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Representation of the genus *Larix* Mill. in the protected areas of Ukrainian Polissia

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Abstract. *Larix decidua* Mill. may become more important than *Picea abies* (L.) Karst for reforestation and restoration of the natural balance, and therefore it is necessary to investigate this species. Therefore, the purpose of this study was to conduct an inventory of *Larix* taxa in the protected areas of the mixed forest zone of Ukrainian Polissia, to analyse their distribution, age structure, and use. Research methods used: route, analytical, comparative analysis, systematisation. It was found that 5 species, one variety and two hybrids of larch grow in the protected areas of the mixed forest zone of Ukraine. It was established that *L. decidua* is the most widespread – it grows in parks-monuments of landscape art, natural monuments, protected tracts, reserves in pure mixed plantings, alleys, row plantings, groups and as a solitaire tree. *L. sibirica*, L. *kaempferi* grow as solitaire trees and in groups of 3 to 10 specimens in 9 and 10 protected objects, respectively. *L. gmelinii* is present in two arboretums, *L. laricina* – in one. *Larix decidua var. polonica* (Racib. ex Wóycicki) Ostenf. & Syrach is not widespread, represented in groups in 6 parks-monuments of landscape art and Bereznivskyi denrorark. *Larix* × *eurolepis* A. Henry. is widespread in pure and mixed stands, grows in an alley in the Slavianskyi park-monument of landscape art, in groups – in the Lisova Aleia Botanical Reserve, Bereznivskyi denrorark, and in mixed stands of the Riznolissia General Zoological Reserve. The age structure is quite diverse, represented by *L. decidua, L. sibirica*, L. *decidua var. polonica* aged from 100 to 200 years. Other species, varieties, and hybrids are

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represented by specimens aged from 3 years (*L.×eurolepis*) to 80 years (*L. kaempferi*). 69.2% of larch stands are in good condition, 28.9% are in satisfactory condition, and only 1.9% are in poor condition. The results of the research can be used in the further creation of pure and mixed stands, alleys, etc. in the mixed forest zone

Keywords: larch; species; park-monument of landscape art; natural monument; arboretum

Introduction

In recent years, there has been considerable attention paid to reforestation for carbon sequestration and biodiversity conservation. European larch (*Larix decidua* Mill.) is one of the most important coniferous species in Europe in economic terms. It is expected that with the decline of *Picea abies* (L.) Karst., this species may become more important for reforestation and restoration of the natural balance by sequestering CO_2. K.F. Suzuki *et al*. (2021) found that the use of introduced species for natural forest regeneration is controversial, but that the use of these species, if they are already present in the ecosystem, can lead to overall benefits for nature and society. V.A. Usoltsev *et al*. (2021) developed a pseudo-allometric model of the biomass structure of larch trees (*Larix* spp.) growing in Eurasia to create prerequisites for predicting changes in the biomass structure of *Larix* spp. trees under the influence of modern climate change. They found that a 1°C increase in temperature with constant precipitation caused a decrease in the aboveground surface, trunk, leaves, and branches of uniform and same-age larch trees. An increase in precipitation of 100 mm at a constant temperature level leads to a decrease in aboveground and stem biomass and an increase in leaves and branches. S. Jansen & T. Geburek (2016) were the first to investigate the artificial spread of European larch in Europe from the 17th to the mid-20th century. They found that during this period, larch genetic resources were displaced with varying intensity. Specifically, plant material from the Alps was transferred outside their natural range throughout Europe, while genetic resources originating in the Sudetenland were mainly distributed in northeastern Germany, northwestern Poland, and outside the Sudetenland. Polish larch is mainly distributed within Poland itself. Genetic resources from the Carpathian Mountains (Tatras, eastern and southern Carpathians) have not been spread over long distances. The local larch populations in the Alps and Poland were hardly affected by allochthonous plant material, while the natural gene pool of larch in the Sudetenland and Carpathians was considerably influenced by alpine plants. According to C. Wu *et al*. (2021), under current climatic conditions, the areas for the spread of *L. kaempferi* are concentrated in Europe and Central and North Asia (especially Japan and Korea), as well as in North America. Globally, about 33.75% of suitable areas are located in China. Modelling future climate change shows that suitable areas are shrinking and shifting to the north of Asia, Europe, and China. *L. kaempferi* may adapt or move to higher latitudes/altitudes, which will affect its productivity. N. Bhusal *et al*. (2020) note that due to climate change, the frequency and severity of droughts will increase, so drought tolerance of tree species should be considered when creating tree stands. They note that Japanese larch is more stable and hardier in morphological and physiological reactions, as well as in the plant's relationship with water, than *Prunus sargentii*, and therefore Japanese larch will be more suitable for stands in regions with water shortages.

S.O. Belelya (2013) investigated the spread of larch in Ukraine. The author found that the largest number of stands with a predominance of larch is concentrated in the western region of Ukraine (49% of larch stands are in Lviv region, 26% – in Ternopil region, 6% – in Ivano-Frankivsk region, 3% – in Rivne region, and 1.5% – in Volyn region). Moreover, mixed stands are 4-8 times more numerous than pure larch stands. V. Zaika *et al*. (2016) investigated the growth and formation of 12-109-year-old stands of *L. decidua* Mill. in different growing conditions of the Kremenets hills. It was found that on relatively poor soils with average moisture, Scots pine is not inferior to European larch in terms of growth intensity. In the protected areas, the distribution of larch was studied in the Steppe zone, in the Forest-Steppe zone, in the broadleaf forest zone, in the Ukrainian Polissia, in the Ukrainian Carpathians – S.Yu. Popovich *et al*. (2020; 2022). The authors have analysed the species composition of dendrosozoexotes, including the representation of larch species, varieties, and hybrids in the protected areas of Ukraine. Categorical and regional representativeness, as well as representation of species of age-old larch were considered. The distribution of unique trees in the protected areas of Ukrainian Polissia, including *L. decidua* Mill. (Dzyba, 2021), taxonomic and ecological structures of potentially old, old, centuries-old, and ancient trees, including: *L. decidua* Mill., *Larix decidua* var. *polonica*, *Larix sibirica* Ledeb. (Dzyba, 2022). Given the numerous studies on larch, the relevance of the subject under study is confirmed. The purpose of this study was to investigate the representation, use, status, biometric indicators, and age structure of Larix genus *taxa* in the protected areas of Ukrainian Polissia.

Objectives: to make an inventory of Larix *taxa* in the protected areas of Ukrainian Polissia and distribute them by age; to determine quantitative and qualitative indicators of larch species, varieties, and hybrids, to identify types of stands created with the participation of larch.

Materials and Methods

The research was conducted during 2014-2021 in parks-monuments of landscape art, reserved areas, nature reserves, national nature parks, dendrological parks, botanical garden, natural monuments, arboretums of the Hamarnia Landscape Reserve and Shatsk National Nature Park. During the field surveys, the condition of larch trees was assessed (Table 1).

Table 1. Assessing the condition of woody plants

Condition of woody plant	Characteristics of tree condition
Good	The trees are healthy, normally developed, needles are dense, evenly distributed on the branches, of normal size and colour, there are no signs of disease and pests, wounds, damage to the trunk and skeletal branches, or hollows
Satisfactory	The trees are healthy, but with signs of stunted growth, with an unevenly developed crown, few needles on the branches, minor mechanical damage and small hollows
Unsatisfactory	The trees are very weakened, trunks are curved, crowns are poorly developed, there are dry branches, the growth of annual shoots is insignificant, trunks are mechanically damaged, presence of hollows

Source: Order of the State Committee for Construction, Architecture and Housing Policy of Ukraine No. 134 (2001)

The DBH (diameter at breast height) (1.3 m) was measured with a tree caliper, and the height was measured with a Suunto PM-5/1250 altimeter. The age structure was established according to the archive materials and inventory description and divided into age groups: 1-20 years and 21-40 years (young), 41-60 years (middle-aged), 61-80 years (premature), 81 to 100 years (potentially old), from 100 to 200 years (old), from 200 to 800 years (centuries-old). The names of the taxa of the genus *Larix* were specified according to the international classification The Word Flora Online (WFO) (n.d.). Species of the *Larix* genus were verified for pertinence to The International Union for Conservation of Nature (IUCN) (IUCN, 2023). The study was conducted in compliance with the Convention on Biological Diversity (1992).

Results and Discussion

The genus *Larix* L. is represented in the world by three North American species (*Larix laricina* (Du Roi) K. Koch., *Larix lyallii* Parl., *Larix occidentalis* Nutt.) and six Euro-Asian species (*Larix decidua* Mill, *Larix sibirica* Ledeb., *Larix gmelinii* (Rupr.) Kuzen., *Larix kaempferi* (Lamb.) Carr., *Larix potaninii* Batalin., *Larix griffithii* Hook.f.), as well as varieties and hybrids.

In the protected areas of Ukrainian Polissia grow 5 species (*L. decidua* Mill., *L. kaempferi* (Lamb.) Carrière., *L. sibirica* Ledeb, *L. gmelinii* (Rupr.) Kuzen., *L. laricina* (Du Roi) K.Koch.), one variety (*L. decidua*var. *polonica*) and two hybrids (*Larix×eurolepis* A.Henry, *Larix×lubarskii* Sukaczev.) in 20 parks-monuments of landscape art (PMLA), four dendrological parks (DP), two national nature parks (NNP) of Shatsk and Kivertsi, and the botanical garden (BG) of Polissia National University, 12 natural monuments (NM), six reserves (two botanical reserves (BR), a general zoological reserve (GZR), a forest reserve (FR), a landscape reserve (LR)), and four protected tracts (PT) (Fig. 1). *L. decidua*, *L. kaempferi*, *L. sibirica*, *L. gmelinii*, *L. laricina* are classified as Least Concern, *L. decidua* var. *polonica* is classified as Endangered in the IUCN Red List. All representatives of the *Larix* genus grow in groups and as solitaire trees in the Bereznivskyi Dendropark. They are 40 years old and were grown from seeds. The largest number of specimens (30) is represented by *L. decidua*, which is in good condition. The average diameter is 34.8 ± 2.0 cm and the height is 15.9 ± 0.5 m.

There are also seven specimens of *L. sibirica* growing in Bereznivskyi DP, their diameter ranges from 16 to 38 cm, height – from 13 to 26 m, the condition of the plants is good and satisfactory (Table 2).

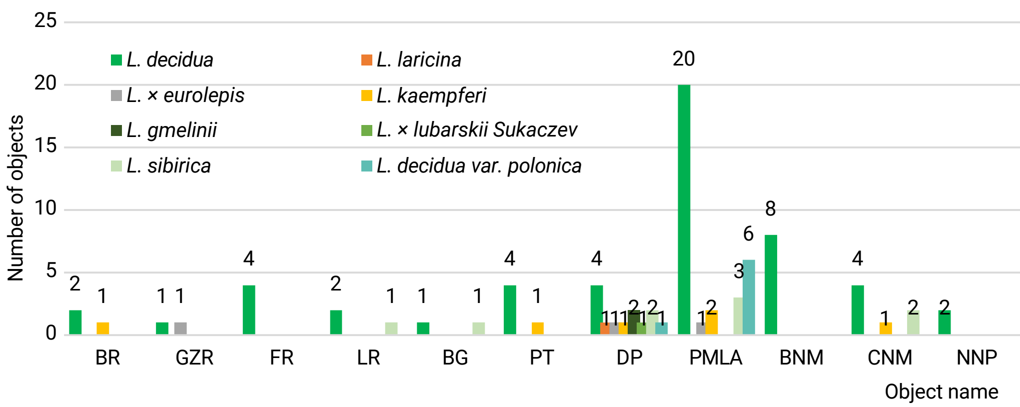

Figure 1. *Larix* species in protected areas of Ukrainian Polissia
Source: compiled by the authors of this study

Table 2. Characteristics of *Larix* L. species in man-made protected areas Ukrainian Polissia

Reserved area	Number of specimens, pcs/area, ha	Age, years	Height, m	Diameter, cm	Condition
Dubechnenskyi PMLA	5/-	60	18.5, 15.5, 16.5, 12.5, 11	21, 18, 25, 14, 16	s
Bairak PMLA	4; 1[1]; 2[2]; 3[4]/-	45	(14, 16, 12), 14[1]; (16, 12)[2]; (16, 12, 14)[4]	(29, 23, 24), 28[1]; (38, 22)[2]; (23, 24, 28)[4]	g
Litynskyi PMLA	20; 13[1]/-	140	31.7 ± 0.1; 32.0 ± 0.2	57.9 ± 2.9; 59.9 ± 1.8	g
Sadyba Lypynskoho PMLA	1/-	130	20	44	s
Novostavskyi Dendropark PMLA	2, 2[4]/-	58	16, 24, (23, 24)[4]	12, 24, (18, 18)[4]	s
Zirnenskyi PMLA	1; 1[1]/-	125	30.5; 30[1]	80; 56[1]	g
Tuchynskyi PMLA	2/-	209; 6	22.5; 2.2	90; 0.4	g
Vilkhivskyi PMLA	2+7/-	150	24, 32 + 35, 32.5, 35, 32.5, 32	70, 94 + 58, 42, 74, 56, 42	g
Horodnytskyi PMLA	10 + 7, 3[2]/-	130, 66, 18	26.6 ± 0.2; 25, 26, 24, 25.5, 26, 24, 24.5, (10, 11, 11)[2]	50.2 ± 3.2, 40, 32, 26, 44, 40, 38, 28 (12, 10, 12)[2]	g
Horodnianskyi PMLA	5/-	55	14, 16, 20, 25.5, 23	23, 18, 16, 24, 22	s
Vahanytskyi PMLA	1/-	120	26	80	g
Lyzohubivskyi PMLA	2/-	130	30, 32	62, 72	g
Miskyi Sad PMLA	1/	60	14	30	g
Vozdvyzhenskyi PMLA	1/-	120	21	47	g
Kochubeivskyi PMLA	5/-	120	30, 37, 38, 35, 34	47, 74, 62, 45, 41	g
Polonskyi PMLA	16, 2[1]/-	140	28.6 ± 1.2, (33, 29)[1]	76.5 ± 7.1, (104, 90)[1]	g
Shatskyi NNP (arboretum)	2/-	50	14.5, 14	21, 23	g
Hamarnia LR (arboretum)	2, 7[4]/-	40	18, 18, (12, 13, 12.5, 12, 20, 22, 19)[4]	28, 30, (16, 21, 14, 11, 20, 24, 18,)[4]	g, s
Rokytnivskyi Dendropark CNM	3, 5[2], 2[4]/-	59	20, 19.5, 15, 16 (22.5, 17.5, 21.5, 22, 21)[2], (22, 21.5)[4]	45, 38, 20, 22 (55, 40, 58, 40, 46)[2], (36, 32)[4]	g, s
Sarnenskyi arboretum CNM	7, 6[4]/-	57	27, 24, 24.5; 26.5; 27.5, 26, 27.5 (17, 12.5, 12, 11, 9, 11)[4]	24, 12; 14, 20; 22; 16; 20; (26, 20, 12, 10, 12, 12)[4]	з
Vysotskyi Dendropark CNM	1/-	55	11.5	24	g
Bilskyi Dendropark CNM	7/-	53	10, 10, 11.5, 12.5, 13.5, 13, 12.5	16, 19, 22, 24, 26, 13, 13	g
Alley of European Larch BNM	30/0.2	90	31.4 ± 0.9	44.6 ± 1.9	g, s, u
Modryna BNM (Mosyr Forestry)	>30/0.5	65	31.3 ± 0.2	41.7 ± 2.0	g
Modryna BNM (Horodnytsia)	>30/36	200	51.1 ± 0.5	84.9 ± 2.5	g, s
Modryna BNM (Dubechnivske Forestry)	7/-	98	31, 32, 30, 30, 30, 31, 32.5	44, 36, 38, 38, 37, 39, 66	g, s
Dereva Ekzoty BNM	>30/3.2	78	28.4 ± 0.4	32.0 ± 1.2	g, s
Smereka BNM	2/-	110	24.5; 21.5	80; 50	g
Modrynovyi Lis BNM	>30/1.6	87	33.8 ± 0.8	36.8 ± 1.7	g

Table 2, Continued

Reserved area	Number of specimens, pcs/area, ha	Age, years	Height, m	Diameter, cm	Condition
Lisovyi Dendrarii BNM	14	75	24.9 ± 0.2	24.4 ± 1.2	g, s
Bereznivskyi DP	30, 1^1; 1^2;1^3, 6^4, 6^5, 2^6, 1^7/-	40, $40^{1,2,3,4,5,6,7}$	15.9 ± 0.5, 15^1; 10^2; 13.5^3; $(24, 25, 22, 26, 14, 13, 21)^4$, $(16, 17.5, 19, 18, 20, 22)^5$, $(15)^6$, $(9.5, 11)^7$	34.8 ± 2.0, 35^1; 15^2; 22^3; $(37, 24, 33, 38, 28, 16, 26)^4$, $(26, 23, 31, 27, 23, 30)^5$, $(25)^6$, $(15, 24)^7$	g, s, u
Piliava DP	17/0.3	140	34.2 ± 0.3/31.9±0.2	63.3 ± 3.4/53.1 ± 1.6	g
Hladkovetskyi DP	7^5,/-	63	$(17, 17, 16, 17, 15)^4$, $(17, 12, 16, 11, 16, 18, 21)^5$	$(24, 20, 18, 21, 17)^4$, $(28, 18, 30, 18, 22, 26, 26)^5$	g, s
Elita DP	1/-	36	13	18	s
Polissia National University BG	6, 1^4/-	70	18, 22, 22, 23, 10, 19	20, 26, 24, 28, 13, 21	g

Note: no number – *L. decidua*, 1 – *L. decidua*var. *polonica*, 2 – *L. kaempferi*, 3 – *Larix×eurolepis*, 4 – *L. sibirica*, 5 – *L. gmelinii*, 6 – *L. laricina*, 7 – *Larix×lubarskii*; g – good condition, s – satisfactory condition, u – unsatisfactory condition; CNM – complex nature monument
Source: compiled by the authors of this study

L. gmelinii – six specimens, 23-31 cm in diameter, 16-22 m in height, good to satisfactory condition. There is one specimen each of *L. decidua*var. *polonica*, *L. kaempferi*, *Larix×eurolepis* in good condition, one specimen of *Larix×lubarskii* in satisfactory condition, two specimens of *L. laricina* in poor condition, their height is 9.5, 11 m, diameter is 15 and 24 cm (Table 2). Therewith, *L. laricina*, *Larix×lubarskii* in Ukrainian Polissia is found only in the Bereznivskyi dendropark. *L. gmelinii* is represented in two dendroparks: Bereznivskyi and Hladkovetskyi. There are 11 specimens of 63-year-old *L. gmelinii* growing in Hladkovetskyi DP, seven of which are in good to satisfactory condition (two have broken tops), their diameter ranges from 18 to 30 cm, height – from 11 to 21 m (Table 2), four specimens are dry.

