquid ("mucus flow"), which slowly scrapes to the soil surface from infected acorns growing on trees. On the territory of Ukraine, the symptoms, features of aetiology (*Erwinia quercina* sp. *nova)* [22], and harmfulness have been known for a long time, thanks to the works of A.F. Goychuk [1]. Apart from the drippy nut of oak, typical manifestations of soft or wet rot of oak acorns (pathogen – *Erwinia carotovora* subsp. *karotovora*) are also recorded [1].

One of the most widespread and dangerous diseases of bacterial origin is bacterial wetwood of common oak [3].

Thus, it becomes clear that pathogens of bacterial diseases – phytopathogenic bacteria, now act not as a concomitant microbiota in the phylosphere of arboreal plant organs but are active and dangerous (sometimes leading) participants in the emergence of pathological phenomena of arboreal plants, specifically common oak. Therefore, they require thorough experimental research and observations.

Since the dieback out of common oak on the territory of Ukraine becomes epiphytotic, and the aetiology of this phenomenon has not yet been established, the purpose of this study lies in experimental confirmation of the immediate causes of this phenomenon, as well as the study of morphological and biochemical properties of the pathogen.

Materials and Methods

The general scheme of pathology studies included reconnaissance and detailed forest pathological surveys of forest stands including common oak with the laying out of 4 experimental plots in the State Enterprise "Fastiv Forestry" of the Kyiv region in the summer and autumn of 2021 according to the SOU 02.02-37-476:2006 "Experimental Plots of Forest Management. Method of Laying Out" (2007) [27]. 7 sample trees were cut down. More than 78 samples (individual tissues and organs) of common oak with visual signs of damage from bacteriosis (trees of the II and III categories of sanitary condition) were selected for microbiological studies.

Bacteriological analysis of the selected samples was performed by homogenisation of plant material, followed by plating in Petri dishes on agarised nutrient media (potato agar, meat-peptone agar, meat-peptone broth, malt extract of agar, etc.) and growing under a thermostat at 28°C for 4-5 days. Colonies were selected for analysis. Glucose-peptone (Eikman's) and Ushinsky media, and medium with asparagine were used to accumulate enterobacteria. King's medium – for identifying Pseudomonas spp based on fluorescein production. Anatomical-morphological and physiological-biochemical characteristics of the selected strains (Gram staining, Voges-Proskauer test, Kovac's oxidase test, dilution of gelatin, growth in 5% NaCl, formation of reducing sugars from sucrose, acid formation from carbohydrates, etc.) were performed respectively to standard protocols and according to the methods of V. Patyka et al. [28] and using the API 20E test system and the NEFERMtest24 MikroLaTEST®, ErbaLachema test system. Omelyansky's mineral medium was used to determine the ability of isolated bacteria to ferment various sources of hydrocarbons (lactose, rhamnose, xylose, trehalose, maltose, raffinose, L-arabinose, sucrose, fructose, galactose, sorbitol, mannitol, glycerol, citrate, salicin) [28]. Milk and gelatin were used to detect proteolytic enzymes in bacteria. Oxidase-negative bacterial isolates were examined to identify them, their properties were investigated and compared with the collection strain *E. nimipressuralis* 8791, and the properties of bacteria given in the Manual of systematic bacteriology [29] and the original works [30]. Pathogenic properties of isolates were detected in laboratory and field conditions by artificial damage to the organs of common oak and indicator plants with a bacterial suspension with a titre of 10^8-10^9 cl×ml^{-1} (according to the turbidity standard). Control – sterile supply water. Subsequently, bacteria were re-isolated from the sites of artificial damage for further comparative studies (Koch's postulates). Latin names of microbiota species are given according to the National Centre for Biotechnology Information [31].

Results and Discussion

Based on the materials obtained during the study, it was found that the mass dieback of common oak covers large areas and all age categories of forests. Identification of the causes of dieback was based on several groups of signs (macroscopic or visual and microscopic). Visual examination of damaged stands revealed macroscopic signs of a bacterial disease – bacterial wetwood, which was later confirmed by laboratory studies [3] based on the D.K. Zabolotnyi Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine. These signs are almost identical to the typical symptoms of bacterial wetwood of arboreal plants described in the literature [15], which indicates persistent symptoms of bacteriosis, regardless of the type of arboreal plant and the region of research. These features include the following morphological, anatomical features and structural modifications of damaged common oak trees:

– local foci of tree death, which cover an average of 6-10 neighbouring trees (Fig. 1a).

Figure 1. Bacterial wetwood on common oak: macroscopic signs (1a – focus of weakened oak trees with an opened crown, water shoots and local ulcers on the trunks; 1b – leakage of bacterial exudate and wet wound development)

– the phenomenon of crown openness, as well as defoliation and dieback of individual apical and lateral shoots, which are atypically curved and coal-black, as if damaged by frost;

– exudate discharge (a dark, usually grey-brown liquid that turns black in the air, with bubbles and a typical smell of butyric acid fermentation) from bark cracks of the affected tree is an important diagnostic sign of wetwood (Fig. 1b). The outflow of bacterial fluid is most often observed in the spring-summer period and does not last long (on average, 10-12 days and significantly depends on the temperature regime), while infected specimens are easily found by formed carboniferous black streaks on the bark of trees, which often go from the primary site of the lesion down the trunk, and then spread out on the soil surface;

– formation of depressed (sunken) necrotic wet wounds in certain areas of the crack. If you remove the top layer of periderm and gradually separate sapwood, you can note that dark brown, sometimes purple-tinged dead areas (ulcers) spread up and down from the primary site of infection by 0.3-0.8 m or more (Fig. 2a), sometimes reaching the basal part of the trunk;

Figure 2. Symptomatic signs of damage by bacterial wetwood of common oak on a cross-section of the trunk: general appearance (2a) and development of a wet pathological core (2b)

– when the bark falls off at the site of wound formation and the source of infection exits, an ulcer with clear edges is formed, the colour of which varies significantly – from dark gray to brown, which is usually associated with the action of saprotrophic mycoflora;

– development of a wet pathological core of rounded or stellated shape (Fig. 2b) with penetration into the shoots and exit along the core rays into cracks and wounds under the pressure of gases that tear the wood fabric. Soft rot with mucus, necrotisation, and maceration of tissues develops in the affected tissues;

– epicormic sprouts on trunks, often underdeveloped, with a light-yellow leaf colour, which indicates the loss of arboreal plants' biological resistance.

All the above-mentioned macroscopic signs of damage from bacteriosis were noted on common oaks of ripening and ripe age, regardless of the growth class and growing conditions. Thus, the detected disease according to all symptomatic signs known from literature sources [15] is a systemic, vascular-parenchymal bacteriosis, known as bacterial wetwood of common oak, which affects all tissues (phloem, cambium, xylem), parts of the plant (branches, trunks, root system) and generative organs (flowers, ovary, fruits, seeds) at all stages of ontogenesis, including self-seeding and seedlings.

It is well-known that based on the analysis of only typical macroscopic symptoms of the disease, it is not advisable to contemplate its aetiology. Therefore, a number of special microbiological experiments (bacteriological analysis) were conducted *in vitro* for the study of morphological, cultural and biochemical properties of isolates (specifically isolates from oak wood samples with typical symptoms of bacterial wetwood) (Table 1).

Table 1. Morphological and biochemical properties of *Lelliottia nimipressuralis*

Test	By Carter	Collection strain (Erwinia nimipressuralis 8791)	Isolated by the authors (2021)
Mobility, peritrich	+	+	+
Gram stain	–	–	–
Yellow pigment	–	–	–
Gelatine dilution	–	–	–
Reaction to milk: coagulation	+	+	+
peptonisation	–	–	–
Litmus serum		+	+
Nitrate reduction	+	+	+
Formation: indole, ammonia	–	–	–
hydrogen sulphide	+	+, –	+, –
Growth on media:			
PA, MPA, MPB, MPA+5% sucrose, Eikman, Ushinsky, with asparagine, Fermi, Liske		+	+
Kohn, Czapek		–	–

Table 1, Continued

Test	By Carter	Collection strain (Erwinia nimipressuralis 8791)	Isolated by the authors (2021)
Absorption of carbohydrates and alcohols:			
arabinose, glucose, maltose, lactose, mannitol	ag	ag	ag
mannose, raffinose, fructose		ag	ag
salicin	+, –	ag	ag
glycerin	+, –	a	a
ramnosa		a*	a
dulcite, inositol		–	–
xylose, sorbitol	ag	ag*	ag*
Assimilation of organic acids:			
ketoglutaric, citric, formic, acetic, malic, succinic, fumaric, lactic		al	al
tartaric, oxalic	–	–	–
Assimilation of amino acids and amides:			
arginine, asparagine, glutamine		al	al
Cysteine, cystine, leucine, tyrosine, tryptophan		–	–
γ- aminobutyric acid		–	–
Enzymatic activity:			
protopectinase, oxidase	–	–	–
catalase, urease		+	+, –
Voges-Proskauer reaction		+	+
Education:			
indole	–	–	–
ammonia		–	–
hydrogen sulphide	+	–*	–

Note: (+) – availability of properties; (–) – lack of properties; (+,–) – variable properties; () – data missing or not researched; (a) – formation of acid; (al) – alkali formation; (g) – gas formation; (r) – reduction; (*) – individual strains have different properties
Source: [3; 32; 33]

It was found that isolates from common oak tissues are straight or ellipsoid gram-negative rods with a size of 0.6-0.8×0.7-1.6 µm, which move using peritrichal flagella. In smears from agar and broth culture, cells are arranged singly, in pairs, and less often – in short chains. They do not form capsules and spores.

On potato agar (PA), colonies are formed rounded, 4-5 mm in diameter, greyish white in colour, less often – with a typical shade of cream colour, translucent to the light, convex in shape, with a weak gloss. The edge of bacterial colonies forms weak waves, occasionally stays smooth, a corrugated strip runs along the periphery, translucent circles and radial rays are clearly visible in the light.

On meat-peptone agar (MPA), bacterial colonies are smaller in size, grey in colour, with a weak gloss, translucent, granular, smooth, slightly convex. The edge of the colonies is slightly radially crossed, ridge-like. In meat-peptone broth (MPB), bacteria grow well, forming a parietal ring, uniform turbidity, swirled sediment, and pellicle.

On Eikman's and Ushinsky's media with asparagine, isolated bacteria also grow well and form a light greyish-white pellicle. Colonies on King's media are characterised by abundant growth and dirty, milky white colour. The lack of growth on a nutrient medium with dulcite is a common property of the strains isolated for this study.

On mineral media with arabinose, galactose, glucose, xylose, lactose, maltose, mannose, mannitol, raffinose, sucrose, sorbitol, salicin, and fructose, all strains form gas and acid. Some amino acids and amides are used as a carbon source. No changes were recorded in the medium with leucine, cystine, tyrosine, cysteine, and tryptophan. Tartaric and oxalic acid strains were not used. During the day, mineral media with sodium salts of succinic, ketoglutaric, citric, lactic, formic, acetic, fumaric, and malic acids were intensively alkalised.

All the bacterial isolates under study had a positive Foges-Proskauer reaction.

The bacteria isolated do not dilute gelatin; coagulate milk quickly, do not form oxidase and protopectinase; form catalase and urease. They do not use Inositol and sorbitol citrate. They do not form indole and hydrogen sulphide (H_2S) but are capable of reducing nitrates. They contain arginine dehydrolase, ornithine decarboxylase, β-galactosidase, but there is no lysine decarboxylase, urease.

Individual properties of bacteria are significantly affected by their habitat, so the current differences between the collection strain (*Erwinia nimipressuralis* 8791) and bacteria by Carter [33] are variability within the species.

Therefore, according to the complex of investigated morphological, cultural, and biochemical characteristics, bacterial isolates from common oak with typical symptomatic signs of bacterial aetiology disease damage are almost identical to the collection strain of the Department of phytopathogenic bacteria at D.K. Zabolotnyi Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine – *Erwinia nimipressuralis* 8791 and correspond to the properties given in the bacterial determinant [29] for *E. nimipressuralis*.

Thus, by their morphological, cultural, and biochemical properties, the isolated bacteria are classified as *Lelliottia nimipressuralis* (Carter 1945) (synonymous names – *Erwinia nimipressuralis* (Carter 1945) Dye 1969 and *Enterobacter nimipressuralis* (Carter 1945), which is a known causative agent of bacterial wetwood of coniferous and deciduous species of arboreal plants [15], including common oak.

Conclusions

One of the main reasons for the mass weakening and dieback of common oak on the territory of Ukraine is the spread of systemic, vascular-parenchymal bacteriosis, which affects all tissues, plant parts, and generative organs at all stages of ontogenesis, including self-seeding and seedlings. According to the identified typical macroscopic symptoms, namely excessive crown openness, as well as defoliation and dieback of 1-2-year-old shoots; cracking of the bark of trunks and the development of depressed necrotic wet wounds, which discharge bacterial exudate during the growing season (especially in the spring) – a gas-filled liquid and mucus of dark (brown or black) colour with a typical smell of butyric acid fermentation; the development of a wet pathological core; the presence of epicormic sprouts, etc., it was found that this bacteriosis is nothing less than bacterial wetwood. At the same time, the prerequisite for active and aggressive development of any disease of infectious aetiology is a decrease in plant immunity due to the development of destructive processes caused or enhanced by adverse abiotic environmental factors. In the case of bacterial dropsy, its mass spread occurs after a dry summer, i.e., it is hydrothermal stress that contributes to the unregulated spread of the causative agent of said bacteriosis and associated organisms (pathogens of root rot, stem pests, and a wide array of microxylotrophs). The bacteriological analysis revealed that the bacterial isolates from common oak with typical symptomatic signs of damage by bacterial wetwood, according to their biochemical, morphological, and cultural properties, are classified as the causative agent of bacterial wetwood of coniferous and deciduous species of arboreal plants, including common oak – *Lelliottia nimipressuralis*. A promising area of future research lies in the development of specific methods and means for protecting arboreal plants, namely for the use of biologics based on Bacillus sp. and other myco- and microorganisms with existing antagonistic properties to phytopathogens.

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Етіологія бактеріальної водянки *Quercus robur* L.

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Анотація. Фітопатогенні бактерії у рослинному організмі виступають невід'ємною компонентою супутньої мікрофлори, а також збудниками патологічних процесів, які не просто ослаблюють рослину, а часто протягом короткого періоду часу (при гострому патогенезі) призводять до явища деградації та повного відмирання. Також варто зауважити, що бактеріозам притаманні типові макроскопічні ознаки перебігу хвороби, проте точну етіологію патологічного процесу можна достовірно встановити лише на основі проведення бактеріологічного аналізу з визначенням морфологічних, культуральних і біохімічних властивостей ізолятів. Метою досліджень є експериментальне підтвердження безпосередніх причин явища деградації дуба, спричиненої бактеріальною водянкою у обстежуваних деревостанах, а також дослідження морфологічних і біохімічних властивостей збудника. В роботі використано класичні мікробіологічні, фітопатологічні та біохімічні методи, за допомогою яких встановлено етіологію захворювання, аналіз типових симптомів, проведена мікроскопія уражених частин дуба, ізоляція та ідентифікація збудника. Властивості ізолятів бактерій визначали за загальноприйнятими методиками та з використанням API 20E тест-системи і тест-системи NEFERMtest24 MikroLaTEST®, ErbaLachema. Експериментально підтверджено, що виявлене нами захворювання за всіма макроскопічними ознаками (ажурність крони, виділення ексудату з тріщин кори, наявність вдавлених (запалих) некротичних мокрих ран на окремих ділянках тріщин, формування мокрого патологічного ядра, присутність водяних пагонів та ін.) є системним, судинно-паренхіматозним бактеріозом, відомим як бактеріальна водянка дуба. Виділені нами ізоляти бактерій, за морфологічними і фізіолого-біохімічними властивостями ідентифіковані як *Lelliottia nimipressuralis* – збудник бактеріальної водянки дуба. Це дає підстави стверджувати, що етіологія деградації дуба звичайного в Україні тісно пов'язана з бактеріозом, а результати наших досліджень дозволяють здійснювати ранню фітосанітарну діагностику стану дуба в природних умовах за типовими симптоматичними ознаками

Ключові слова: дуб звичайний, фітопатогенні бактерії, збудник, патогенез, бактеріоз, *Lelliottia nimipressuralis*, раптове відмирання

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Experimental Felling in Assistance to Natural Forest Regeneration in Kyiv Region

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Abstract. Forest management in Ukraine should be conducted considering climate change, as well as degradation and mass drying of forests. It also must follow the principles of preserving the conditions for the reproduction of biologically stable, highly productive tree stands and rational and sustainable use of forest resources. Therefore, one of the main tasks of forest management is to maximize the use of the natural seed potential of forest stands. Felling corresponds to this principle, being aimed at maximizing the use of natural seed regeneration of the forest, and as a methodological basis for creating highly productive, biologically stable forest stands. The purpose of this study is to develop a felling method that promotes natural forest regeneration and offers organizational and technical indicators for its implementation. Accounting of natural forest regeneration was performed per the A.V. Pobedynskyi's method; the natural forest regeneration was estimated according to V.G. Nesterov's scale; the projective cover of the forest ground vegetation was figured out on the Brown-Blanquet scale; the dryness of the climate was figured out according to the De Martonne's aridity index; the humidification conditions at the experimental site were investigated using G.T. Selyaninov's hydrothermal coefficient; the sum of active temperatures was figured out according to the method of the Ukrainian Hydrometeorological Centre. The regulatory framework for felling to form and sanitise forests was analysed. It was found that the current rules do not make provision for felling that would be most favourable for the natural renewal of economically valuable tree species in forests of any category, age, composition, and structure. The results of accounting and evaluation of natural forest regeneration in felled circular areas are presented. It was found that under the condition of average (3 points) and higher points of seed bearing (fruiting) and sufficient moisture on circular plots with a diameter of 1.5 of the average height of the stand (H_{avg}), there was a very dense, healthy, evenly distributed natural forest regeneration. Dense understorey and significant sodding of the soil surface (over 50% of the area) with forest ground vegetation negatively impact the natural forest regeneration in the first year of life. Otherwise, special tillage is ineffective. In 2020, despite the decade-long droughts in March-April, as well as in August-September, favourable conditions for natural forest regeneration developed. In May and June, there was an increase in precipitation compared to the previous and subsequent months after the emergence of seedlings, which positively affected their rooting and growth. Feeling that contributes to the natural forest regeneration should be classified as felling for the formation and sanitation of forests, and the proposed organizational and technical indicators should be set up for it. The conclusions of this study will serve as a methodological framework for the introduction of a new method of felling in forest stands, which would be as favourable as possible for a sufficient amount of high-quality, viable natural regeneration of economically valuable tree species

Keywords: climatic indicators, stand, circular area, seedlings, viability of understorey, natural forest regeneration

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Introduction

Forests cover approximately 31% of the planet's land area and 35% of Europe's area [1; 2]. The important role of forests in terms of ecological, economic, social, and aesthetic values, as well as the source of natural resources, ecosystem services, and functionality, including protection of watersheds, prevention of soil erosion, and mitigation of climate change [3; 4], makes forest management crucial, and the topic of natural forest regeneration – extremely relevant [1; 5].

It is known that forest stands of natural seed origin are characterized by high biological stability. Given the current soil degradation [6] and massive drying of forests [7], increasing the biological stability of forest stands is an extremely urgent issue for the forests of Ukraine. In this context, natural forest regeneration is of particular importance, which contributes to the formation of biologically stable forest cenoses compared to artificial stands [4].

Over the past decades, an area with naturally restored forests in Europe has increased substantially [1]. Studies have shown that between 2018 and 2019, more than half (66%) of European forests were restored naturally [1; 5]. In 2010-2020, France, Spain, Portugal, and Italy experienced an increase in the share of naturally reproduced forests from 2,600 (Portugal) to 52,700 hectares per year (Italy) [5]. However, during 2005-2015, Europe's share of natural forests substantially decreased [1]. According to official data of the State Agency for Forest Resources of Ukraine, the share of natural forests is about 40% [8]. During 2003-2021, the share of natural forests stayed consistently low at 9.0-13.0 thousand ha/year, which is about a third of the annual reforestation area [8]. Therefore, in the context of climate change, an important task for foresters in different countries is to increase the share of natural forests by developing approaches and tools for versatile assistance to natural forest regeneration [9].

The purpose of this study is to develop a felling method that contributes to the natural forest regeneration and organizational and technical indicators for its implementation. To fulfill this purpose, it was planned to perform the following tasks: to analyse the results of scientific research of natural forest regeneration by scientists-foresters of Ukraine and other countries; to investigate the influence of environmental factors on natural forest regeneration; to set up quantitative and qualitative indicators of natural forest regeneration; to analyse felling for the formation and sanitation of forests to promote natural forest regeneration in forest stands; to develop organizational and technical indicators for the proposed method of felling that contributes to natural forest regeneration.

Literature Review

Successful natural renewal of forest stands in Ukraine occurs in many types of forest. In general, for natural seed forest renewal, more favourable conditions are formed in the forest natural zone, which is characterized by an increased amount of precipitation, low evaporation, and moderate development of understorey and forest ground vegetation in forest stands [10]. Forest stands of seed renewal, in contrast to vegetative ones, are characterized by greater durability, long growth in height and volume, high technical qualities of wood, accumulation of the most valuable varieties and a larger mass of wood before the age of ripeness [1; 4].

It is known that forest stands of natural seed origin are characterized by high biological stability [4; 11]. Given the current soil degradation and massive drying of forests, increasing the biological stability of forest stands is an extremely urgent issue for the forests of Ukraine. In this context, natural forest regeneration is of particular importance, which contributes to the formation of biologically stable forest cenoses compared to artificial stands [4; 12; 13]. Forest management should be based on an understanding of the processes of formation and development of natural forest ecosystems. Therefore, foresters should apply in practice the approaches of close to nature forestry, as one of the tools of forestry management.

At the stage of germination, the younger generation of the forest often suffers from insufficient moisture in the soil, which leads to its drying out. Seedlings of woody species can withstand some lack of light, and over time, having turned into understorey, they need it more. For normal growth and development of understorey, illumination and fertility of the upper soil horizon corresponding to the tree species are necessary. This stage of seed renewal is characterized by gradual adaptation of the understorey to the environmental conditions under the stand canopy. With age, the understorey becomes more suppressed, its demand for light increases. Therefore, from the very first years of life, it is characterized by the improvement of the adaptations inherent in each tree species and the acquisition of new adaptive features. Understorey usually suffers from a lack of light and soil moisture. This is confirmed by a small height increment, underdeveloped leaves or needles, weak foliage or entanglement of branches, presence of ascomycete fungi, disease lesions, etc. If the fastidiousness of a tree species to light and nutrients, which increases with age, is not satisfied, then the least adapted specimens die off [4; 6; 7].

Thus, the preservation, growth, and development of self-seeding and understorey of common oak under the canopy of parent stands is most affected by Illumination. Under the canopy of high (0.8-1.0) relative density oak-hornbeam stands, it is 0.5-3.0% of full illumination, which leads to the gradual death of the young generation of common oak in the second or third year of life [14]. Under the canopy of medium (0.6-0.7) and high (0.8-1.0) relative density stands (aged 41-111 years) of fresh and moist hornbeam oakery, the age of understorey of common oak did not exceed three years. At an older age, its shade endurance decreases, and plants eventually die [15; 16].

In Scots pine stands of fresh and moist fairly poor soil conditions (B_2, B_3) as part of the natural forest regeneration, Scots pine has the largest share, and in wet fairly rich soil conditions (C_3) – common oak. The intensity of natural forest regeneration depends on the degree of soil moisture. Thus, in fresh fairly poor soil conditions of self-seeding and understorey, there were 0.3-0.7 thousand pcs·ha^{-1}; in transitional conditions of soil moisture content from fresh to wet – 0.2-4.8 thousand pcs·ha^{-1}; in wet fairly poor soil conditions – 0.6-12.4 thousand pcs·ha^{-1}. In wet fairly rich soil conditions, where the forest ground vegetation develops intensively, the smallest amount of natural forest regeneration is observed – 0.2-0.5 thousand pcs·ha^{-1}. All stands are dominated by 3-10-year-old Scots pine understorey. In a smaller number, Scots pine understorey is observed at the age of 10-20 years and younger. Natural regeneration of Scots pine is most often observed in forest stands with a stand's relative density of 0.6-0.8. In high (0.8-1.0) stand's relative density, the natural regeneration of Scots pine is limited by insufficient lighting and a thick layer of forest floor, and in low (0.4-0.5) stand's relative density – by intensive development of herbaceous plants [17; 18].