According to F.R.A. Widagdo *et al*. (2020), the area of *Larix gmelinii* stands in northeastern China has increased significantly following a massive reforestation programme initiated by the Chinese central government to provide biomass for global carbon emissions reduction and industrial sectors. According to the authors, a combination of *L. gmelinii* and *L. kaempferi* can achieve better growth and create ornamental stands in protected areas, and the latter species has been spreading in protected areas of Ukrainian Polissia for the last 30 years.

Of the five identified species growing in natural and man-made protected areas of Ukrainian Polissia, *L. decidua* Mill. is the most widespread. In the PMLAs and in NMs, *L. decidua* grows mainly as a solitaire tree and in groups of 2-15 specimens. Moreover, *L. decidua* is used as an accent both in the parks created in the 19th century (Figs. 2b, 2c, 2d) and in the parks of the 20th century (Fig. 2a). Their age ranges from 45 (Bairak PMLA) to 209 years (Tuchynskyi PMLA). J. Michalczuk & M. Michalczuk (2022) note that man-made parks perform many useful functions for people and are also a centre of biodiversity. Researchers have found that the size of the park and the presence of large trees have a positive effect on the amount of biodiversity. Such areas are important for species with greater ecological plasticity and can support biodiversity in the agricultural landscape. To preserve ecologically valuable trees and reduce the adverse anthropogenic impact, it is necessary to create “wild zones” in parks (Michalczuk & Michalczuk, 2022). In the authors’ opinion, when developing the functional zoning of the PMLAs, the places where trees over 100 years old grow should be designated as reserved areas of parks.

a b c d

Figure 2. *Larix decidua* in man-made protected areas of Ukrainian Polissia

Note: a – Dubechnenskyi PMLA (Volyn region); b – Vahanytskyi PMLA (Chernihiv region); c – Polonskyi PMLA (Khmelnytskyi region); d – Lyzohubivskyi PMLA (Chernihiv region)

Source: photographs taken by the authors of this study

One of the most common of protected areas is natural monuments (NMs), where *Larix decidua* grows in groups (Modryna Botanical Nature Monument (BNM) (Dubechny Forestry), Smereka BNM (Fig. 3b), Bilskyi Dendropark BNM). In pure (Modryna BNM (Fig. 3a), Modrynovyi Lis BNM (Fig. 3c), with an area of 0.2 to 1.6 ha) and mixed stands (Alley of European Larch BNM (Fig. 3d), Dereva Ekzoty BNM, with an area of 0.2 to 3.2 ha). The Modrynovyi Lis BNM is located in Volyn region, in the Hubyn Forestry, quarter 13, stand 19, and covers an area of 1.6 ha (Table 2). *L. kaempferi* (Rokytnivskyi Dendropark CNM) also grows in small groups (Table 2). On the territory of the Hubyn BR, there are 90-year-old monocultures of *L. decidua* (Modrynovyi Lis BNM). At 60 years old, the average height of the larch trees was 27 m, with a diameter of 32 cm. At the age of 90, the average diameter is 36.8 ± 1.7 cm and the height is 33.8 ± 0.8 m. The condition is good (Table 2).

a b c d

Figure 3. *Larix decidua* in man-made areas of Ukrainian Polissia

Note: a – Modryna BNM (Zhytomyr region); b – Smereka BNM Sirche LR (Volyn region); c – Modrynovyi Lis BNM (Volyn region); d – Alley of European larch BNM (Volyn region)

Source: photographs taken by the authors of this study

In Volyn region, in Kopachiv forestry quarter 17, stand 1, a 90-year-old mixed larch-oak-hornbeam stand with the status of Alley of European larch BNM is growing on an area of 0.2 ha (Fig. 3d). The composition is dominated by *L. decidua*, which grows in a row along the road. Planting scheme row *L. decidua*, row *Q. Robur*, row *Carpinus betulus* L., row *Q. robur,* row *C. betulus*, row *Q. robur,* row spacing 2 m. There is occurrence of *Tilia cordata Mill.* In the undergrowth – *Euonymus verrucosus* Scop. The condition of *L. decidua* is good and satisfactory. Suppressed *L. decidua* grow in a satisfactory condition, or have fallen out, provided that the next row has *Q. robur*. Plants opposite to which *Q. robur* is absent are in good condition. The average diameter of *L. decidua* is 44.6 ± 1.9 cm, and the average height is 31.4 ± 0.9 m. The average diameter of *Q. robur* – 37.4 ± 1.7 cm, height – 27.0 ± 0.6 m. In the Volyn region, Dubechny forestry, quarter 40, stand 13, there is a 98-year-old mixed stand of *Pinus sylvestris* L., Quercus *robur* L. and *L. decidua* on an area of 0.2 ha. *L. decidua* grows as a group of 7 specimens (Table 2), which were assigned the status of Modryna BNM. The average diameter of *L. decidua* is 42.3 ± 4.0 cm, and the average height is 30.8 ± 0.3 m. The condition is good and satisfactory. The minimum diameter of *L. decidua* is 36 cm, the maximum is 66 cm, the minimum height is 30 m, and the maximum is 32.5 m. *L. decidua* forms self-seeding in open areas at a distance of 50 m from a group of larch trees. Modryna BNM (Affiliate "Liubomyl Forestry" the State Enterprise "Forests of Ukraine"), Mosyr Forestry, quarter 14, stand 18, 0.5 ha, 65-year-old *L. decidua* in a mixed stand with P. sylvestris, *Q. robur* and *C. betulus*. The condition of the plants is good. In 2015, on the eastern side of the stand, in the bordering allotment where *P. sylvestris, Q. robur* grew, the principal felling was performed, after which *L. decidua* began to fall out, uprooted in westerly winds. In the harvested areas, *L. decidua* began to regenerate by self-seeding (Fig. 4) at a distance of 40 to 100 m to the north of the stand with *L. decidua* (Modryna BNM). The amount of self-seeding is one specimen of *L. decidua* per 3-4 m^2, the self-seeding covers an area of 0.05 ha. The height of *L. decidua* varies from 0.25 cm to 2.65 m, the trunk diameter from 0.5 cm to 3 cm.

a b c

Figure 4. Restoration of *L. decidua* and *L. kaempferi*
in the protected areas of Ukrainian Polissia (Volyn region)

Note: a – Modryna BNM, *L. Decidua* self-seeding; b – Riznolissia GZR, *L. Decidua*; c – Riznolissia GZR, *L. kaempferi*

Source: photographs taken by the authors of this study

M. Dekker *et al*. (2007) concluded that natural regeneration in gaps in Douglas-fir forest stands in the Netherlands consists mainly of *Betula pendula* (Roth.), *Pinus sylvestris* (L.), *Larix kaempferi* (Carr.) and *Pseudotsuga menziesii* (Mirb. Franco). Although these species are well-known, the autogenous development of these species in an unmanaged plant community is beyond the scope of conventional forestry experience. During the regeneration, *Betula, Larix, Pseudotsuga* will share the available light, but *Pinus* will be shaded and given its need for light, may not be able to compete. During natural regeneration at the Modryna BNM, 10-year-old *L. decidua, P. sylvestris, and B. pendula* do not compete and there is enough light at this age.

BNM of local importance Dereva Ekzoty in Chernihiv region, Radomske Forestry, quarter 62, stands 15 (2.4 ha) and 16 (0.8 ha) is represented by a 78-year-old mixed stand of *P. sylvestris*, *L. decidua*, *Abies alba* Mill. *Picea abies* Karst. and *Q. robur*, where *L. decidua*, *A. alba* are exotic plants for this region (Fig. 5a). The condition of *L. decidua* is good and satisfactory, and the condition of *A. alba* is satisfactory and unsatisfactory; there are dry plants and only a few specimens in good condition. The average diameter of *L. decidua* is 32.0 ± 1.2 cm, and the average height is 28.4 ± 0.4 m (Table 2). The average diameter of *A. alba* is 15.8 ± 1.1 cm, and the average height is 13.5 ± 0.8 m. Biometric parameters and condition of *L. decidua* are much better than those of *A. alba*.

a b c d

Figure 5. *Larix decidua* in natural and man-made protected areas of Ukrainian Polissia

Note: a – BNM Dereva Ekzoty (Chernihiv region); b – CNM Bilskyi Dendropark (Rivne region); c – Piliava DP (Rivne region) (Zhytomyr region); d – Tsumanska Pushcha PT (Rivne region)

Source: photographs taken by the authors of this study

In 1951, a group of 6 specimens of *L. decidua* and one specimen of *Larix sibirica* Ledeb were planted in the Polissia National University BG. *L. decidua* that have survived to date are in good condition (Table 2). In the Piliava Dendropark, quarter 63, stand 16, 140-year-old *L. decidua* grows on an area of 0.3 ha (Fig. 5c), the average height is 31.9 ± 0.2 m, the average diameter is 53.1 ± 1.6 m. The condition of *L. decidua* is good. *L. decidua* was planted in historical parks during the 20th and 21st centuries, e.g., in 1961, a forest nursery of *L. decidua* was established in the Ivnytskyi PMLA on an area of 0.1 ha, with a planting scheme of 1×1 m. Currently, the diameter of 60-year-old *L. decidua* ranges from 14 cm to 36 cm, the height from 17 to 22 m, and the condition of the plants is good and satisfactory. In 1968, there were 13 European and Siberian larch trees in Yuri Gagarin Park PMLA, and now there are two 90-year-old European and Siberian larch trees and five 25-year-old *L. decidua* trees. Plant condition – good. The 90-year-old *Larix sibirica* is 52 cm in diameter and 17 m high (Fig. 6a). There is one 8-year-old specimen of *L. decidua* growing in the Horodotskyi PMLA. An alley with *L. kaempferi* has been created in the Slovianskyi PMLA. *L. kaempferi* is 20 years old. Plant condition – good. *L. decidua, L. gmelinii* are part of the collection of arboretums and dendrological parks (Figs. 6b, 6d).

a b c d

Figure 6. Larix *species* in man-made protected areas of Ukrainian Polissia

Note: Y. Gagarin Park PMLA, *L. sibirica* (Zhytomyr region); b – Hamarnia LR (arboretum), *L. decidua* (Zhytomyr region); c – Rokytnivskyi Dendropark CNM, *L. kaempferi* (Rivne region); d – Hladkovetskyi DP, *L. gmelinii* (Zhytomyr region)

Source: photographs taken by the authors of this study

In the Tsumanska Pushcha protected tracts (Kivertsivskyi NNP)**,** Horynske Forestry (Volyn region), 70-year-old *L. decidua* grows as an alley and as a row planting along oak-pine-hornbeam-linden stands (quarter 19, stand 11) (Fig. 5d) and 80-year-old L. *decidua* – pine-birch-oak-linden stands (quarter 19, stand 12), respectively, the average height of *L. decidua* is 33.2 ± 0.3 m, the average diameter is 41.9 ± 1.2 cm and the average height is 33.0 ± 0.3 m, the average diameter is 37.8 ± 1.4 cm, respectively. In the oak-hornbeam-linden stands (quarter 19, stand 20), 70-year-old *L. decidua* have an average height of 32.6 ± 0.5 m and an average diameter of 42.9 ± 1.9 cm, in pine-birch-linden stands, 80-year-old *L. decidua* have an average height of 32.9 ± 0.4 m and an average diameter of 38.2 ± 1.5 cm.

Modrynnyk FR (Irzhava forestry, Affiliate "Nizhyn Forestry" the State Enterprise "Forests of Ukraine", Chernihiv region), total area 6.9 ha. In quarter 4, stand 7, there is a stand of *L. decidua* on an area of 1.2 ha (Fig. 6a), established in 1907. The stand is represented by 252 *L. decidua* trees (good condition), and there are also isolated *B. pendula* trees, *Ulmus laevis*Pall., *Acer negundo* L., *Ulmus glabra* Huds., *Quercus rubra* L., *Picea abies* Karst., *Pyruspyraster* (L.) Burgsd., *Sorbus aucuparia* L., in the undergrowth - *Rubus caesius* L., *Rubus idaeus* LL.*, Euonymus europaea* L., *Euonymus verrucosus*Scop.L., *Chamaecytisus ruthenicus* (Fisch. ex Wol.) Klásk. Since

1968, the site has served as a permanent forest seed base. The minimum diameter of *L. decidua* is 20 cm, the maximum diameter is 76 cm, the minimum height is 29 m, and the maximum height is 36.5 m. The average height of 113-year-old *L. decidua* is 33.0 ± 0.8 m, the average diameter is 52.1 ± 1.7 cm (Table 3). In 1903, in quarter 17, stand 2, on the area of 5.7 ha, a stand was created where *L. decidua* dominates (90%), B. pendula *makes up 10%* and *Q. robur, Q. rubra* – up to 0.5%). The 117-year-old *L. decidua* has an average height of 38.5 ± 0.4 m and an average diameter of 51.0 ± 1.5 cm. The condition of the plants is good (Table 3). In the undergrowth grow *S. aucuparia, E. europaea*, *E. verrucosus*, *Sambucus nigra* L., *Corylus avellana* L. Permanent forest seed base since 1967 and genetic reserve. Six plus trees grow on the site.

Table 3. Characteristics of species of the genus *Larix* L. in the natural protected areas of Ukrainian Polissia

Reserved area	Number of specimens, pcs/ area, ha	Age, years	Height, m	Diameter, cm	Condition
Tsumanska Pushcha PT	43; 24, 33; 30/-	70, 80	33.2 ± 0.3; 32.6 ± 0.5, 33.0 ± 0.3; 32.9 ± 0.4	41.9.0 ± 1.2; 42.9±1.9, 37.8 ± 1.4; 38.2 ± 1.5	g
Zhukivske PT	>30/4.0	80	32.3 ± 0.2	38.7 ± 1.1	g, s
Papyky PT	11/-	100	32.7 ± 0.3	60.7 ± 4.5	g
Riznolissia GZR	>30, > 30^2/1.4; 2.9^2	55, 52	29.1 ± 0.4; $(26.0 \pm 0.6)^2$	39.5 ± 1.7 $(36.1 \pm 1.6)^2$	g
Hubyn BR	>30/-	100	35.9 ± 0.5	50.0 ± 2.1	g
Lisova Aleia BR	20/2.3	90/23	31.6 ± 0.6/14	40.0 ± 2.6/18	g
Modrynnyk FR	>30/1.2; 5.7	113; 117	33.0 ± 0.8 38.5 ± 0.4	52.1 ± 1.7 51.0 ± 1.5	g

Note: no number – *L. decidua* Mill., 2 – *L. kaempferi*; g – good condition, s – satisfactory condition
Source: compiled by the authors of this study

The Lisova Aleia BR is located in the Volyn region, Moshchanytsia Forestry, quarters 46, 50, 51, on an area of 110.4 ha. The 90-year-old *L. decidua* grows in a pine stand along the Lutsk–Rivne Road in quarter 51, stand 21, with an area of 3.0 ha (Fig. 6d). The condition of *L. decidua* is good. The average height is 31.6 ± 0.6 m, and the average diameter is 40.0 ± 2.6 cm (Table 3). In quarter 51, stand 9, a mixed stand was created on an area of 2.3 ha, including *Pinus sylvestris* L., *L. decidua, L. kaempferi*, *Q. rubra*, *B. pendula, C. betulus,* the latter two species of natural origin. 23-year-old *L. decidua, L. kaempferi* are in good condition, bear fruit, their diameter is 14-18 cm, height is 13-14.5 m, and diameter 10-23 cm, height 13-14 m, respectively. On the territory of the Hubyn BR, quarter 18, stands 1 and 2, there is a 100-year-old stand of *L. decidua*. The average diameter of *L. decidua* is 50.0 ± 2.1 cm, height – 35.9 ± 0.5 m. Condition – good. In the Hubyn BR, quarter 12, stand 25, self-seeding of three *L. decidua* 70-100 cm tall was detected.

In 2015, mixed larch-oak-pine cultures were established in the Radomska Dacha PT with 2-year-old seedlings in quarter 80, stand 9 (according to the scheme: 2 rows of *L. decidua,* 1 row of *Q. robur*, 3 rows of *P. sylvestris,* 1 row of *Q. robur,* 2 rows of *L. decidua*). The distance between the rows is 2.5-3 m. The condition of the plants is good. In quarter 74, stand 7, on an area of 2.1 ha, 5 rows of *P. sylvestris*, 1 row of

Q. robur, 3 rows of *L. kaempferi* and *L. decidua* were planted in 2012. The condition of the plants is good. Yu. Debrynyuk & M. Belelya (2017) note that in 1-2-year-old forest cultures, European larch (1.5-2.1 times) and broadleaf larch (3.1 times) have a significant advantage in height compared to Scots pine. In 3-year-old crops, the advantage of European larch over Scots pine in terms of average height is 1.5 times, and the maximum is 1.7 times. The protected tracts of local importance Papyky is located in Moshchanytsia Forestry in quarters 27-36 on an area of 606 ha. The 100-year-old *L. decidua* grows in quarter 34, stand 8 and in quarter 29, stand 22 as an alley along the forest road in the amount of 7 and 4 specimens, respectively (Table 3).

The Zhukivske PT covers an area of 4.6 ha in Smorzhivske Forestry quarter 3, stands 2, 3, 7, 34. The 80-year-old *L. decidua* grows in mixed larch-oak-hornbeam stands on the area of 1.5 and 2.5 ha (stands 2 and 7) (Fig. 7b). The plants were planted as follows: row *L. decidua*, row *C. betulus,* row *Q. robur,* row *C. betulus,* row *L. decidua.* The average height of *L. decidua* is 32.3 ± 0.2 m, the average diameter is 38.7 ± 1.1 cm (Table 3), the average height of *Q. robur* is 30.3 ± 0.5 m, the average diameter is 36.1 ± 1.5 cm, the average height of *C. betulus* is 19.5 ± 0.5 m, the average diameter is 19.5 ± 2.1 cm. The condition of *L. decidua* is good. Today, an accurate estimation of the growth of forest ecosystems is essential for understanding carbon sequestration and achieving carbon neutrality goals. However, the key environmental factors that influence volume growth differ across scales and functional plant types. H. Tian *et al*. (2022) note that altitude has a positive effect on stock growth in *Larix* forests, but a negative effect on stock growth in *Quercus* forests. Similarly, the impact of other environmental factors on stock growth varies depending on the origin of the stands (man-made and natural) and the functional types of plants *(Larix* vs. *Quercus*).

a b c d

Figure 7. Species of the genus *Larix* in the natural protected areas of Ukrainian Polissia

Note: a – Modrynnyk FR, *L. decidua* (Chernihiv region); b – Smorzhivske PT, *L. decidua* (Rivne region); c – Riznolissia GZR, L. kaempferi (Volyn region); d – Lisova Aleia BR, *L. decidua* (Volyn region)

Source: photographs taken by the authors of this study

Riznolissia GZR covers an area of 128 ha, *L. decidua* and *L. kaempferi* grow in quarter 32 on two objects in stand 19 on an area of 1.4 ha. This is a mixed larch-oak-willow-birch forest, dominated by *L. decidua*. The average diameter of *L. decidua* is 39.5 ± 1.7 cm, the average height is 29.1 ± 0.4 m (Table 3), the average diameter of *Q. robur* is 31.3 ± 1.8 cm, the average height is

26.6 ± 0.5 m, the average diameter of *Alnus glutinosa* (L.) Gaerth. is 30.8 ± 5.8 cm, the average height is 25.7 ± 0.5 m. The condition of *L. decidua* is good. Specimens of *L. kaempferi* occur on the site. Propagated by self-sowing. A group of self-sowing *L. decidua* plants consisting of seven specimens on an area of 4 m^2 aged 4-5-7 years was found. Their heights are 1 m, 1 m, 1 m, 2 m, 3.5 m, 3.5 m, 4.5 m. In stand 16, on an area of 2.9 ha, *L. kaempferi* makes up 5% of the mixed oak-birch-alder stand (Fig. 7c). The average diameter of *L. kaempferi* is 36.1 ± 1.6 cm, the average height is 26.0 ± 0.6 m, the average diameter of *Q. robur* is 22.5 ± 0.9 cm, the average height is 21.6 ± 0.4 m. The condition of *L. kaempferi* is good, it reproduces by self-sowing (Fig. 4c). A single specimen of 2-year-old *L. kaempferi*, 10 cm high, was found at 20 m from the mother plant. K.F. Suzuki *et al*. (2021) note that *L. kaempferi* stands can protect native species from prevailing winds and promote natural forest regeneration by improving local environmental conditions for native species in the short term. In ecosystems where introduced species have already adapted, harnessing their positive functions rather than rapidly eradicating them from the landscape can be beneficial for long-term restoration goals. F. Chen *et al*. (2015) found that the introduction of *Larix kaempferi* (Lam.) from Japan to China in the 1960s resulted in significant changes in microbial functional diversity and soil activity, as well as in soil physicochemical properties in Dalaoling National Forest Park (Hubei Province, China). The change increased with the age of the stands.