The age-class composition of natural regeneration of common oak under the canopy of forest stands (forest type – fresh and rich maple-linden oakery soil conditions) is dominated by seedlings (46.1%), 2-3-year regeneration is 29.8%, 4-8-year-old – 22.7%, 9-15-year-old – 1.4%. As the relative density of the stand grows, the density of common oak shoots increases, and the density of 4-8-year-old oak understorey decreases due to insufficient lighting or competition from other plants [19]. The total growth of common oak in open space conditions (on timber blockings) up to the age of three increases almost twice with each subsequent year. While under the canopy of a stand with a completely felled second storey of hornbeam, this indicator has a negative trend [14].

Preserving and increasing the natural regeneration of Scots pine under the canopy of parent stands is possible if complex felling methods are used and measures are taken to promote natural forest regeneration [20].

According to the research of A.M. Zhezhkun [21], in square-shaped spaces with a side length of 1.5-2.0 H_{avg} of the stand (the ratio of side lengths is 1:1) and in rounded spaces with a diameter of 1.0-1.5 H_{avg} of the stands, as well as in rounded gaps with a diameter of 1.0-1.5 $H_{avg.}$ in the forest stand with uniform thinning in the strip around the gaps, there were 22.9-26.2 thousand pcs.·ha^{-1} of self-seeding, of which common oak – 0.6-1.1 thousand pcs.·ha^{-1}, Scots pine – 7.4-11.6 thousand pcs·ha^{-1}.

The natural regeneration of pine occurs worst in stands with uniform thinning of the stand to a relative density of 0.5, and best of all – in gaps of rounded shape, created on the principle of group-gradual felling. On rounded gaps with a diameter of 1.0 H_{avg}, in a stand with furrows, the natural regeneration of pine in the age group of 4-8 years is 12-21 thousand pcs·ha^{-1}, and in the variant with soil loosening with a disk tiller – 11-12 thousand pcs·ha^{-1} [22].

Suppression of 2-5-year-old understorey of common oak is observed at 15-20% of the illumination of an open space. The best growth and development of the younger generation of common oak is observed in circular areas with a diameter of 1.5 H_{avg} of the stand, where there is more light during the day and there is no suppression of common oak growth from 10 to 16 hours (23.5-68.0% of the illumination of an open space). This is confirmed by the higher average height (1.8 m) of five-year-old oak in these areas, compared to the average height (0.9 m) of five-year-old oak in circular areas with a diameter of 1.0 H_{avg} of the stand. On circular plots with a diameter of 0.5 H_{avg} in the stand, where the lowest illumination and greatest suppression of common oak is observed during the day, mass drying of the younger generation of common oak occurred at the age of three years [23].

Under favourable conditions (the presence of seed years, a sufficient amount of soil moisture, light, the absence of dense understorey and dense forest ground vegetation, a thick layer of forest floor, etc.), a sufficient amount of understorey of economically valuable species can accumulate under the canopy of the stand to regenerate the plot naturally. Without the above conditions, frequent cases are the presence of signs of suppression in the understorey – a small increase in height, underdevelopment of leaves or needles, the presence of ascomycete fungi, etc. Therefore, the issue of obtaining high-quality, viable natural regeneration of economically valuable species to the age of maturity of the stand, which is characterized by high biological stability, and also better corresponds to particular forest vegetation conditions from a genetic and ecological standpoint, is relevant.

To create favourable conditions for natural forest regeneration in forest stands, it is necessary to carry out appropriate economic measures. One of such measures to promote natural forest regeneration is the use of felling, which contributes to the emergence and preservation of the younger generation of the forest.

The rules for improving the qualitative composition of forests [24] do not make provision for felling that would be most favourable for the natural renewal of economically valuable species. Maintenance felling only to some extent solves this issue, especially for the natural regeneration of light-demanding tree species. Starting from the age of cleaning and older, maintenance felling involves the uniform placement of trees on the plot, which are left for further growth. Such placement of trees in medium (0.6-0.7) and high (0.8-1.0) stands relative density mainly adversely affects the safety and normal growth and development of the younger generation of the forest under the canopy of the parent stand.

Re-formation felling considers the bioecological properties of tree species to a greater extent than maintenance felling for their successful natural regeneration. According to the rules for improving the qualitative composition of forests [24], re-formation felling is aimed at gradually turning same-age pure forest stands into mixed multi-storeyed forest stands of different ages. They combine the simultaneous felling of individual trees or their groups and the promotion of natural forest regeneration, provided that the forest exists continuously. Such felling is performed to form a target stand when the composition and structure of the stand do not correspond to optimal parameters close to the natural state. According to the same principles, felling is also performed in foreign countries. Thus, German foresters in recent decades have widely used re-formation felling in Scots pine forests, which makes provision for gradual reproduction on the plot instead of a pure single-storeyed pine stand of indigenous, mixed, multi-age, and multi-storeyed stands [4; 8; 25].

Therefore, if the stand corresponds to the management of the forestry and its composition and structure are optimal, then felling is not carried out, and natural forest regeneration occurs mainly under the above-mentioned adverse factors.

Felling is associated with the reconstruction of low-value young and derived stands, is performed to replace low-value and derived young stands with targeted ones and is combined with the implementation of measures related to artificial forest regeneration. Reforestation felling is performed in mature and over-mature multi-storeyed stands of different ages and stands of simple structure to restore valuable tree species in forests where principal felling is forbidden [7]. Landscape felling is performed to form forest-park landscapes and increase their aesthetic, health-improving value and sustainability in recreational and health-improving forests, forests with historical and cultural purposes, as well as in recreational areas of national natural and regional parks.

Materials and Methods

To fulfill the purpose of this study, in 2020, an experimental site was laid in a monodominant pine stand of the Plesetskyi Forestry of the Separate Subdivision of the National University of Life and Environmental Science of Ukraine "Boiarka Forest Research Station" (SS NULES of Ukraine "Boiarka FRS") (Fig. 1, Table 1).

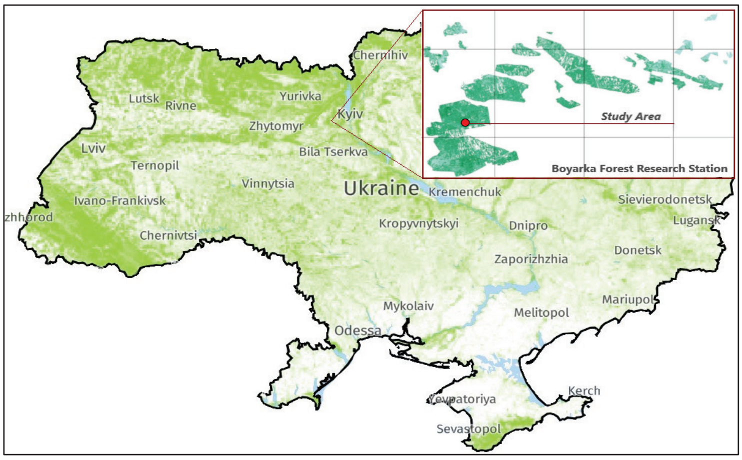

Figure 1. Experimental site in Plesetskyi Forestry of the SS NULES of Ukraine "Boiarka FRS", Kyiv region

Accounting for natural forest regeneration was performed according to A.V. Pobedinsky's method [26] on accounting plots measuring 1.0x1.0 m, which were laid on cut-down circular areas in two mutually perpendicular directions. In terms of quality, the younger generation of the forest was divided into: dry – dead specimens; doubtful – suppressed, with signs of drying out of aboveground parts, mechanical damage, etc., which is still capable of further life; healthy – reliable, without mechanical damage and signs of disease and suppression [26]. In terms of height, natural forest regeneration was divided into: shallow – up to 0.50 m, medium – 0.51-1.50 m, high – above 1.50 m [27].

Table 1. Forest inventory indicators of the stand before felling

Enterprise, forestry, quarter, allotment	Forest category	S, ha	Stand	Site index class	A, years	P	Average		M $m^3 \cdot ha^{-1}$
							H, m	D, cm	
SS NULES of Ukraine "Boiarka FRS", Plesetske, 393, 1	Recreational	6.0	10Ps	I^a	77	0.60	27.0	30.0	360

Source: [28]

The V.G. Nesterov's scale was used to estimate natural forest regeneration [29]. Simultaneously with the study of natural forest regeneration on circular plots, the projected coverage of forest ground vegetation was evaluated on the Brown-Blanquet scale [30]. The experimental site is used during all-Ukrainian research-to-practice seminars and training practices for students of bachelor's and master's degrees with specialties in forestry.

To investigate climate indicators, the authors used archival weather data of the Ukrainian Hydrometeorological Institute of the State Emergency Service of Ukraine and the National Academy of Sciences of Ukraine [31].

The degree of dryness (aridity) of the climate for 2019-2021 was investigated using the De Martonne's aridity index [7], which is calculated according to the following formula:

$$IA = \frac{(12 \cdot R)}{(T+10)}, \quad (1)$$

where *IA* – De Martonne's aridity index; *R* – monthly average precipitation, mm; *T* – monthly average air temperature, °C.

Humidification conditions at the experimental site were investigated using the G.T. Selyaninov's hydrothermal moisture coefficient (HTC) [32]. HTC is a universal indicator of the humidity of the territory, which is used by the Ukrainian Hydrometeorological Centre. It is set as the ratio of the amount of precipitation in mm for a period with average daily air temperatures above 10°C to the sum of temperatures for the same period, reduced by 10 times. The HTC is calculated according to the following formula:

$$HTC = \frac{R}{(0{,}1 \cdot \Sigma T)}, \quad (2)$$

where *HTC* is the G.T. Selyaninov's hydrothermal moisture coefficient [32]; *R* is the precipitation for the period with temperatures above 10°C, mm; *ΣT* is the sum of active temperatures >10°C, °C.

To estimate the moisture content of the territory, the HTC assessment scale was used based on the obtained value, with the HTC indicator <0.4 – very severe drought, 0.4-0.5 – severe drought, 0.6-0.7 – average drought, 0.8-0.9 – weak drought, 1.0-1.5 – sufficient humidity, and >1.5 – excessive humidity.

The demand of plants for heat during the growing season is characterized by the sum of active temperatures [33]. Accordingly, average daily temperatures exceeding 10°C are called active. The sum of active temperatures for 2019-2021 was calculated according to the following formula:

$$\Sigma t_{act} = t_{avg} \cdot n , \tag{3}$$

where Σt_{act} is the sum of active air temperatures for a given period, °C; t_{avg} is the average active air temperature for a given period, °C; n is the number of days in the period.

The age of principal felling for pine stands of the forestry part of the green zone of the SS NULES of Ukraine "Boiarka FRS" is 101 years or more. By this age, pine stands can already be subjected to selective sanitary felling several times, which is an indicator of their low biological resistance. By the age of 100, mainly suppressed natural regeneration of pine trees accumulates under the canopy of such stands. Therefore, to set up optimal conditions for natural forest regeneration at the experimental site (Table 1), trees were cut down partially on six circular plots with a diameter of 1.5 H_{avg} of the stand – 40.5 m (0.13 ha per each plot). This will provide normal conditions for the emergence and preservation of natural forest regeneration (Fig. 2). The circular plots were placed on the experimental site considering the available forest glades and rare (up to 3 thousand units·ha^{-1}), medium (0.5-1.5 m), suppressed natural regeneration of Scots pine.

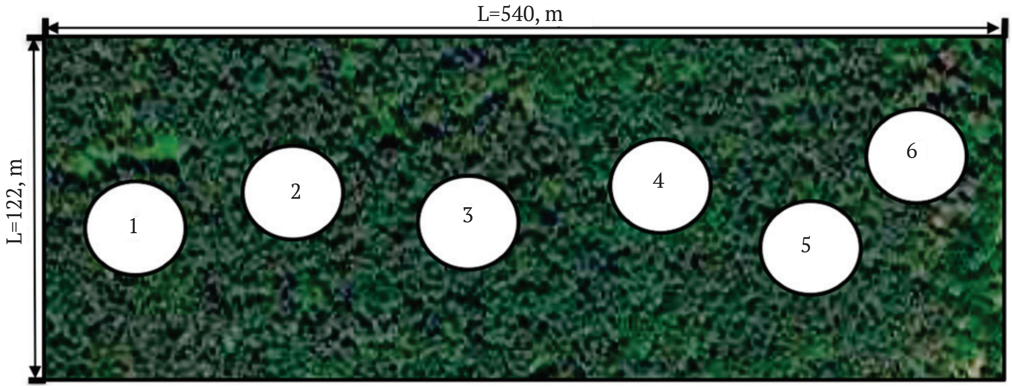

Figure 2. Placement of circular plots in the Scots pine stand of the Plesetske Forestry of the SS NULES of Ukraine "Boiarka FRS" (q. 393, al. 1)

For rational use of the average seed year (3 points) in a pine stand, felling on circular plots was performed in early spring (March) 2020 before the mass discharge of seeds from pinecones. The reserve of felled wood per 1 ha is 46 m^3. This accounted for 13% of the stock of stands before felling. Felling remains were stacked in piles and burned on circular plots.

To find the best conditions for the germination of Scots pine seeds after felling (March) on circular plots No. 2, 6, the surface of the soil was loosened with a disc harrow BDN–1.8 in two tracks, and on circular plots No. 3, 4 the surface of the soil was not processed. At circular site No. 5, after felling (March), the soil surface was loosened with a BDN–1.8-disc harrow in two tracks and Scots pine seeds were manually sown. To remove sodding of the soil surface by bushgrass (*Calamagrostis epigejos* (L.) Roth.) at circular site No. 1, furrows were cut with a PKL–70 plough, considering the existing understorey of Scots pine. Annual seedlings of Scots pine and common oak were planted at the bottom of the furrow.

Results and Discussion

Analysis of climate indicators. Perennial and seasonal fluctuations in climate indicators directly affect the preservation and viability of natural forest regeneration after its emergence [1; 8]. Among the limiting weather indicators, we can distinguish the temperature and humidity of the air, the sum of active temperatures, precipitation, as well as their number and frequency [3; 34]. At the experimental site, the mass emergence of natural regeneration of Scots pine was noted during the spring of 2020, which was preceded by the seed year. To investigate the weather parameters before and after the emergence of natural forest regeneration, the climate indicators for 2019-2021 were analysed.

Statistical characteristics of the climatic indicators of the region under study for 2019-2021 are presented in Table 2. The following conventions are used: T_{avg} – average monthly value of air temperature, °C; U_{avg} – average monthly value of air humidity, %; R – average monthly rainfall, mm; N_{dp} – average monthly value of the number of days with precipitation, days; *IA* is the average monthly value of De Martonne's aridity index; n – number of months; M – arithmetic mean; *Me* is the median; σ – standard deviation; v – coefficient of variation; *As* – coefficient of asymmetry; *Es* is the kurtosis coefficient.

Table 2. Descriptive statistics of weather parameters by year

Indicators	Year	n	M	M_e	min	max	σ	ν	As	Es
T_{avg}, °C	2019		10.5	10.8	-4.5	23.6	8.95	84	-0.13	-1.17
	2020		10.9	11.2	-0.5	22.4	8.42	77	0.10	-1.58
	2021		9.2	8.2	-4.5	24.6	9.90	108	0.18	-1.25
U_{avg}, %	2019		70.4	68.0	54.0	87.0	11.60	16	0.28	-1.46
	2020		69.2	67.5	41.0	92.0	15.15	22	-0.15	-0.68
	2021		71.6	67.5	61.0	88.0	9.41	13	0.74	-0.98
R, mm	2019		43.4	40.5	14.0	82.0	21.52	50	0.48	-0.59
	2020	12	50.3	42.5	15.0	123.0	35.05	70	1.59	1.62
	2021		45.0	53.5	1.6	77.0	24.41	54	-0.42	-1.25
N_{dp}	2019		14.8	15.5	9.0	25.0	5.43	37	0.50	-0.72
	2020		13.5	13.0	6.0	24.0	5.90	44	0.49	-0.77
	2021		15.7	14.5	4.0	27.0	5.87	37	0.04	0.92
IA	2019		31.0	26.3	7.4	100.4	23.99	77	2.43	7.33
	2020		31.7	23.7	10.9	65.9	20.95	66	0.84	-1.03
	2021		42.4	25.2	1.0	135.3	42.77	100	1.33	0.58

Table 2 suggests that during the year, the vast majority of weather parameters are marked by significant variability in the coefficient of variation (*ν>25 %*), except for the indicator U_{avg} (*ν>11-25 %*), which shows substantial scattering of the minimum and maximum values of the random variable from the distribution centre. The greatest variability can be traced by indicators (T_{avg}) and (*IA*), which is explained by the considerable range (84-98%) of the average monthly air temperature, considering temperatures below zero in winter and the aridity index (83-99 %) during the year.

Precipitation, air temperature, and their characteristics are of great importance for seed germination in spring, development, and preservation of Scots pine seedlings during the growing season. Figure 3 presents the dynamics of precipitation and air temperature by month during 2019-2021.

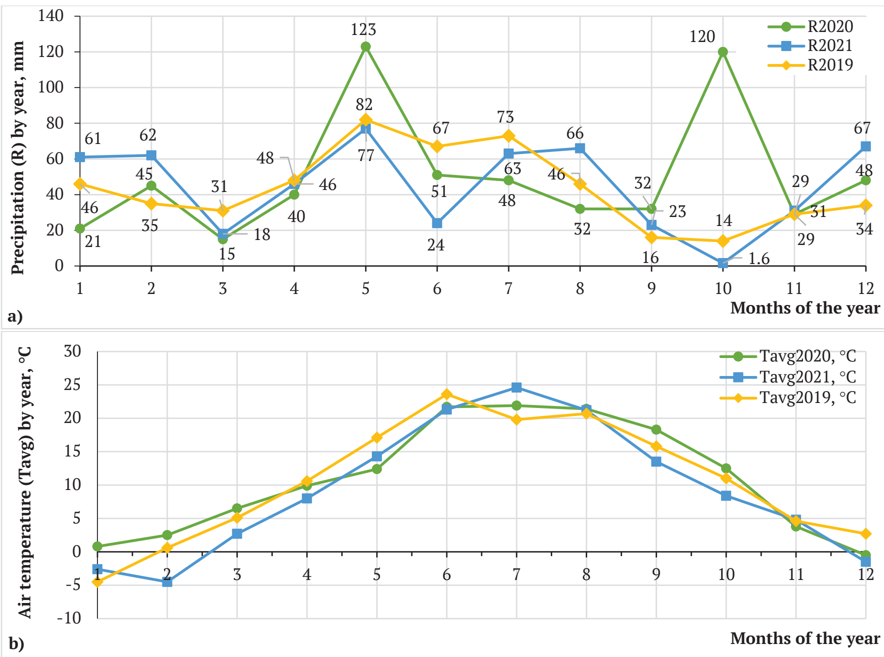

Figure 3. Dynamics of precipitation (a) and air temperature (b) by month during 2019-2021

Monthly precipitation fluctuations during 2019-2021 are heterogeneous, as evidenced by the data in Fig. 3. The total annual precipitation by year has the following distribution: 2019 – 521 mm, 2020 – 604 mm, and 2021 – 540 mm; annual precipitation in months with an average air temperature ≥10°C: 2019 – 346 mm, 2020 – 446 mm, and 2021 – 253 mm; the sum of active temperatures in 2019 – 3626°C, 2020 – 3610 °C, and 2021 – 2904°C. During March 2020, a dry period was noted, which lasted until the third decade of April. It is known that the absence of precipitation in early spring does not substantially affect seed germination, since moisture availability is important at the time of emergence and in subsequent months [3; 6]. Subsequently, spring-summer and autumn rain highs were observed in May-June and October. Thus, in 2020, despite the decade-long droughts in March-April, as well as in August-September, favourable conditions for natural forest regeneration developed. In May and June, there was an increase in precipitation (174 mm) compared to March-April (55 mm) and July-August (80 mm), as well as for the same period in 2019 (17%) and 2021 (72%). Sufficient moisture in May and June had a positive effect on the emergence and subsequent rooting of natural renewal in the experimental site.

To investigate the dynamics of the aridity of the climate and the humidification of the territory in the experimental areas during 2019-2021, the average monthly fluctuations of the R and T_{avg} indicators and their dependence on the De Martonne aridity index and G.T. Selyaninov's hydrothermal moisture coefficient were analysed [32].

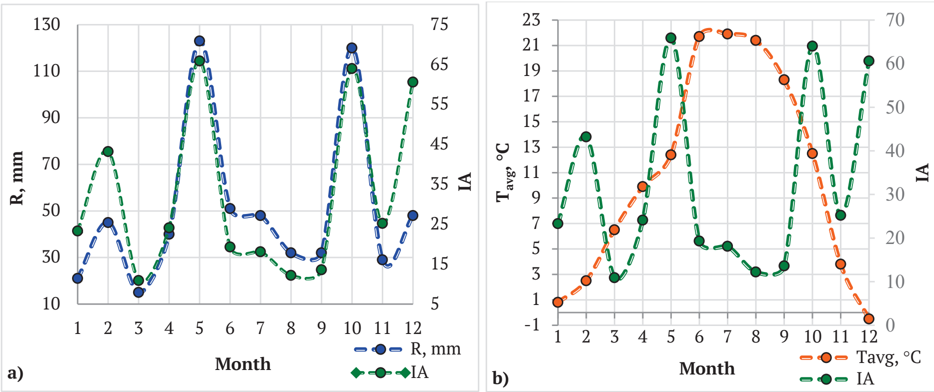

Figure 4. Dynamics of precipitation (a) and aridity index (b) by month during 2019-2021

Results of nonparametric correlation analysis (Fig. 4) indicate a naturally close relationship between the average monthly precipitation and the aridity index (r=0.85) and a moderate inverse relationship between the aridity index and the average monthly air temperature (r=-0.62). The aridity index, as an indicator of climate dryness, turned out to be sensitive to climate indicators, namely the humidification regime of the territory, where its growth is noted with an increase in precipitation. Extended periods of rainlessness and an increase in air temperature have close feedback, which affects the decrease in the aridity index in the region under study.

The HTC value during 2019-2021 was not substantially changed, specifically in 2019-2020 this indicator was 1.0 and 1.2, respectively, which on the scale of assessment of the coefficient values belongs to Group 5 – sufficiently wet conditions, which is crucial for the normal development of seedlings. In 2021, the humidity of the territory changed, and the HTC indicator decreased to 0.9, which corresponds to Group 4 – a weak drought in the region under study. The decrease in the HTC indicator in 2021 is explained by the decrease in the amount of precipitation during the growing season, with average monthly air temperatures ≥10°C.

During 2020-2021, climate indicators were generally favourable for the emergence, growth, and development of natural renewal of Scots pine in experimental site. Further studies of the growth and development of natural forest regeneration allow obtaining more detailed results on the impact of climate indicators and other environmental factors on natural regeneration of pine forests in the region under study.

Natural forest regeneration at the experimental site. In the first years of life, natural forest regeneration suffers from suppression and intense competition from grass vegetation and shrubs, which adversely affects the further development of seedlings [3, 35]. To avoid the adverse impact of the grass-shrub storey in the autumn (September) of 2020, forest sanitation was performed by felling the bushes of the understorey on all the circular plots of the experimental site.

The results of accounting for natural forest regeneration in the first year of life after felling indicate its good success. The characteristics of natural forest regeneration on circular plots are presented in Table 3.

Table 3. Characteristics of natural forest regeneration on circular plots in the Scots pine stand of the Plesetske Forestry of the SS NULES of Ukraine "Boiarka FRS" (thousand pcs·ha^{-1})

Circular plot number	Composition of forest regeneration	Age and height of forest regeneration		Total	Projected cover of forest ground vegetation (numerator – points, denominator – %)
		up to 1 year, up to 0.50 m	5-7 years, 0.51-1.50 m		
1	100% Scots pine	18.3	0.7	19.0	5 / 90 (*Calamagrostis epigejos* (L.) Roth.)
2	100% Scots pine	29.9	–	29.9	4 / 60 (*Calamagrostis epigejos* (L.) Roth., *Rubus caesius* L.)
3	100% Scots pine + Common oak + Silver birch	Scots pine – 40.0; Common oak – 0.1; Silver birch – 0.1	–	40.2	3 / 30 (*Calamagrostis epigejos* (L.) Roth.)

Table 3, Continued

Circular plot number	Composition of forest regeneration	Age and height of forest regeneration		Total	Projected cover of forest ground vegetation (numerator – points, denominator – %)
		up to 1 year, up to 0.50 m	5-7 years, 0.51-1.50 m		
4	100% Scots pine + Common oak + Silver birch	Scots pine – 50.3; Common oak – 0.7; Silver birch – 0.3	–	51.3	3 / 30 (*Calamagrostis epigejos* (L.) Roth.)
6	100% Scots pine + Common oak	Scots pine – 31.9; Common oak – 0.1	–	32.0	4 / 70 (*Calamagrostis epigejos* (L.) Roth.)