Modryna BNM covers an area of 36 ha (SE Horodnytsia Forestry), where *L. decidua grows*. There are 29 plus trees of *L. decidua*. The average height of 200-year-old *L. decidua* is 51.1 ± 0.5 m, and the average diameter is 84.9 ± 2.5 cm. *L. decidua* has a maximum diameter of 174 cm and a height of 47 m. In 1998, there was a storm on the territory of Modryna BNM, after which some trees were broken or uprooted. As a result, sanitary felling was performed, after which self-seeding of *L. decidua appeared*. Based on dendroecological studies in mixed *Larix decidua–Picea abies* forests in the Tatras (Western Carpathians) over the past 200 years, they found that wind-driven windstorms prevailed in the 19^{th} and 20^{th} centuries, which were more extensive in the 19th century, but their frequency in the two centuries was similar. The intervals between major events were long enough to form dense stands that could be easily blown away over wide areas, but the gaps were short enough to allow light-demanding *L. decidua* to grow in stands of shade-tolerant *P. abies*. C. Wu *et al*. (2022) note that thinning measures are valuable proposals for changing forest density, can promote tree growth, and provide valuable information for assessing future forest dynamics and changes in carbon sequestration and carbon neutrality under climate change. The practice of thinning in 15 parks over 5 years in Korea has increased biodiversity in stands by preventing the spread of invasive species, resulting in a species composition similar to that of natural forests (Cho *et al*., 2020).

The species, varieties, and hybrids of the *Larix* genus were used to create 6 types of stands in the protected areas: solitaire trees, groups, row plantings, alleys, pure and mixed stands (Fig. 8). Groups predominate (48%), with groups of one species or variety and mixed groups. The condition of the plants depends on the composition of the group. In the monogroup with *Larix decidua*, the condition of the plants is good (Litynskyi PMLA, Polonskyi PLMA, Rokytnivskyi Dendropark CNM). In the Novostavskyi Dendropark PMLA, where *Larix decidua* Mill. grows with *Juglans nigra* L., *Juglans cinerea* L., *Juglans cinerea* L. – the condition is satisfactory; *Larix sibirica* Ledeb., growing with *Quercus rubra* L. and *Betula pendula* Roth. also have a satisfactory condition (Table 1). There are 5 specimens of *Larix decidua* in the Horodnianskyi PMLA growing in a group surrounded by *Tilia cordata* Mill., *Picea abies* Karst., *Ulmus glabra* Huds. – in satisfactory condition, fruiting is weak.

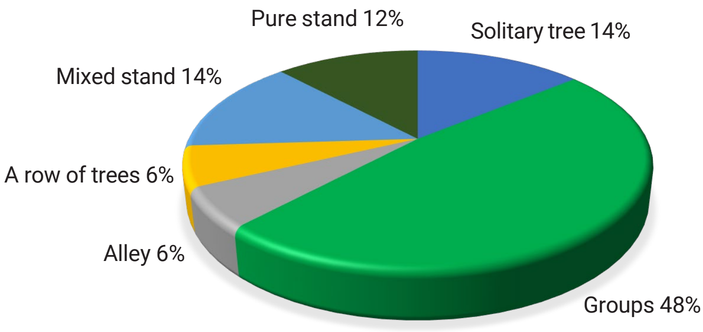

Figure 8. Stand types of *Larix* L. taxa
Source: compiled by the authors of this study

The age structure is mainly represented by medieval and old larch (Fig. 9). There are slightly fewer plants of potential age and ripeness, which is 15% each.

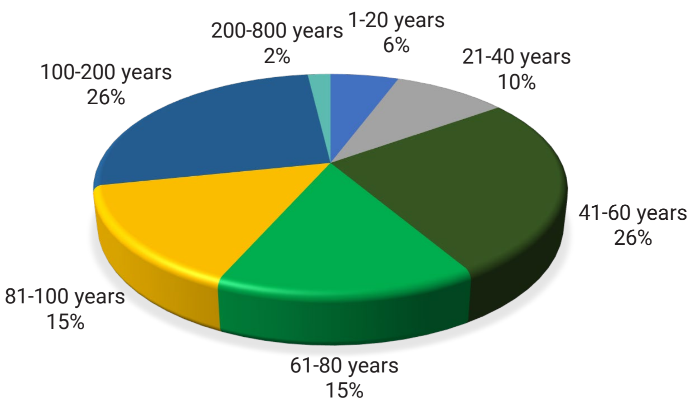

Figure 9. Age structure of *Larix* L. taxa in the protected areas of Ukrainian Polissia
Source: compiled by the authors of this study

Seven species, one variety, and two hybrids grow in protected areas of Ukraine (Table 4). *Larix decidua* and *Larix sibirica* are most widespread in all natural zones of Ukraine. *Larix laricina* (Du Roi) K. Koch, *Larix*×*lubarskii* Sukaczev, *Larix griffithii* Hook. f. grow mainly in arboretums. *Larix kaempferi* (Lamb.) Carrière has also proved to be a good performer in the protected areas, reaching the age of 100 years in five sites. 200-year-old representatives of *Larix decidua* grow in 5 protected areas, and 270-year-old specimens in Mala Sofiivka PMLA (Vinnytsia region, Forest-Steppe zone). 250-year-old *Larix decidua* var. *polonica* in the Pidhirivtsivskyi PMLA in the Ukrainian Carpathians region.

Table 4. Representation of the genus *Larix* L.
in the protected areas of Ukraine (number of objects)

Taxa	Zone				
	mixed forests	Forest-Steppe	Steppe	broadleaf forests	Ukrainian Carpathians
Larix decidua Mill.	52 (25)*	98 (45)	12 (1)	77 (24)	53 (11)
Larix decidua var. *polonica*.	7 (4)	10 (5)		20 (10)	17 (3)
Larix kaempferi (Lamb.) Carrière	7	9 (1)	5	16 (2)	11 (2)
Larix × *eurolepis* A. Henry	3	- (1)			- (1)
Larix sibirica Ledeb	9 (1)	41	8	13 (1)	9
Larix gmelinii (Rupr.) Kuzen.	2	10	4	2	6
Larix laricina (Du Roi) K. Koch	1			1	1
Larix ×lubarskii Sukaczev	1				
Larix griffithii Hook. f.		1			1
Larix occidentalis Nutt.		5	1	1	1
Larix czekanowskii Szafer		3	1		1

Note: ()* – trees over 100 years old are indicated in brackets

As cities grow, green spaces play a more central role in providing ecosystem services. Many ecosystem services depend on the interaction of soil-plant systems, and the type and age of plants affect the quantity and quality of services. Having investigated 41 urban parks and five non-urban forest areas in the cities of Helsinki and Lahti (Finland), G. Francini *et al*. (2021) found that urban green spaces function similarly to non-urban green spaces. Specifically, plants lead to changes in the soil environment, similar to modifications in non-urban ecosystems. The choice of plants when building or renovating parks can improve the quality and quantity of ecosystem services provided by urban green spaces. Although vegetation changes the soil of urban green spaces over time, similar to non-urban green spaces, the effect of vegetation type is greater in non-urban green spaces. Tree species that are appropriate for the area can provide greater environmental benefits by improving the physical and chemical properties and fertility of the soil and increasing carbon sequestration.

Conclusions

Eight species, one variety, and two hybrids of larch grow in Ukraine's five protected areas. Four species (*Larix decidua*, *Larix kaempferi*, *Larix sibirica*, *Larix gmelinii*) are represented in Ukraine in the zone of mixed and broadleaved forests, Forest-Steppe, Steppe zones, in the Ukrainian Carpathians. In Ukrainian Polissia, 34% of objects with representatives of the genus *Larix* are concentrated in Volyn region, slightly less – 21.3% each in Rivne and Zhytomyr region, 17% – in Chernihiv region. *L. decidua* grows in pure stands and as a part of mixed pine-larch-fir-spruce-oak, larch-oak-alder-birch, oak-pine-hornbeam-linden, larch-oak-alder-birch, larch-oak-hornbeam, larch-pine stands. *L. decidua* has better biometric parameters and condition than *Q. robur*, *P. sylvestris, A. alba*, *A. glutinosa.* A total of six types of stands with larch were identified, with solitaire trees and groups predominating in the PMLAs and NMs. The age structure of species, varieties, and hybrids in the mixed forest zone is represented by 26% of plants aged 41-60 and 100-200years, 15% of potentially old (81-100years) and larch trees aged 61-80years. Only one *L. decidua,* 209 years old, grows in Tuchynskyi PMLA. Larch trees under 20 years old and 21-40 years old *(L. kaempferi* and *L. decidua*) are rare. At six objects, *L. decidua* is renewed by self-seeding. At two objects is *L. kaempferi* renewed.

The obtained results will allow comparing quantitative and qualitative indicators of *L. decidua*, *L. kaempferi*, *L. sibirica*, *L. gmelinii*, *L. laricina*, *Larix×eurolepis*, *Larix×lubarskii* success of introduction and their status in different natural zones of Ukraine. Using the obtained quality indicators of *L. decidua*, *L. kaempferi*, *L. sibirica*, *L. gmelinii*, it will be possible to select the best specimens, considering the availability of reproduction to obtain high-quality planting material for the subsequent creation of diverse types of stands in various protected areas. Research can be aimed at creating an optimal composition of stands with *L. decidua*, *L. kaempferi, L. gmelinii*.

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None.

Conflict of Interest

None.

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Представленість роду *Larix* Mill. на заповідних територіях Українського Полісся

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Анотація. *Larix decidua* Mill. може стати більш важливою ніж *Picea abie*s (L.) Karst для заліснення територій і відновлення природного балансу, тому необхідним є вивчення даного виду. Саме тому метою дослідження була провести інвентаризацію таксонів роду *Larix* на заповідних територіях зони мішаних лісів Українського Полісся, проаналізувати їхнє поширення, вікову структуру, застосування. Застосовано методи дослідження: маршрутні, аналітичні, порівняльного аналізу, систематизації. Встановлено, що на охоронних територіях зони мішаних лісів України зростає 5 видів, один різновид та два гібриди модрин. Визначено, що *L. decidua* набула найбільшого поширення – вона зростає у парках-пам'ятках садово-паркового мистецтва, пам'ятках природи, заповідних урочищах, заповідниках у чистих та мішаних насадженнях, алеях, рядових посадках, групах та як солітер. *L. sibirica*, *L. kaempferi* зростають як солітер та у групах від трьох до 10 екземплярів у 9 та 10 охоронних об'єктах відповідно. *L. gmelinii* є у двох дендропарках, *L. laricina* – у одному. *Larix decidua var. polonica* (Racib. ex Wóycicki) Ostenf. & Syrach малопоширена, представлена групами у 6 парках-пам'ятках садово-паркового мистецтва та Березнівському дендропарку. *Larix* × *eurolepis* A. Henry. набуває поширення у чистих та мішаних насадженнях, зростає в алеї у парку-пам'ятці садово-паркового мистецтва Слов'янський, у групах – у ботанічному заказнику Лісова алея, Березнівському дендропарку та у мішаних насадженнях загальнозоологічного заказника Різнолісся. Вікова структура досить різноманітна, представлена *L. decidua, L. sibirica*, *L. decidua var. polonica* віком від 100 до 200 років. Інші види, різновид та гібрид представлені екземплярами віком від 3 років (*L.×eurolepis*) до 80 років (*L. kaempferi*). 69,2 % насаджень з модрин мають добрий стан, 28,9 – задовільний і лише 1,9% – не задовільний стан. Результати досліджень можуть бути використані при подальшому створенні чистих на мішаних насаджень, алей тощо в зоні мішаних лісів

Ключові слова: модрина; види; парк-пам'ятка садово-паркового мистецтва; пам'ятка природи; дендропарк

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Impact of forestry on ecosystems and the economy: Regional case studies

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Abstract. In modern conditions, environmental protection, and forests in particular, is becoming one of the main components of effective public policy, given their importance in the context of the state's welfare. Hence, it is essential to consider the impact of forestry on the development of the country's economy and its ecological systems. The study aims to conduct a comprehensive analysis of all aspects of the development of the forestry sector in Ukraine, paying attention to the problems existing in this area. The main methods used in the study were analysis, forecasting, and abstraction. The study described the role of forestry and its impact on the economy in different regions of Ukraine and the environment. The study analysed statistical data describing the current rate of logging according to open statistical sources and forest restoration in Ukraine. The study found

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that the current state of forestry and use of forest resources in Ukraine is insufficient to promote the economic and environmental development of the country and that Russia's full-scale invasion significantly affects the prospects for solving existing problems. Therefore, recommendations were made to improve the current state of affairs in forestry, including expanding the responsibility of forest users and wood products producers, increasing the efficiency of forest management, promoting innovation in forestry. The work brings new knowledge in the context of the study of the state of environmental development in Ukraine, and in particular the state of its forest resources. Its conclusions may be important in the context of formulating public policy and creating their development directions for forestry enterprises: woodworking, logging, tourism

Keywords: environment; sustainable regional development; forest sector of the economy; state forestry and environmental policy; law enforcement

Introduction

The role of forestry in terms of economic and environmental impact is significant. Wood-based products are an important component of certain sectors and industries, including construction, furniture, paper, packaging. Forests create places for recreation, attract tourists and improve the health of residents. The environmental impact of forest management can be significant and has both positive and negative consequences. Responsible forest management helps to preserve the diversity of plant and animal species, allows for the rational use of water resources, and reduces carbon emissions. At the same time, negative impacts can lead to loss of biodiversity, reduced soil fertility, water pollution, and large-scale environmental losses associated with deforestation. Unbalanced forest use and ineffective forest management lead to resource depletion, forest degradation and negative environmental impacts. Therefore, sustainable development of forest use and management is becoming an important task to ensure the long-term well-being of both the economy and the environment, and research into the development of this area in different countries remains relevant.

Many scientists and researchers have been studying the state of forestry in Ukraine and its impact on the country's socio-economic development and ecology in recent years. G. Poiasnyk (2023) studied the peculiarities of Ukrainian nature management and its prospects in the context of global instability. He described in some detail all the peculiarities associated with the use of natural resources in Ukraine during the war, paying attention to the problems of forestry. He proposed several measures to improve the current situation for both forestry enterprises and government officials. M.A. Khvesyk & O.V. Sakal (2019), investigated what instruments of financial and economic regulation of environmental management exist and how they can be used in Ukraine. V. Kovalyshyn (2023) conducted a detailed analysis of the reform of the forestry system in Ukraine, which took place in 2022-2023, pointing out its strengths and weaknesses and potential threats to sustainable forest management.

S. Kovalchuk (2023) also considered the possibilities of the country's transition to sustainable forestry recovery in the post-war period. The scientist noted that this requires reforming the forestry sector with the implementation of environmental and economic instruments. O.P. Yaremko (2021) focused on the study of forestry development, in particular in the Podilskyi economic region. The scientist noted that the forestry of this region has significant prospects for development, provided that forestry processes are coordinated. N.I. Tsehelnyk (2021) studied the economic state of the forestry industry in Ukraine and its impact on the sustainable development of forestry enterprises. T.V. Kobylynska & N.Yu. Huseva (2020). She noted the increasing role of forestry in the economic and environmental situation of the country, identifying key areas for improving forestry accounting. Among the above-mentioned works of scientists, rather little attention is paid to the component of regional development, which, among other things, makes this study relevant. The issues of addressing socio-economic and environmental problems in the forestry sector, in particular, optimising the ratio of deforestation, restoration, and meeting the needs of the market and local communities for forest resources, also require additional attention. Thus, the purpose of this study is to assess the impact of forestry on ecosystems and the economy in Ukraine.

Materials and Methods

The study used certain statistics taken from the website of the State Statistics Service of Ukraine, which characterised open data on deforestation and reforestation in Ukraine (Environment of Ukraine, 2023). However, it should be noted that this source provides rather limited data: for example, in terms of reforestation, information was available only from 2018 to 2022, while data on deforestation was provided for 2000-2020. Thus, data on the reduction of forest area was calculated for the period from 2018 to 2020, with their gradual restoration in the following period. The calculation was performed using the formula:

$$X = D - R, \tag{1}$$

where: D – deforestation in thousand ha (D – deforestation); R – restoration (forest restoration in thousand ha); X – real volumes of forest restoration/deforestation in thousand ha as of a certain year (if the value of X is positive, then there was a "net deforestation", i.e. a decrease in the volume of forest resources in real current terms; if the indicator was negative in a given year, then forest regeneration was present).

The analysis also used data from the State Agency of Forest Resources of Ukraine on the country's forest area by region to further determine the share of regeneration/deforestation. This made it possible to calculate the percentage growth rates of logging in individual regions and oblasts of Ukraine, which is very important for concluding the future effective development of forestry in the country. All calculations and plots were made using the Microsoft Excel spreadsheet processor and recorded in tables.

The main approach used in the study was systematic. It was used to build a unified system within which various factors affecting both the development of certain regions of the country (from an economic and environmental point of view), in particular Polissia and the Carpathian region, and the state of its forestry interact with each other, which makes it possible to increase the efficiency of such a model and, consequently, the conclusions. This analysis considered both quantitative and qualitative data used in the study to understand the state of forestry in Ukraine. The historical method was used to evaluate trends from the past that have a significant impact on the current state of development of this component, and thus to gain a more accurate understanding of the reasons for current trends in it. Forecasting was used to conclude the future development of the forestry sector in the country and, in particular, its impact on the economic and environmental components. Abstraction was used to increase the effectiveness of the conclusions drawn by reducing the number of factors considered during the study. This method was used to consider only those factors that had a sufficiently high impact on the object of study and, therefore, were important in the analysis. The tabular method was used to present the information collected during the study on the state of the forest fund in Ukraine in a simpler way. This study complies with ethical standards and considers the requirements set out in international conventions such as the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973).

Results

Forestry in general is a branch of agriculture that includes forest management, maintaining and preserving the conservation functions of forests, and exploiting forest resources to meet various needs, including economic, environmental, and social. Its main goal is the conservation and responsible use of forests, ensuring the rational use of timber and other forest resources. Forestry includes planning as a primary management function (development of forest management plans related to logging, reforestation and maintenance, control of forest fires and pests, as well as assessing the sanitary condition and structure of forests), organising forestry activities (harvesting timber, forest products, mushrooms and berries that can be used for industry, construction, energy and food), environmental monitoring (monitoring the impact of forestry on the environment and the sanitary condition of forests and developing measures to preserve biodiversity and protect natural ecosystems).

Forestry in Ukraine is an important component of the agricultural and natural resource management sectors. In general, Ukraine is a forest-deficient country, with only 15.9% of its territory covered by forests. A significant number of Ukrainian forests also perform important public (environmental, protective, social) functions and have limited commercial value. At the same time, Ukraine has highly productive commercial forests, concentrated mainly in the Carpathians and Polissia, which are subject to large-scale industrial exploitation. Forests in Ukraine also serve as a place for recreation and tourism, which is particularly important for the Carpathian region, where local people and businesses are heavily involved in providing these services. Accordingly, attention should be paid to the significant role of forests in maintaining ecosystem services, which is important for sustainable development and environmental protection in the country (Reim *et al.*, 2019; Parks & Abatzoglou, 2020). Forestry in Ukraine is controlled by authorised state bodies in the forestry and environmental sphere (Kobetska *et al.*, 2019), including the State Ecological Inspectorate of Ukraine, departments of ecology and natural resources operating under regional state (military) administrations.

Table 1 below shows some key indicators of the use of forest wood resources obtained from the website of the State Statistics Service of Ukraine, which characterise the development of forestry and forest resource endowment in certain regions of Ukraine.

Table 1. Indicators characterising deforestation in the forestry sector of Ukraine in the period from 2000 to 2020

Indicator	**Area covered by logging from 2000 to 2020, thousand ha**	**The area on which logging was carried out on average per year in this period, thousand ha**	**Average area of logging from 2000 to 2004, thousand ha**	**Average area of logging from 2016 to 2020, thousand ha**
1	2	3	4	5
Ukraine	8957.7	447.9	451.5	414

Table 1, Continued

1	2	3	4	5
Autonomous Republic of Crimea	54.6	2.7	4.5	-
Vinnytsia region	417.5	20.9	24.4	16.4
Volyn region	708	35.4	37	28.9
Dnipropetrovsk region	57.8	2.9	3.3	3.2
Donetsk	78.7	3.9	3.1	3.8
Zhytomyr region	1132.2	56.6	44.5	63.2
Zakarpattia region	510.7	25.5	23.9	23
Zaporizhzhia region	36.9	1.8	1.6	1.6
Ivano-Frankivsk region	497.4	24.9	24.1	24
Kyiv region	598.4	29.9	29.6	31.9
Kirovohrad region	99.3	5	6.2	4.4
Luhansk	228.1	11.4	10.1	9.4
Lviv region	502.8	25.1	24	24
Mykolaiv region	64.6	3.2	5.6	2.1
Odessa region	118.5	5.9	9	3.9
Poltava region	179.6	9	10.2	7.9
Rivne region	879.7	44	45.9	38
Sumy region	455.2	22.8	21.7	21.9
Ternopil region	189.3	9.5	10.8	7.2
Kharkiv region	291.4	14.6	12.9	16.6
Kherson region	72.8	3.6	3.2	1.7
Khmelnytskyi region	341.4	17.1	20.2	15.3
Cherkasy region	392.9	19.6	20.4	18.8
Chernivtsi region	279.9	14	13.4	11.7
Chernihiv region	650.6	32.5	37.5	27.7

Note: data within the State Statistics Service of Ukraine are available only as of 2020
Source: compiled by the authors based on data from the State Statistics Service of Ukraine (Environment of Ukraine, 2023) and General characteristics of the forests of Ukraine (2023)

As can be seen from the data in Table 1, in the period from 2000 to 2020, the largest volumes of logging in Ukraine were in Zhytomyr, Rivne, Volyn and Chernihiv oblasts, which are located in the Polissia region and have significant reserves of exploitable forest resources. An important indicator is the change in the volume of logging in the country over a certain period. For this purpose, the average logging volumes for the first and last 5 years of the selected period was calculated. As can be seen from the table, the volume of logging in general tended to decrease in Ukraine. The highest relative growth rate of this indicator is observed in the Zhytomyr region, while the largest decrease is observed in Mykolaiv, Odesa, and Kherson regions. It is also necessary to understand how quickly forest regeneration is taking place in Ukraine in deforested areas. Data on the volume of forest regeneration by region are presented in Table 2.

Table 2. Volumes of forest restoration in Ukraine in the period from 2018 to 2022, thousand ha

Region	2018	2019	2020	2021	2022
Ukraine	51.52	48.84	44.8	49.36	36.85
Vinnytsia region	1.79	1.63	1.51	1.34	1.2
Volyn region	5.67	7.11	5.89	5.63	3.01
Dnipropetrovsk region	0.16	0.33	0.4	0.42	0.39
Donetsk	0.34	0.3	0.23	0.23	-
Zhytomyr region	8.46	8.17	8.01	10.66	9.72
Zakarpattia region	2.67	2.46	2.18	2.17	1.47
Zaporizhzhia region	0.62	0.52	0.45	0.76	-
Ivano-Frankivsk region	3.04	2.33	2.27	2.21	1.72
Kyiv region	4.34	3.71	3.09	2.94	1.61
Kirovohrad region	0.54	0.56	0.41	0.45	0.31
Luhansk	1.02	1.45	0.89	1.6	-
Lviv region	3.15	2.53	2.44	2.47	2.4
Mykolaiv region	0.1	0.25	0.25	0.23	0.22
Odessa region	0.21	0.06	0.07	0.14	0.05
Poltava region	1.38	1.2	1.04	1.43	1.38
Rivne region	6.27	5.13	5.33	5.44	4.65
Sumy region	1.7	1.69	1.62	1.93	1.64
Ternopil region	0.77	0.71	0.68	0.78	0.42
Kharkiv region	0.58	0.55	0.49	0.25	0.2
Kherson region	0.19	0.14	0.22	0.62	-
Khmelnytskyi region	1.54	1.62	1.38	1.33	0.98
Cherkasy region	1.49	1.4	1.31	1.39	0.96
Chernivtsi region	1.59	1.46	1.47	1.64	1.5
Chernihiv region	3.69	3.4	3.06	3.27	3.02

Note: data is available only for the period from 2018 to 2022
Source: compiled by the authors based on data from the State Statistics Service of Ukraine (Environment of Ukraine, 2023)

Table 2 shows that the volume of reforestation in Ukraine is also significant and varies significantly from oblast to oblast. For example, the Zhytomyr and Rivne regions have the highest rates, which is predictable given that these regions have the largest amount of clear-cut logging that requires further reforestation. However, it is important to understand how the pace of reforestation in Ukraine differs from the pace of logging. This can be analysed using the example of Table 3.

Table 3. The value of reforestation and deforestation in the period from 2018 to 2020, thousand ha

Region	Logging			Restoration			The difference in area between logging and restoration		
	2018	2019	2020	2018	2019	2020	2018	2019	2020
Ukraine	445.5	436.8	382	51.52	48.84	44.8	393.98	387.96	337.2
Vinnytsia region	17.6	18.4	13.7	1.79	1.63	1.51	15.81	16.77	12.19
Volyn region	31.3	33.4	23.9	5.67	7.11	5.89	25.63	26.29	18.01
Dnipropetrovsk region	2.9	2.7	2.8	0.16	0.33	0.4	2.74	2.37	2.4

Table 3, Continued

Region	Logging			Restoration			The difference in area between logging and restoration		
	2018	**2019**	**2020**	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
Donetsk	3.8	4.5	3.8	0.34	0.3	0.23	3.47	4.21	3.57
Zhytomyr region	68.1	68	63.8	8.46	8.17	8.01	59.64	59.83	55.79
Zakarpattia region	24.4	22.7	20.7	2.67	2.46	2.18	21.73	20.24	18.52
Zaporizhzhia region	1.3	1.4	1.4	0.62	0.52	0.45	0.68	0.88	0.95
Ivano-Frankivsk region	28.3	21.8	18.6	3.04	2.33	2.27	25.26	19.47	16.33
Kyiv region	29.9	35.6	36.9	4.34	3.71	3.09	25.56	31.89	33.81
Kirovohrad region	4.7	4.7	4.2	0.54	0.56	0.41	4.17	4.14	3.79
Luhansk	10	8.2	9.2	1.02	1.45	0.89	8.99	6.76	8.31
Lviv region	27.8	23.3	19.9	3.15	2.53	2.44	24.65	20.77	17.46
Mykolaiv region	1.8	2.1	1.8	0.1	0.25	0.25	1.7	1.85	1.55
Odessa region	4.3	4.1	2.2	0.21	0.06	0.07	4.09	4.04	2.14
Poltava region	8	8.6	7.7	1.38	1.2	1.04	6.63	7.4	6.66
Rivne region	42	42.8	39.4	6.27	5.13	5.33	35.73	37.67	34.07
Sumy region	24.1	23	19.9	1.7	1.69	1.62	22.4	21.31	18.29
Ternopil region	7.5	7.6	5.7	0.77	0.71	0.68	6.73	6.89	5.02
Kharkiv region	18.4	18.9	15.6	0.58	0.55	0.49	17.82	18.35	15.11
Kherson region	1.3	1.2	2	0.19	0.14	0.22	1.11	1.07	1.78
Khmelnytskyi region	17.1	15.5	14.4	1.54	1.62	1.38	15.56	13.89	13.02
Cherkasy region	20.2	17.7	19.9	1.49	1.4	1.31	18.72	16.3	18.59
Chernivtsi region	12.6	11.2	8.4	1.59	1.46	1.47	11.01	9.74	6.94
Chernihiv region	29.2	30.5	26.1	3.69	3.4	3.06	25.51	27.1	23.04

Note: the values are only for the period from 2018 to 2020, given that more data on restoration is available from 2018 to 2022, while deforestation is available until 2020

Source: compiled by the author based on the report of the State Statistics Service of Ukraine (Environment of Ukraine, 2023)

Although the data in Table 3 is not sufficient to show the full picture (it is only available for the period from 2018 to 2020), it indicates that the pace of forest regeneration in Ukraine is currently low. It is also important to note that a direct comparison of logged areas and reforestation areas is not always correct, as logging is often carried out selectively and, therefore, does not require further reforestation. Only clear cut sites are further restored by artificial (forest planting) or natural way. Therefore, a direct comparison is only appropriate for areas covered by clear-cutting and areas of reforestation. In general, the highest logging rates are observed in Zhytomyr, Rivne, and Kyiv regions. This suggests that forest exploitation in these regions is significant. Although data for 2021 and 2022 are not fully available, which can be attributed to the outbreak of hostilities on the territory of Ukraine, the closure of certain databases, and the difficulty of collecting information, especially in the temporarily occupied territories, it can be assumed that this trend in logging continues, including due to the outbreak of war and the need to use wood resources to maintain the country's defence capability. Table 4 shows the ratio of the so-called "net" deforestation (resulted of clearcuts) to the total area of forests in the regions.

Table 4. Indicators of logging rates in Ukraine in the period from 2018 to 2020

Region	Forest covered area, thousand ha	Percentage of forest covered area, thousand ha	The volume of "net" felling, thousand ha			Share of deforestation, %		
			2018	2019	2020	2018	2019	2020
Vinnytsia region	346.5	13.1	15.81	16.77	12.19	4.6	4.8	3.5
Volyn region	624.6	31	25.63	26.29	18.01	4.1	4.2	2.9
Dnipropetrovsk region	179.2	5.6	2.74	2.37	2.4	1.5	1.3	1.3
Donetsk	184.1	6.9	3.47	4.21	3.57	1.9	2.3	1.9
Zhytomyr region	1001.6	33.6	59.64	59.83	55.79	6	6	5.6
Zakarpattia region	656.7	51.4	21.73	20.24	18.52	3.3	3.1	2.8
Zaporizhzhia region	101	3.7	0.68	0.88	0.95	0.7	0.9	0.9
Ivano-Frankivsk region	571	41	25.26	19.47	16.33	4.4	3.4	2.9
Kyiv region	624.1	22.2	25.56	31.89	33.81	4.1	5.1	5.4
Kirovohrad region	164.5	6.7	4.17	4.14	3.79	2.5	2.5	2.3
Luhansk	292.4	11	8.99	6.76	8.31	3.1	2.3	2.8
Lviv region	621.2	28.5	24.65	20.77	17.46	4	3.3	2.8
Mykolaiv region	98.2	4	1.7	1.85	1.55	1.7	1.9	1.6
Odessa region	203.9	6.1	4.09	4.04	2.14	2	2	1
Poltava region	247.4	8.6	6.63	7.4	6.66	2.7	3	2.7
Rivne region	729.3	36.4	35.73	37.67	34.07	4.9	5.2	4.7
Sumy region	425	17.8	22.4	21.31	18.29	5.3	5	4.3
Ternopil region	183.2	13.3	6.73	6.89	5.02	3.7	3.8	2.7
Kharkiv region	378.3	12	17.82	18.35	15.11	4.7	4.9	4
Kherson region	116.3	4.1	1.11	1.07	1.78	1	0.9	1.5
Khmelnytskyi region	265.1	12.8	15.56	13.89	13.02	5.9	5.2	4.9
Cherkasy region	315.1	15.1	18.72	16.3	18.59	5.9	5.2	5.9
Chernivtsi region	236.7	29.2	11.01	9.74	6.94	4.7	4.1	2.9
Chernihiv region	665.7	20.9	25.51	27.1	23.04	3.8	4.1	3.5
Kyiv	31.3	37.2	8.66	8.75	-	27.7	27.9	-
Ukraine	9573.9	15.9	393.98	387.96	337.2	4.1	4.1	3.5

Source: compiled by the authors based on data from the State Statistics Service of Ukraine (Environment of Ukraine, 2023)

However, when analysing the statistical data have to be taken into account that many clear cutting areas, as a rule, are restored by forest planting during the next year after cutting was done. This also impacts on statistics of deforestation and reforestation for one year, and does not provide us with "clear picture" in forest cover change. As can be seen from Table 4 above, the largest volumes of logging are observed in Zhytomyr, Cherkasy, Khmelnytsky and Rivne oblasts. Accordingly, the pace of restoration should be higher in these oblasts, given that forests are restored over a long period. Therefore, local authorities and state-authorised bodies should pay attention to this component to promote forest restoration and reduce the area of clear-cutting that potentially can lead to deforestation. It is possible to conclude that there are certain problems associated with amount of clear cuttings in some regions, in particular in Zhytomyr and Rivne oblasts, as shown in the Tables above. Some researchers warn that if this trend continues, the entire area of forests in these regions could decline significantly within 30-38 years (Favero *et al.*, 2020; Tkachuk, 2020). At the same time, the environmental risks associated with deforestation will increase significantly, including erosion, water pollution, increased number, and scale of floods, especially in the mountainous region of the Carpathians, and reduced biodiversity.

Large-scale logging is still a problem in the Carpathians, affecting local ecosystems, biodiversity, and local communities. The Carpathian Mountains, which span several countries including Ukraine, Slovakia, Romania, Poland, and others, are facing increasing environmental challenges due to human activities, including intensive logging, urban development increasing human impact, and intensified agriculture, which is not always organic. In particular, Romania, home to the largest part of the Carpathian Mountains, has also experienced significant changes in forest due to intensive forest exploitation, driven by strong demand for timber from leading European timber companies, as well as an increase in agricultural land. Forest changes caused by clearcuts in the Carpathian Mountains have far-reaching consequences, including loss of biodiversity, erosion, and a negative impact on climate change. The forested mountains play a crucial role in regulating water flows, protecting against natural disasters, and sequestering carbon, which negatively affects the country's ecological status. Addressing these changes in the Carpathians requires a multifaceted approach, including effective law enforcement and enforcement measures, increased fines for illegal logging, sustainable forestry practices, and socially oriented initiatives to support local communities. Ecotourism and agroforestry can provide alternative sources of income for local communities and reduce pressure on forests, while reforestation and afforestation projects can increase forest cover and conserve biodiversity and ecological functions (Nayha, 2019; Guimaraes *et al.*, 2020).

From a socio-economic perspective, poor forest management can lead to loss of profits and jobs in the long term, reduced tax revenues, and reduced export opportunities for value-added products. This will result in losses for the state budget, as well as for communities and the population as a whole. The current state of use of Ukraine's forest resources does not meet the needs of economic development. At the same time, the set of environmental and economic problems described above has become more acute. Their solution is quite difficult to implement in a time of war (Raihan *et al.*, 2023). Thus, it is expected that real effective actions in this area will be taken only after the end of hostilities. After the war is over, the country will face serious environmental problems, including the destruction of ecosystems, soil and water pollution, and loss of biodiversity, especially in the territory of environmental institutions that are directly located in the war zone. The problem of mining a large part of the forested area, especially in Chernihiv, Kyiv, and Sumy regions, is extremely urgent. This makes traditional forest management, including logging operations, and the development of forest ecosystem services impossible.

Increased intensity of forest exploitation will have both regional and transboundary consequences, affecting neighbouring European countries through pollution of aquatic ecosystems and groundwater, and climate change. With this in mind, several recommendations can already be made to improve the environmental and economic situation in the forestry sector. Thus, it is necessary to implement actions aimed at increasing the responsibility of forest users and logging companies, promoting the creation of local wood processing industries for in-depth processing of wood and its reuse, creating jobs in forestry-related sectors, attracting investment. It should be remembered that forests have a very important social value, so effective forest management should also be aimed at maintaining and enhancing the social functions of forests. In addition, it is advisable to implement measures to improve the efficiency of forest management in the country and to increase the powers of administrations responsible for environmental safety. Overall, further trends in innovation and digitalisation of the economy should help improve the efficiency of forest management at the regional level in Ukraine.

Discussion

The paper describes the existing problems and difficulties in the forestry sector of Ukraine's economy. The current approaches to forest management are not always effective in the current realities of Ukraine and may lead to an aggravation of negative environmental and economic consequences over time. Therefore, some recommendations can be made (in terms of public policy) that can help avoid undesirable results in the long term in the Ukrainian context. For example, it is important to improve the system of monitoring and supervision of forestry and forest resource use, especially in regions with significant volumes of forest wood resources (Polissia and the Carpathian region). In addition, sustainable forest management practices should be promoted, including responsible logging, reforestation and conservation of forest ecosystems, and forest certification should be encouraged to ensure compliance with international standards of sustainable forest management. Where possible, efforts should be made to raise awareness of these issues among local communities, not only among local authorities but also among ordinary citizens. It is effective to support public initiatives aimed at developing agroforestry on the lands of legal entities and individuals, developing forest ecosystem services, including the introduction of ecotourism, to provide alternative sources of income and reduce pressure on forests caused by excessive logging. It is important to attract investment in forestry, including for the development of local infrastructure, transport, and logistics links, including the construction of forest roads, and the development of recreational facilities and public recreation areas. In forest management, it is advisable to use financial and economic regulation tools: economic incentives and guarantees, market, credit and mortgage, fiscal and budgetary, and innovative tools.