Results of autumn (September) accounting of natural forest regeneration on circular plots No. 1, 2, 3, 4, 6 in the year of felling show that the composition of natural forest regeneration is dominated by Scots pine. Participation of other tree species (Common oak, Silver birch) in the natural forest regeneration does not exceed 5%. The natural forest regeneration on the above-mentioned circular plots is 19.0-51.3 thousand pcs·ha^{-1}, including natural regeneration of Scots pine – 18.3-50.3 thousand pcs·ha^{-1}, which is explained by the 100% presence of Scots pine trees in the parent stand (Table 1) and their average (3 points) seed bearing. This amount of natural forest regeneration is sufficient to restore the felled circular site naturally. Natural regeneration in circular plots is evenly distributed (over 85% of the area) and is healthy and shallow (up to 0.5 m). A small amount (0.7 thousand pcs·ha^{-1}) of previous, medium-height (0.51-1.50 m) natural regeneration of Scots pine is observed only on circular site No. 1. The amount of natural reforestation on circular plots No. 3, 4 without measures to promote natural regeneration is greater (40.2-51.3 thousand pcs.·ha^{-1}) than on circular plots No. 2, 6 (29.9-32.0 thousand pcs.·ha^{-1}), where the soil surface was loosened with a BDN–1.8 disc harrow in two tracks. This is explained by the fact that on all circular plots there is a direct dependence of the amount of forest regeneration on the projected cover of the forest ground vegetation.

The smallest amount of natural reforestation (19.0 thousand pcs.·ha^{-1}) on the circular site No. 1 is explained by the continuous sodding of the soil surface between the furrows by bushgrass (*Calamagrostis epigejos* (L.) Roth.). The natural regeneration of Scots pine on this circular site is mainly found in the furrows formed by the PKL–70 plough and in a small amount between the furrows. Given the average (3 points) degree of soil sodding by bushgrass (*Calamagrostis epigejos* (L.) Roth.), the amount of natural forest regeneration is 40.2-51.3 thousand pcs·ha^{-1} (circular plots No. 3, 4). With an increase in soil cover from 50% to 75% of the area (4 points), the amount of natural forest regeneration decreases – 29.9-32.0 thousand pcs·ha^{-1} (circular plots No. 2, 6).

In the future, for the growth of the main species (Scots pine), it is necessary to provide appropriate care (agrotechnical care; cutting of understorey bushes and parts of the understorey of secondary species that suppress the growth of the main species; cutting the worst specimens of the understorey of the main species; uniform placement of the best specimens of the understorey on circular plots, etc.).

The next method of felling should be assigned subject to the completion of the regeneration of the main rock on previously felled circular plots according to the standards defined in the instructions for design, technical acceptance, accounting, and quality assessment of forest-cultural objects for the transfer of natural renewal to areas covered with forest vegetation [36]. The next felling method should also be performed in years of average (3 points) and above seed-bearing points by expanding existing circular plots or setting up new circular plots with a size of 1.5-2.0 H_{avg} of the stand. The area of existing circular plots is doubled by felling trees on it, measuring 1.5-2.0 H_{avg} of the stand that are adjacent to existing circular plots in a southerly direction. This will contribute to better illumination of the natural forest regeneration. New circular plots are being expanded according to the same principle. To evenly fell the stand on the site, circular plots with a size of 1.5-2.0 H_{avg} of the stand on the site in the first step of felling should be placed at a distance of 1.5-2.0 H_{avg} of the stand apart from each other.

Scientists-foresters [4; 5; 6] indicate that the reforestation by natural seeding is vital for the formation of long-lasting, biologically stable, and highly productive stands. At the same time, the current “Rules for improving the qualitative composition of forests” [24] do not make provision for felling that would allow for a sufficient amount of healthy, viable natural regeneration of economically valuable species in tree stands of any age class, composition, and structure. According to some authors [12; 13; 25], this task is particularly relevant for recreational and health-improving, protective forests, forests of nature protection, scientific, historical, and cultural purposes, where it is necessary to perform felling so that the forest is reproduced, if possible, naturally, and its structure has a complex structure.

The natural regeneration of coniferous and deciduous tree species is influenced by numerous factors that can hinder its growth processes at different stages of development. Dry periods [4; 12; 37], fires [5; 35], insufficient lighting [6; 9], suppression by bush and grass vegetation [6; 38], stand density [4, 8, 23] are the most common and decisive environmental factors affecting the quantitative and qualitative indicators of natural forest regeneration [6; 9]. Climate change is also one of the most difficult challenges facing forestry [9]. It is expected that the impact of climate on forests will substantially increase in the coming decades [2; 38; 39]. Rising temperatures, prolonged droughts, and insufficient precipitation during the growing season can be crucial environmental factors for preserving the natural forest regeneration [2; 4; 5].

The results of the study of natural forest regeneration on circular plots are confirmed by A.V. Vishnevsky’s conclusion [20] on the better preservation and increase in natural regeneration of Scots pine under complex felling methods and measures to promote natural forest regeneration and the conclusions of A.M. Zhezhkun [21], I.V. Porokhniach [22] on the better passage of natural regeneration of Scots pine in rounded gaps and a smaller amount of natural regeneration of Scots pine after loosening the soil surface with a disk harrow. The established dependence of the amount of natural forest regeneration on the projective cover of forest ground vegetation is also confirmed by studies of M. Arend, R. Link, R. Patthey, G. Hoch, B. Schuldt, A. Kahmen [3], M. Poore [6], C. Senf, A. Buras, C. Zang, A. Rammig, R. Seidl [38], M. Gordienko, N. Gordienko [17], V. Rybaka [18].

Conclusions

In 2020, despite the ten-year droughts in March-April, as well as in August-September, favourable conditions for natural forest regeneration developed. Sufficient moisture in May-June had a positive effect on the emergence and subsequent rooting of natural renewal in the experimental site.

To obtain viable, high-quality seed natural regeneration of economically valuable species in forests of any category, age class, composition, structure, the Rules for improving the quality composition of forests must make provision for felling to promote natural forest regeneration in compliance with organizational and technical indicators:

1) the felling area is determined by the area of the intended survey (economic) plot;

2) circular platform size – 1.5-2.0 H_{avg} of the stand;

3) the distance between circular plots in the first step of felling is 1.5-2.0 H_{avg} of the stand;

4) the direction of expansion of the circular plots is southern;

5) the next reception of felling is assigned subject to the completion of the regeneration of the main rock on a pre-felled circular plots;

6) measures to promote natural forest regeneration (special tillage; care for forest renewal; formation of an open edge around a circular site; fencing of the area with natural forest regeneration; prohibition of grazing; the simplest forest crops in places with no regeneration; felling season; clearing of felling sites).

Adverse impact on natural forest regeneration on circular plots measuring 1.5 H_{avg} of the forest stand is made up of a dense understorey and soil sodding with a forest ground vegetation. Therefore, it is mandatory to carry out agrotechnical care for natural forest regeneration. It is established that felling to promote natural forest regeneration should be assigned in the years of average (3 points) and more points of seed bearing (fruiting) of trees in the stand. Felling should begin before the mass departure of seeds or fruit falls and finish before they germinate. It is advisable to carry out special treatment of the soil surface under the condition of significant soil sodding (over 50% of the area) with a forest ground vegetation. Otherwise, such measures are ineffective.

Further studies of the growth and development of natural forest regeneration will give more detailed results on the impact of environmental factors and proposed organizational and technical indicators of felling on natural forest regeneration.

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Експериментальна рубка сприяння природному поновленню лісу у Київській області

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Анотація. Ведення лісового господарства в Україні необхідно здійснювати з урахуванням змін клімату та деградації і масового всихання лісів, а також з дотриманням принципів збереження умов відтворення біологічно стійких, високопродуктивних насаджень та раціонального і невиснажливого використання лісових ресурсів. Тому одним із головних завдань ведення господарства у лісах є максимальне використання природного насіннєвого потенціалу лісових насаджень. Такому принципу відповідають рубки, які спрямовані на максимальне використання природного насіннєвого поновлення лісу, як методологічної основи створення високопродуктивних, біологічно стійких лісових насаджень. Мета дослідження – розробити спосіб рубки, який сприяє природному поновленню лісу та запропонувати організаційно-технічні показники для його проведення. Облік природного поновлення лісу проводили за методикою А.В. Побединського; оцінку природного лісопоновлення здіснювали за шкалою В.Г. Нестерова; проективне покриття живого надґрунтового покриву визначали за шкалою Браун-Бланке; сухість клімату визначали за індексом аридності Де Мартонна; умови зволоження на дослідній ділянці вивчали з використанням гідротермічного коефіцієнту Г. Т. Селянінова; суму активних температур визначали за методикою Укргідрометцентру. Проаналізовано нормативно-правову базу проведення рубок формування і оздоровлення лісів. Встановлено, що діючі Правила не передбачають проведення рубок, які були б максимально сприятливими для природного поновлення господарсько цінних деревних порід у лісах будь-якої категорії, віку, складу і структури. Представлено результати обліку та оцінки природного поновлення лісу на вирубаних кругових площадках. Встановлено, що за умови середнього (3 бали) і вище балів насіннєношення (плодоношення) та достатньої кількості вологи на кругових площадках діаметром 1,5 Нср. деревостану спостерігалося дуже густе, здорове, рівномірно розміщене по площі природне поновлення лісу. Негативний вплив на природне лісопоновлення у перший рік життя чинять густий підлісок та значне задерніння поверхні ґрунту (більше 50 % площі) живим надґрунтовим покривом. У противному випадку останнього, проведення спеціального обробітку ґрунту є малоефективним. У 2020 році, не зважаючи на декадні посухи у березні-квітні, а також у серпні-вересні склалися сприятливі умови для природного поновлення лісу. У травні та червні відмічено зростання кількості опадів порівняно з попередніми та наступними місяцями після появи сходів, що позитивно вплинуло на їх укорінення та ріст. Рубку, яка сприяє природному поновленню лісу, слід віднести до рубок формування і оздоровлення лісів та встановити для неї запропоновані організаційно-технічні показники. Одержані висновки слугуватимуть методологічною основою для запровадження у лісових насадженнях нового способу рубки, який був би максимально сприятливим для отримання у достатній кількості якісного, життєздатного природного поновлення господарсько цінних деревних порід

Ключові слова: кліматичні показники, деревостан, кругова площадка, сходи, життєздатність підросту, природне лісопоновлення

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Modelling of Thermal Conductivity of a Wooden Wall with a Reed Thermal-Insulating Mat

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Abstract. The problem of using natural building materials in low-rise construction lies in ensuring their durability during operation in conditions of atmospheric fluctuations, as well as in ensuring their thermal insulation properties. The purpose of this study is to find the thermal insulation properties of materials, namely thermally modified common hornbeam wood (the outer surface of the building), common pine wood (the inner surface of the building) and a thermal insulation layer of reeds, which allow justifying the effectiveness of their use in construction. The study uses a comprehensive research method, which included figuring out the thermal insulation properties of materials and justifying their feasibility in construction. The thermal insulation properties of wood and reed materials were calculated based on thermophysical dependences. The coefficient of thermal conductivity for wood reaches 0.0082 W/(m·K), and for reed – 0.0022 W/(m·K). Therewith, the thermal conductivity is no more than $0.19 \cdot 10^{-6}$ m²/s, the heat capacity of wood is within 70÷90 kJ/(kg·K), and the heat capacity of a reed product is 337.2 kJ/(kg·K) respectively, which refers them to thermal-insulating materials. The practical value of this study lies in the substantiation of the method of establishing thermal insulation characteristics of building materials by finding their physical and thermophysical properties. The obtained results also expand the scope of application of products and building structures made of wood and reed

Keywords: natural building materials, wood and reeds, thermal insulation products, thermal conductivity, thermophysical properties

Introduction

Products made of organic materials, namely wood and its modifications, such as thermally modified wood, reeds, etc., are used in construction. Since they have several unique characteristics – low volume weight, low coefficient of thermal conductivity, rather high weather resistance. Furthermore, they are described by high strength and elasticity.

Wood and reed products are widely used in low-rise construction. Thermally modified wood is used for exterior decoration of structures, as it can withstand atmospheric fluctuations [1]. Reed boards are mainly used in the construction of walls, partitions, floors, and roofs, which are protected by thermal-insulating and sound-proofing material. Having a tubular stem structure, reeds have a low weight and low thermal conductivity, and due to the presence of flint deposits in reed cells, they are less susceptible to rot than wood. The production of construction products from reeds is not difficult and without excessive costs can be organised in places with reed stands. Reed nodes are thickened rings-joints and are placed along the stem every 15-20 centimetres. Inside the rings, there are partitions that do not allow air and water to pass through. Such structure of reeds causes low thermal conductivity of products made from it and sufficient strength.

Thus, the use of products made of wood, including thermally modified, and reed, for the construction of walls, requires the establishment of certain characteristics of the materials. For effective design and subsequent manufacture of construction products, it is necessary to establish thermophysical properties. Therefore, conducting these studies is relevant and of great practical importance.

The use of plant-based materials in construction has gained great importance recently. Therefore, the search and

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justification of technological aspects of the production of building structures based on wood panel boards with the necessary thermal insulation characteristics is the basis of many studies [2; 3]. However, the task does not make provision for an analysis of the physical condition of the product during long-term operation in an environment with changes in temperature and humidity. Technologies for moulding materials with the addition of mineral impurities to plant fibres are increasingly being developed. Various combinations of hydrophobic components with natural materials such as asbestos, mica, basalt, etc. are used [4; 5]. As a result of this combination, structures of increased rigidity are obtained, but their resistance to atmospheric fluctuations has not been studied.

In [6], the authors investigated the dependence of the density and plasticity of a material made from a mixture of linen fibres and cotton on quantitative changes in plant components. In addition, the authors studied the indicators of flexibility of such thermal insulation products, which change depending on the applied binding element. The issue of thermal conductivity stays unresolved, which reduces the effectiveness of the results obtained.

The study [7] estimates the influence of the environmental conditions of operation of products made of fibreboards on their thermal conductivity. It was proven that the reliability of data on the thermal properties of insulation materials is crucial in numerical modelling, which increases efficiency with the correct design of structures. However, the method for determining thermal conductivity has not been covered.

The study [8] presents the data on the production technology of a construction material based on hemp fibre glued with alabaster binding material, as well as the thermophysical properties of the material. The authors substantiated the possibility of its use as a thermal-insulating construction element. But finding the influence of structural components on its thermal insulation stays an unresolved issue. The products presented in [9] are made based on of basalt fibre and are described by prominent thermal insulation properties. However, the production technology and methodology for determining thermal insulation and strength properties are not given.

The cited studies [10] substantiate the modelling that describes the regularities of heat distribution and its retention in the insulating material, considering the features of the thermal insulator. Combinations of both natural and synthetically produced fibres were considered as structural elements. However, the dependence of heat transfer on changes in the pore shape of composite particles in this model is not considered.

The study [11] presents a method of a hot disk transition plane source, which allows characterising the thermal properties of various materials in a few minutes. This method is increasingly used to estimate the thermal conductivity of insulating building materials. Three types of materials are tested: conventional isotropic materials (e.g., extruded polystyrene foam), anisotropic compressible materials (e.g., wood fibre insulation), and heterogeneous anisotropic materials (e.g., lightweight bio-concrete). The influence of tuning parameters (volume heat capacity, time limit for estimation) is analysed in the light of repeatability and reproducibility errors. The suitability of the hot disk method based on an isotropic or anisotropic model for characterising non-contiguous isotropic heterogeneous materials is discussed and compared with steady-state measurements. The results obtained for particular cases cannot be generalised, especially for heterogeneous materials, such as biological-based building insulation materials.

The study [12] presents an assessment of environmental impact by analysing the life cycle of a new type of wood-based sandwich panel. To identify the processes that most affect the environment of the proposed cross-laminated timber (CLT) panel solution during the life cycle. The analysis is performed considering various life cycle completion scenarios during production. The study includes a comparative assessment of changes in the thickness of wood layers relative to the optimised cross-insulated timber (CIT) panels; the use of an alternative to the base material, namely insulation cork board (ICB); the use of structurally equivalent CLT panels. The results show that the CIT panel manufacturing process, namely polyurethane foam production and the moulding and curing processes during panel assembly, are the ones that have the highest impact. This means that an optimised solution in terms of economic costs is also the solution that has the least impact on the environment. Compared to equivalent CIT panels with ICB core and CLT solutions, the environmental characteristics of the proposed panel were better for some impact categories, while they were worse for others. However, there is still the need to switch to natural materials in the future.

The study [13] focused on the possibility of reducing the amount of diphenylmethane diisocyanate (pMDI) in the composition of insulating wood fibreboards by 50% by adding 1% BioPiva 395 or Indulin as two types of soft wood kraft lignin and lignin-rich canola husk together with propylene carbonate as a solvent. As a result, panels with a density of 160 kg/m^3 and 40 mm thick were obtained. The curing of this material was investigated using two types of methods: hot steam (HS) and the innovative hot air/hot steam (HA/HS) process. The insulating wood fibreboards were then tested for their physical and mechanical properties. The equilibrium moisture content was found under two different climatic conditions. An approximate study of thermal conductivity was also performed. The plates under study also underwent further chemical analysis for the content of extractives and elemental (C, N) composition. The results show that it is possible to produce insulating wood fibreboards with less pMDI resin and the addition of lignin with improved physical and mechanical properties of the board, which do not lose thermal conductivity or moisture absorption, especially when curing using the HA/HS process.

The paper [14] investigated the use of plaster filled with two untreated plant-based fibres – wood fibre and grain straw fibre, for their use in the thermal insulation of buildings. Composite materials were made with different densities (0%; 5%; 10%; 15%; 20% by volume). Their thermophysical features were described in terms of chemical structure, crystallinity, thermal conductivity, thermal conductivity coefficient, and water absorption. Two linear correlations were established regarding the thermal conductivity and thermal conductivity of the samples. The results show that the introduction of wood fibres and grain straw fibres reduces the thermal conductivity, as well as the heat capacity and weight of composite materials. A comparison of other composite materials shows that the proposed composite is a good competitor compared to the materials used in insulation.

Thermal insulation is considered one of the key technologies to combat the ever-increasing energy consumption. In [15], the authors propose an efficient method for developing innovative and cost-effective basic materials for vacuum insulation panels (VIP). They contain natural and resistant wood pulp fibres with the addition of various amounts of glass fibre as a reinforcing component. To create such a hybrid multi-level network composite, the usual wet paper manufacturing is used. The authors investigated the main features of both wood pulp and glass fibre, including the effect of glass fibre on the texture properties and thermal insulation characteristics of composite panel core materials. The results showed that all components achieved a uniform distribution over the thickness of the material, and the fibre axes were randomly placed in a three-dimensional structure. As the glass fibre content increased, the thermal conductivity of the panels gradually decreased due to structural changes in the filling materials. Both the pore diameter and porosity increased along with the glass fibre content. As a result, thermal conductivity of 6.48 and 4.69 mW/(m·K) was obtained, respectively, for panels made of 100% wood pulp fibre and wood pulp/glass fibre composites (mass ratio of 50%). Furthermore, after 365 days of storage, the composite material with 50% fibreglass maintained a thermal conductivity of 7.42 mW/(m·K) without a gas absorber or dehumidifier. Even under conditions of accelerated ageing, after 28 days the increase in thermal conductivity was less than 5.00 mW/(m·K).

Given the current environmental awareness and growing interest in advanced and sustainable materials, the use of waste wood fibre and phosphogypsum has led to the development of environmentally friendly composites. The article [16] presents a study of a new composite material made from a phosphogypsum matrix reinforced with waste wood fibre made from used fibreboard or natural wood fibre obtained from natural wood. Fibre in the samples was included in the amount from 0 to 5%. Furthermore, a certain amount of synthetic zeolite waste has been added to reduce the content of harmful soluble acid impurities. It was found that wood fibres from boards improve the mechanical strength of the material more effectively than natural fibres. The highest values of compressive strength – 25.1 and 21.9 MPa – were achieved with the addition of 0.5% of fibres from boards and 1% of natural fibres, respectively. A further increase in their number reduced the compressive strength of the samples by reducing the density of the material. Thermal conductivity decreased due to the addition of fibre, while the level of sound absorption did not change. Considering the comprehensively investigated properties, the optimal recipe for phosphogypsum composite samples includes 3% wood fibre obtained from boards, demonstrating a compressive strength of 13.5 MPa, a thermal conductivity of 0.39 W/mK and a sound absorption level of 64.5 dBA.

Thermal insulation materials made by mixing carpet waste with a solution of raw colemanite ore and with the addition of colemanite waste were also studied [17]. It is shown that adjusting the content of components becomes possible to ensure the process of thermal insulation.

Thus, the use of a wall from wood and reeds, primarily in construction, requires the establishment of thermophysical properties. Finding these indicators is a relevant area of research and is aimed at the effectiveness of design and subsequent manufacture of products with thermal insulation features.

The purpose of this study was to establish the thermophysical characteristics of construction products made of wood and reeds for determining the conditions of thermal insulation of a building structure.

To achieve this result, the following tasks were set:

– to establish the features of reducing the heat exchange process for walls made of thermally modified wood (external), pine wood (internal) and reed as a thermal insulator;

– to substantiate the features of the heat transfer process between the elements of a building structure made of wood and reed.

The scientific originality of this study lies in finding the thermophysical properties in a combination of a building structure made of thermally modified common hornbeam wood, common pine wood and a thermal insulation layer made of reeds, as well as in substantiating their use in the manufacture of building walls.

Materials and Methods

For the study of thermal conductivity, the authors used samples of thermally modified common hornbeam wood (outer surface), common pine wood (inner surface) with dimensions of about 150x150x20 mm, and reeds with a diameter of up to 10 mm (thermal-insulating layer) bound in a mat with dimensions of about 150x150x25 mm (Fig. 1). Therewith, reed stems of different layers were placed perpendicular to the previous one.

a) b) c)

Figure 1. Samples of materials for research: a – thermally modified common hornbeam wood, b – thermal-insulating reed mat, c – common pine wood

Special equipment was used to investigate the thermal insulation properties of materials [3].

The essence of studies to determine thermal conductivity is that a thermocouple of a heater was placed in a sample of the material, and a thermocouple was placed on the reverse side of the wall to control heat transfer (Fig. 2). The end of the thermocouple was fixed so that the sample was pressed against it. The heater voltage was turned on and the temperature on the sample surface was measured.

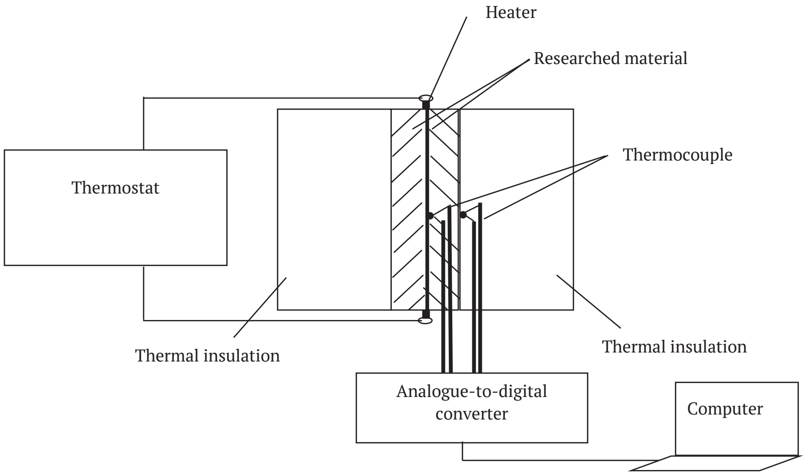

Figure 2. Device for studying the thermal conductivity of materials

When the temperature reached 70°C, the heater was switched off, continuing to measure the temperature until the value was set $0.5T_{max}$ on the reverse side of the assembly wall. The thermal-insulating properties of the sample were figured out from the measured values.

The criterion for determining the thermal conductivity of the material from the heat source is the time it takes to reach the temperature at $0.5T_{max}$ from the back surface of the wall.

Modelling of parameters of heat exchange processes in various materials of building structures. It is precisely the method of figuring out the thermal conductivity for a plate that is proposed to establish the thermophysical characteristics of the materials under study [3]. One of the sample surfaces is heated by a heat flow passing through the wall, and the temperature changes along the same vector (Fig. 2). To establish the thermal insulation properties, it is necessary to find the temperature distribution along this vector at any time.

To describe the heat transfer process, a differential equation is applied, which has the following form [18]:

$$\frac{\partial^2 T(x,\tau)}{\partial x^2} - \frac{1}{a}\frac{\partial T(x,\tau)}{\partial \tau} = 0, (\tau > 0; 0 < x < \infty). \quad (1)$$

For this equation, the initial and boundary conditions are as follows:

$$T(x,0) = T_0, \quad (2)$$

$$\lambda \frac{\partial T(x,\tau)}{\partial x} = q = const, \quad (3)$$

$$T(\infty,\tau) = 0, \quad (4)$$

$$\frac{\partial T(\infty,\tau)}{\partial x} = 0, \quad (5)$$

where T_0 is the temperature of the material in the initial period, °C; $T(x, \tau)$ is the temperature field of the wall at points with coordinates x at a time τ, °C; a is the coefficient of thermal conductivity of the wall, m^2/s; τ is the duration of stay of the sample in a high-temperature field, s; q is the temperature flow, W/m^2; λ is the coefficient of thermal conductivity of the wall, W/(m·°C).

In the paper [3], the solution of equation (1) is given considering the initial and boundary conditions (2)-(5), and the thermophysical characteristics for a flat sample are determined – Table 1:

Table 1. Formulas for finding the thermophysical characteristics of solid materials

Thermal activity coefficient	$b = \frac{2q\cdot\sqrt{\tau}}{\sqrt{\pi}\cdot\Delta T_n}$
Temperature conductivity coefficient	$a = \frac{1}{4\cdot\tau_2}\left(\frac{x}{B}\right)^2$
Thermal conductivity coefficient	$\lambda = b\cdot\sqrt{a}$
Specific heat capacity	$c = \frac{\lambda}{a\cdot\rho}$

where ΔT_n is the temperature difference between the heater and the reverse side of the sample, °C; B is the argument of the error integral function; ρ is the material density, kg/m^3.

Results and Discussion

To establish the thermophysical characteristics of materials, namely common pine wood, thermally modified common hornbeam and reed, the features of the heat transfer process from the heating source are studied (Fig. 1).

The characteristics of the heater are as follows: an electrical insulation plate measuring 100×100 mm with a thickness of 1 mm, a winding made of nichrome wire, the resistance of which is 84 Ohms. During the experiment, a voltage of 24.6 V was applied. To partially reduce heat consumption around the perimeter, the installation was placed in a thermal-insulating plate.

The studies on finding the temperature level and induction rate of heat transfer through a wall sample, which includes common pine wood and thermally modified common hornbeam wood, as well as thermal insulation from reeds, were performed on the equipment and according to the methodology described above. The results of thermal conductivity are presented in Figures 3, 4.

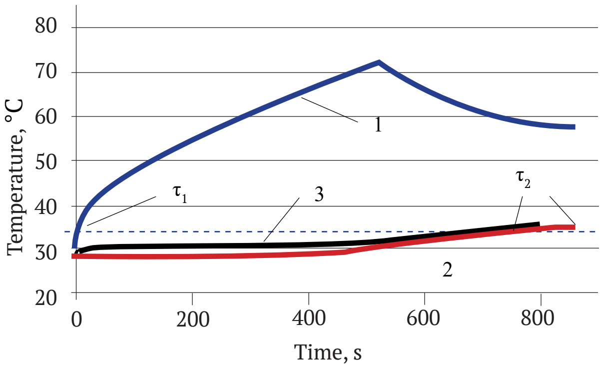

Figure 3. The results of thermal conductivity tests: 1 – heating curve, 2 – temperature level from the back surface of common pine wood, 3 – temperature level from the back surface of thermally modified wood. Points τ_1 correspond to the average temperature of the heating curve and τ_2 – to the average temperature value on the reverse surface

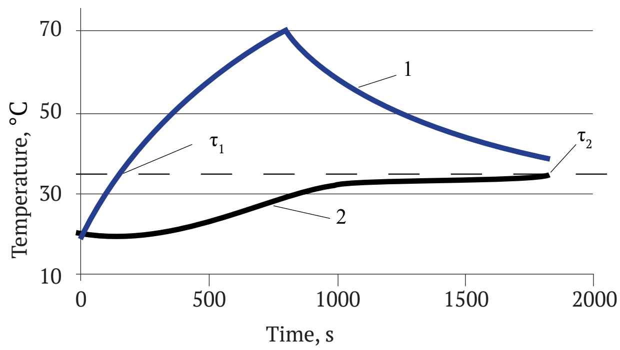

Figure 4. Results of tests of thermal conductivity of reeds: 1 – heating curve, 2 – temperature level from the back surface of reeds. Points τ_1 correspond to the average temperature of the heating curve and τ_2 – to the average temperature value on the reverse surface

Analysis of Figure 3 and Figure 4 shows that heating with heat transfer along the thickness of the sample began immediately when it was brought to the surface of the heater. However, on the reverse side of the wall, a slight increase in temperature was recorded in the period over 800 s. For the reed sample, the time to reach the temperature on the reverse surface surpassed 1900 s. That is, when using reeds as thermal insulation, it was found that the thermal conductivity of this sample is described by a prolonged heat transfer, namely, the heat transfer is inhibited by the air barriers formed in the reeds, which allows influencing the thermal insulation.

Based on the results of the measured temperature using the method given above, the thermophysical characteristics of wood and reed materials were calculated (Table 2).

Table 2. Thermal insulation properties of wood and reed

Material name	Thickness, mm	Weight, g	Calculated parameters					
			Density ρ, kg/m³	Thermal activity, W·s/(m·K)	Temperature conductivity, m²/s	Thermal conductivity λ, W/(m·K)	Heat capacity, kJ/(kg·K)
Pine wood 150×150 mm	19.8	214	475	18.7	$0{,}19 \cdot 10^{-6}$	0.0082	90.8
Thermally modified hornbeam wood, 150×150 mm	20.0	308	684	18.7	$0{,}15 \cdot 10^{-6}$	0.0073	71.2
Reed 150x150 mm	26	133	172.7	11.5	$0{,}039 \cdot 10^{-6}$	0.0022	337.2

When figuring out the thermal insulation properties of materials, it was found that the thermal conductivity of wood does not exceed $0.19 \cdot 10^{-6}$ m²/s, whereas for reed, this value decreases by almost 5 times. The thermal conductivity of the wood sample did not exceed 0.0082 W/(m·K), and for the reed product it is 0.0022 W/(m·K). Furthermore, the heat capacity of wood corresponds to a value within 70÷90 kJ/(kg·K), and the value of heat capacity for a reed product is 337.2 kJ/(kg·K), respectively. Thus, these materials correspond to the values of the thermal insulation material [19].

The calculation of the thermal parameters of the outer wall is based on finding the following basic values – the required heat transfer wall resistance R_0^r and the wall thickness δ determined on its basis [20].

Finding of R_0^r:

$$R_0^r = \frac{n \cdot (t_{in} - t_{out})}{\Delta t_{in} \cdot a_{in}}, \quad (6)$$

where n is the coefficient that depends on the position of the outer wall to the environment, ($n=1$); t_{in} is the calculated value of the internal air temperature taken according to the house design standards, °C, ($t_{in}=18°C$); t_{out} is the calculated outdoor temperature in winter, taken as the average daily value of the 5 coldest days, °C, ($t_{out}=-20°C$); Δt_{in} is the standard temperature difference between the indoor air temperature and the temperature of the inner surface of the wall, °C, ($\Delta t_{in}=7°C$); a_{in} is the heat transfer coefficient of the inner surface of the wall, ($a_{in}=7.5 \cdot 1.163$ W/m²·°C).

Thus:

$$R_0^r = \frac{1 \cdot (18 - (-20))}{7 \cdot 7.5 \cdot 1.163} = 0.62 \text{ m} \cdot \frac{\text{K}}{\text{W}}.$$

The estimated wall thickness is calculated according to the following formula [20]:

$$\delta_p = \left[R_0^r - \left(\frac{1}{a_{in}} - \frac{1}{a_{out}}\right)\right] \cdot \lambda, \quad (7)$$

where a_{out} is the heat transfer coefficient of the outer surface of the wall (per the DBN B.2.6-31:2016 [20]), ($a_{out}=20 \cdot 1.163$ W/m²·°C); λ is the coefficient of thermal conductivity of the wall material.

The coefficient of thermal conductivity is found according to the following formula [20]:

$$\lambda = \lambda_{nom} \cdot K_p \cdot K_x, \quad (8)$$

where λ_{nom} is the nominal value of the coefficient of thermal conductivity; found by a diagram constructed from experimental data for pine wood across the fibres depending on temperature; $\lambda_{nom}=0.45$ $W/(m^2 \cdot K)$; K_p is a coefficient that considers the basic density of wood; $K_p=1.11$ at δ=550 kg/m³; K_x is the coefficient that considers the vector of heat flow; $K_x=1$.

Hence,

$$\lambda = 0.45 \cdot 0.87 \cdot 1 = 0.39 \text{ W/(m}^2 \cdot \text{K)},$$

$$\delta_p = \left[0.62 - \left(\frac{1}{7.5 \cdot 1.163} - \frac{1}{20 \cdot 1.163}\right)\right] \cdot 0.39 = 0.204 \text{ m}.$$

Thus, the thickness of the house wall will be 0.20 m (wall width) (Fig. 5).

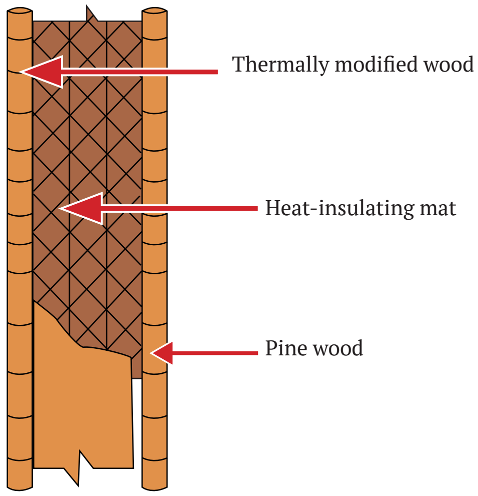

Figure 5. Scheme of thermal insulation of the house wall

Based on consumer demand, there are increased requirements for the appearance of thermal-insulating materials used for furnishing premises, therefore the use of natural thermal-insulating materials is more effective. Thus, thermomodified wood with increased weather resistance is reliable for the manufacture of external structures, and it is advisable to use reed as a thermal-insulating material.

Thermal conductivity through the wall of the building is considered as the process of heat energy transfer from the room to the outside and occurs until the temperature balance, which follows from the obtained results (Table 2). This phenomenon is caused by the formation and application of large and coupled pores in the material structure and the use of materials with low volume weight. Furthermore, the heat transfer is influenced by the following factors: the nature of the material and its structure, the degree of porosity, the nature of the pores, humidity and the average temperature at which heat transfer occurs. Thermal insulation products must meet the following requirements: have stable thermal insulation indicators, be environmentally safe and resistant to atmospheric fluctuations. This coincides with the results in [8; 9], where the authors associate the effectiveness of thermal insulation with the use of natural low-density materials. However, unlike in [14; 15], the data obtained by the authors of this study regarding the influence of natural and sustainable fibres of wood cellulose and straw of cereal crops allow stating the following:

– the main parameter for suppressing thermal conductivity is both the density and porosity of the material, since low values of these properties inhibit heat transfer;

– substantial influence on inhibition of heat transfer upon using natural materials is exercised towards the formation of a thermal insulation structure resistant to destruction under temperature and humidity fluctuations.

The obtained results are of practical importance, as they allow for a reasonable approach to figuring out the required amount of thermal insulation materials and products in a building structure. From a theoretical standpoint, this allows asserting the determination of the mechanism of inhibition of heat transfer by the wall, which constitutes a certain advantage of this study.

However, the calculated results indicate an ambiguous effect of natural materials on changes in thermal conductivity. This uncertainty imposes some restrictions on the use of the results obtained, so in the future it is necessary to conduct added experiments to identify the time from which a sharp jump in thermal conductivity begins. Thus, it will be possible to figure out the factors influencing the heat exchange process.

Conclusions

Thermal insulation properties of wood and reed materials were calculated based on thermophysical dependences. The coefficient of thermal conductivity of wood reaches 0.0082 W/(m·K), and for a reed product, this coefficient is 0.0022 W/(m·K). Therewith, the thermal conductivity does not exceed $0.19 \cdot 10^{-6}$ m^2/s, while the heat capacity of wood is within 70÷90 kJ/(kg·K), and the heat capacity of a reed product is 337.2 kJ/(kg·K), respectively, which refers them to thermal-insulating materials.

The speed of the heat transfer between the elements of the structure made of wood and reed lies in the formation of air pores. The inhibition of heat transfer in the material is caused by the lack of air movement in the air pores.

In the future, it is necessary to conduct added experiments to obtain updated data. It is necessary to create conditions sufficient for the qualitative conduct of the heat transfer and detect the time point at which the drop in heat resistance begins. Such detection allows investigating the transformation of the surface of the material based on thermally modified wood and reed, moving towards low temperature with increasing transfer time. This also allows finding those variables that substantially affect the beginning of the transformation of this process.

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Моделювання теплопровідності дерев'яної стінки з очеретяним теплоізоляційним матом

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Анотація. Проблема застосування природних будівельних матеріалів в малоповерховому будівництві полягає в забезпечені їх довговічності при експлуатації в умовах атмосферного коливання, а також у забезпечені теплоізолювальних властивостей. Мета проведених досліджень полягає у визначені теплоізолювальних властивостей матеріалів, зокрема, термічно модифікованої деревини граба (зовнішня поверхня будівлі), деревини сосни (внутрішня поверхня будівлі) та теплоізоляційного шару з очерету, що дозволяють обґрунтувати ефективність застосування їх у будівництві. В роботі використано комплексний метод дослідження, що полягав у визначені теплоізоляційних властивостей матеріалів та обґрунтуванні їх доцільності у будівництві. За теплофізичними залежностями розраховано теплоізоляційні властивості матеріалів з деревини та очерету, зокрема, коефіцієнт теплопровідності для деревини сягає 0,0082 Вт/(м·К), а для виробу з очерету становить 0,0022 Вт/(м·К). При цьому температуропровідність складає не більше 0,19·10-6 м2/с, теплоємність деревини знаходиться в межах 70÷90 кДж/(кг·К), а теплоємність для виробу з очерету складає 337,2 кДж/(кг·К) відповідно, що відносить їх до теплоізоляційних матеріалів. Практична цінність отриманих результатів полягає у тому, що обґрунтовано метод становлення теплоізоляційних характеристик будівельних матеріалів через визначення фізичних і теплофізичних властивостей та розширити сферу застосування виробів і будівельних конструкцій з деревини і очерету

Ключові слова: природні будівельні матеріали, деревина і очерет, теплоізоляційні вироби, теплопровідність, теплофізичні властивості

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Estimation of Circular Saw Tooth Microgeometry

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Abstract. This study solves the problem of estimating the microgeometry of a circular saw tooth. For research, a circular saw with one false tooth, equipped with a VK6M hard alloy plate, was used as a cutting tool. The purpose of this study is to attempt to estimate the real wear curve of a wood-cutting tool edge. The cutting was performed on an experimental installation, which is a drive shaft with a saw attached to it, with the possibility of adjusting the cutting and feeding speeds. The tooth tip was photographed after some wear in a plane perpendicular to the short blade edge with 30-50^x magnification. The tooth contour was measured using a large BMI-2 toolmaker microscope. As a result of the study, a method for estimating the sharpness of the tool edge using tangent and subsequent calculations has been developed, which allows figuring out both the local curvature and the average curvature of the entire form of tooth. This method allows finding the sections of the form of tooth with minimal and maximum curvature, as well as figuring out the curvature of a particular section of the form of tooth and the area (wear) of this section. The proposed solution allows transitioning from qualitative features of wear to accurate quantitative estimates, expressed either in units of area or units of mass, which allows comparing the tool materials from which teeth are made in cases where microgeometry is approximately the same, while wear is different. The practical significance of this study lies in the possibility of estimating the state of the parameters of the cutting unit and allows predicting its changes during operation (the degree of wear, the frequency of re-sharpening, finding the ultimate tool service life)

Keywords: tool edge, wood cutting tool, wear, blunting

Introduction

Woodworking production is based on obtaining parts and products of the required shape, size, and roughness of the treated surface [1]. This can be achieved by using a cutting tool, the active part of which is the tooth (tool edge), which forms new cutting surfaces in the material.

One of the main operational requirements [1] for wood-cutting tools is to maintain its cutting capacity for a certain time. The microgeometry of the tool edge undergoes considerable changes during operation – the tooth is blunted due to wear of the tooth line material.

Blunting of cutting units is characterised by a change in their microgeometry, which occurs due to wear of the front and back of tooth during cutting. Tooth microgeometry is characterised by "wear curves" of the front and back of tooth. The nature of blunting, i.e., changes in the microgeometry of tooth, determine the cutting properties of the tool [2-4]. The degree of wear and the nature of changes in the microgeometry of the tool edge depends on several factors, the main of which are as follows:

– physical and technological properties of wood (type, humidity) [5-7];

– physical and mechanical properties of wood-cutting tool material;

– geometry of cutting units (cutting and sharpening angles);

– processing conditions and modes (cutting types, cutting speed, and feed rate) [8-10];

– conditions and modes of operation of the tool (accuracy and rigidity of the tool, duration of operation, geometric accuracy of the machine);

– quality of sharpening of cutting units.

An essential role in ensuring the required quality and accuracy of cutting is played by the tooth line with a

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certain microgeometry. When cutting wood, one needs to strive to ensure that the radius of rounding of the tooth line surface is minimal. Apart from transverse microgeometry, the saw tooth line is also characterised by longitudinal microgeometry.

The cutting unit has tooth lines, surfaces, and angles. The angular parameters must meet the cutting conditions and position the cutting part in space. Linear parameters must provide the necessary margin of safety and stability of the cutting unit.

Compliance of the tool with modern requirements is laid down during its design. The correct choice of tool design, material, dimensions, angular parameters, operating conditions, manufacturing technology, restoration, and repair directly affects its operational properties.

The scientific originality of this study lies in a new method for estimating the parameters of the form of tooth of the cutting unit, wherein the curvature is estimated by drawing tangents with a discrete step.

From the literature sources [11-15], it is known that many well-known Ukrainian and foreign scientists have estimated the parameters of microgeometry of saw teeth. The versatility of the parameters is significant, but not all of them are available for direct measurement [16-18]. Analysis of these studies has shown that most authors simplify the approach to real microgeometry of tooth, noting the rounding of the tool edge as a circle with a certain radius. The authors of the study proposed one of the methods for measuring the linear dimensions of saw teeth [19].

In most cases, the real tooth line of the tool is shown as a surface with a radius *ρ=const* (with constant curvature) [1; 20; 21]. In fact, as a result of the authors' earlier studies of microgeometry of cutting units under various cutting conditions using a large BMI-2 toolmaker microscope, it was found that the curvature of the surface between the front and the back of tooth of the cutting unit is not a constant value of a certain radius, but a curve of variable value, which can only be conditionally estimated as a circular arc.

The purpose of this study is to establish a method for estimating the blunting curve of the edge of the cutting unit.

Materials and Methods

A circular saw was used as a cutting tool (Fig. 1) with one false tooth (Fig. 2), equipped with a VK6M hard alloy plate. Laminated particle board was used as the processed material. The scheme of cutting a particle board blank is presented in Figure 3. The cutting was performed on an experimental installation, the general view of which is presented in Figure 4.

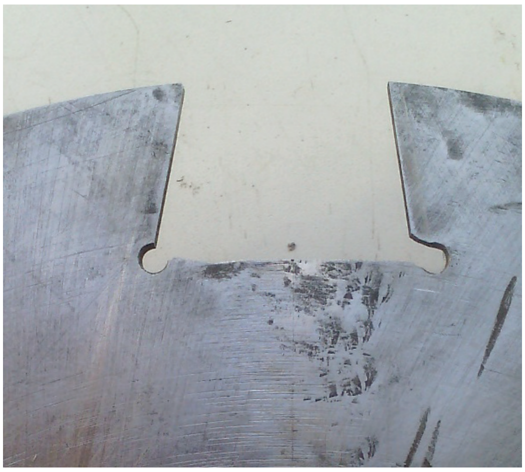

Figure 1. Saw disc fragment

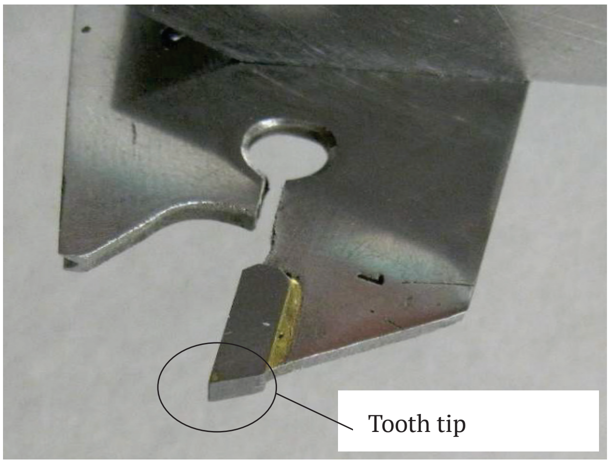

Figure 2. Inserted tooth of a circular saw

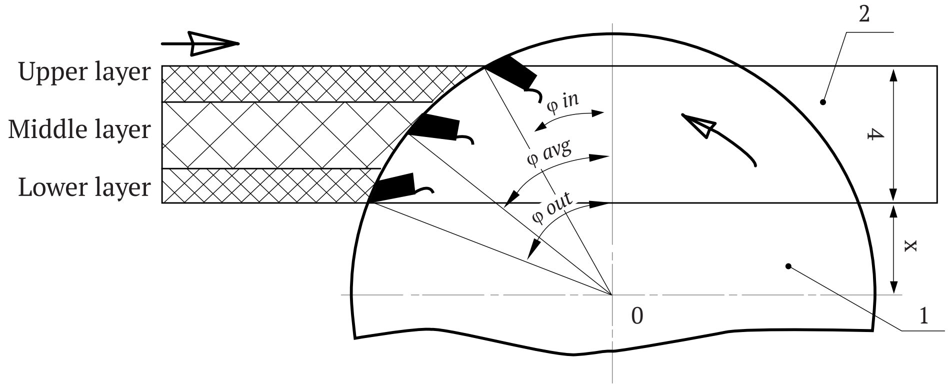

Figure 3. Particle board cutting scheme: 1 – saw; 2 – board

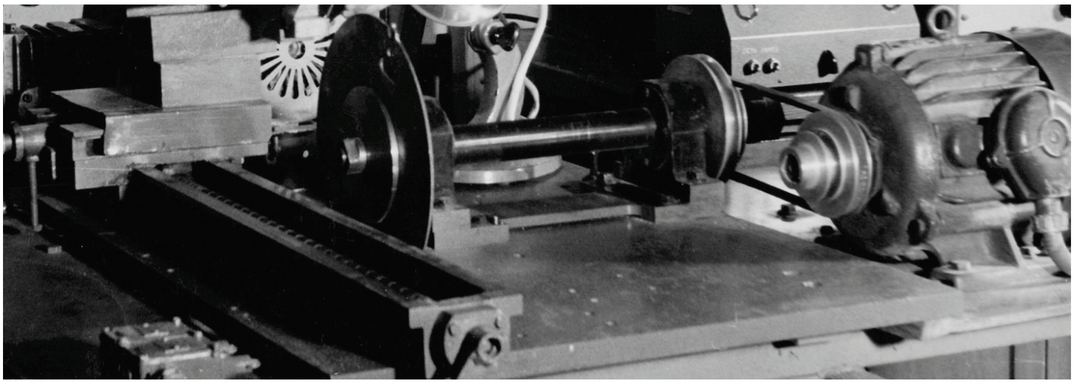

Figure 4. General view of the experimental setup

On a steel plate with a thickness of 25 mm, two bearing supports are mounted, in which the saw shaft rotates. On the one hand, the saw shaft is connected to an electric motor via a two-stage V-belt transmission. On the other hand, a saw blade is fixed between the flanges. The carriage with the fixed sample of the material under study is moved in rigid metal guides. The carriage is driven by an electric motor through a continuous variable transmission and a screw shaft. The particle board sample can move along three coordinate axes and is fixed in the desired position. The cutting disc has a wedge-shaped cutout into which a replacement tooth is inserted. The tooth is a metal plate of reverse wedge shape with a soldered hard alloy plate. The properties of the hard alloy and the geometry of the plate are dictated by the requirements of the experiment. The unit allows controlling and setting the cutting speed, feed rate, and working angle of incidence over a wide range of values. The high rigidity of the installation structure and the sturdy foundation on which it is installed eliminate any deformations and fulfil the conditions for reproducing experiments regardless of the time factor.

Experiments with a single-toothed saw avoid the influence of vibration from variable cutting forces, radial and tangential runout, out-of-roundness of the saw hole and the seat of the root flange, and non-flatness of the cutting disc.

The authors of this study conducted an experiment. Experiment conditions:

– saw tooth material: VK6M grade hard alloy;
– blade speed: 2960 min^{-1};
– cutting diameter: 396 mm;
– cutting path length in material: 4000 m;
– visualisation: large BMI-2 toolmaker microscope;
– angle of tooth point: 60°C.

The tooth under study, after operating to a given wear, was installed on the table of a large BMI-2 toolmaker microscope, the back of tooth was combined with the X-axis and photographed in this position with a magnification of $30\text{-}50^x$ (Fig. 5).