Previously, the forest management system in Ukraine was characterised by significant shortcomings, primarily related to the combination of economic functions and regulatory powers in the relevant state bodies (Tate *et al.*, 2019; Santoro *et al.*, 2020). This caused state interference in economic activity, corruption risks, and inadequate control over the use of forest resources. This issue was partially resolved in 2022-2023 by reforming the forestry system and establishing a single-state forest management enterprise in Ukraine based on the corporate principle. Many methods can improve the condition of forests (Zada *et al.*, 2019). However, it is necessary to understand that all of them should be applied only in a complex way, as this is the only way to achieve maximum results in improving the environmental and economic efficiency of forest resources use.

The global experience of scientific research in the field of effective forest management aimed at ensuring various functions of forests and regional development is worthy of attention. Y. Wang *et al.* (2021) studied the latest advances in the impact of research and continuous learning on improving forest management. The authors also noted that in the future, the development of in-depth training on the effectiveness of forest management will be on par and in synergy with other new-generation information technologies, such as the use of the cloud environment, the ability to work with large databases used for data analysis in forestry. The use of such technologies can indeed help solve certain problems related to forest management, including in Ukraine. However, under current conditions, their application is still unlikely due to the ongoing military conflict and the country's overall limited capacity (it is likely that even after the war is over, the country will lack the investment to implement such projects).

J. Iglhaut *et al*. (2019) substantiated the importance of data collection tools and software parameterisation to address specific research questions in the field of forest management in a transformed environment. Among the advanced tools for collecting and updating data in Ukraine, the use of drones for forest monitoring, detection of logging areas and reforestation is considered to be particularly effective. However, their use under martial law is virtually impossible due to the existing restrictions on the use of this tool for civilian purposes at present. A. Raihan & M.N. Said (2022) assessed the cost-effectiveness of climate change mitigation measures in the forestry sector, including forest conservation, afforestation, and natural regeneration, through a benefit-cost analysis. The findings confirm the importance of the forestry sector in mitigating climate change. In the context of Ukraine, as mentioned above, this is also relevant: forests as such bring many benefits to the country, including climate change mitigation.

The impact of forestry on economic development was studied by Y. Li *et al.* (2019). The authors showed that the forestry sector has a significant direct, indirect, and induced impact, creating more jobs in other related sectors of the economy than in the forestry industry itself. After reviewing and analysing the situation in terms of individual industries, the researchers showed that the woodworking industry received the greatest economic effect and benefit (it had the largest multiplier). Such conclusions suggest that, after logging, it is worth monitoring how wood is used, as it can bring different benefits in different areas.

Conclusions

The study assessed the impact of logging activities on both the environment and the economy of Ukraine. The study describes the role of the forestry sector in addressing various development needs of the country and its important role, in particular, in conserving biodiversity, providing economic opportunities, and maintaining ecological functions. The study presents a comprehensive analysis of deforestation and reforestation trends in different regions of Ukraine, highlighting the challenges and problems associated with them.

The data presented in the article shows that the problem of effective forest management is a pressing issue, as intensive logging is observed: in particular, this is evidenced by the fact that in the period from 2018 to 2020, according to the State Statistics Service of Ukraine, about 4% of the forest was cut down annually. Although the volume of clear cutting leading to potential deforestation in the country is gradually decreasing (according to available statistics from open sources, from 445.5 thousand ha in 2018 to 382 thousand ha in 2020), and there is a gradual transition to gradual and selective logging methods, the issues of responsible forest management and proper reforestation remain relevant. The data also suggests that it is important to accelerate the pace of forest regeneration to offset the impact of deforestation. Another important issue is the problem of illegal logging, which, although reduced compared to previous years, is still a pressing concern for Ukraine. It is important to address the problem of illegal logging because it poses an environmental and economic threat to the country. Although efforts have been made to combat illegal logging, more substantial actions are needed to effectively address the problem.

Further research should be devoted to assessing the state of other regional systems important for economic development and environmental well-being. For example, it remains important to analyse the impact of economic activity on water resources, as well as on carbon storage capacity and global climate change. Regular assessment of international experience in this area should be conducted to understand global trends in forest management and environmental protection.

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Conflict of Interest

None.

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Вплив лісового господарства на стан екосистем та економіку: аналіз регіональних прикладів

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Анотація. В сучасних умовах захист навколишнього середовища, та зокрема лісів, стає однією із основних складових формування ефективної державної політики, зважаючи на їхню важливість у контексті добробуту держави. Це робить актуальним розгляд впливу лісового господарства на розвиток економіки країни та її екологічних систем. Метою даного дослідження було провести комплексний аналіз усіх аспектів розвитку лісового господарства України, звертаючи увагу на наявні в даній сфері проблеми. Основними методами, що були використані під час дослідження, стали аналіз, прогнозування та абстрагування. В рамках роботи було описано роль лісового господарства та його вплив на економіку в різних регіонах України та навколишнє середовище. В рамках дослідження аналізувалися статистичні дані, що описували існуючі темпи лісозаготівель за даними відкритих статистичних джерел та відновлення лісів в Україні. Під час проведення дослідження встановлено, що сучасний стан ведення лісового господарства та використання лісових ресурсів України є недостатнім для сприяння економічному та екологічному розвитку країни, а повномасштабне вторгнення Росії значно погіршує перспективи вирішення існуючих проблем. Зважаючи на це, були надані рекомендації для покращення ситуації існуючого стану справ в лісовому господарстві, що включають в себе розширення відповідальності лісокористувачів та виробників деревної продукції, підвищення ефективності управління лісовими ресурсами, сприяння розвитку інновацій в сфері лісового господарства. Робота приносить нові знання в розрізі дослідження стану розвитку навколишнього середовища в Україні, та зокрема стану її лісових ресурсів. Її висновки можуть стати важливими у контексті формування державної політики, та створенні власних напрямів розвитку для підприємств в сфері лісового господарства: деревообробних, лісозаготівельних, туристичних

Ключові слова: навколишнє середовище; сталий регіональний розвиток; лісовий сектор економіки; державна лісова та екологічна політика; правозастосування

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The current status and future prospects for the production of ornamental planting materials in forestry nurseries in Ukraine

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Abstract. The reduced demand for seedlings has created the conditions for the introduction of new profitable production areas, such as the cultivation of ornamental seedlings of woody plants. Therefore, there is a need to explore new ways to increase the profitability of growing ornamental plants. The purpose of this study was to investigate and estimate the capacity and condition of the forestry industry's planting base, identify its main problems, available reserves, and outline the main ways to improve its efficiency under self-financing conditions. The methodological framework was based on general scientific methods of analysis, synthesis, and generalisation, which allowed for the investigation of the reporting materials of forestry enterprises and statistical data of the State Agency of Forest Resources. The study characterised the state of seedling production of forestry enterprises and trends in the dynamics of its production capacities

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during the period of the State Target Programme “Forests of Ukraine” for 2010-2015 (the last 4 years of 2012-2015) and after its completion (2016-2019). The study indicated the favourable conditions and expediency of increasing the production of ornamental planting material. The prospects for the wider introduction of the production of ornamental planting material in forestry nurseries were identified. The ways of modernisation of ornamental seedling production of forestry enterprises and increase of its profitability were proposed and substantiated. It was emphasised that the increase in the production of ornamental planting material in nurseries and the implementation of the recommended measures will not only increase the flow of extra-budgetary funds, but will also contribute to the modernisation of the process of growing forest seedlings, including those with a closed root system, as well as improve their quality. The results obtained will help accelerate a scientifically sound solution of problems related to modernisation and efficiency in the production of ornamental planting materials in nurseries. This, in turn, will help attract additional financial resources for forestry enterprises

Keywords: seedling; sapling; productive area; forest nursery department; forest seedlings; assortment

Introduction

In the Anthropocene, the processes of deforestation and degradation of natural ecosystems, especially green spaces that determine the quality of the environment and life, have become widespread and are one of the greatest threats to the sustainable development of humankind, causing serious environmental, social, and economic problems (University of Plymouth…, 2018). These challenges are also extremely acute in Ukraine, especially in densely populated and overly urbanised areas. According to Roshani *et al*. (2022), R. Vasylyshyn *et al*. (2023), since the late 1990s, they have been intensifying due to the acceleration of global climate change, accompanied by an increase in average annual temperatures, and a more frequent recurrence of extreme weather events, including dry periods that are not typical for certain regions.

The reasons for the deterioration of the environment and living conditions on the planet are complex and have their own historical background. Of particular significance is the deterioration of the ecologically balanced ratio between land covered with forests and green spaces and technologically disturbed areas. This is due to the use of technologies that do not consider the adverse consequences in the long term.

The above and the current trend of accelerating urbanisation of the environment show that the only realistic and effective way to stabilise environmental conditions is to expand forest reproduction and substantially increase the area of green spaces in populated cities and adjacent lands. It is important to understand that if necessary and timely measures are not taken, the negative consequences of the Anthropocene for the environment and humanity will be catastrophic.

At the same time, Ukraine has accumulated some experience of a comprehensive, scientifically sound approach to solving the above-mentioned problems of greening settlements and urban landscapes, the main of which is the development of the following:

- propagation and cultivation of high-quality planting material for ornamental woody plants of a wide range of cultivars and different types (assortments) (Vereshchagina, 2014);

- improving the overall sanitary condition, decorative design and urban amenities through uniform and complete greening of urban and suburban areas (Levon, 2004; Order of the Ministry of Construction, Architecture and Housing and Communal Services of Ukraine No. 105..., 2006);
- reforestation of badlands and wastelands, creation of all types of park and protective plantations, harmonious placement of forests, parks, and gardens on the territory (Sheremeta & Tikhomirova, 2019);
- enriching the suburban landscape by introducing woody plants, forming green belts around settlements, and creating favourable conditions for environmentally safe recreation and health improvement (Kushnirenko, 2012; Shumyk, 2016).

The implementation of these important tasks requires some organisational and economic measures and, above all, the appropriate provision of forest restoration and greenspace expansion with the necessary forest and ornamental planting material, the production of which largely depends on governmental bodies and capacity of Ukrainian tree nurseries.

Prior to independence, the main producers of forestry and ornamental planting material of woody plants in Ukraine were state nurseries of forestry enterprises and communal regional green building companies of the Ministry of Housing and Communal Services (Kosenko, 2017). Most of the current permanent nurseries of forestry enterprises were designed and established in the second half of the last century, at a time when large-scale forestry operations were carried out and forest seedlings were in great demand. Therefore, despite the presence of forest nursery branches in the structure, their activities were mainly focused on growing a wide range of seedlings. V.M. Maurer *et al*. (2016) found that their production was carried out with sufficient budget funding. The decorative planting material was usually produced for one's own needs, rather than to raise extra-budgetary funds. Y.I. Kosenko (2017) concluded that since the years of independence, Ukraine has formed a fairly strong private sector of ornamental seedling production, which has substantially increased the share (up to 50-70% according to expert estimates) of local planting material in the Ukrainian market of tree plant seedlings for landscaping.

At the same time, despite Ukraine's geographical location (central Europe), favourable soil and climatic conditions and available labour reserves, the capacity of ornamental nursery farming has not achieved its potential and, therefore, is unable to meet Ukraine's needs for planting material for landscaping and for exporting its products to foreign markets. The results of the study by V.M. Yezhov & I.V. Grinyk (2017) indicate the relevance of strengthening the Ukrainian base of ornamental seedling production and introducing the latest technologies to improve the production of woody plant seedlings.

A significant reserve for strengthening the Ukrainian base of ornamental nursery production is the forest tree nursery of the state nurseries of the forestry industry of Ukraine. V.M. Maurer (2019) argued that their use is not only possible, provided the state has an appropriate attitude and sufficient investment in production, industry science, and professional education, but is necessary for both the industry and the country, since ornamental nursery can become a powerful source of attracting extra-budgetary funds and foreign currency for forestry enterprises and increasing jobs in the country.

Due to the completion of the State Target Programme "Forests of Ukraine" for 2010-2015 (State target programme..., 2009) and a sharp decline in forestry and reduced need for seedlings, there was a significant release of space in the sowing departments. Given the production areas that are not being used for their intended purpose, favourable conditions have been created for expanding or introducing new profitable production areas. This includes the cultivation of ornamental seedlings of woody plants, the production of which in forest nurseries does not require considerable capital investment. The relevance of its introduction is due not only to the possibility of using the production of ornamental planting material to attract extra-budgetary funds, especially in the absence of budgetary funding for forestry, but to the need to improve the supply to the Ukrainian market with seedlings for landscaping and gardening and reduce the share of imported products.

At the same time, there has been no thorough and comprehensive research on the state and prospects of growing ornamental planting material in nurseries of forestry enterprises since Ukraine gained independence, except for the above-mentioned scientific works, by both Ukrainian and foreign scientists. This is added evidence of the relevance of the findings presented in this paper.

The purpose of this study was to summarise the state of the forestry industry's seedling base and identify ways to improve its profitability in the absence of budget funding.

Materials and Methods

For this study, we researched professional publications on this subject by both Ukrainian and foreign scholars. We also reviewed studies by forestry enterprises and statistical data from the forms LG-14 and LG-15 published by the State Agency of Forest Resources of Ukraine (SAFR of Ukraine) for 2012-2019 (Reports on the availability…., 2012-2019).

To follow the methodological principles for comparing data characterising the relevant production processes, the reporting materials of the last four years of the State Target Programme "Forests of Ukraine" for 2010-2015 (2012-2015) and the first four years (2016-2019) after its completion were used. There is no information for the following years.

During the research, the authors used philosophical and worldview approaches to formulate their scientific opinions on the subject and object of study. They employed these approaches to ensure appropriate evaluation of the results obtained, identification of trends, and use of accepted scientific methods. An evaluation was conducted using analysis, synthesis, and generalisation techniques to collect data on the quantity and size of the nurseries belonging to State Forest Resources Agency (SFRA) of Ukraine, with a focus on the natural zones and production areas, such as the sowing, cuttings, forest nursery, and nursery departments. The assessment also included an inventory of the types of plants found in the ornamental and fruit and berry nurseries, categorised according to genera and species. Additionally, the study involved an examination of the growth dynamics of tree nurseries under the auspices of the State Specialised Economic Enterprise "Forests of Ukraine" (SE "Forests of Ukraine") in terms of height.

The research findings were verified using verification methods and techniques that involved quantitative and qualitative analysis throughout the period under study.

The dialectical method of cognition helped investigate the trends in the development of the nursery base of Ukrainian forestry enterprises and the dynamics of production of forest and ornamental planting material of tree species in the context of the introduction of sustainable, balanced nature management and development of society, considering environmental, economic, social, and agrotechnical factors.

The formal logical method was used to define the system-forming concepts of the outlined research problem. This method helped consider the opinions of researchers on the subject under study. Analysis and synthesis, as methods of cognition were used to investigate the scientific works of scholars on the subject under study and evaluation of current regulations (Law of Ukraine No. 3116-XII…, 1993; Law of Ukraine No. 411-IV… 2002) governing relations in the field of production of planting material.

Results and Discussion

According to the 2019 Green Economy Report of the Ministry of Communities and Territories Development of Ukraine (Nature-oriented solutions…, 2019), the total area of ornamental nurseries of its subordinate enterprises producing woody planting material is about 1.6 thousand ha. The analysis of the report's data shows a significant uneven territorial distribution of the production area of tree nurseries of the agency responsible for the country's green economy. Almost half of the total area of ornamental nurseries (729 ha) is concentrated in the enterprises of Odesa region. The area of nurseries in the south-eastern regions is significant: Kharkiv (over 300 ha), Dnipro (about 100 ha), Poltava (72 ha), Mykolaiv (48 ha) and Kyiv (123 ha). At the same time, in a third of the country's regions (Donetsk, Lviv, Sumy, Ternopil, Khmelnytskyi, Cherkasy, etc.), the Ministry's enterprises do not grow ornamental planting material of woody plants due to the lack of nurseries, most of which have been privatised or re-profiled. Given the rising need for ornamental seedlings for landscaping and gardening, this situation is unacceptable.

In this context, it is important to search for reserves and capacities, the use of which would not only substantially increase the share of Ukrainian ornamental planting material of tree species in the total volume of landscaping work in the country but export it to countries with less favourable conditions for its production. Y.I. Kosenko (2015) testified to the export of small-sized ornamental planting material to European countries by the industry's enterprises in Soviet times at the end of the last century, and a preliminary analysis by V.P. Yukhnovska (2013) suggests that a considerable reserve for strengthening the Ukrainian ornamental nursery base is the capacity of tree nurseries of the forestry industry. Their use, given the availability of space, specialists, interest of farms, and with the appropriate attitude of the industry's management and sufficient investment, is not only possible but also highly advisable.

In this context, it is important to objectively estimate the current state and capacity of the nursery base of forestry enterprises, identify the main problems and determine the prospects for the production of ornamental planting material of woody plants in state forestry nurseries.

Currently, 590 permanent and 1,380 temporary nurseries with a total area of about 3.4 thousand ha produce planting material for artificial reforestation, afforestation, and landscaping for the forestry industry (Fig. 1). Between 2012 and 2019, their total number and area decreased, which, given the outstanding professional value and potentially high profitability of producing planting material, especially large-sized material, indicates that the industry's nursery is not being used for its intended purpose. The substantial (17%) decrease in the number of nurseries and the reduction of their area by one third (by 1,566 ha) has its own reasons and regional specific features. Thus, in the Forest-Steppe, their number remained almost constant, but at the same time, the area of permanent nurseries almost halved. Given that the soil and climatic conditions of the region are most favourable for growing large-sized ornamental planting material, it is not advisable to reduce the area of permanent nurseries.