In the photo, the intersection point of the back and the front of tooth was aligned with the origin of coordinates, and tangent lines were drawn to the tooth contour in increments $\Delta\Phi$ =15. The intersection points of tangents with the abscissa axis were determined and the abscissa values at these points were measured (Fig. 6).

If the wear line is divided into several sections $\Delta\Phi$ within which a continuous arc is replaced with a tangent to it, then a polyline can be obtained that describes the original curve with a slight loss of accuracy (Fig. 6). Therewith, the estimation of straight-line parameters (angle, coordinates of the ends of segments) is greatly simplified. The proposed tangent method is simple and easy to implement in practice. Coordinates of construction points are calculated using analytical and descriptive geometry methods.

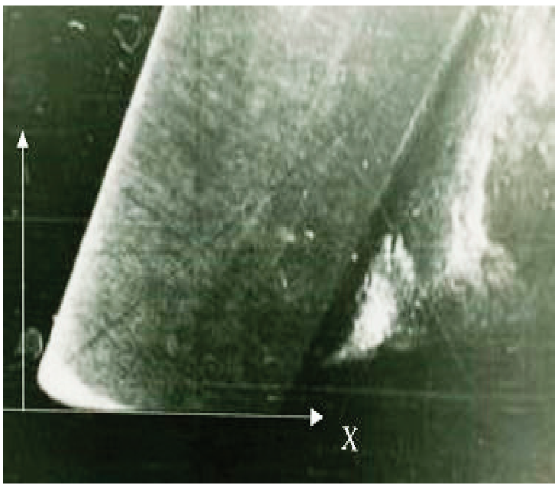

Figure 5. Micro-image of the tooth tip

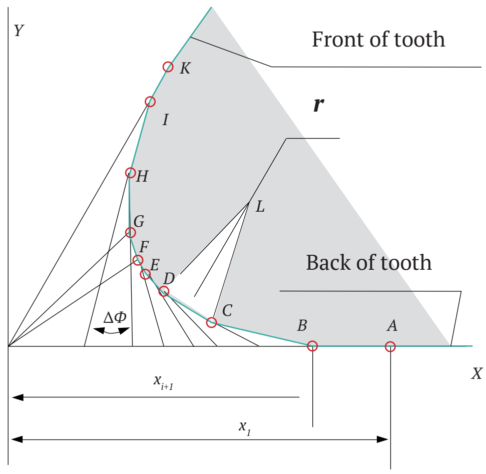

Figure 6. Form of tooth blunting curve

The profile of the cutting unit is obtained (e.g., using the optical method and image magnification), it is divided into separate segments using point marks. The smaller the distance between the points, the more the form arc tends to the straight line and the more accurately the real curvature of the tooth line can be described. The coordinates of the intersection point of adjacent tangents with angles Φ_i and Φ_{i-1} were calculated sequentially according to formulas:

$$X_i = X_{\phi i} - [(X_{\phi-1} - X_{\phi i}) \times Sin(\Phi_i - \Delta\Phi)/Sin\Delta\Phi] \times Cos\Phi_i; \quad (1)$$

$$Y = \left[(X_{\phi 1} - X_{\phi i}) \times \frac{Sin(\Phi_i - \Delta\Phi)}{Sin\Delta\Phi}\right] \times Sin\Phi_i. \quad (2)$$

The distance d_i was found between two consecutive points of intersecting tangents (e.g., DC), as presented in Figure 6:

$$d_i = [(X_i - X_i - 1)^2 + (Y_i - Y_i - 1)^2]^{-2}. \quad (3)$$

For each interval $\Delta\Phi$ (e.g., DC) the radius of curvature r was calculated according to equation 4:

$$r = d/(2 \times Tg(\Delta\Phi/2)). \quad (4)$$

Wear areas, or rather the area of the OABCDEFGHIKO shape, which is defined as the sum of the areas Si of the triangles ΔOGF (shown in the figure), ΔOFE, ΔOED and others are calculated using the formula:

$$S = \sum[0,5(-x_i + 1)(y_i - y_i + 1) + (y_i + 1)(x_i - x_i + 1)]. \quad (5)$$

Results and Discussion

An ideal tool edge is understood as a line of intersection (for a two-dimensional representation – a point) of the front and the back of tooth. It is impossible to obtain the face intersection as a line due to chipping of the tooth material near the face intersection. Therefore, the real tool edge is a curve of indeterminate direction located at some distance from the centre of coordinates. The real tool edge with a time in service constitutes a curved surface between the front and the back of tooth (for a two-dimensional representation – a curved line). Thus, from a geometric standpoint, blunting is the transformation of a point (conditionally) into a curve and the subsequent increase in the parameters of this curve.

The microphotograph of the tooth has markings, which adequately reflect the microgeometry of the worn-out tool edge. Figure 7 shows the contour of the form of tooth presented in Figure 6. Tangents illustrate the identity of the image in the photo presented in Figure 5 and the measuring diagram presented in Figure 8.

The given data of the measurement results refer to Figure 6 but without regard for the image scale. The measurement data is summarised in Table 1.

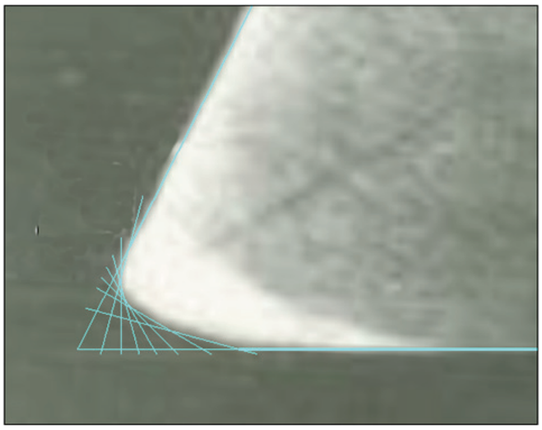

Figure 7. Tangents to the form of tooth

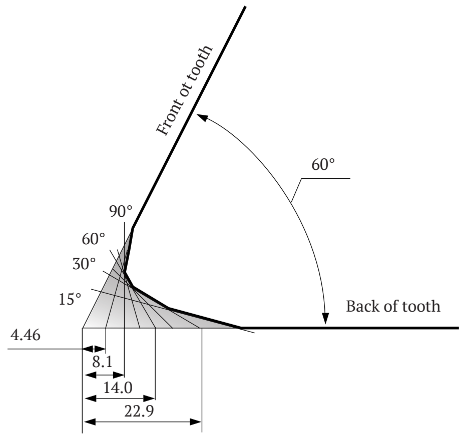

Figure 8. Measurement scheme

Table 1. Results of measurements and calculations of the blunting curve

Interval number	Angle of arrival	Coordinate, x	Distance, d	Curvature radius, r	Wear and tear area,S	
	degree	mm	mm	mm	mm²	%
1	15	29.5	12.77	48.84	48.70	34
2	30	22.9	8.02	30.67	45.90	33
3	45	17.5	1.60	6.12	9.95	7
4	60	14.0	1.14	4.36	6.91	5
5	75	11.0	1.78	6.81	9.49	7
6	90	8.1	2.25	8.61	9.07	6

Table 1, Continued

Interval number	Angle of arrival	Coordinate, x	Distance, d	Curvature radius, r	Wear and tear area,S	
	degree	mm	mm	mm	mm^2	%
7	105	4.5	5.20	19.89	11.20	8
	Mean		*4.68*	*17.90*	*20.17*	
	Max		*12.77*	*48.84*	*48.70*	
	Min		*1.14*	*4.36*	*6.91*	
	Sum				*141.22*	*100%*
Length of the form projection on the back of tooth, mm				*21.50*		
Length of the form projection on the front of tooth, mm				*9.25*		

The second column of Table 1 shows the values of the angles at which tangents to the form of tooth were drawn. Column X shows the coordinates of the intersection points of tangents with the X-axis. The bottom of Table 1 shows statistical indicators of average and extreme values.

Calculation results in Table 1 are illustrated by graphs in Figure 9. The distribution of tooth curvature along the contour, the area of the worn surface and the distance between the intersection points of tangents are given.

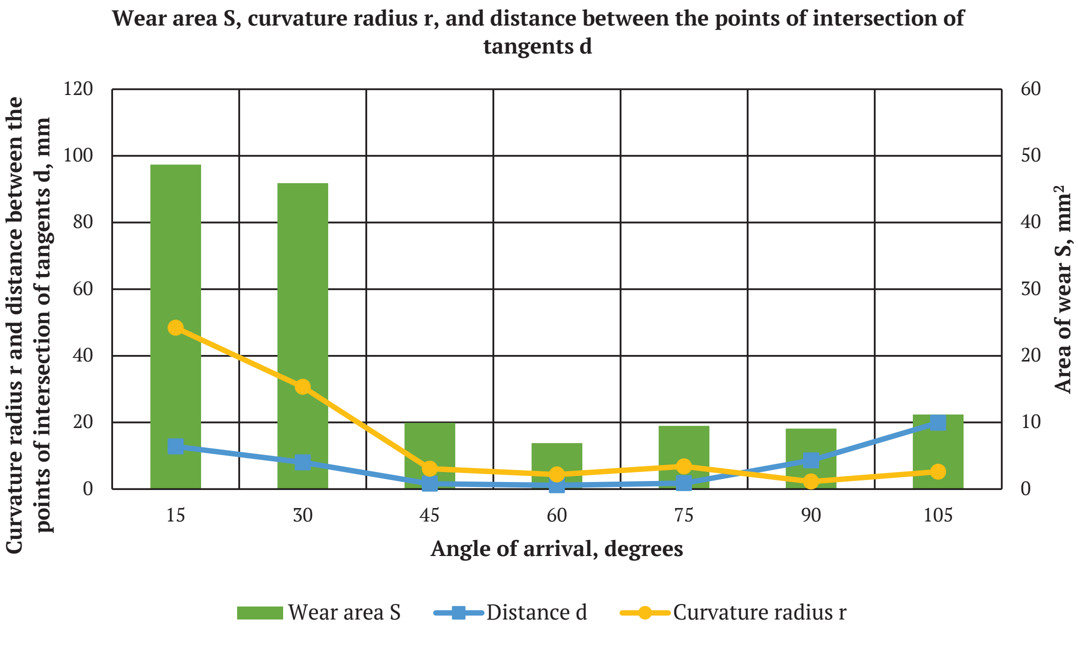

Figure 9. Distribution of saw tooth curvature

Clearly, the greatest curvature r_{min}=4.36 mm falls on the interval corresponding to the 60° angle of arrival. This is precisely the median interval No. 4. The curvature in the adjacent sections on the left and right is approximately the same (the radius of curvature is 1.5 times larger). The radius of curvature in Sections 6 and 7, i.e., adjacent to the front of tooth, slightly increases and reaches r_{min}=4.6. The radius of curvature in Sections No. 2 and No. 1, i.e., those adjacent to the back of tooth, increases significantly and reaches r_{min}=11.2. The radius of curvature adjacent to the back of tooth is 11.2 times the minimum radius and 2.5 times the radius of curvature in the area adjacent to the front of tooth.

The projection of the blunting form on the back of tooth (similar to the radius of curvature) is 2-3 times longer than on the front of tooth. This is inherent in saws that process laminated particle boards.

Table 1 shows the wear areas for each interval and the form as a whole. Clearly, as the radius of curvature (or distance d) increases, so does the wear area. The presence of interval wear values allows figuring out the intensity of wear of the tooth depending on the sawing conditions.

Knowing the distribution of the radius of curvature from the angle of inclination of the corresponding tangents, the reverse transformation can be performed, and the original form of tooth can be obtained. Figure 10 shows the form of tooth, which is constructed according to the data from Table 1.

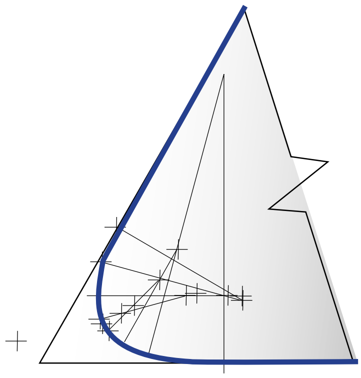

Figure 10. The form of tooth, constructed according to Table 1

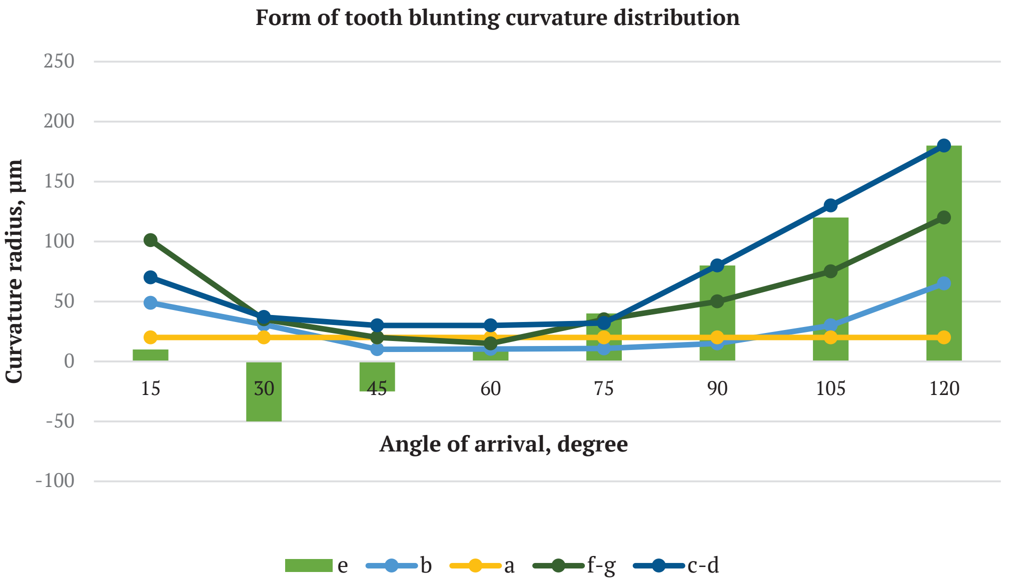

Figure 11. Form of tooth curvature

The form of tooth wear estimates for different cases of such wear are presented in Figure 11. The diagram suggests that the curvature of the form of tooth in the areas near the front and the back of tooth is always substantially less than the curvature in the central sections of the form.

For instance, if the curvature of the form of tooth is constant (circular arc), then it will be displayed on the graph as a straight line parallel to the abscissa axis (Fig. 11a). The sharper the tooth, the closer the line runs to the abscissa axis. The graph line of an absolutely sharp tooth completely coincides with the abscissa axis.

For the form of tooth in Figure 11e, which has worn out on the front of tooth in the form of a hole, the curvature in this area will have negative values, which is well observed in Figure 11e.

All graphs presented in Figure 11 suggest that the greatest sharpness of the form of tooth is always in the central parts of the form. Furthermore, they show exactly which part of the curvature reaches the highest value.

For instance, if the graph looks like a curve (Fig. 11f-g), which has one local minimum, then it is at this point that the tool edge is located. This is the point where the tangent to the form of tooth will be at an angle of approximately 50°. For the case presented in Figure 11a, the tool edge is the entire section of the form from 0°C to 120°C. If the graph looks like a curve (Fig. 11b), which has a weakly expressed extremum, then the tool edge is located in a region of approximately 40-60C°, and in the case of a curve (Fig. 11c-d) – within 30-75C°.

One of the possible methods for evaluating the form of tooth of a cutting unit is proposed, which is implemented as follows.

If in other studies [1; 4; 14] the tool edge wear curve had a circular shape, then in the authors' study the curve has a complex shape, which indicates a different nature of wear on both the front and the back of tooth.

Conclusions

Based on the conducted research, the following conclusions can be drawn:

1. Estimation of the tool edge sharpness by performing tangent and subsequent calculations is much more informative and objective than the method of selecting circles and allows finding both the local curvature and the indirect curvature of the entire form of tooth. In the future, using more modern toolmaker microscopes, the accuracy of further studies will considerably increase.

2. The proposed estimate allows finding sections of the form of tooth with minimal and maximum curvature.

3. During changes in sawing conditions (feed rate or

working angle of incidence), the estimation provides insight into the drift of the form of tooth sections with minimum and maximum sharpness or minimum and maximum wear. This means that by evaluating the parameters of the form of tooth after changing the sawing parameters, the process can be controlled, and the best (from a certain perspective) results can be achieved.

4. The tangent method allows not only to find the curvature of a particular section of the form of tooth (i.e., its microgeometry), but also to figure out the area (i.e., wear) of this section.

5. The tangent method allows moving away from the qualitative "more-less" characteristics of wear towards precise quantitative estimates expressed either in units of area or units of mass. This allows comparing the tool materials from which the teeth are made in cases where microgeometry is approximately the same, but the wear is different.

6. The tangent method is available for extensive application and does not require special equipment.

7. This method can be called numerical with confidence, since the result of applying the tangent method is a matrix of size 2×n (where n is the number of intervals or tangents). This is convenient for data transfer since there is no need to create graphic images.

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Оцінка мікрогеометрії зуба дискової пили

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Анотація. В статті вирішується проблема оцінки мікрогеометрії зуба дискової пилки. Для досліджень в якості різального інструменту використовували дискову пилу з одним вставним зубом, що оснащений пластинкою твердого сплаву марки ВК6М. Метою дослідження є спроба оцінити криву реального зношення леза дереворізального інструменту. Процес різання здійснювали на експериментальній установці, що представляє собою приводний вал із закріпленою на ньому пилою з можливістю регулювання швидкостей різання та подачі. Вершину зуба пили фотографували після деякого зношення в площині, перпендикулярній короткій різальній крайці із збільшенням 30-50х. Вимірювання контуру зуба проводили за допомогою великого інструментального мікроскопу БМІ-2. В результаті досліджень розроблено метод оцінки гостроти леза за допомогою дотичних та наступних розрахунків, які дозволять визначити як локальну кривизну, так і середню кривизну всього профілю. Цей метод дозволяє виявити ділянки профілю з мінімальною та максимальною кривизною а також визначити кривизну конкретної ділянки профілю та площу (зношення) цієї ділянки. Запропоноване рішення надасть можливість здійснити перехід від якісних характеристик зношення до точних кількісних оцінок, які виражені або в одиницях площі або одиницях маси, що дозволить порівнювати інструментальні матеріали, із яких зроблені зуби, між собою у випадках, коли мікрогеометрія приблизно однакова, а зношення різне. Практична значущість роботи полягає в можливості оцінки стану параметрів різального елемента та дозволяє прогнозувати його зміни в процесі експлуатації (ступеня зношення, періодичності перезагострювання, визначення максимального ресурсу інструмента)

Ключові слова: лезо, дереворізальний інструмент, зношення, затуплення

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Pyrological Characteristics of Forest Edges under Intensive Recreational Loads

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Abstract. The increase in fires in urban landscapes causes adverse and sometimes irreversible changes in forest ecosystems. The modern solution is to find the places of primary fires and the most dangerous areas. The purpose of this study was to find dependences between the forest typological features of forest stands and their fire danger. To fulfil this purpose, a systematic analysis of forest fire danger and phytoindication were performed. The composition of the flora of edge biotopes was figured out using the route geobotanical method. The article analyses forest fires that occurred in urban forests of Kyiv during 2014-2021. Primary ignition locations have been identified. It was proved that fires often occurred on the forest edges, as well as along highways and railways. Among the standard indicators of fire danger (number and area of forest fires), the method makes provision for establishing the fire frequencies in the same forest area. This indicator allows figuring out the most dangerous areas from the pyrogenic standpoint. It was found that the simple edge is characterised by a minimal taxonomic composition in the ground vegetation and its projective cover of up to 20%. The grass tier stabilises the environment and mitigates the effects of extreme natural phenomena. The vegetation cover of an elementary and multicomponent edge is one of the barriers that can stop surface fires. Taxonomic diversity, especially of deciduous species, determines the pyrological features of forest edges. Analysis of the flora of marginal biotopes showed that oligotrophs, xerophytes, and xeromesophytes predominate among the species of simple edges. The share of ruderal elements in the ground vegetation was 36%, which indicates a significant anthropogenic impact and synanthropisation of the flora of the edges. These processes adversely impact the conservation of typical species but have a fire-retaining effect. Analysis of forest fires dynamics under intensive recreational loads allows substantiating the vectors for fire safety improvement, choosing a strategy for ensuring fire safety, and increasing the economic and social efficiency of fire prevention measures. It is proved that the forest edge is one of the decisive factors in the fire behaviour arising from a nonwooded area. The formation of multicomponent edges will help minimise the risks of fires

Keywords: fire safety, forest edge biotopes, ground vegetation, biodiversity, conditions of intensive recreational loads on forest stands

Introduction

Extreme weather events that humanity has observed over the past 30 years pose a threat to the world's forests due to the increased probability of forest fires. Every year, up to 400 thousand cases of fires are recorded in the forests of our planet, which damage about 0.5% of the total area of forest areas [1]. An analysis of the world's forests affected by fires has shown that about 67 million hectares of forest are burned annually in the world [2]. It is expected that in the future, climate change will lead to longer fire seasons, more intensive fires around the globe, including areas where fires were previously absent [3; 4]. It is possible to prevent the occurrence of fires or localise them on a small area, provided the understanding of the causes of the fire and the ecology of the fire sites.

In Ukraine, most fires occur for social reasons [5]. In recreational forests, the anthropogenic factor of promoting the spread of fire occurs in almost 100% of cases. Preventing the occurrence and spread of forest fires is one of the most urgent and important tasks of forestry in Ukraine. Anthropogenic forest landscapes are of particular importance, given the probability of fires. Most often, forest fires are recorded near settlements, roads, and recreation

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areas. On the territory of the forest fund of Ukraine, the risk of forest fires directly depends on the recreational load on forest stands, and with an increase in the recreational development of forest areas, the number of forest fires increases. Careless handling of fire under favourable natural and weather conditions causes most fires. Urbanised landscapes are exposed to anthropogenic impact, which is often accompanied by fires of varying intensity. Forest flammability analysis allows setting up fire highs and lows. Prevention of forest fires under intensive anthropogenic stress should also include research on the ecological structures of forest stands. A separate task of the forest sector is to create fire-resistant landscapes that include natural barriers that can limit the spread of fire in the forest.

In the complex of fire prevention, restrictive measures occupy a prominent place and allow creating a system of barrier strips that prevent the rapid spread of fires, as well as simplifying their extinguishing. Fire curtains are arranged using the fire-resistant properties of deciduous tree species. Forest edges can serve as a natural barrier that can protect forest landscapes from fires and stop their spread deep into the forest. In this case, the forest edges perform regulatory functions, which lie in changing the behaviour of fires. Forest edges of the desired structure and composition can be formed artificially. At the edge of the forest, the density and biomass of individual species is higher compared to the neighbouring forest and open space. According to their morphology, the edges of the forest can be of three types [6]: simple, elementary, and multicomponent. In the simple edge of the forest, trees differ slightly in height, diameter, and crown size from those that grow deep in the forest. The simple edge is unstable to the negative influence of external factors. An elementary edge of the forest has a distance to the depth of the forest less than the average height of the trees. The elementary edge of the forest does not differ in species diversity. The multi-component forest edge has a depth of 1.5 or more heights of the tree stand. The composition of trees and bushes forming it can be more than 6-10 species.

The multidimensional nature of the fire regime includes fire frequency, interval, seasonality, intensity, spatial aspects (size, configuration), and the study of the relationship between fire danger and biodiversity [7]. In the context of forest fires, the importance of restoring biodiversity from fires also remains relevant.

In terms of their pyrogenic properties and influence on the spread of fires, forest edges were investigated by the authors of [8] using remote sensing methods. Considerable attention is paid to the investigation of the impact of fires on forest fragmentation and changes in the tax characteristics of trees [9]. Scientists pay special attention to studying the structure of forest stands covered by fires [10]. Mensuration of stands revealed that the edges can have a unique composition, structural features, and accumulate dry wood [11].

It is proved that in most cases fires were caused by critical weather conditions [3; 5; 12]. Fires often occurred regardless of the excessive cost of extinguishing forest fires and the level of preparedness in the countries where they occurred. Therefore, some scientific publications specifically investigate the influence of temperature and other conditions on the occurrence and spread of forest fires. The area of fires depends on weather conditions – wind strength, stocking, spacing of trees by area, humidity of combustible materials [12].

Pyrological characteristics and specific features of forest edges associated with recreational load have not been previously studied. In addition, the scientific literature holds no information on the relationship between the type of forest edge and the probability of fires. The originality of the results obtained lies in the justification of the pyrological properties of the forest edges that have undergone changes from recreational loads. This study is the first to compare the pyrological characteristics of forest edges of different forest types.