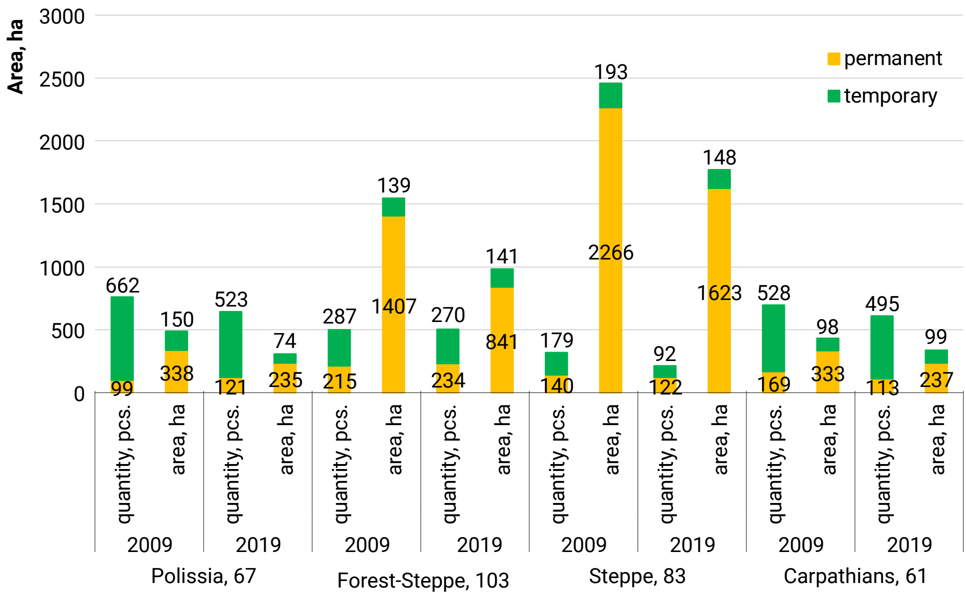

Figure 1. Number and area of nurseries of the SFRA of Ukraine by natural zones
Source: developed by the authors of this study based on reporting data from the State Statistics Service of Ukraine (Reports on the availability…., 2012-2019)

The decrease in the number of nurseries and their areas in the Steppe is conditioned upon a substantial reduction in reforestation after the completion of the State Target Programme "Forests of Ukraine for 2010-2015" and the termination of budget funding, and in the forestry enterprises of Polissia and the Carpathians, apart from the above reason, the share of natural reforestation in the total volume of forest reproduction is also increasing. The authors of this study believe that the areas withdrawn from forest nursery could be used for the cultivation of ornamental planting material with open (Forest-Steppe and Carpathians) and closed (Polissia and Steppe) root systems.

Large-sized planting material is more efficiently grown on permanent nurseries with an area of more than 5 ha (Nature-oriented solutions…, 2019). From this perspective, the data on the average area of permanent nurseries by regional forestry and hunting departments (SFRA, Table 1) are of some interest. These data indicate better conditions for the production of ornamental planting material in Polissia in the permanent nurseries of the enterprises of the Volyn Department, in the Forest-Steppe – in Vinnytsia, Khmelnytskyi, Kharkiv, and Cherkasy, in the Carpathians – in Chernivtsi, and in the Steppe in the enterprises of almost all regional departments.

Of no less interest are the data on the dynamics of the productive area of permanent forestry enterprises according to the type of use in the context of production departments during 2012–2019 (Fig. 2). Given the completion of the aforementioned State Programme, it is understandable that the total area of cultuvation will decrease. At the same time, it is difficult to explain the steady downward trend in the area of nurseries against the backdrop of growing demand for ornamental seedlings in the country and abroad, and given the potential for a substantial increase in their production in forest nurseries, where significant areas are used for other purposes, there is no budget funding, which necessitates the attraction of extra-budgetary funds, etc.

Table 1. The number and average area of permanent nurseries in the forestry industry by region in 2012-2019

Regional Forestry and Hunting Department, natural area	Characteristics of nurseries enterprises under SFRA of Ukraine				
	total		including permanent		
	area, ha	quantity, pcs.	area, ha	quantity, pcs.	average area, ha
Volyn	71.0	157	63.7	5	12.7
Zhytomyr	110.0	190	71.0	26	4.3
Chernihiv	42.8	103	28.9	39	0.8
Total for Polissia	329.9	663	248.1	132	1.9
Vinnytsia	230.3	31	213.4	14	15.3
Kyiv	139.8	116	99.4	35	2.8
Poltava	62.3	18	62.3	18	3.5
Sumy	87.0	69	75.4	16	4.7
Ternopil	53.2	70	20.5	15	1.4
Kharkiv	142.4	40	131.0	12	10.9
Khmelnytskyi	143.1	59	124.5	21	5.9
Cherkasy	207.8	46	184.5	22	8.4
Total for Forest-Steppe	1,065.9	459	911.0	153	6.0
Dnipro	162.1	29	148.4	11	13.5
Donetsk	128.0	11	124.0	5	24.8
Zaporizhzia	237.7	32	170.4	14	12.1
Kropyvnytskyi	87.0	30	75.3	25	3.0
Luhansk	270.3	36	256.9	9	28.5
Mykolaiv	187.2	32	184.5	30	6.2
Odesa	523.8	20	511.6	17	30.1
Kherson	177.3	24	152.7	12	12.7
Total for Steppe	1,773.3	214	1,623.8	123	13.3
Zakarpattia	62.0	140	44.1	46	1.0
Ivano-Frankivsk	73.0	210	52.7	26	2.0
Lviv	108.6	168	87.9	30	2.9
Chernivtsi	84.4	82	46.0	2	23.0
Total for the Carpathians	328.0	600	230.7	104	2.2
Total	**1,936**	**3,497.1**	**512**	**3,013.6**	**5.9**

Source: developed by the authors of this study based on reporting data from the State Statistics Service of Ukraine (Reports on the availability..., 2012-2019)

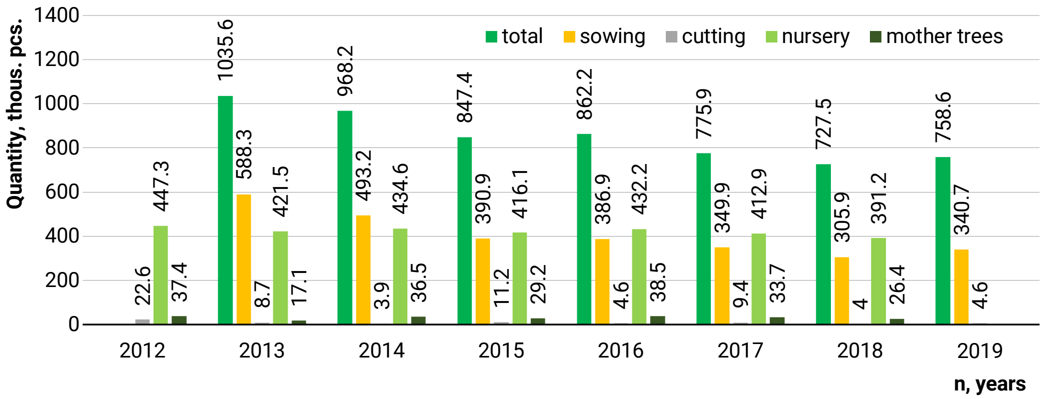

Figure 2. Dynamics of the productive area of nurseries of the enterprises under SFRA of Ukraine according to types of use by production departments

Source: developed by the authors of this study based on reporting data from the State Statistics Service of Ukraine (Reports on the availability..., 2012-2019)

In this context, the data on the dynamics of changes in the area of ornamental trees in the nurseries of industry enterprises according to natural zones during 2012-2019 are of interest (Fig. 3). The largest fluctuations in the surface area of forestry nurseries have had a tendency to decrease after the elimination of funding. During the analysed period were inherent in the nurseries of resource forestry enterprises in the Carpathians (33%) and Polissia (32%), and the smallest – in the Forest-Steppe (11%) and Steppe (18%).

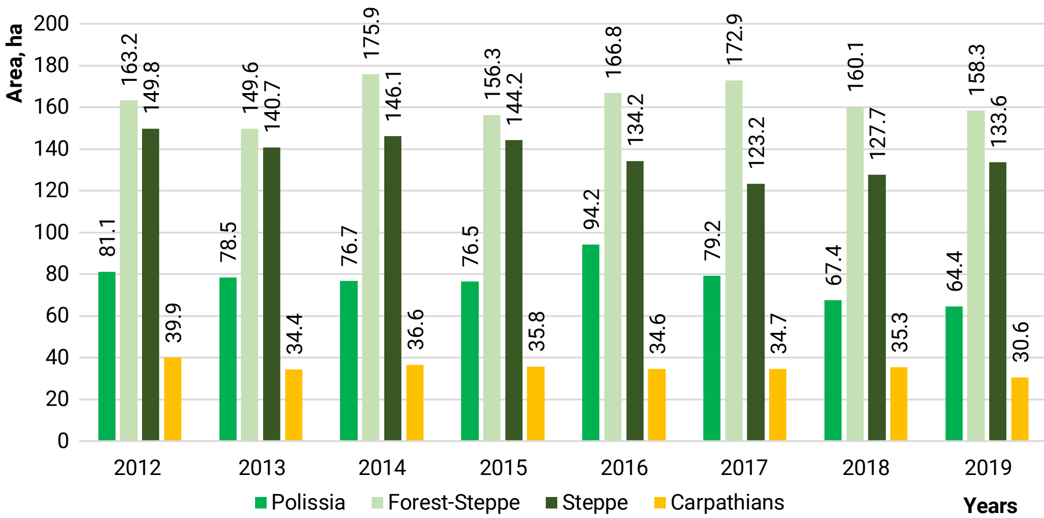

Figure 3. Dynamics of changes in the area of tree ornamental nursery trees in the nurseries of the SFRA of Ukraine according to natural zones

Source: developed by the authors of this study based on reporting data from the State Statistics Service of Ukraine (Reports on the availability..., 2012-2019)

The decrease in the area of nurseries of forestry enterprises continued last year, except for the nurseries of low-resource forestry enterprises in the Steppe, which have been showing an upward trend over the past two years. This is indirect evidence that the production of ornamental planting material is an affordable and effective source of extra-budgetary funds even in the unfavourable soil and climatic conditions of the Steppe. At the same time, the profitability of producing ornamental tree and shrub seedlings largely depends on a range of factors: natural conditions, the technology used to produce the variety (with an open or closed root system, with a shaped or unshaped crown) and the range of nursery products.

Thus, in modern conditions, a considerable reserve for increasing the demand for ornamental seedlings of forest nurseries is the expansion of the range of plants grown, according to which the products of the industry's enterprises are substantially inferior to the range offered on the Ukrainian market by foreign (Bojanowski Szkółka, n.d.) and private Ukrainian producers (Permanent forestry nursery..., 2019). The assortment of foreign producers is dominated by woody plants of form and variety levels, whereas in forest nurseries, a considerable share belongs to species-specific planting material (Shepeliuk *et al.*, 2021).

Equally important is a significant increase in the volume of container culture – the cultivation of planting material with a closed root system, the production of which has several organisational, agrobiological, economic, and technological advantages.

This should be facilitated by amending the current statistical reporting form LG-15, which concerns the volume, variety, and range of ornamental planting material grown in the nurseries of the SFRA of Ukraine, a portion of which is presented in Table 2. The current reporting materials do not contain complete information on the range of woody plants grown (their species, form, variety) and the range of planting material (seedlings with a closed root system, open root system, with a clump, etc.). This complicates the professional analysis of production results and the adoption of scientifically sound decisions to improve both the process of producing ornamental planting material in forest nurseries and its sale.

Table 2. Report on the availability of seedlings in ornamental and fruit and berry nurseries of the SFRA of Ukraine, 2012-2019

No. Seq.	Species, genus	Decorative and other forest nurseries					
		total		of which seedlings for sale, thous. pcs.			
		area, ha	thous. pcs.	total	including height, m		
					up to 0.7	0.8-1.8	1.9 and >
1	2	3	4	5	6	7	8
1	Conifers, including	215.30	2,959.5	1,922.2	1,504.8	346.5	70.9
2	Scots pine	13.42	89.5	31.6	25.4	5.8	0.4
3	Crimean pine	43.25	184.8	89.7	37.5	38.3	13.9
4	spruce	48.85	647.7	457.5	360.3	75.4	21.8
5	fir	4.31	339.1	184.2	176.5	7.6	0.1
6	larch	2.30	75.4	37.5	32.9	4.1	0.5
7	thuja	59.19	958.8	615.7	470.2	126.3	19.2
8	juniper	31.77	391.1	293.9	216.2	67.4	10.3
9	other	12.21	273.1	212.1	185.8	21.6	4.7
10	Deciduous, incl.	92.09	811.2	664.0	432.5	147.2	84.3

Table 2, Continued

1	2	3	4	5	6	7	8
11	common oak	5.76	39.9	24.6	21.9	1.3	1.4
12	red oak	4.99	25.3	16.8	4.5	6.9	5.4
13	common ash	0.94	16.6	10.7	8.5	1.3	0.9
14	common beech	0.52	83.4	74.4	74.2	0.1	0.1
15	small-leaved linden	19.24	108.4	81.8	37.2	26.3	18.3
16	maples	7.29	63.2	51.2	36.8	7.4	7.0
17	birch	12.56	53.0	46.5	19.0	14.0	13.5
18	nuts	5.31	42.4	33.9	12.0	10.6	11.3
19	poplars	0.16	1.8	1.8	0.7	0.5	0.6
20	willow	2.73	21.8	19.1	7.8	10.0	1.3
21	alder	0.30	2.1	2.1	0	1.1	1.0
22	robinia	0.02	0.2	0.2	0.1	0.1	0
23	honey locust	0.05	0.2	0.2	0	0.1	0.1
24	hornbeam	0	0	0	0	0	0
25	elms	0.34	2.2	2.2	0.7	0.7	0.8
26	mulberry	0.35	1.7	1.7	0.1	1.5	0.1
27	rowan	7.88	28.7	18.9	5.2	7.6	6.1
27	rowan	7.88	28.7	18.9	5.2	7.6	6.1
28	apple	1.03	5.5	5.2	2.6	2.4	0.2
29	pear	0.01	0.1	0.1	0.1	0.0	0
30	stone fruits	2.74	6.9	6.7	1.3	2.2	3.2
31	other	19.87	314.1	265.8	199.7	53.1	13.0
38	Tatar maple	0.01	0.1	0.1	0	0.1	0.0
32	Shrubs, including	79.50	1,372.9	1,053.5	937.3	109.3	6.9
33	rosehip	0.07	1.2	1.2	1.0	0.2	0
34	sea-buckthorn	0.09	0.4	0.4	0	0.1	0.3
35	currant	0.45	1.9	1.4	0.9	0.3	0.2
36	viburnum	2.02	17.8	15.1	6.8	7.8	0.5
37	hazel	0.17	1.1	1.1	0.1	0.7	0.3
39	chokeberry	9.94	21.4	21.4	1.1	19.9	0.4
40	privet	2.32	18.7	17.7	14.0	3.6	0.1
41	dogwood	0.29	2.8	2.8	0.5	1.3	1.0
42	honeysuckle	0.14	2.1	2.1	1.4	0.7	0.0
43	spirea	0.99	20.9	16.9	9.4	7.5	0.0
44	elderberry	0.10	0.1	0.1	0.1	0	0
45	cherries	0.63	20.7	15.0	14.3	0.6	0.1
46	other	62.28	1,263.7	958.2	887.7	66.5	4.0
TOTAL		**386.89**	**5,143.6**	**3,639.7**	**2,874.6**	**603.0**	**162.1**

Source: developed by the authors of this study based on reporting data from the State Statistics Service of Ukraine (Reports on the availability…, 2012-2019)

As the data presented in Table 2 suggests, in 2019, the largest area in forestry nurseries (about 60%) was occupied by seedlings of coniferous trees. The proportion of the area of large-sized planting material of deciduous species was about 24%. Seedlings of shrubs were grown on the remaining areas of forest nurseries. Among the coniferous species, the largest area of nurseries (about 28%) was occupied by representatives of the genus Thuja. At the same time, the area of spruce, juniper, and Crimean pine (Palasciana) cultivars was significant. In terms of the number of seedlings in the coniferous forest nurseries, species and decorative forms of thuja, spruce, and juniper were predominant.

Among the seedlings of deciduous trees, the largest area in the forest nursery departments of the SFRA nurseries of Ukraine was occupied by linden, hanging birch, mountain ash and maple, and among shrubs – by chokeberry, privet, viburnum, and spirea.

In general, the range of ornamental woody plant seedlings grown by forestry enterprises is considerably inferior to the range of the best Ukrainian private and foreign nurseries. The majority of their products are species-level woody plants, which are in much lower demand on the green market than seedlings of decorative forms and varieties. This shows that to increase the competitiveness of ornamental nursery products of forest nurseries, it is advisable to substantially expand the range of woody plants grown, primarily with competitive forms and varieties. Particular attention should be paid to cultivars that are in steady demand among landscape architects and are currently imported to Ukraine in significant volumes.

Another way to increase the competitiveness of ornamental nursery products of forestry enterprises and their profitability is to make adjustments to the size structure of planting material, which is realised by increasing the share of large-sized planting material in total volumes. In 2019, the share of seedlings up to 0.7 m in height among the planting material of coniferous and deciduous trees intended for sale was 75%, and the share of much more profitable seedlings, 0.8-1.8 m and over 1.9 m in height, was 19% and 6% (Table 2). An analogous distribution was observed in previous years (Fig. 4). For branch tree nurseries, with significant land areas that are not always rationally used for their intended purpose, such size distribution cannot be considered normal. Considering the cultivation of ornamental shrubs, the ratio between tree seedlings of different sizes is close to the optimum: about 50% – up to 0.7 m, 35% – 0.8-1.8 m, and 15% of plants 1.9 m and above.

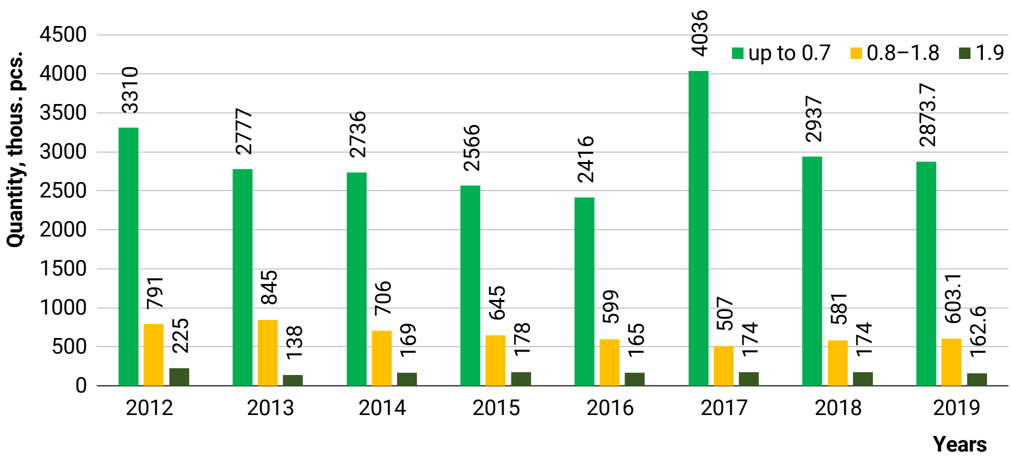

Figure 4. Dynamics of the volume of ornamental seedlings of different heights in the nurseries of the State Specialised Economic Enterprise "Forests of Ukraine"
Source: developed by the authors of this study based on reporting data from the State Statistics Service of Ukraine (Reports on the availability..., 2012-2019)

V.M. Maurer *et al*. (2019) found that an increase in the share of large-sized ornamental planting material would not only make it possible to use the production area of forestry nurseries more rationally and increase the profitability of their activities, but also help to attract investment funds that are essential for strengthening and modernising the nursery base and modernising the technologies used.