The purpose of this study was to find dependencies between the forest typological features of forest stands and their fire danger. Forest combustible materials are an essential factor in the spread of fires. The sanitary condition of forest stands also serves as one of the pyrological characteristics of forest stands. The results of pest activity and the impact of forest diseases contribute to the accumulation of forest combustible materials on the edges. To fulfil this purpose, the qualitative and quantitative indicators of the components of edge biotopes that determine their pyrogenic features were analysed and generalised. The research objectives included statistical analysis of the number of cases and areas of fires, distribution of fires depending on the types of forest edges, phytoindication and assessment of the systematic structure of the flora of anthropogenically modified edges.

Materials and Methods

The study was conducted in the urban forests of Kyiv based on Darnytsia Communal Forest-Park Enterprise, Sviatoshino Communal Forest-Park Enterprise and Koncha Zaspa Communal Forest-Park Enterprise. According to physical and geographical zoning, the territory of enterprises belongs to Kyiv Polissia. The initial data for system analysis were obtained from the "Forest fire accounting books" of forest park enterprises in Kyiv [13-15]. The research period was eight years (2014-2021). In each of the forest park enterprises, more than 10 plots were surveyed by the route method, and a forest description was carried out. Biometric indicators, species composition, and sanitary condition of the tree stand were investigated using well-known methods in forestry [16].

Forest types were figured out according to Professor B. Ostapenko's method [16]. The grass tier and its biomorphological structure are presented using the reconnaissance method of geobotanical studies [17]. The composition of the flora of marginal biotopes was performed using the route geobotanic method, with identification of species and estimation of the projective cover of ground vegetation on the Braun-Blanquet scale [17]. Ukrainian names are given according to Yu. Kobiv [18], and Latin names are given according to S.L. Mosyakin, M.M. Fedoronchuk [19; 20]. Established trophomorphs: oligotroph (OgTr); mesotroph (MsTr); megatroph (MTr). Hygromorphs were also diagnosed: hygrophiton (Hg); mesophiton (Ms); xerophiton (X). To find the degree of anthropogenic transformation, a five-point scale of stages of recreational digression was used [7].

The study included materials from the latest state forest accounting in the specified region. Statistical data was processed using the Microsoft Excel computer program.

Results and Discussion

On the territory of urban forests in Kyiv during the fire-hazardous period, forest fires occur with different frequency [21]. According to official statistics, during the audit period, over 8 thousand cases of forest fires were registered in pine forest stands with a total area of more than 1.5 thousand hectares. The average area of the plot covered by the forest fire was 0.86 hectares. Within the fire hazard period, the fire maximum (according to the number of fires) was observed in June, and the fire minimum – in October. The time of detection of fires was mostly between 1200 and 1600. All the fires found were surface fires. The area under study is characterised by a relatively high average class of natural fire danger – II,27 [13-15]. The probability of a forest fire is quite high. The analysis of annual preventive and restrictive measures confirms the elevated level of readiness of enterprises for the fire-hazardous season. Therewith, areas where the probability of fires is elevated require added research.

Places of primary ignition were as follows: edges, unfurnished recreation areas, territories along highways and railways, agricultural land, as well as, directly, forest areas. The span diagram (Fig. 1.) presents the quantitative characteristics of fires for the period under study.

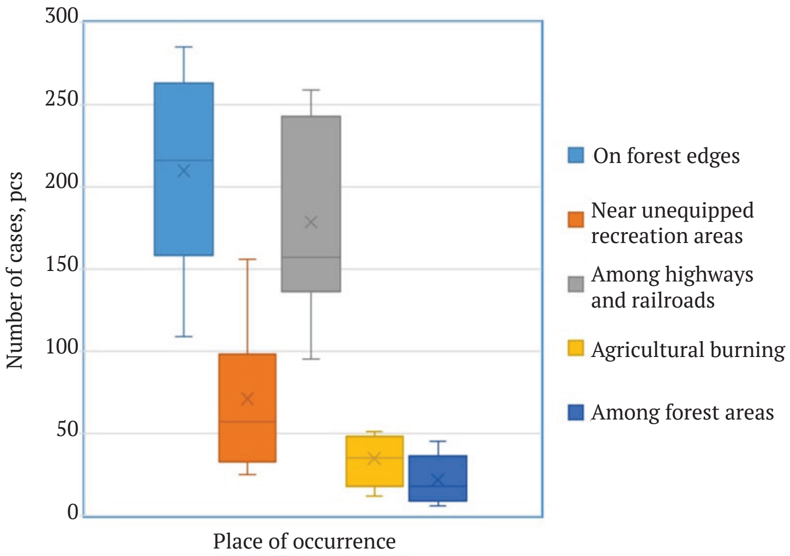

Figure 1. Statistical data on the number of cases of forest fires

The distribution of the number of fire cases is uneven and focuses mainly on the forest edges (34%) and along highways and railways (26%), the lowest number of cases was recorded among forest areas (7%). Fires near recreation areas were found only in places that were not properly equipped. Studies have also proved [12] that due to the considerable number of visitors to forests during the fire-hazardous period, conditions of elevated risk of fire are created on dry days. It is during such periods that sources of controlled fire often turn into fires. Due to the small areas of agricultural lands near the urban forests of Kyiv, the number of fires that have moved from these lands is relatively lower.

The average number of cases of forest fires can be figured out from the median. The highest median was recorded at the edges. The scale of the number of detected fires also falls on the territory of the forest edges (from 109 to 285 cases).

Depending on the type, the edge of the forest may be the place where forest fires occur, or the place where they stop. Figuring out the features and pyrological characteristics of firebreak edges will help combat fires by limiting their spread. The main indicators for assessing forest fires are their number, area, and average repeatability in the same location (Table 1).

Table 1. Distribution of fires depending on the type of forest edge

Edge type	Share of forest fires by number, %	Share of forest fires by area, %	Average repeatability, times
Simple	76	89	6
Elementary	21	8	2
Multicomponent	3	3	–

Source: developed by the authors

As Table 1 shows, most often forest fires occur in simple edges (76% of the total number), where they occupy the largest area (89% of the area of all fires on the forest edges). The average frequency of fires is also highest in the simple edge of the forest. Thus, from a pyrogenic standpoint, the most dangerous is a simple edge.

Due to the considerable proportion of forest fires on the edges, it is important to form multicomponent edges, by planting deciduous tree species and cutting down to improve the quality composition of forests. Such edges should become a barrier to the spread of fire, curbing the spread of fire from the forest to the locality and vice versa.

The realisation that forest fires are an integral part of many ecosystems encourages the study of fire-resistant forest areas compared to more sustainable ones [22]. The floral composition of edge biotopes is usually typical and has a set of common species. This is especially true for the living ground cover, which includes ruderal and synanthropic species. Plants of living ground cover perform many functions in the landscape, including the formation of primary biomass, regulation of land runoff, and the formation of a local microclimate. Thus, land cover stabilises the environment and mitigates the effects of extreme natural phenomena. Currently, land cover is one of the barriers that can stop forest fires. The floral structure is an indicator not only of taxonomic richness, but also of pyrological characteristics of the edges (Table 2).

Table 2. Floral structure of ground vegetation in diverse types of forest edges

Edge type	General projective cover moss tier shrub tier, %	Most common plant species	Taxonomic diversity, species
Simple	0-5 15	*Pinus sylvestris* L. *Centaurea Marschalliana* Spreng. *Chamaecytisus singeri* (Nenuk.) Klaskova *Euphorbia seguierana* Neck. *Festuca ovina* L. *Helichrysum arenarium* (L.) Moench *Keleria glauca* (Spreng.) DC. *Veronica incana* L. *Dicranum polysetum* Sw. *Cladonia mitis* Sandst.	up to 15
Elementary	0-5 35–110	*Pleurozium Schreberi* (Brid.) Mitt. *Urtica dioica* L. *Viola arvensis* Murr. *Veronica chamaedrys* L. *Stellaria graminea* L. *Sedum telephium* L. *Hieracium pilosella* L. *Impatiens parviflora* DC. *Geranium robertianum* L. *Festuca ovina* L. *Dactylis glomerata* L. Carex *ericetorum* Poll. *Berberis vulgaris* L. *Betula pendula* Roth. *Acer tataricum* L. *Crataegus monogyna* Jacq. *Pinus sylvestris* L. *Pyrus communis* L.	up to 37
Multicomponent	0 15–70	*Populus tremula* L. *Quercus robur* L. *Quercus borealis* Michx. *Prunus spinosa* L *Sambucus racemosa* L. *Spiraea media* Franz Schmidt. *Sorbus aucuparia* L. *Achillea submillefolium* Klok. et Krytzka *Festuca pratensis* Huds. *Geum urbanum* L. *Impatiens parviflora* DC. *Poa trivialis* L. *Rubus caesius* L. *Sedum telephium* L. *Stellaria media* (L.) Vill. *Polygonatum odoratum* (Mill.) Druce.	up to 58

Source: developed by the authors

The simple edge is characterised by a minimal taxonomic composition, especially in the ground vegetation, as well as a low projective cover of the grass tier. Lichens and mosses are most often burned by surface fire [8], and the grass layer of the ground vegetation is more resistant to fire. In the areas of the forest edges where the highest species richness of fires was recorded, there were no fires, while the territories covered by surface fires have almost equally low rates of the number of species [9]. We confirmed the study of the above-mentioned works and found that the taxonomic richness of forest edge biotopes and projective cover define the probability of forest fires and contribute to its localisation.

Species of ground vegetation on the forest edges that were covered by surface fires were studied. Analysis of the flora of edge biotopes in relation to nutrition showed (Fig. 2) that oligotrophs (69.4%) and mesotrophs (25.3%) predominate among the species, megatrophs are represented by the smallest number (5.3%). Among hygromorphs in the flora of marginal biotopes (Fig. 3), xerophitons (37%), xeromesophitons (26%), and mesophitons (12%) predominate, the lowest number is represented by mesohygrophitons (3%) and hygrophitons (1%).

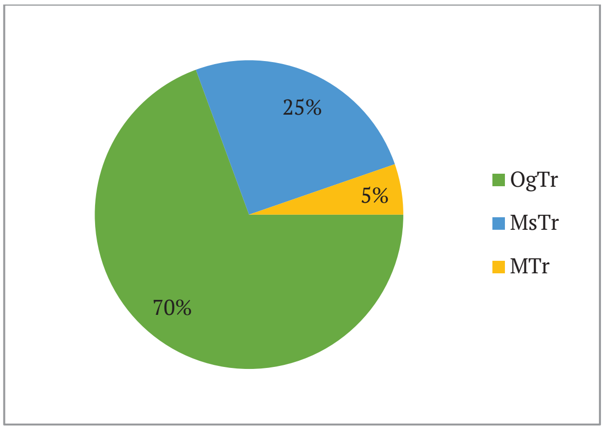

Figure 2. Trophomorph species spectrum

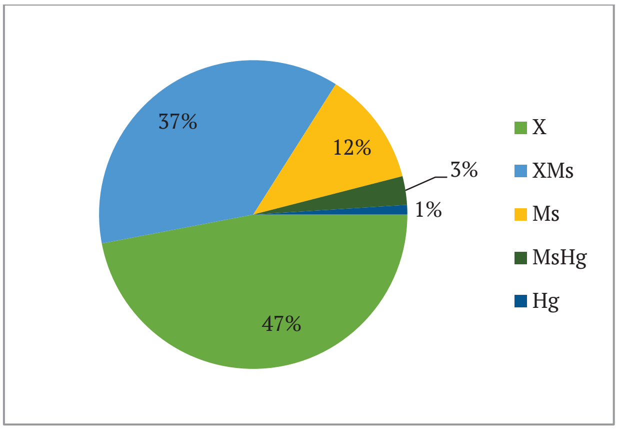

Figure 3. Hygromorph species spectrum

The consequences of anthropogenic impact on the herbaceous vegetation lead to changes in the ecotope, cause transformation of the grass tier with changes in the systematic structure, invasion of meadow species, synanthropisation, and also inhibit the natural renewal and development of trees [17; 23]. A study of edge species of ground vegetation showed that the share of ruderal elements is 36%. This indicates a powerful anthropogenic impact on the research area and diagnoses an elevated level of synanthropisation of the forest edge flora. These processes set back the conservation of typical species but have a fire-retaining effect. Some authors explain the increased fire vulnerability of individual areas by fragmentation of the forest cover, which creates favourable conditions for the spread of fire [10]. In cases where the intensive recreational load leads to a decrease in species diversity, and, accordingly, to fragmentation and increased insolation of the site, it is possible to claim an increase in the fire hazard of the territory.

An important pyrological feature of forest edges is the sanitary condition. Phytophage insects and pathogens adversely affect the sanitary condition of the forest and contribute to the accumulation of forest combustible materials on the forest edges. The most common pathological factors of weakening forest edges in the urban forests of Kyiv are white mistletoe *Viscum album* L., *Phellinus pini* (Thore et Er.) Pil., *and Fomitopsis annosa* (Fr.) Karst. The following pathogens were found in the examined tree stands: *Piptoporus betulinus* (Bull. ex Fr.) Karst., *Phellinus tremulae* (Bond.) Bond. et Boriss., *Inonotus dryophilus* (Berk.) Murr., *Ganoderma applanatum* (Pers. ex Wallr.) Pat., *Pseudomonas quercina* Schem., *Nectria galligena* Bres., *Sphaeropsis malorum* Peck., *Cronartium flaccidum* (Alb. et Schw.) Wint., *Lophodermium pinastri* Chev. Among the harmful insects that often focus on the edges, the most common include *Acrocercops brongniardella* F., *Hyponomeuta rorella* Hb., *Aradus cinnamomeus* Panz., *Argyrestia glabratella* Z. *and Operophthera brumata* L.

The results of the study highlight the pyrological features of edge biotopes and are important in detecting direct links between the features of the floral structure and the frequency of forest fires.

Conclusions

During 2014-2021, a third of fires in urban forests were recorded on the edges (34%) and along highways and railways (26%). Fires near recreation areas were found only in territories that were not properly equipped.

The pyrological features of forest edges in recreational forests directly depend on the type of forest edge and the sanitary condition of the forest stand. An increase in ruderal species positively affects the fire resistance of forest stands. The taxonomic richness of edge biotopes is directly proportional to the probability of forest fires and contributes to its localisation.

Analysis of forest fires dynamics under intensive recreational loads allows substantiating the vectors for the improvement of forest protection systems in Ukraine, choosing a strategy for ensuring fire safety, and increasing the economic and social efficiency of fire prevention measures. The analysis suggests that the edge of the forest is one of the decisive factors in the behaviour of forest fires. The formation of multicomponent forest edges can be one of the strategic directions of forestry development to ensure fire safety, which is aimed at minimising the risks of fires.

Further studies of the pyrological features of the edges allow establishing the optimal composition and structure of the stand in terms of preventing the occurrence and development of forest fires. Identifying the components of stands that affect their pyrogenic features will be of practical importance in the formation of fire-resistant urbanised landscapes.

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Пірологічна характеристика лісових узлісь за умов інтенсивних рекреаційних навантажень

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Анотація. Збільшення пожеж в урболандшафтах спричиняють негативні та інколи незворотні зміни в лісових екосистемах. Сучасне вирішення проблеми, в першу чергу, полягає у виявленні місць первинних займань та найбільш небезпечних ділянок. Мета досліджень передбачала виявлення залежностей між лісотипологічними характеристиками деревостанів узлісь та їхньою горимістю. Для досягнення поставленої мети здійснено системний аналіз горимості лісів та фітоіндикацію. Склад флори узлісних біотопів проводився за допомогою маршрутного геоботанічного методу. У статті проаналізовано лісові пожежі, які виникали в міських лісах Києва упродовж 2014-2021 рр. Визначені місця первинного займання. Доведено, що пожежі часто виникали на узліссях, а також вздовж авто та залізничних доріг. Серед стандартних показників горимості (кількість та площа лісових пожеж) методикою передбачено встановлення повторюваності пожеж в одній і тій самій лісовій ділянці. Даний показник дозволяє виявити найбільш небезпечні з пірогенної точки зору площі. Встановлено, що несправжнє узлісся характеризується мінімальним таксономічним складом у живому надґрунтовому покриві та його проективним покриттям до 20 %. Трав’яний ярус стабілізує стан навколишнього середовища та пом’якшує наслідки екстремальних природних явищ. Рослинний покрив елементарного та багатокомпонентного узлісь є одним із бар’єрів, який здатний зупинити низові пожежі. Таксономічне багатство, особливо листяних видів, визначає пірологічні особливості лісових узлісь. Аналіз флори узлісних біотопів показав, що серед видів несправжніх узлісь переважають оліготрофи, ксерофіти та ксеромезофіти. Частка рудеральних елементів в живому надґрунтовому покриві становили 36 %, що свідчить про значний антропогенний вплив та синантропізацію флори узлісь. Зазначені процеси несуть негативний вплив на збереження типових видів, але мають пожежостримуючий ефект. Аналіз динаміки виникнення лісових пожеж за умов інтенсивних рекреаційних навантажень дає змогу обґрунтувати напрями покращення пожежної безпеки, обрати стратегію забезпечення пожежної безпеки, підвищити економічну і соціальну ефективність протипожежних заходів. Доведено, що узлісся є одним з вирішальних факторів поведінки лісових пожеж, що виникають з безлісної території. Формування багатокомпонентних узлісь сприятиме мінімізації ризиків виникнення пожеж

Ключові слова: пожежна безпека, узлісні біотопи, живий надґрунтовий покрив, біорізноманіття, умови інтенсивних рекреаційних навантажень

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Structure of Sequestered Carbon in the Biomass of Forest Stands in the Garden Art Park-Monument of National Significance "Feofania"

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Abstract. The state of forest ecosystems and processes of carbon sequestration have both global and local significance upon investigating the influence of natural and anthropogenic factors on biogeochemical cycles. The study of the consequences of their impact on forest stands is initiated by international and state environmental programs aimed at solving the problems of climate change. Sequestration of carbon in the biomass of forest stands depends on the productivity of stands, the formation of tree mortality and the conduct of economic activities. The purpose of the study was to establish the regularities of changes in the reservoir of sequestered carbon in the biomass components of the stands in the garden art park-monument "Feofania". The processes of transformation of forest ecosystems were investigated on permanent experimental plots of the "Feofania" Park territory using the methods of forest inventory. The observations results confirmed the general increase in the reservoir of sequestered carbon in the biomass of tree stands and the multi-vector dynamics of the sequestered carbon structure in the live biomassand mortmass of tree stands. Evidence of decrease in the carbon-sequestering potential of stands under intense mortality and lesser increase in the live biomass of stands was obtained. From an ecological standpoint, a positive trend towards an increase in the share of coarse woody debris (mortmass) in the biomass structure of permanent plots was established. The main carbon structure of biomass, according to the species composition, is represented by common oak, common hornbeam, and Norway maple. Nature protection decisions and measures implemented in the territories of the natural reserve fund should increase the intensity of carbon sequestration in biomass and the resistance of forest ecosystems to the influence of environmental factors. Given the priority of carbon sequestration in the biomass of tree stands as an ecological function, it is necessary to practice measures to promote current increment in carbon sequestered in the biomass and increase the resistance of trees to natural and anthropogenic disturbance

Keywords: live biomass, mortmass, woody debris, mortality, snagss, logs

Introduction

Over the past three decades, the world community has been actively looking for ways to reduce the risk of rapid climate change on the planet and is joining efforts to reduce anthropogenic impact on the environment. One of the main tasks for scientists and governments of all countries worldwide at the turn of the second and third millennia was to counteract the acceleration of climate warming. This initiative was clearly formulated within the framework of global events and conferences, starting with the United Nations Conference on Environment and Development in Rio de Janeiro and the adoption of the United Nations Framework Convention on Climate Change [1]. The adoption and ratification of the Kyoto Protocol [2] and the Paris Agreement [3] had a key role on the way to solving climate change problems, which declare the importance of preserving and strengthening absorbers and accumulators of greenhouse gases. In 2016, Ukraine signed and ratified Paris Agreement, which recommends actions to support strategic approaches and positive incentives to reduce emissions from deforestation and forest degradation, develop sustainable forest management and increase carbon sequestration in forests [4]. United nations framework convention on climate change United nations framework convention on climate change.

The purpose of this study is to figure out the specific features of the dynamics and structure of the sequestered carbon in the components of the biomass of the tree stands in "Feofania", a garden art park-monument of national

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significance. The originality of this study lies in the comprehensive investigation of the formation of the reservoir of sequestered carbon in forests with conservation status within urban ecosystems, as opposed to the investigation of this issue in stands of other forest categories, namely commercial ones.

Forest ecosystems are one of the key absorbers of carbon dioxide and carbon accumulators. Therewith, studies [5] on the impact of disturbances on the carbon cycle in the forest ecosystems of Ukrainian Polissia indicate a volatile balance of carbon absorption and emission, which substantially depends on the heterotrophic respiration of soils and the loss of biomass of stands as a result of biotic, abiotic, and anthropogenic disturbances. The occurrence of disturbances in forest ecosystems has substantially increased over the past decades, and the adverse impact of large-scale disturbances is becoming increasingly significant for the achievement of forestry goals. Thus, to fulfil the role of a carbon accumulator, forest ecosystems need sustainable management, which over time will make it impossible to exceed the emission of carbon compared to its sequestration.

If it is practically impossible to influence the heterotrophic respiration of forest soils (except for some solutions, such as minimising erosion and soil damage caused by economic activities), then increasing biomass growth and the resistance of stands to agents of large-scale disturbances are the main tasks of conventional forestry.

Compared to commercial forests, conservation stands in Ukraine are minimally affected by economic activities, namely felling, formation, and sanitation. That is why the investigation of the growth and development of stands and the formation of mortality, specifically in urban forests [6], allows estimating the role of stands as carbon reservoirs [7; 8].

The conclusion and ratification of Kyoto Protocol [2] and Paris Agreement [3] led to the rapid development of research on forests as the main absorbers of carbon dioxide, capable of naturally reducing its concentration in the atmosphere [9-11]. Studies of organic carbon stocks in forest live biomass are characterised by a variety of methodological approaches and experimental plots [12-14].

Studies of the regularities of the carbon cycle of forest ecosystems [15; 16] are currently becoming even more relevant to achieve the goals of low-carbon development [17]. The study of patterns of carbon sequestration in the components of forest ecosystems reflects the accumulative potential of forest biomass [18-20] in conditions of anthropogenic transformation of the environment [21]. Based on the scale of production and, especially, the duration of carbon sequestration in woody plants, forests are recognised as a relatively stable system for preventing the greenhouse effect [22-24].

At the same time, according to the "Global assessment of forest resources 2020" report, global processes related to the condition of forest ecosystems indicate a decrease in forest cover globally [25]. The rate of forest mortality has slowed over the past two decades, with the rate of net forest mortality dropping from 7.8 million ha per year in 1990-2000 to 5.2 million ha in 2000-2010 and 4.7 million ha per year in 2010-2020 [4]. The greatest rates of decline in net mortality of forest stands were observed during the last decade. The total stock of wood in the world decreased slightly from 560 billion m^3 in 1990 to 557 billion m^3 in 2020, while carbon stocks in forests decreased from 668 Pg in 1990 to 662 Pg in 2020 [4].

Forest ecosystems in conditions of anthropogenic impact, performing conservation functions and improving the quality of the natural environment, are affected by external and internal factors, because of which they may partially or completely lose their useful properties [26]. One of the important ecological functions of forest stands is carbon sequestration. The dynamics of tree stock is closely related to changes in carbon sequestration and the production of other ecosystem services. Forest stands affected by anthropogenic factors may lose these basic functions.

The main share of absorbed carbon accumulates in the live biomass components of forest stands. However, the accumulation of mortmass of forests also plays a significant role in long-term carbon sequestration. Earlier analytical studies [27] proved that the carbon reservoir of the forest biomass of the garden art park-monument "Feofania" can comprise 92-93% of the live biomass carbon and 7-8% of the mortmass carbon. The total amount of sequestered carbon in the biomass of the forest ecosystems of the "Feofania" park as of 2013 was about 11 GgS, and the carbon density decreased from 15.1 $kgS{\cdot}m^{-2}$ in 1979 to 10.7 $kgS{\cdot}m^{-2}$ in 2013. It is the decrease in the density of accumulated carbon in the biomass of the stands in the "Feofania" park that raises an important question about the productivity of carbon sequestration by urban forest stands under conditions of minimal economic intervention.

Materials and Methods

The study was performed on four permanent experimental plots (EP), which in 2016-2017 were laid out on the territory of the garden art park-monument of national significance "Feofania" (the "Feofania" Park) and considered in the international database data of the Forest Observation System (FOS). The total area of the object under study is 107 hectares, which is in the southern part of Kyiv [28].

During the field work, four permanent experimental plots (EP No. 1-4) were set up considering the age-class composition of forest stands. EP No. 1 and 4 are ~80 years old, while EP No. 2 and 3 are 180 years old (Table 1). According to the general geomorphological and bioclimatic characteristics, the park belongs to the Forest-Steppe zone of Ukraine. The territory of the "Feofania" Park is located at an altitude of 75-189 m above sea level. The landform is represented by a valley-ravine relief with steep slopes. The climate of the area under study is humid continental, the average monthly temperature ranges from -5.6°C (January) to 19.3°C (July), the average annual temperature is 7.7°C. Average monthly precipitation ranges from 35 mm (October) to 88 mm (July), while the average total annual precipitation is 650 mm [29].

The species composition of the object under study is represented by common hornbeam (*Carpinus betulus* L.), Norway maple (*Acer platanoides* L.), common oak (*Quercus robur* L.), small-leaved linden (*Tilia cordata* Mill.), European white elm (*Ulmus laevis* Pall.), black locust (*Robinia pseudoacacia* L.), common ash (*Fraxinus excelsior* L.).

As a result, it was found that in terms of species composition (by the number of trees) in the research stands of the "Feofania" Park on permanent trial plots, common hornbeam (EP No. 2 and 3) and Norway maple (EP No. 1 and 4) prevail. The number of trees of common oak, small-leaved linden, European white elm, black locust, and common ash in the experimental plots is lesser. According to the dynamics of the formation of snagss during 2016-2021, the predominant amount falls on dead common oak and common hornbeam trees, and according to permanent trial areas it was: EP No. 1 – 40, EP No. 2 – 20, EP No. 3 – 22, EP No. 4 – 19 units (Table 1-2).

Table 1. Characteristics of the investigated EP No. 1-4 by species composition and dynamics of formation of snagss (pcs.), 2016 (2017)

Type	EP No.							
	1 (2016)		2 (2016)		3 (2017)		4 (2017)	
	0*	1	0	1	0	1	0	1
Common oak	98	6	33	5	7	–	63	8
Common hornbeam	–	–	215	2	181	1	57	8
Common ash	–	–	–	–	–	–	1	–
Norway maple	142	6	36	–	8	–	73	2
Black locust	5	–	–	–	1	–	–	–
Small-leaved linden	1	–	23	–	6	–	9	4
European white elm	2	–	–	–	10	–	1	–
Total	**260**		**314**		**214**		**226**	

Note: 0 – living tree; 1 – snagss

Table 2. Characteristics of the investigated EP No 1-4 by species composition and dynamics of formation of snagss (pcs.), 2021

Type	EP No.							
	1		2		3		4	
	0*	1	0	1	0	1	0	1
Common oak	73	31	31	7	7	–	57	14
Common hornbeam	–	–	204	13	162	20	50	15
Common ash	–	–	–	–	–	–	1	–
Norway maple	138	10	35	1	7	1	68	7
Black locust	5	–	–	–	1	–	–	–
Small-leaved linden	1	–	23	–	5	1	5	8
European white elm	2	–	–	–	10	–	1	–
Total	**260**		**314**		**214**		**226**	

Note: 0 – living tree; 1 – snagss

On experimental plots such tasks as geodetic survey, determination the GPS coordinates of each tree using Garmim Dakota10, measuring the diameter at breast height (1.3 m) using a Codimex caliper with an accuracy of 0.1 m and tree height using Halgöf EC-II-D electronic clinometer were performed. The list of trees by species composition and assessment of their life status was composed according to the method of taxation. The sequestered carbon stock of live biomass components was estimated using classical formulas for calculating the volume of growing tree trunks and the use of forest inventory reference books and standards [30; 31] for estimating the above-ground live biomass components of trees of the main forest-forming species of Ukraine.

Results and Discussion

The results of the study showed that the live biomass of common oak trees accounted for the largest share in the live biomass structure of the stands under study (Figs. 1-4). In EP No. 1 (Fig. 1), the stock of sequestered carbon in 2016 was 88.5 Mg C·ha^{-1}. 72.6% accounted for common oak, 20.8% – Norway maple, 6.3% – black locust, and a small share accounted for European white elm (0.2%) and small-leaved linden (0.1%). As of 2021, the stock of carbon sequestered by the live biomass of the forest stand was partially transformed into the mortmass carbon and decreased to 81.9 Mg C·ha^{-1}, including 68.4% of the carbon sequestered by the live biomass of common oak, 24.1% – by Norway maple, 7.1% – by black locust, 0.3% – by European white elm, and 0.1% – by small-leaved linden (Fig. 1). Thus, the share of common oak live biomass carbon decreased, and the share of Norway maple and black locust increased in 2021, compared to the 2016 data. This is explained by the natural mortality of mature common oak trees and more intensive growth of younger Norway maple and black locust trees.

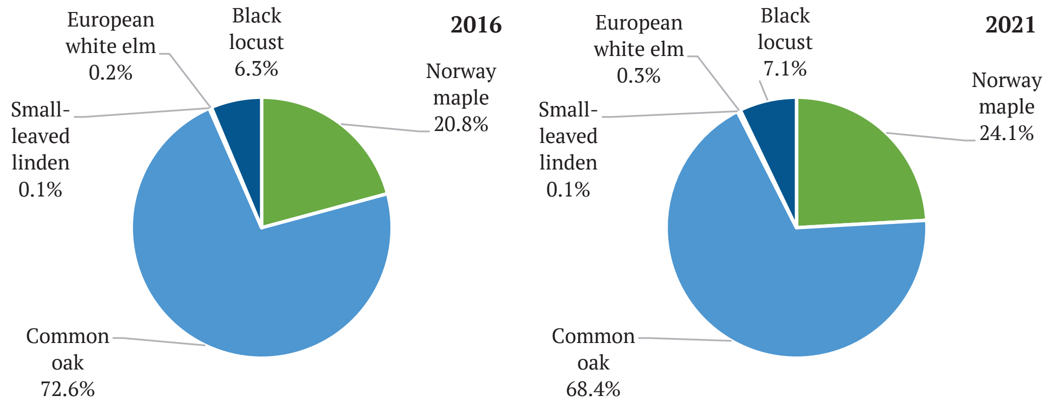

Figure 1. Structure of carbon stock sequestered by living trees, depending on the species composition of the stand on EP No. 1, 2016-2021

The largest stock of carbon sequestered by the live biomass among all permanent plots was on EP No. 2, which in 2016 amounted to 190.3 Mg C·ha^{-1}, of which 58.3% of carbon was sequestered by the live biomass of common oak, 22.0% – by common hornbeam live biomass, 14.2% – by Norway maple live biomass, 5.5% – by small-leaved linden live biomass. As of 2021, the stock of carbon sequestered by the live biomass increased to 194.1 Mg C·ha^{-1} and a slight redistribution in the carbon structure took place: 58.0% of carbon was sequestered by common oak, 22.5% – by common hornbeam, 13.7% – by Norway maple, and 5.8% – by small-leaved linden (Fig. 2).

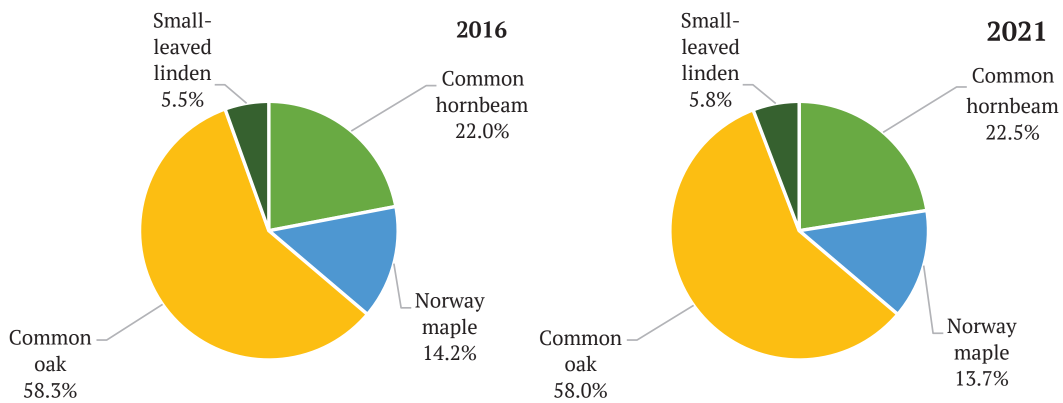

Figure 2. Structure of carbon stock sequestered by living trees, depending on the species composition of the stand on EP No. 2, 2016-2021

74.0 Mg C·ha^{-1} was estimated on EP No. 3, of which 49.0% fell upon common hornbeam, 45.4% – on common oak, 2.5% – on European white elm, 1.7% – on small-leaved linden, as well as an insignificant share characterised by black locust (0.8%) and Norway maple (0.6%). Already in 2021, the carbon sequestered by the live biomass of the permanent plot amounted to 79.4 Mg C·ha^{-1}, the main shares of the carbon stock belonged to common hornbeam (47.8%) and common oak (45.8%), the share of European white elm increased to 3.3%, and the shares of small-leaved linden, black locust, and Norway maple stayed unchanged compared to 2017 (Fig. 3).

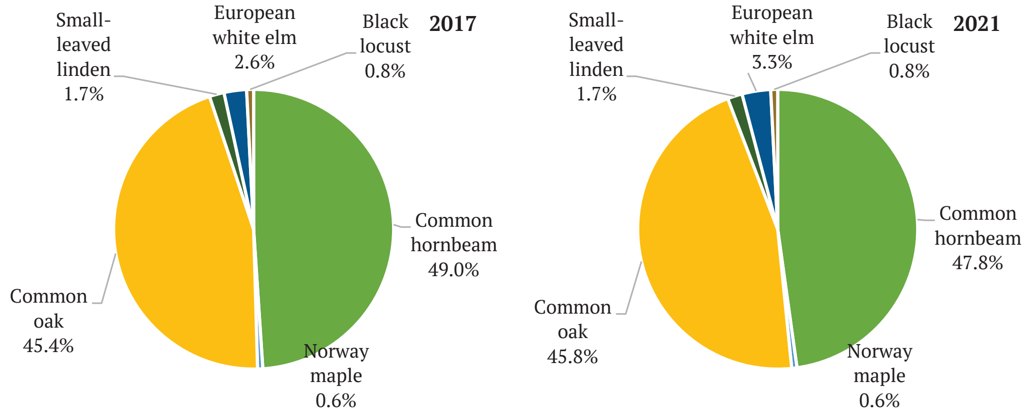

Figure 3. Structure of carbon stock sequestered by living trees, depending on the species composition of the stand on EP No. 3, 2017-2021

Among the permanent plots, the lowest carbon stock (44.6 Mg C·ha^{-1}) in 2017 was found on EP No. 4, where the main share fell upon common oak (80.3%), Norway maple accounted for 11.8%, common hornbeam – 3.7%, common ash – 3.3%, small-leaved linden – 0.8%, and European white elm – 0.1% (Fig. 4).

Over four years, the carbon stock increased only by 0.2 Mg C·ha^{-1} and in 2021 amounted to 44.8 Mg C·ha^{-1}. In the structure of sequestered carbon, compared to 2017, the share of common oak decreased slightly and amounted to 77.7%. The share of Norway maple increased to 14.2%. The share of common hornbeam (3.7%) and European white elm (0.1%) stayed unchanged, the share of common ash slightly increased (3.7%), and small-leaved linden decreased to 0.6%.

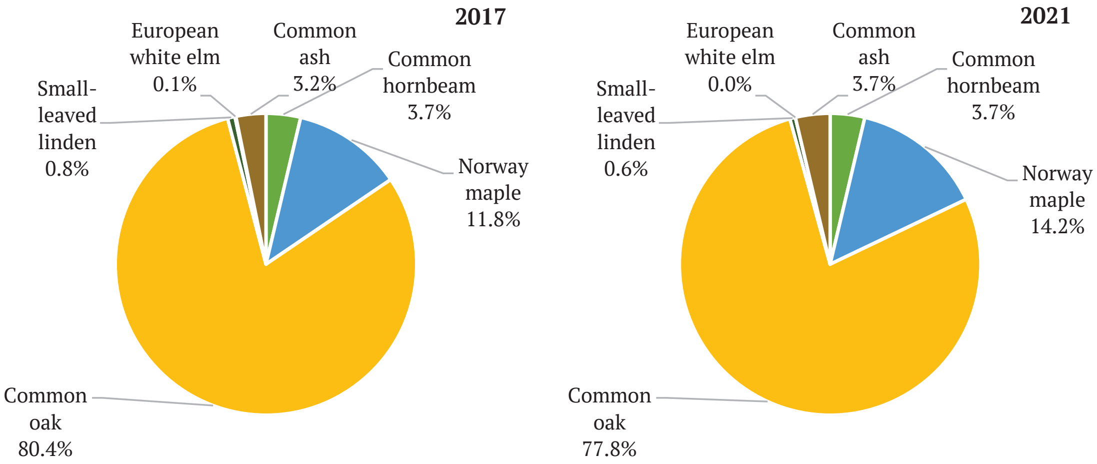

Figure 4. Structure of carbon stock sequestered by living trees, depending on the species composition of the stand on EP No. 4, 2017-2021

Much smaller in volume, but no less valuable carbon reservoir of forests is woody debris or mortmass of forest ecosystems (Figs. 5-8). The results of inventory of carbon sequestered by mortmass components of snagss and logs on EP No. 1 established the amount of 1.92 Mg C·ha^{-1}, which is mainly represented by carbon of the debris from common oak (86.5%) and Norway maple (13.5%).

During 2016-2021, a relatively intensive mortality took place on EP No. 1, which led to an increase in the stock of carbon sequestered by snagss and logs in 2021 to 13.43 Mg C·ha^{-1}. Specifically, 12.6 Mg C·ha^{-1} of common oak (93.9%) and 0.83 Mg C·ha^{-1} of Norway maple (6.1%). The share of carbon from the mortmass of snagss and logs in the structure of the total biomass in EP No. 1 increased from 2.2% to 16.4%. Notably, during the experimental 5-year period, the sequestered biomass carbon increased by 5.4% compared to 2016.

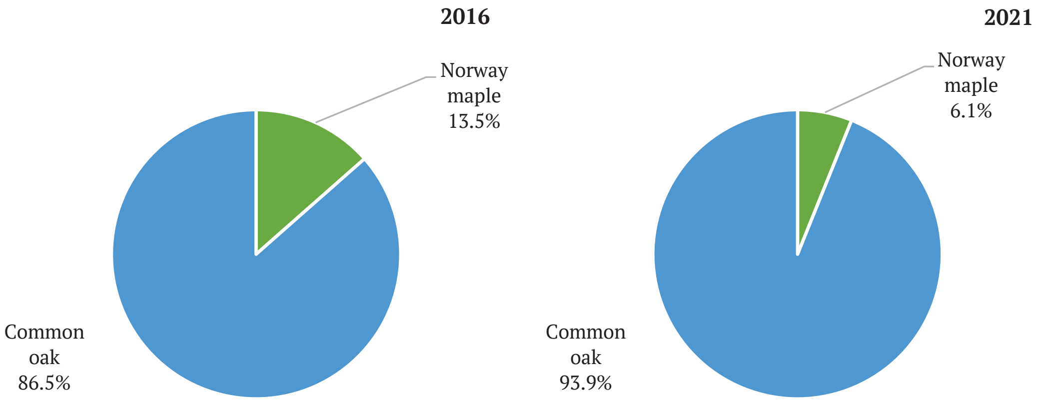

Figure 5. Structure of carbon stock sequestered by mortmass of snagss and logs by the species composition of the stand on EP No. 1, 2016-2021

As of 2016, estimation of carbon sequestered by the mortmass of snagss and logs on EP No. 2 showed a reserve of 7.00 Mg C·ha^{-1}. The carbon sequestered by common oak was 6.89 Mg C·ha^{-1} (98.4%) and common hornbeam – 0.11 Mg C·ha^{-1} (1.6%). In 2021, the stock of carbon sequestered by snagss and logs increased to 15.54 Mg C·ha^{-1}.12.63 Mg C·ha^{-1} accounted for the carbon from coarse woody debris of common oak (81.3%), 1.63 Mg C·ha^{-1} – Norway maple (10.5%) and 1.28 Mg C·ha^{-1} – common hornbeam (8.2%). Thus, the share of carbon sequestered by mortmass of snagss and logs in the total carbon of biomass increased to 8% in 2021, compared to 3.7% in 2016.

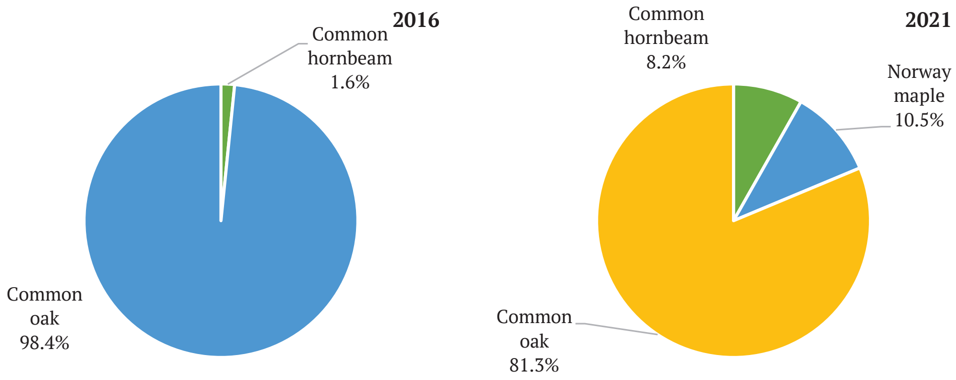

Figure 6. Structure of carbon stock sequestered by the mortmass of snagss and logs by the species composition of the stand on EP No. 2, 2016-2021

In terms of species composition, common hornbeam and Norway maple prevailed on EP No. 3, and the mortality on this plot was less intense. At the beginning of the study in 2017, the stock of carbon sequestered by the mortmass was 0.04 MgS·ha^{-1}, which was completely represented by the woody debris of common hornbeam (100%). In 2021, 1.42 Mg C·ha^{-1} was sequestered by the mortmass of common hornbeam (98.8%) and 0.02 Mg C·ha^{-1} of Norway maple (1.2%). Consequently, the share of carbon sequestered by the mortmass from snagss and logs in the total carbon of biomass increased to 1.8% in 2021, compared to 0% in 2017.

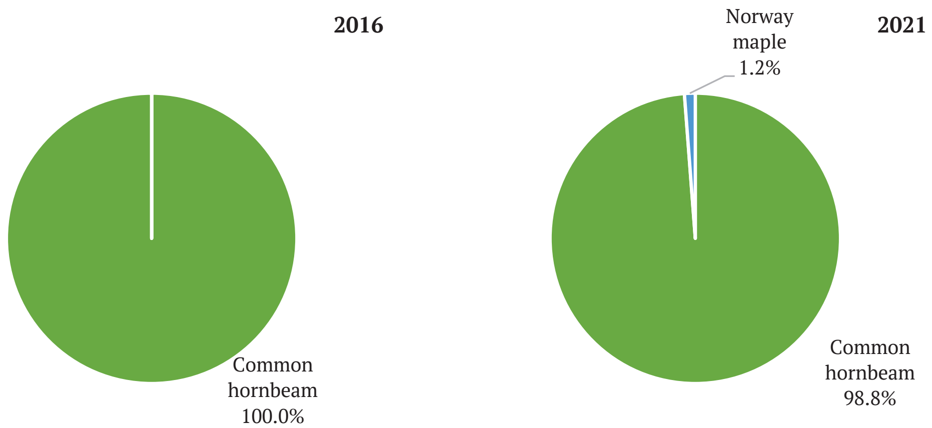

Figure 7. Structure of carbon stock sequestered by mortmass from snagss and logs by the species composition of the stand on EP No. 3, 2017-2021

In 2017, in the permanent plot on EP No. 4, 2.91 Mg C·ha^{-1} was sequestered by mortmass of snagss and logs of four tree species: 2.52 Mg C·ha^{-1} was sequestered by mortmass of common oak (86.7%), 0.27 Mg C·ha^{-1} – common hornbeam (9.2%), 0.09 Mg C·ha^{-1} – small-leaved linden (3.0%), 0.03 Mg C·ha^{-1} – Norway maple (1.1%). In 2021, on the same EP No. 4, 5.43 Mg C·ha^{-1} was sequestered, of which 4.79 Mg C·ha^{-1} – by common oak (84.0%), 0.18 Mg C·ha^{-1} – by common hornbeam (8.1%), 0.28 Mg C·ha^{-1} – by small-leaved linden (4.8%) and 0.18 Mg C·ha^{-1} – by Norway maple (3.1%). Overall, from 2017 to 2021, the stock of carbon sequestered by the mortmass of snagss and logs increased by 86.6%, which led to an increase in the share of carbon sequestered by mortmass from 6.1% in 2017 to 10.8% in 2021 in the total carbon structure of aboveground biomass.

Admittedly, the difference in the structural dynamics of carbon sequestered in different experimental plots is explained by the specific features of productivity, species and age-class composition of trees in forest stands. Tellingly, during the period under study, the proportion of carbon sequestered by mortmass of Norway maple increased on EP No. 2-4.

The estimation data of the dynamics of the sequestered biomass carbon indicate a natural tendency to increase the carbon reservoir over the years in each of the permanent plots. On EP No. 1, 2, 4, the main share of sequestered carbon falls upon common oak trees and, respectively, amounts to 12.6, 12.6, and 4.8 Mg C·ha^{-1} in 2021. At the same time, on EP No. 3, the amount of carbon was 1.4 Mg C·ha^{-1}, sequestered by common hornbeam trees.

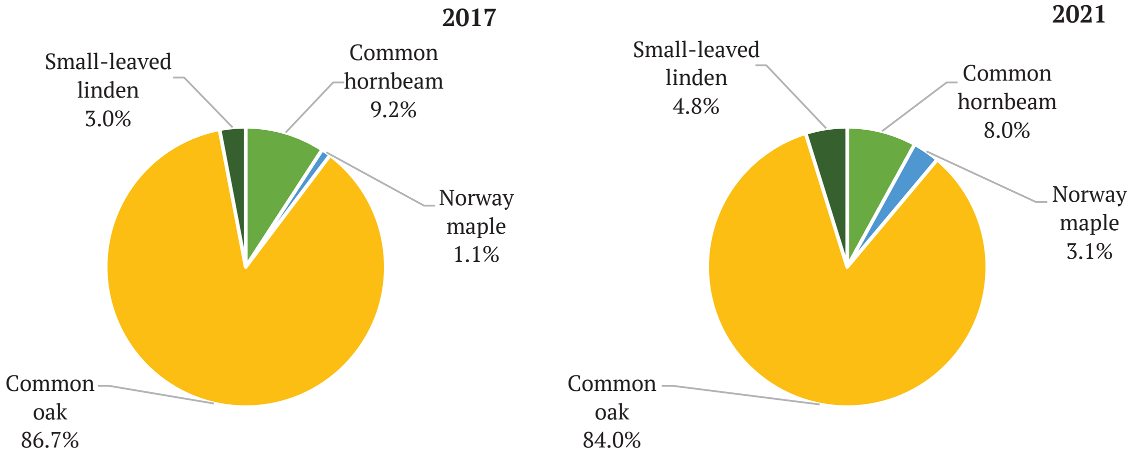

Figure 8. Structure of carbon stock sequestered by mortmass from snagss and logs by the species composition of the stand on EP No. 4, 2017-2021

The total volume of the biomass carbon reservoir of permanent plots forms the total volume of carbon sequestered by live biomass and mortmass in the respective years (Table 3, 4) as follows: on EP No. 1 in 2016, it was estimated at 90.4 Mg C·ha^{-1} and in 2021 – 95.3 Mg C·ha^{-1}; on EP No. 2 in 2016 – 197.3 Mg C·ha^{-1} and in 2021 – 209.6 Mg C·ha^{-1}; on EP No. 3 in 2017 – 74.1 Mg C·ha^{-1} and in 2021 – 80.9 Mg C·ha^{-1}; on EP No. 4 in 2017 – 47.5 Mg C·ha^{-1} and in 2021 – 50.5 Mg C·ha^{-1}.

Table 3. Carbon sequestered by permanent plots in the "Feofania" Park, 2016-2021

EP No.	2016 (2017)		2021		2016 (2017)	2021
	Live biomass carbon, Mg C·ha^{-1}	Mortmass carbon, Mg C·ha^{-1}	Live biomass carbon, Mg C·ha^{-1}	Mortmass carbon, Mg C·ha^{-1}	Biomass carbon, Mg C·ha^{-1}	Biomass carbon, Mg C·ha^{-1}
1	88.5	1.9	81.9	13.4	90.4	95.3
2	190.3	7.0	194.1	15.5	197.3	209.6
3	74.0	0.0	79.4	1.4	74.1	80.9
4	44.6	2.9	44.8	5.7	47.5	50.5

Table 4. Dynamics of the carbon structure sequestered by aboveground biomass components of permanent plots, %

EP No.	2016 (2017)		2021		Change in share of mortmass carbon
	Share of live biomass carbon	Share of mortmass carbon	Share of live biomass carbon	Share of mortmass carbon	
1	97.9	2.1	85.9	14.1	+12.0
2	96.5	3.5	92.6	7.4	+3.9
3	100	0	98.2	1.8	+1.8
4	93.8	6.2	88.7	11.3	+5.1

Therewith, the largest share of biomass carbon in the experimental plots fell upon: on EP No. 1 in 2016 – common oak (73.0%), Norway maple (20.8%) and in 2021 – common oak (68.4%), Norway maple (24.1%); on EP No. 2 in 2016 – common oak (58.3%), common hornbeam (22.0%) and in 2021 – common oak (58.0%), common hornbeam (22.5%); on EP No. 3 in 2017 – common hornbeam (47.7%), common oak (45.9%) and in 2021 – common hornbeam (47.8%), common oak (45.8%); in EP No. 4 in 2017 – common oak (80.3%), Norway maple (11.8%) and in 2021 – common oak (77.7%) and Norway maple (14.2%). For all surveyed experimental plots, the main share of biomass carbon, by species composition, is sequestered by common oak, common hornbeam, and Norway maple.