One of the ways to modernise the nursery base and upgrade the technologies used is to introduce various types of planting material into the practice of nursery production by industrial enterprises, specifically microclonal propagation of woody plants and the cultivation of seedlings and saplings with a closed root system. In this context, the creation of a sectoral biotechnology centre with departments of microclonal reproduction and genetic engineering of woody plants deserves special attention. Such a centre would combine the efforts of scientists and practitioners in the field of genetics, breeding and mass production of regenerative plant material for the production of forestry and ornamental planting material that meets modern requirements (Bojanowski Szkółka, n.d.). As for the appropriateness of increasing the share of production of ornamental seedlings with a closed (non-injured) root system in the total volume, G. Krussmann *et al*. (1997) concluded that due to the numerous advantages of such planting material (the possibility of planting during the entire growing season, almost 100% survival rate, organisation of efficient production in regions with different soil and climatic conditions, etc.), it will also contribute to the industrialisation of the process of growing all types of planting material and the uniform load of labour and machinery and tools for mechanisation of work throughout the year.

Special attention should be paid to the issue of scientific substantiation of the ratio of growing planting material with a closed and open root system in regions with differing natural conditions. Considering the specific soil and climatic conditions of natural zones, the share of planting material with a closed root system should be higher in nurseries in Polissia (with poor soils) and in the Steppe (with arid conditions). In the Forest-Steppe and Carpathian regions with fertile soils, it is worth growing seedlings with an open and clumped root system.

Most of the forestry industry's current permanent forest nurseries were designed and established in the second half of the 20th century, at a time when forestry operations were extensive. Therefore, despite the presence of forest nurseries in their organization, they were focused mainly on growing a wide range of seedlings of both major and minor and shrubby tree species. Their production activities were carried out with sufficient budget funding (European Nurserystock Association..., 2019). As a rule, the ornamental planting material was produced for one's own needs, rather than to raise extra-budgetary funds. According to M.S. Mahmud *et al*. (2023), the main products of forest nurseries were and still are seedlings, seed and cuttings with an open root system. Therewith, in recent years, forestry has seen an intensification of efforts to introduce innovative agricultural technologies that are now widely used in advanced countries. This primarily concerns the cultivation of forest planting material with a closed root system using industrial technologies.

The scientific and practical significance of the generalisations made based on the research results regarding the current state, capacities of the ornamental seedling production base of the industry enterprises and its potential production capabilities is important.

The implementation of prospects and tasks for increasing the volume and improving the production of ornamental planting material in forest nurseries should be based on a scientifically sound concept that considers the best foreign practices (Salaš, 2002; Radoglou *et al.*, 2008; Mattsson *et al.*, 2010), as well as the state and achievements of Ukrainian private nursery production. Therewith, they believe that the forest industry's ornamental nursery can only be effective if it produces competitive planting material using innovative technologies and modern related materials that are not inferior in quality to imported planting material.

Considering the proposals of the above-mentioned scientists and the results of the conducted research, the wide introduction of decorative nursery planting requires factoring in the characteristic features of the modern state of forest nurseries in the industry. Among these are the lack of specialized tools, equipment, related materials, modern automated lines and funds necessary to produce decorative planting material for their purchase. Other significant factors include the depletion of the soil of production departments as a result of long-term use and insufficient observance of the basics of agricultural technology (scientifically sound crop rotation, soil cultivation, fertiliser application, etc.); lack of a formed chain of study of the demand for decorative planting material of woody plants and established ways and methods of its implementation.

On the other hand, to effectively use the current capabilities of Ukrainian forest nursery to increase production and improve the cultivation of ornamental planting material, it is necessary to make the most of the experience of foresters and available reserves. Particular attention should be paid to the following:

- an unjustified trend towards a decrease in productive areas and an increase in the share of cultivated land of permanent forest nurseries of the country's industry enterprises that are used for other purposes;
- there are reserves and considerable potential for introducing modern, cost-effective production of ornamental planting material in forest nurseries;
- the need to expand the range of cultivars of ornamental plants and the range of types of ornamental planting material (seedlings from closed root system, regenerated seedlings, architectural forms, hedges, etc.);
- the expediency of wider introduction of modern industrial technologies for the production of seedlings of ornamental woody plants with a closed root system in container culture and the modernisation of agricultural technologies for growing planting material with an open root system;
- the need to increase the share of large-sized tree and shrub seedlings in the total production of woody planting material to increase the profitability of ornamental nursery farming;
- the appropriateness of introducing an industry network to monitor the demand for ornamental planting material of woody plants and the ways and means of its sale.

In general, the wider introduction of modern technologies for the production of ornamental planting material into the practice of forest nursery will not only increase the flow of extra-budgetary funds, which are extremely necessary for enterprises in the industry, but will also contribute to the modernisation of the process of growing forest seedlings and improve their quality.

Conclusions

Due to the reduction in the forest area, the increase in the production of forest planting material with closed root systems have led to a reduction in the need for seedlings and the release of land in sowing departments. Additionally, because of the availability of free and unused land, the industry's nurseries have favourable conditions for expanding or introducing new profitable production areas. This includes the cultivation of ornamental seedlings of woody plants, the cultivation of which in forest nurseries does not require significant capital investment, as it has many organisational and agro-technological features in common with the cultivation of seedlings.

The introduction of this type of planting material makes it possible to use the production of decorative planting material to attract extra-budgetary funds, especially in the absence of budgetary funding for forestry, and the need to improve the supply of the Ukrainian market with seedlings for landscaping and gardening and reduce the share of imported products. In this context, it is important to search for reserves and capacities, the use of which would not only substantially increase the share of Ukrainian ornamental planting material of tree species in the total volume of landscaping work in the country, but also export it to neighbouring countries.

The introduction of the production of ornamental planting material for woody plants in permanent forest nurseries, given the availability of free space, specialists, appropriate agricultural techniques, and the strong interest of farms in attracting extra-budgetary funds and the appropriate attitude of the industry's management, is not only possible but also highly advisable.

Given that large-sized ornamental planting material is more efficiently grown on permanent nurseries with an area of more than 5 ha, the best conditions for its production are in Polissia at the enterprises of the Volyn Forestry and Hunting Range Administration, in the Forest-Steppe – in Vinnytsia, Khmelnytskyi, Kharkiv, and Cherkasy, in the Carpathians – in Chernivtsi, and in the Steppe – on the farms of almost all regional administrations.

An important reserve for increasing demand for ornamental seedlings in forest nurseries is the expansion of the range of woody plants grown with many varieties and quality characteristics, which are substantially inferior to the range of foreign and Ukrainian private nurseries.

An important way to increase the competitiveness of ornamental nursery products of forestry enterprises and the profitability of their activities in this area is to make adjustments to the size structure of planting material by increasing the share of large-sized planting material in total volumes.

In the future, it will be necessary to investigate the use of modern agricultural technologies to produce ornamental seedlings, primarily the cultivation of planting material with a closed (uninjured) root system, which is being actively introduced to industrialise the process of producing forest planting material at modern seed and nursery complexes in Ukraine.

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Conflict of Interest

The authors of this study declare no conflict of interest.

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Стан і перспективи виробництва декоративного садивного матеріалу в розсадниках лісової галузі в Україні

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Анотація. У зв’язку зі скороченням потреби у сіянцях, сформувалися передумови для запровадження нових рентабельних напрямків виробництва таких як вирощування декоративних саджанців деревних рослин. Тому виникла необхідність у вивченні нових шляхів підвищення рентабельності вирощування декоративних рослин. Метою роботи було дослідити та оцінити потужність і стан бази розсадництва лісової галузі, виявити його головні проблеми, наявні резерви та окреслити основні шляхи підвищення його ефективності за умов самофінансування. Методологічною основою слугували загальнонаукові методи аналізу, синтезу та узагальнення, які дозволили дослідити звітні матеріали підприємств лісової галузі та статистичні дані Державного агентства лісових ресурсів. Охарактеризовано стан розсадництва підприємств лісової галузі та тенденції динаміки його виробничих потужностей у період дії Державної цільової програми «Ліси України» на 2010-2015 роки (останні 4 роки 2012-2015) та після її завершення (2016-2019 рр.). Вказано на сприятливі умови та доцільність збільшення обсягів виробництва декоративного садивного матеріалу. Було визначено перспективи ширшого запровадження виробництва декоративного садивного матеріалу у розсадниках лісової галузі. Запропоновано та обґрунтовано шляхи осучаснення декоративного розсадництва підприємств лісової галузі і підвищення його рентабельності. Підкреслено, що збільшення обсягів виробництва декоративного садивного матеріалу в розсадниках і запровадження рекомендованих заходів дозволить не тільки збільшити надходження позабюджетних коштів, а і сприятиме осучасненню процесу вирощування лісових сіянців, у тому числі. і із закритою кореневою системою, та покращенню їх якості. Отримані результати сприятимуть прискоренню науково обґрунтованого вирішення завдань, пов’язаних з модернізацією та підвищенням ефективності виробництва декоративного садивного матеріалу у розсадниках. Це в свою чергу сприятиме залученню додаткових фінансових ресурсів підприємствами лісової галузі

Ключові слова: сіянець; саджанець; продукуюча площа; шкільне відділення; саджанці деревних рослин; асортимент

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Urban parks as an important component of environmental infrastructure: Biodiversity conservation and recreational opportunities

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Abstract. The ecological development of a modern urbanised territory is grounded in the fundamental concepts of sustainable green development, the concept of which reflects the satisfaction of the city's needs while preserving the environment. The study has the objective

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of formulating recommendations to enhance the institutional structure of urban parks. These recommendations are aimed at aligning park operations with the principles of sustainable green development in cities. Additionally, the study seeks to improve the social and economic efficiency of the environmental infrastructure in urban areas. To achieve these goals, the study employed general scientific methods of cognition. They include analysis, abstraction, synthesis, induction, and deduction. The study also utilized methods of specification and formalisation. Throughout the research, the focus was on investigating the existing state of the management system for urban parks and evaluating the reserves of their recreational capabilities. It is established that the park economy of Ukraine is currently functioning in isolation, so the environmental optimisation of this area requires the formation of a modern approach to the management and organisation system. It has been determined that green areas of the city are a basic prerequisite for preserving the species diversity of local ecosystems. The primary directions for development of urban park systems in the direction of recreation are highlighted. The specifics of their management process with the involvement of modern monitoring and investment opportunities are investigated, and further development prospects are outlined. The study recommends key measures to improve the situation in the examined field. These measures encompass the enhancement of recreational opportunities within parks, the monitoring and control of anthropogenic impact on the environment, the regulation of quality and safety standards, and the preservation of biodiversity in local ecosystems. The practical significance of the research results is evident in their potential application in the development of programs. These programs are designed to enhance the efficiency of urban parks, elevate their recreational value, and establish a resilient ecological park network in Ukraine

Keywords: green areas; sustainable urbanisation; climate change; smart cities; optimisation

Introduction

High urbanisation rates, the rise in urban population, coupled with the escalating influence of transportation and industrial operations on environmental conditions, including the quality of air, soil, and water environments, along with global negative trends in climate change, are causing a significant deterioration in urban living conditions. Theoretically, the formation of the planning structure of urbanised areas should be inextricably linked to the development of green spaces (Ferreira *et al.*, 2022). There is an opposite trend - minimising the area allocated for urban parks and squares results in a reduction in the comfort of the environment, directly affecting the health of the population. Functional zoning of the green zone, allocation of its primary structural components, as well as calculation of areas for various purposes within urban development, is currently often carried out without considering the ecological characteristics of landscape ecosystems, with the priority given to the factor of economic benefit. Simultaneously, it is crucial to acknowledge that urban parks constitute an exceedingly significant element of the city's framework, directly influencing the quality of the urban ecosystem.

Many scientists have extensively explored the organization, utilisation, and rejuvenation of urban parks, with numerous publications delving into these issues. Within the European Union, there exist numerous programs and projects dedicated to optimising the state of green spaces in urban regions (Chen *et al.*, 2020). These initiatives aim to comprehensively tackle environmental challenges in urban areas and enhance the living environment quality for the urban population.

Analysing the outcomes of scientific research related to the study's subject reveals that a predominant focus among most scientists is directed toward the landscape and architectural aspects in the organisation and planning of urban park areas. As such, P. Polko & K. Kimic (2021) argue that careful planning of urban development is a priority. This means determining the optimal location of parks, their size, and specifications so that they are accessible and convenient for all city residents. N. Guneroglu & M. Bekar (2022) recommend implementing strict measures to control its implementation in practice. According to their data, the establishment of a building code and urban zone planning is imperative, as these constitute the primary instruments for regulating land plot development and usage. These documents play a pivotal role in delineating rules and constraints for development, city zoning, and the allocation of spaces for various types of activities. O. Bondar *et al.* (2022) and V. Emelyanova (2022) focus on examining the biogenic component of parks and its influence on the health and psycho-emotional well-being of the population. Simultaneously, I. Shvydenko & M. Shvydenko (2023) extensively explore the pollution aspects of green spaces in urban parks resulting from substantial anthropogenic pressures. The scientists argue that the system of city parks should acquire optimising alternative variations, and, therefore, develop in the spatial and temporal aspect synergistically with the development of the city itself.

Several scientific publications by Ukrainian researchers examine the criteria used for the development and assessment of preventive and regeneration measures of environmental, socio-economic, and managerial nature aimed at improving existing strategies for the development of park systems in urban areas and developing alternative options for development programmes. In particular, I. Kuraieva *et al.* (2021) emphasised that green park areas play the role of a buffer between natural ecosystems of the urban environment and industrial and urban complexes. At the same time, N.V. Vernihorova (2023), V. Scherba & O. Pylypovych (2023) focused on the complexities of the dualistic uniqueness of landscape complexes of this kind, because, on one hand, they are often places of increased recreational pressure and anthropogenic pressure, and on other hand, they often perform the functions of preserving the species diversity of local and regional biocoenosis.

Despite significant attention from the scientific community, there is a notable gap in the analysis of the algorithm for the successful functioning of urban parks as centres for biodiversity conservation. Additionally, the effective management of these parks utilising the potential of a recreational reserve remains insufficiently explored and warrants further scientific investigation. The study's objective is to devise approaches to optimise the situation and enhance the role of green areas as recreational resources and hubs for biodiversity conservation, aligning with the principles of balanced sustainable development in urban areas.

Materials and Methods

The research is based on a theoretical and methodological foundation influenced by the dialectical method, the systemic approach, and the prioritised principles of conducting thorough investigations. By employing the systemic approach, the study facilitated the exploration of urban park complexes as an interlinked system. The investigation utilized abstract-logical and dialectical methods of scientific knowledge, in addition to the scientific abstraction method. These methods were applied to develop theoretical generalisations, enhance the conceptual framework, and draw conclusions.

The abstraction method was utilised to pinpoint essential concepts and categories. This approach facilitated the delineation of the concept of a comprehensive process within the management system of the green urban space domain. This conceptualisation was characterised as an organised and consequential arrangement of interrelationships. In this structure, the management process occupies a prominent position alongside the primary planning and organisational factors. Analytical and synthetic methods were employed to uncover the essence of the organisational and economic mechanism of the subject under scrutiny. These methods were also utilised to determine the strategic directions for the development of effective management in the sector of park systems in urbanised areas. The analysis method played a role in establishing structural relationships among the elements of the phenomenon under investigation. Moreover, the analysis and synthesis methods were integral in identifying the principal aspects of functioning and the key determinants within the studied object.

The concretisation method played a crucial role in the study by documenting the effectiveness and feasibility of a set of management measures in the optimisation of the recreational functionality of urban parks. It was also utilised to uncover ideal circumstances and resolutions for the conservation of biodiversity and the mitigation of environmental risks in the landscape complexes of urban park areas.

The comparative method was used to identify the details of growth and intricacies in the dynamics of both quantitative and qualitative aspects of the ecological condition within urban park systems. In turn, the inductive approach was applied to predict development indicators, while deduction played a crucial role in crafting recommendations to enhance management processes in the examined area.

The formalisation method was implemented in the study, particularly during the derivation of priority vectors for optimising the functional state of urban park systems based on "green" sustainable development. It was also applied during documenting the findings of the study that are intended for practical application in the management of urban parks as centres for recreation and conservation of the regional biocenotic fund. The study was conducted in accordance with all the provisions of the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973).

Results

Green spaces in contemporary cities fulfill more than just aesthetic functions. Parks and squares play a crucial role in the urban environment, serving as spaces for recreation and rejuvenation. The presence of natural ecosystems within urban areas contributes to creating a favourable environment for the existence and propagation of local biodiversity. Additionally, trees play a significant role in effectively purifying the air by filtering out dust and harmful substances, while also acting as barriers to noise pollution (Santos *et al.*, 2019).

In the present stage of global community development, urban parks are growing in significance and diversity, aligning with the evolving needs and expectations of the population. Consequently, trends in urban park development undergo continuous modernisation and optimisation to address crucial environmental and social issues. Simultaneously, these efforts aim to enhance the role of parks in fostering recreation, tourism, and investment. Green areas of modern cities are often subject to the destructive impact of anthropogenic activities. The problem of preserving parks in urbanised areas for comfortable living and environmental protection is becoming more acute every year. Guided by the findings of the International Bank for Reconstruction and Development, which conducted a comprehensive analysis of urbanisation processes in Ukraine and the world, it can be asserted that the degree of urbanisation in the twenty-first century is substantial, and the human impact on the environment is poised to intensify in the near future (Scherba & Pylypovych, 2023). In this regard, to achieve harmonious and sustainable development, Ukrainian cities need to strengthen and expand the functionality of environmental infrastructure, as well as optimise and improve its components, with the implementation of successful foreign experience following domestic realities and legal requirements.

City parks, as an important component of environmental infrastructure, perform several important functions to ensure an optimal microclimate in the city, including cooling urbanised space in the heat, regulating humidity and groundwater reserves, assimilating excess carbon dioxide and pollutants, optimising wind conditions, and neutralising noise pollution. The functional zoning of the green zone in Ukraine is implemented by sectoral regulations (Vernihorova, 2023), according to which the greening of the development area should reach 40-50%. In general, the area of urban green spaces for public utilisation is influenced by factors such as the city's size, its natural and climatic conditions, and the specifics of building planning. Overall, the spatial organisation of urban green spaces should cater to the establishment of areas for recreation and leisure, including the designation of zones with special conservation value to maintain the normal functional state of park ecosystems. Concurrently, in accordance with existing legislation, urban parks fall within the category of public green spaces (Kuraieva *et al.*, 2021).

Based on their functional attributes, parks can be categorised into two main groups: multifunctional and specialised. It is noteworthy that in Ukraine, the common practice is to establish multifunctional parks, which may include citywide mass recreation parks. Concurrently, there is a contemporary relevance in the creation of specialized parks, such as sports parks, children's parks, recreational parks, and those with a distinct environmental status aimed at preserving the biodiversity of local landscape ecosystems (Scherba & Pylypovych, 2023). Considering the ongoing urbanisation processes and the increasing urban population, which consequently heightens the demand for recreational spaces, there is a necessity to systematically organise and optimise the natural resource foundation for the recreational utilisation of urban park complexes. Determining the amount of recreational load creates the prerequisites for assessing the degree of recreational use of certain territories and is a defining criterion for the implementation of functional zoning, establishing quantitative and qualitative benchmarks for enhancement and developing systems of optimisation and regeneration measures are essential to ensure the judicious recreational utilisation of urban parks (Fig. 1).