Accumulation of sequestered carbon in biomass components is noted according to cumulative changes in life status and inventory parameters of trees in all experimental plots. First of all, this is due to more intensive carbon sequestration by younger trees, even in stands where the storey of old common oaks has reached natural maturity, as well as carbon sequestration by mortmass, which is conditioned upon mortality and the formation of snagss and logs. Naturally, mortality and its intensity depend not only on the age and productivity of trees, but also on natural and anthropogenic disturbances affecting the biogeochemical cycle in forest ecosystems.

Comparing the obtained data with the results of earlier studies [32], it is worth noting that carbon sequestration largely depends on formation and accumulation of snagss and logs. Therewith, the different-aged and mixed composition of the permanent plots, which contain old and young trees, ensures an increase in live biomass and positive dynamics of sequestered carbon.

In all four permanent experimental plots in the forest stands of the "Feofania" Park, during the period under study, an increase in the reservoir of sequestered carbon in the biomass of the stands was found. Therewith, a decrease in the carbon sequestered by live biomass on EP No. 1 and a slight increase in live biomass carbon by 0.2 Mg C·ha^{-1} on EP No. 4 were found, which indicates a decrease in the carbon-sequestering potential of stands under more intense mortality and lesser current increment of live biomass of tree stands.

Estimation of ecosystem services and functions of forest stands should include the analysis not only of the regularity of live biomass growth, but also the specific features of the formation of mortality and the destruction of mortmass of stands of the main forest-forming species of Ukraine. This will open opportunities for a more comprehensive understanding of carbon cycle patterns and will serve as the basis for international reporting on forest resources and the implementation of effective forest surveying measures for forest management in the context of fulfilling the tasks and provisions of Paris Agreement.

Conclusions

In the territories of the Nature Reserve Fund of Ukraine, an essential indicator of the effectiveness of forest management lies in carbon sequestration processes, which determine the productivity of stands and the formation of net primary products and affect the mortality under small and large-scale disturbances of natural and anthropogenic origin.

Observations on permanent test areas within the "Feofania" Park indicate the transformed state of forest ecosystems under anthropogenic activity and natural processes, which determine the multi-vector redistribution of carbon stock in the biomass components of forest stands.

Given the prioritisation of carbon sequestration in the biomass of stands as an ecological function, it is necessary to practice measures to raise the current increment of sequestered carbon in the biomass and increase the resistance of trees to natural and anthropogenic disturbances.

Considering the nature conservation status and the formidable ecological importance of the garden art park-monument "Feofania", it is worth noting a positive trend towards an increase in the share of coarse woody debris (mortmass) in the biomass structure of permanent plots.

Promoting the formation of mixed and different-age stands ensures a more sustainable sequestration of carbon by the biomass of stands and reduces the risks of a negative balance of the carbon cycle in forest ecosystems. Further long-term observation of carbon dynamics on permanent experimental plots allows substantiating the impact of climate changes and anthropogenic factors on the development of forest stands and their carbon-sequestering function.

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Структура депонованого вуглецю в біомасі лісових деревостанів парку-пам’ятки садово-паркового мистецтва загальнодержавного значення «Феофанія»

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Анотація. Стан лісових екосистем, процеси накопичення вуглецю мають як глобальне, так і локальне значення при вивченні впливу природних і антропогенних факторів на біогеохімічні цикли. Вивчення наслідків їхнього впливу на лісові насадження ініційовано міжнародними і державними екологічними програмами, спрямованими на вирішення проблем змін клімату. Депонування вуглецю у біомасі лісових насаджень залежить від продуктивності деревостанів, формування відпаду дерев та проведення господарських заходів. Метою досліджень було встановлення закономірностей зміни резервуару депонованого вуглецю в компонентах біомаси деревостанів парку-пам’ятки садово-паркового мистецтва загальнодержавного значення «Феофанія». Процеси трансформації лісових екосистем досліджено на постійних пробних площах території парку-пам’ятки «Феофанія» за допомогою методів таксації дерев, що ростуть. Результатами спостережень підтверджено загальне збільшення резервуару депонованого вуглецю в біомасі деревостанів і різновекторну динаміку структури депонованого вуглецю у фітомасі та мортмасі деревостанів. Отримано свідчення про зменшення вуглецедепонуючого потенціалу насаджень за умов інтенсивнішого відпаду і меншого поточного приросту фітомаси деревостанів. Встановлено позитивну, з екологічної точки зору, тенденцію до збільшення частки грубого деревного детриту (мортмаси) у структурі біомаси дослідних насаджень. Основну структуру вуглецю біомаси, за видовим складом порід, представлено дубом, грабом і кленом. Природоохоронні рішення і заходи, впроваджені на територіях природо-заповідного фонду мають підвищувати інтенсивність депонування вуглецю в біомасі та стійкість лісових екосистем до впливу чинників довкілля. За умови пріоритетності депонування вуглецю в біомаси деревостанів, як екологічної функції, необхідно практикувати заходи для збільшення поточного приросту депонованого вуглецю в біомасі та підвищення стійкості дерев до природних та антропогенних порушень

Ключові слова: фітомаса, мортмаса, деревний детрит, відпад дерев, сухостій, деревна ламань

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Screening of the Effect of Chloramine on the Mycobiota of *Ulmus Laevis* Pall. Plant Tissues *in vitro*

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Abstract. European white elm (*Ulmus laevis* Pall.) tissue *in vitro* is a donor material for obtaining cultures with stable resistance to pathologies of infectious origin, namely to Dutch elm disease. To solve this problem, it is necessary to develop an effective protocol for the regeneration of *U. laevis in vitro*. The purpose of this study is to investigate the effect of chloramine concentrations on the mycobiota of *U. laevis* plant tissues for propagation *in vitro*. 10-15 cm parts of shoots from 25-year-old *U. laevis* were used as plant material. The study was conducted in the autumn of 2021. Microshoots previously sterilized with chloramine (1.0%, 2.5%, 5.0%, 10.0%) for 10 min were cultivated on a solid nutrient medium according to the WPM recipe (McCown & Lloyd, 1981) with the addition of 0.2 $mg \cdot l^{-1}$ *2* - iP (6-(γ,γ- Dimethylallylamino)purine) and 2.0 $g \cdot l^{-1}$ of activated carbon. For microbiological analysis, sterilised plant material was cultured by accumulation in Petri dishes with a nutrient medium (sour potato agar) in a thermostat without lighting at +26 ± 1°C and a relative humidity of 68 ± 2%. Methods of biotechnological, mycological, and statistical research were employed in this study. Over 95% of the samples were found to be infected with microscopic fungi of the genus *Mucor* Fresen., *Penicillium* Link, *Chaetomium* Kunze and *Trichoderma* Pers. The effect of preparation concentration on the total number of infected explants is statistically insignificant at 5%. It was found that 5.0% preparation is effective for neutralising mycobiota of the genus *Chaetomium* and *Trichoderma*; 10.0% – for neutralising *Penicillium* mycobiota. If the concentration of chloramine increases, the intensity of infection of explants with mycobiota of various genera decreases. As a result of the research, a small amount of aseptic cultures were obtained from the shoots of *U. laevis* isolated in autumn. This study is relevant for biologists, biotechnologists, microbiologists, and biological scientists

Keywords: European white elm, Dutch elm disease, asepsis, infection, microclonal propagation

Introduction

European white elm (*Ulmus laevis* Pall.) is a valuable forest, decorative, soil protecting, forest improvement, honey-bearing, medicinal, and fodder plant. Medicinal features of the plant are conditioned upon the presence of valuable biologically active substances that have antimicrobial properties [1-3]. Elms are successfully used in settlement gardening and landscape design. According to the results of forest pathology examinations, plants are damaged by pests, namely the winter moth, the clouded magpie, the elm leaf miner, and *Exaereta ulmi* [4]. Currently, the Dutch elm disease (DED), which causes mass drying of European and Asian species, is particularly dangerous. The causative agent of the DED is sac fungi *Ophiostoma ulmi* Melin & Nannf. (*Ceratocystis ulmi*) and *Ophiostoma novo-ulmi* with the conidial stage of *Graphium ulmi*, which spread in the vessels, obstruct the flow of water, and cause the death of individual branches or the tree in general. The disease is mainly spread by bark beetles or insects (*Scolytus scolytus* F., *Scolytus multistriatus* Marsh., *Scolytus* pygmaeus F.) [4; 5]. However, many researchers have established that infectious vascular pathogens are not the main cause of the mass disease of oaks and other deciduous plants, their spread as a consequence or a secondary phenomenon [6; 7]. Furthermore, there is no consensus on pathogenicity of *Ophiostoma*. In a normal state, species of the *Ophiostoma* genus vegetate as saprophytes in dry branches of

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the crown, but in conditions of increased air in the vessels, they change to a parasitic state [6]. Therefore, the root cause of the mass drying out of *Ulmus* is still debatable.

During the decades of spread of DED in Europe and North America, various recommendations have been proposed and tested to prevent the drying out of these species and to minimize damage to forest and urban plantations (use of systemic insecticides by injection into wood or vessels, pruning of branches with the first symptoms of the disease, treatment of felled trees with insecticides and sanitation treatment). However, the proposed methods are currently ineffective. Innovative *in vitro* technologies, in contrast to conventional methods, allow obtaining artificial hybrids/somaclonal variants/mutants with disease resistance using protoplast culture, cell selection, and genetic engineering [8-10]. This strategy can only be initiated after the establishment of efficient plant regeneration protocols from *Ulmus* tissues [11].

The purpose of the study is to figure out the effect of chloramine concentrations on the mycobiota of *U. laevis* plant tissues for microclonal propagation. Tasks: 1) to find the total proportion of infected explants under the action of chloramine concentrations; 2) to find the mycobiota of the samples under study and the intensity of infection; 3) to investigate the effect of chloramine concentrations on the mycobiota. The originality of this study lies in the identification of mycobiota of shoots isolated in autumn from a 25-year-old *U. laevis,* after sterilisation with chloramine.

Literature Review

The important value of *Ulmus* plants predetermined several biotechnological scientific studies [12-14]. It was found that the combination of *Ulmus davidiana* and *Cornus officinalis* extracts has an inhibitory effect on osteoporotic bone loss and contains biologically active substances; *Ulmus pumila* plants have antimicrobial properties against *Escherichia coli*, *Proteus vulgaris*, *Klebsiella pneumoniae*, and *Enterobacter cloacae* [1-3]. It was proved that the use of stem fungal endophytes from the *Cystobasidiomycetes*, *Eurotiomycetes*, and *Dothideomycetes* classes stimulates the induction of the protective metabolism of *Ulmus minor* plants to pathogens [10]. Aseptic elms *in vitro* are used for microclonal propagation, reintroduction of elite germplasm, creation of plant banks and long-term cryopreservation [5; 9; 11].

Asepsis of explants – is a prerequisite for microclonal propagation of plants. At the stage of obtaining an aseptic culture, it is important to choose the correct sterilisation mode. Currently, a wide range of sterilising substances is used to obtain aseptic culture of woody plants [15; 16]. One of the most common is chemical sterilisation with substances containing active chlorine. In different years, the culture of *Ulmus in vitro* was investigated by many scientists [17-19]. The authors of [14] disinfected nodal segments with buds of *Ulmus americana* L. plants in 70% ethanol (1 min), washed with sterile water (3 min), surface-sterilised in 15% commercial bleach (5.5% sodium hypochlorite) with the addition of Tween- 20 (2-3 drops, 10 min) followed by washing three times with sterile water. The study was conducted from April to September. Another group of scientists [5] sterilised buds of *U. laevis* and *Ulmus glabra* Huds. plants with the following regimes: 70% ethanol (10 min) followed by exposure to 10% hydrogen peroxide (3 h) / 70% ethanol (20 min) / hydrogen peroxide with constant stirring (10 min). PPM (Plant Preservative Mixture™), antibiotics, and sodium hypochlorite were also used. After sterilisation, the buds were kept on a filter with 100 mg·l^{-1} 1-vinyl-2-pyrrolidone (PVP, Polyvidone). For the use of sodium hypochlorite in early summer, the researchers obtained an aseptic culture from the tops of shoots of *Ulmus procera* Salisb. [17]. Researchers [20] observed the prominent efficiency of regeneration of *U. glabra* plants due to the effects of meta-Topolin (6-(3-hydroxybenzylamino)purine) in the nutrient medium. MS [21], WPM [22], and DKW [23] media with the addition of antibiotics were used for the proliferation of microshoots. Dormant buds collected in February were washed with running water and sterilised in 0.1% $NaClO_3$ (10 min), followed by immersion in 0.01% $HgCl_2$ and rinsed three times in sterile distilled water [19]. Other researchers sterilised seeds collected from two *Ulmus parvifolia* 'Pathfinder' lines, P-6 and P-10, in 15% Clorox with 15 drops of Tween 20 for 15 min followed by rinsing in sterile distilled water. Under such sterilisation conditions, 100% of aseptic viable explants were obtained. Plant material was cultivated on DKW nutrient medium with 3% sucrose, 1.0 mg·l-^{1} thiamine, 0.5 mg·l^{-1} pyridoxine, 0.5 mg·l^{-1} nicotinic acid, 100 mg·l^{-1} inositol, 0.1 mg·l^{-1} 1 BA (6-benzylaminopurine) and 0.2% Phytogel, the pH was adjusted to the level of 5.8 [9].

At the same time, studies have found that the sterilisation mode of *Ulmus* plant material depends on several factors. Therefore, the right type of explant is selected experimentally, considering morphological and physiological features.

Materials and Methods

For research, the authors used 10-15 cm parts of shoots isolated from 25-year-old *U. laevis* in the autumn of 2021. As explants, 1.0-1.2 cm parts of shoots with one bud were used. Sterilisation of plant material involved exposure to a soapy solution with a few drops of Tween-80 (20 min), washing in tap water (10-12 min), rinsing in distilled water, immersion in 70% ethanol (2-3 min), sterilisation in chloramine solutions (1.0%, 2.5%, 5.0%, 10.0%) for 10 min and subsequent three-time washing in sterile distilled water (5-6 min each). The content of active chlorine in chloramine is ⩾ 26 mg·l^{-1}. At the stage of introduction into *in vitro* culture, nutrient medium was used according to WPM prescription. 100 mg·l^{-1} of inositol, 0.2 mg·l^{-1} of 2 – iP (6-(γ,γ-Dimethylallylamino)purine), 2.0 g·l^{-1} of activated carbon, 30 g·l^{-1} of sucrose and 7.0-7.3 g·l^{-1} of microbiological agar were added to the nutrient media. The acidity index of the medium (pH) was adjusted to 5.6. The total share of infected explants (%) was determined on the 10th day of cultivation (the ratio of the amount of infected plant material to the total amount introduced is expressed as a percentage). Biotechnological methods were applied, namely microclonal reproduction using the culture of fragments of plant shoots *in vitro* [24-26].

For microbiological analysis, sterilised explants (Fig. 1a) were cultured according to the accumulation method in Petri dishes with acidic potato agar [27], 5 pieces in each. The plant material was cultured in a thermostat without lighting at +26 ± 1°C and a relative humidity of 68 ± 2%. The samples were examined under a KONUS

BIOREX-3 microscope according to the method adopted in mycological studies [28]. The genus of isolated fungi was figured out according to a generally recognised identifier [29]. The intensity of infection of samples after sterilisation was investigated on the 7th day of cultivation according to DSTU 7127:2009 [27]. MS Excel software tools were used to process the research data. The results are presented as M ± m (M is the arithmetic mean, m is the standard error). One-way analysis of variance (ANOVA) was performed to analyse the influence of chloramine concentrations on the infection of explants. The study was conducted in the Plant Biotechnology Laboratory of the Separate Subdivision of the National University of Life and Environmental Sciences of Ukraine "Boyarka Forest Research Station" and in the State Organisation "Ukrainian Forest Breeding Centre" (SO "UFBC").

Results and Discussion

Using all experimental concentrations of chloramine for 10 days, significant mycoses were detected in explants of U. laevis (over 95% infection) cultivated on a modified nutrient medium for WPM tree species. Low asepsis, according to the authors, is caused by insufficient techniques during surface sterilisation of plant material, which is consistent with the results of other studies by other authors [30].

To stimulate the growth and development of microscopic fungi, sour potato agar was used as a nutrient medium in the experiment. Studies on the 2nd day of cultivation recorded the growth of mycobiota near the top of the *U. laevis* explant on the surface of the nutrient medium after using 1.0% chloramine (Fig. 1b).

Figure 1. Plant material of *U. laevis in vitro* on a nutrient medium: a) fragments of shoots as explants on the first day of cultivation (1 cm line); b) infected explants on the second day (arrows show the mycobiota); c), d) general appearance of infection of explants for 10 days using 5.0% chloramine

In case of 5.0% and 10.0% concentrations, infection was observed somewhat later (on 4-5 days). On day 10, over 95% of tissue contamination was recorded using all experimental concentrations of chloramine (Fig. 1c, d; Table 1, 2).

Table 1. Results of sterilisation of microshoots of *U. laevis* plants using chloramine *in vitro*, %

No. seq.	Chloramine concentration, %	Total proportion of infected explants, %	Intensity of explant infection with mycobiota*, %			
			Mucor Fresen.	*Penicillium* Link	*Chaetomium* Kunze	*Trichoderma* Pers.
1	1.0 %	97.4 ± 1.9	Strong	Weak	Single	Single
2	2.5 %	96.4 ± 1.6	Strong	Weak	Single	Single
3	5.0 %	95.6 ± 1.7	Strong	Single	–	–
4	10.0 %	95.8 ± 1.0	Single	–	–	–

*__Note:__ Sporadic – up to 5% of infection, weak – up to 25%, medium – up to 50%, and strong – over 50%

Table 2. Final results of univariate analysis of variance

Variance analysis						
Variation source	*SS*	*df*	*MS*	*F*	P_{value}	$F_{critical}$
Between groups	9.8	3	3.2667	0.26081	0.8526	3.2389
In the middle of groups	200.4	16	12.525			
Total	210.2	19				

where α is the level of reliability; *SS* is the sum of squares; *df* is the number of degrees of freedom; *MS* is the variances; *F* is the calculated value of the Fischer criterion; P_{value} is the calculated value of the minimum significance; $F_{crit.}$ is the critical value of the Fischer criterion

Morphological and physiological features of plant material isolated in the autumn period are one of the reasons for the significant intensity of infection, which is consistent with studies by other authors [14]. At the same time, according to the data of some researchers [7], it is shown that in autumn, the number of cases of release of potentially dangerous fungi, namely *Ceratocystis sp*. from samples of *Quercus robur* L. increases, compared to the summer period.

As a result of mycological analysis, microscopic fungi belonging to the *Zygomycota* and *Ascomycota* divisions were found. A mycobiota belonging to four genera *Mucor* Fresen., *Penicillium* Link, *Chaetomium* Kunze, *Trichoderma* Pers. was isolated from the chloramine-sterilised plant material of *U. laevis*. A group of researchers [7] isolated 129 species of microscopic fungi of various taxonomic groups in samples of different organs of control and drying out *Q. robur*, namely genera were present and identified by the authors in the microshoots of *U. laevis*. It was also found that the species composition of fungi differed slightly from that on roots, bark, and wood of *Q. robur* [7]. Pathogenic fungi of the genus *Ophiostoma* were not recorded in the samples of *U. laevis* under study.

The authors of this paper, unlike other researchers [9; 14; 17], did not obtain enough aseptic explants when using a chlorine-containing preparation. Thus, other researchers have shown the expediency of using sodium hypochlorite for introducing microshoots of *U. americana* [14] and *U. procera* [17] in the spring and summer period. According to research results, it is advisable to use 15% Clorox with 15 drops of Tween 20 for 15 minutes to sterilise *Ulmus parvifolia* "Pathfinder" [9]. The difference in results, according to the authors, is caused by the different period of isolation and the type of plant material. According to ANOVA results, the effect of 1.0-10.0% chloramine on total explant infection is statistically insignificant at a 5% level ($F < F_{crit.}$, $P<0.05$). At the same time, it was found that the intensity of infection with exogenous mycobiota of different genera differed. Microscopic fungi of the genus *Chaetomium* and *Trichoderma* were effectively neutralised using 5.0% and 10.0% chloramine; using 10% – *Penicillium.* The presence of *Mucor* mycobiota was observed on the explants under different sterilisation variants. Its increased intensity of infection was recorded on plant material treated with 1.0% and 5% preparation. It was found that in case of an increase in the chloramine concentration (from 1.0% to 10%), the intensity of infection decreased (from strong to sporadic).

Conclusions

The total share of infected explants of *U. laevis* isolated in the autumn period after exposure to 1.0-10.0% chloramine was over 95%. Among them, microscopic fungi of the genus *Mucor* Fresen., *Penicillium* Link, *Chaetomium* Kunze, *Trichoderma* Pers. were found. Chloramine acted on the corresponding mycobiota of *U. laevis* plant shoots. It was found that 5.0% preparation is effective for neutralising mycobiota of the genera *Chaetomium* and *Trichoderma*; 10.0% – for neutralising *Penicillium mycobiota*. By using experimental concentrations of chloramine, the presence of *Mucor* mycoses was recorded. In case of an increase in the chloramine concentration (from 1.0% to 10%), the intensity of infection decreases (for *Mucor* – from strong to sporadic). The effect of 1.0-10.0% chloramine on total explant contamination is statistically insignificant at the 5% level. As a result of the research, a small amount of aseptic cultures were obtained from the plant shoots of *U. laevis* isolated in autumn. Further studies are aimed at establishing the best mode of introduction of *U. laevis* plants for microclonal propagation.

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Скринінг дії хлораміну на мікобіоту тканин рослин *Ulmus Laevis* Pall. *in vitro*

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Анотація. Тканини в'язу гладкого (*Ulmus laevis* Pall.) *in vitro* – донорний матеріал для одержання культур зі стійкою резистенстністю до патологій інфекційного походження, зокрема до голландської хвороби. Для вирішення цієї задачі необхідно розробити ефективний протокол регенерації *U. laevis in vitro*. Дослідження дії концентрацій хлораміну на мікобіоту тканин рослин *U. laevis* для розмноження в умовах in vitro – мета дослідження. Як рослинний матеріал використовували 10–15 см частини пагонів із 25-річного U. laevis. Дослідження виконували восени 2021 року. Мікропагони, попередньо простерилізовані хлораміном (1.0 %, 2.5 %, 5.0 %, 10.0 %) упродовж 10 хв, культивували на твердому живильному середовищі за прописом WPM (McCown & Lloyd, 1981) з додаванням 0.2 $мг·л^{-1}$ 2 – іП (N-ізопентеніламінопурин) та 2.0 $г·л^{-1}$ активованого вугілля. Для мікробіологічного аналізу простерилізований рослинний матеріал культивували методом накопичення у чашках Петрі з живильним середовищем (кислий картопляний агар) у термостаті без освітлення за температури +26 ± 1 °C та відносної вологості повітря 68 ± 2 %. Використовували методи біотехнологічних, мікологічних та статистичних досліджень. Виявлено понад 95 % зразків інфікованих мікроскопічними грибами роду *Mucor* Fresen., *Penicillium* Link, *Chaetomium* Kunze та *Trichoderma* Pers. Вплив концентрації препарату на загальну кількість інфікованих експлантатів статистично незначущий на 5 % рівні. Установлено, що 5.0 % препарат ефективний для нейтралізації мікобіоти роду *Chaetomium* і *Trichoderma*; 10.0 % – *Penicillium*. У разі зростання концентрації хлораміну зменшується інтенсивність інфікування експлантатів мікобіотою різних родів. У результаті проведених досліджень із пагонів *U. laevis*, ізольованих восени, одержали асептичні культури у незначній кількості. Матеріал статті актуальний для біологів, біотехнологів, мікробіологів та науковців біологічного профілю

Ключові слова: в'яз гладкий, голландська хвороба ільмових, асептичність, інфікування, мікроклональне розмноження

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