To explore the characteristics and untapped potentials of urban parks as multifunctional entities, a comprehensive approach is necessary. This involves conducting a multifactorial examination of landscapes, identifying key indicators of their functional state, establishing a monitoring and analytical system, and formulating strategies for the optimal utilisation and development of these territories.

One of the primary requirements for optimising the state and fostering innovative development within the park system in urban areas is regular and comprehensive environmental assessment based on monitoring observation programmes (Chen *et al.*, 2020; Song *et al.*, 2022). Institutional management functions for urban parks in Ukraine are performed by local governments, which narrow their competence to issues of financing and economic regulation in the sector. Simultaneously, the recreational, health and environmental potential of urban parks is usually untapped.

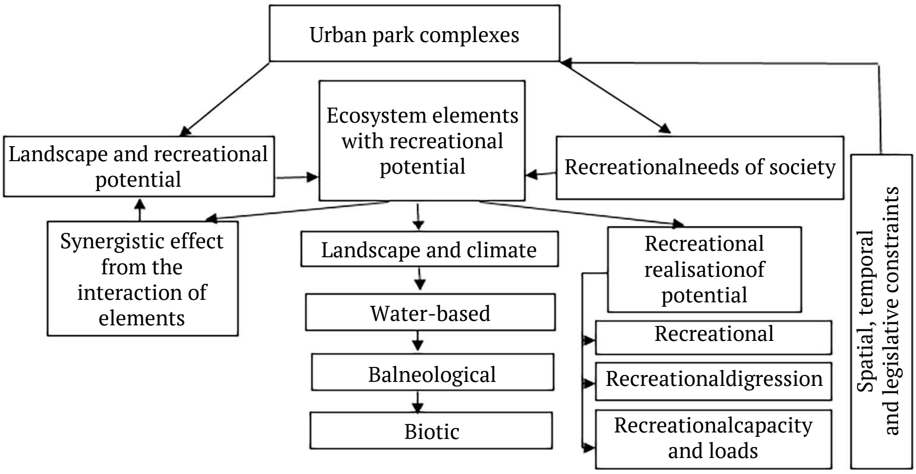

Figure 2. Recreational potential of urban park complexes
Source: compiled by the authors

The current global trend of developing the concept of "smart" parks, which involves the active use of modern technologies, allows for optimising the park's resource management system and increasing the level of environmental safety. Such prospects open up variations for expanding the multidisciplinary nature of urban parks. In modern green park areas of urbanised areas, considerable attention is paid to ensuring environmental sustainability and biodiversity conservation, eliminating air and noise pollution, and optimising water quality in rivers and lakes within urban parks. To this end, various technological innovation opportunities are being applied, in particular in the areas of water treatment systems, waste management and the introduction of renewable energy sources. The role of urban parks is progressively gaining significance in the realms of tourism and recreation. This shift in focus directs attention to the urbanised areas hosting these parks. These conditions open up new avenues for developing the economic potential of cities and attracting investment opportunities, aligning with global initiatives supporting projects geared towards the practical implementation of sustainable development principles across various spheres of socio-economic activity.

The conceptual basis of "green" sustainable urban development envisages the degree of greening as a crucial metric for assessing the capability of an urban area to provide comfortable living conditions for the population. A commonly accepted indicator in global practice is sufficient greening at the level of 20-30 m^2 or more of public green space per city resident (Kulczyk-Dynowska & Stacherzak, 2020). At the same time, urban parks play a substantial role in addressing the challenge of recreational recuperation for the population. Aesthetic possibilities, a comfortable microclimate in the hot season, air filled with phytoncides, reduced levels of dust, noise and vibration, and increased oxygen content synergistically have a reproductive, strengthening, and regenerative effect on humans (Emelyanova, 2022).

The management of park systems in Ukrainian cities, based on practical experience, underscores the necessity to formulate and implement specific management methods, functions, organisational structures, and systems. These elements are essential prerequisites for ensuring the effective management of green urban areas (Table 1).

Table 1. Principles of management of urban park complexes

No.	Principle	Meaning
1	Eco-friendliness	Any managerial, organisational, and technological decisions should be founded upon the maximum preservation of the natural potential
2	Transparency	Engaging in successful international experience, participation in programmes and grants
3	Adaptability	Ability to make dynamic adjustments in the course of implementing the management strategy due to the impact of external and internal factors
4	Prospectivity	Sustainable development in the future is a priority
5	Economic effect	Implementation of cost-effective measures to support parks for the economic sustainability of cities
6	Monitoring	The execution of management measures should constitute a thoroughly monitored process, with accounting, coordination, regular performance review and evaluation
7	Social Orientation	Priority for decision-making is given to social needs, health improvement and rehabilitation of the population, and "green" development of the city

Source: compiled by the authors

The primary objective of the contemporary approach to managing the functionality of urban parks should be the safeguarding, conservation, and rejuvenation of existing green spaces. This involves fostering synergy with the urban landscape, and creating resilient complexes capable of withstanding adverse environmental conditions and substantial anthropogenic pressures. It is considered necessary to expand the recreational opportunities of urban park areas while ensuring the implementation of biosecurity functions and the ecological balance of the city's ecosystem.

The contemporary urban green park, fulfilling its socio-economic, environmental, and urban planning functions, shapes the "green" system within the city as an integral component of the regional ecological network. This system contributes to establishing a balanced framework for the ecological and economic development of urban areas. Key areas of optimisation for urban park systems include the preservation and restoration of biological and landscape diversity, the minimisation of noise pollution and airborne pollutants, and the promotion of regulated recreation. These efforts aim to enhance the sanitary and hygienic parameters of urbanised areas and ensure optimal living conditions for the city's population. When optimizing the functional state of urban park systems, it is crucial to consider a range of environmental factors, both natural and anthropogenic. Additionally, it's essential to account for the functional state, pace, and direction of the city's ecosystem development. A priority in this optimisation is restructuring the structure of urban green spaces, introducing new greening technologies, and reconstructing existing urban parks based on functional zoning, emphasising recreation and nature conservation. This approach facilitates the creation of ecological hubs within the city's network, enhancing species diversity, increasing recreational appeal, and promoting environmentally friendly nature management.

Building upon the examination of the theoretical foundations of recreational reserves within contemporary urban park areas and their potential adaptation to real-world conditions, it is deemed prudent to develop a strategic management concept for urban parks. This strategic management approach aims to enhance the recreational functionality of urban parks, with a focus on biodiversity conservation and the sustainability of landscape ecosystems. It also seeks to stimulate increased efficiency in the zonal utilisation of urban parks while achieving optimal outcomes with minimised costs. It's noteworthy that effective management necessitates flexibility, adaptability, and regular reassessment of goals and programs. Moreover, the incorporation of modern innovative monitoring, modelling, and forecasting capabilities is considered a fundamental prerequisite for successfully optimising the environmental functionality of urban parks.

The envisaged outcomes of the proposed concept for optimising the state of urban parks in Ukraine include a comprehensive enhancement of the sanitary and epidemiological well-being of the population. This is coupled with the expansion of the recreational functionality of park complexes in urban areas, a reduction in the impact of detrimental natural and anthropogenic factors on the ecological state of the city, the preservation of biological and landscape diversity through the enlargement of nature protection sites, and the establishment of a rigorous control system to prevent the misuse of park territories. Considering the multifunctionality of management support for the stabilisation of urban park systems, their regeneration and future development, it is necessary to organise a multidisciplinary sectoral structure at the state level, specialising in ensuring an appropriate level of urban parks' improvement, maximising their recreational functionality and opportunities for biodiversity conservation and protection of landscape ecosystems. The combination of urban park improvement, recreation and economic efficiency programmes requires professional coordination and the allocation of individual development priorities for each of the green infrastructure facilities (Vernihorova, 2023).

The sectoral structure of the above-mentioned direction should optimally play an intermediary role between authorities of different levels, communities, and urban parks (Slätmo *et al.*, 2022). Its important function should be practical collaboration with international organisations in the realm of park improvement. The latter will provide an opportunity to fill the gaps in the sector's financing through grants and credit opportunities. In particular, the international organisation World Urban Parks is open to cooperation, which stimulates the optimisation of urban park systems by solving financial and personnel problems of parks to offset the socio-environmental problems of urbanised areas (Vernihorova, 2023). The proposed state structure should cover a wide range of issues related to the development of parks, their recreational and environmental protection functions, and, as a result, public welfare.

Competent recreational planning requires determining the permissible loads on the landscape ecosystem, as the sustainability of natural complexes is a fundamental requirement for safeguarding the recreational potential of the area (Kulczyk-Dynowska & Stacherzak, 2020; Yang *et al.*, 2020). Unregulated recreation causes a decrease in the growth, completeness, and stock of tree composition, increased thinning processes, disruption of natural regeneration processes, and degradation of the indigenous phytocenosis (Ferreira *et al.*, 2022). The development of an adequate concept of recreational nature management within urban parks should be based on the principle of rational use of natural resources to meet human recreational needs without causing destructive environmental impact. Adherence to the principles of zoning the park territory to reduce the manifestations of digression, the allocation of protected areas, regular sanitary cleaning, elevating the environmental awareness of the population and implementing organised algorithms to streamline recreational usage will enable the complete realisation of the city park's potential. This includes serving as a space for the physical and neuropsychological recovery of the population while simultaneously preserving representative landscapes and species diversity within the ecosystem.

Discussion

Many contemporary scientists regard urban park systems as foundational elements for developing the ecological network within urbanised areas. This perspective establishes several organisational and economic prerequisites for the effective reproduction and rational utilisation of the resource capabilities inherent in the city's green spaces. Researchers, such as J. Palliwoda *et al.* (2022), have demonstrated that the environmental dimensions of modern city development hinge primarily on optimising the overall ecological state of the natural environment and adhering to the principles of sustainable urban development. The scholars emphasize that the directions for unlocking the ecological potential of urban parks are chiefly shaped by the optimal design of the city's functional and planning structure.

J.Z. Farkas *et al.* (2023) emphasised the need to ensure that the anthropogenic load is proportionate to the adaptive resources of park ecosystems, without violating the morphological and functional parameters of the green zone. Based on the findings of S. Ming & Q. Du (2021), who consider the management support of urban parks as a key prerequisite for the conservation of biodiversity in urban areas, it can be asserted that urban green spaces have considerably broadened their range of functions in contemporary times, becoming a basic element of the system of modern urban ecosystems. Scientists emphasise that urbanisation processes are mostly accompanied by a significant destabilising transformation of the environment. In this regard, the primary task of the urban ecosystem management system is currently to minimise anthropogenic destructive pressure by regulating the balance between the urban and natural environment.

X. Zhao *et al.* (2022) identified the main reasons for the need to maximise the protection and conservation of biodiversity within urban landscapes, including air purification, comfortable thermal conditions in different periods of the year, protection against landslides and erosion of urban cover and soil, formation of a sustainable landscape ecosystem, runoff regulation, conservation of diverse landscapes, and reproduction of human-nature synergy. Examining the practices of foreign management systems in the realm of green urban areas, researchers have observed that their initiatives are tailored to meet local needs and preferences in each country. Consequently, it becomes crucial to emphasise that, in the context of Ukraine, there is a need to formulate a specific strategy for the development of green spaces in urbanized areas. This strategy should align with the restoration of the state, fostering increased sustainability, and enhancing competitiveness.

Researchers F.A. La Sorte *et al.* (2023) emphasised the fact that intensive use of transport causes one of the key environmental problems of the city – air quality, which directly affects the health of city residents. Biodiversity, in particular, meadow crops and herbs, significantly improve air quality, mitigating the situation with respiratory diseases. The authors argued that urban greenery largely regulates air and surface temperatures in different periods of the year and times of day, and on windy autumn and winter days, the high massifs of city parks create barriers to wind gusts. Plants and their root systems keep the soil loose and aerated, which creates better conditions for insects and worms. This assertion is supported by the research conducted by J. Winkler *et al.* (2022). Degraded areas that have lost their vegetation cover are vulnerable to direct rain and strong winds. The root system of plants significantly strengthens local soil cover and prevents it from shifting in places with steep terrain, or during floods or flooding. In Ukraine, a striking example of such a phenomenon is the emergence of landslides in Carpathian towns due to the massive felling of trees whose roots held the soil cover (Scherba & Pylypovych, 2023).

A. Addas (2023) notes that the primary task of urban landscapes is to form sustainable ecosystems that can mitigate negative climate change and help the city adapt to the dynamics of weather and climate conditions. According to the scientist, biodiversity is a key element of sustainable landscapes. It is thanks to it that ecosystems are formed that can exist on their own without requiring significant investments from the local budget or excessive attention, and simultaneously, benefit the city in the form of a renewable recreational resource. The researcher analyses the spatial structure of the city's green zone, arguing for the need to expand park areas and the need to allocate investments in green spaces. It is hard to disagree with the scientist. X. Zhao *et al.* (2021) focus on the need to identify specific areas of urban park systems that could have a special environmental protection status. Specifically, leveraging local biodiversity, it is deemed advisable to establish accessible open botanical and zoological parks for the public. However, this initiative should be augmented with a recognition of the imperative to provide special protection to habitats hosting rare representatives of local and regional biocoenosis.

The research by S. Štrbac *et al.* (2023) underscores the importance of synergizing the green infrastructure of a modern city with the principles of sustainable development. The scientists argue that the urban green infrastructure within a sustainable urbanised area constitutes a network of human-managed natural ecosystems that optimize public health, promote ecosystem sustainability, and preserve landscape biodiversity. The study also emphasises several challenges in implementing sustainable urban park management principles, including issues related to financing, investment, and the availability of qualified personnel.

In the context of post-war recovery, Ukraine has the potential to engage international cooperation mechanisms and targeted investment opportunities, expanding the horizons for urban environmental solutions. The future entails actively promoting the use of urban greening projects at national, regional, and local levels through sustainable development programs (Chen *et al.*, 2023; Evans & Hardman, 2023). The anticipated long-term outcomes of such a management strategy encompass the enhancement of social and environmental microclimates in cities, increased economic efficiency of projects, and an overall improvement in the living environment (Kruize *et al.*, 2020; Rehman *et al.*, 2022; Grigoletto *et al.*, 2023).

Preserving biodiversity in cities necessitates concerted efforts to develop a sustainable system of management and governance for green spaces in Ukrainian cities. Based on the findings of this study and the conclusions from the analysed works, it can be anticipated that urban park complexes will play an increasingly significant role in the successful management of urban ecosystems in modern Ukraine. This would enable the deliberate enhancement of productivity, the implementation of innovative solutions, and adherence to the principles of sustainable green development.

Future scientific research in this domain should aim to delineate strategic priorities for establishing a resilient system for developing green space networks in Ukrainian cities. Additionally, the focus should be on creating and integrating an information monitoring system, positioned as a primary resource for optimizing the situation. There is a crucial role assigned to leveraging international practical experience, developing novel methodologies, and refining existing ones within the scope of an integrated multifactorial approach to managing urban park systems. The prospects for further research lie in constructing the institutional framework for the operation of urban parks in the context of European integration and the post-war regeneration of Ukraine.

Conclusions

The study successfully analysed the multifaceted nature of the management paradigm to enhance the efficiency of urban park complexes based on sustainable development principles. It also assessed the role and significance of greening in the context of socio-economic transformations in urbanized areas.

The findings indicate that the development of urban park systems plays a crucial role in enhancing urban amenities, reinforcing the prioritisation of green living, and optimising the living standards of the population concerning restoration and recreation. The study thoroughly analysed the objective conditions for the functioning of green urban areas in modern Ukraine and asserted that the establishment of park ecological infrastructure should play a central role in the management systems of urbanised areas. Furthermore, the recommended functions of these systems include the development of recreational opportunities in parks, control of anthropogenic pressure on the environment, regulation of quality and safety standards, and preservation of biodiversity in local ecosystems.

The study concluded that achieving these goals requires the optimisation of management policies in the field of research. It emphasized that strategic planning, operational management, and the implementation of effective regeneration and preventive measures should be integral components of the strategic management of urban park complexes. Such an approach allows for a timely response to emerging challenges, such as the increasing importance of environmental safety standarts. The study has identified inter-sectoral gaps that currently require urgent elimination through regulatory and legal regulation, establishment of strict measures of liability for violations, and involvement of international levers to regulate the situation: neglect of the norms of territory development and status of territories, misuse of territories, spontaneous development of recreational and nature protection areas within park areas, and disregard for urban planning norms. Following the study, the author argues for the significance of creating a unified management body dedicated to addressing urban park issues in Ukraine. Additionally, a comprehensive concept for the activities of this management body is proposed.

The foundation of sustainable "green" urban development, as outlined, should rest on principles such as environmental safety, the conservation of landscapes and biodiversity, the integration of green practices in production, and the utilisation of available natural resources for recreation. These initiatives collectively contribute to the establishment of a favourable urban microclimate. The international experience of positioning environmental priorities of urban development as the main tool for ensuring sustainable development is summarised. The problematic aspects of urban greening that require a change in strategic management approaches towards the targeted preservation and restoration of green spaces in urban areas are analysed.

The proposed measures for the optimisation and development of urban park complexes can be used to form targeted concepts of integrated landscaping, as well as a component of environmental assessment of the urban environment and preventive diagnosis of negative changes in local ecosystems. An effective approach to managing urban parks involves an integrated set of methods and tools that are interconnected to enhance their functionality in terms of recreation and biodiversity conservation. This approach should be grounded in the implementation of a sustainable development strategy, with environmental safety serving as an integral component of the management paradigm. There is a pressing need for further research to explore the potential application of management measures, drawing on international practical experience, to formulate optimal programs for the regeneration and development of green spaces. In combination, these measures will establish the prerequisites for addressing immediate challenges in the functioning of urban parks and identifying opportunities to enhance their operational efficiency, taking into account a range of influencing factors from both the internal and external environments.

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Conflict of Interest

None.

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Міські парки як важливий компонент екологічної інфраструктури: збереження біорізноманіття та забезпечення рекреаційних можливостей

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Анотація. Екологічний розвиток сучасної урбанізованої території базується на засадах сталого «зеленого» розвитку, концепція якого відображає задоволення потреб міста при збереженні навколишнього середовища. Метою статті є розробка рекомендацій щодо оптимізації інституційного устрою міських парків для організації їхнього функціонування відповідно до засад сталого «зеленого» розвитку міст, а також підвищення соціальної та економічної ефективності екологічної інфраструктури урбанізованих територій. Дослідження проводилось з використанням загальнонаукових методів пізнання: методи аналізу, абстрагування, синтезу, індукції та дедукції, а також методи конкретизації та формалізації. У ході роботи досліджено сучасний стан системи управління міськими парками, резерви їх рекреаційних можливостей. Встановлено, що паркове господарство України наразі функціонує відособлено, тому екологічна оптимізація даної сфери вимагає формування сучасного підходу до системи управління та організації. Визначено, що зелені зони міста є базовою передумовою для збереження видового різноманіття місцевих екосистем. Виділено пріоритетні вектори розвитку міських паркових систем в напрямку рекреації. Досліджено специфіку процесу управління ними з залученням сучасних можливостей моніторингу та інвестування, окреслено подальші перспективи розвитку. Запропоновані основні заходи з оптимізації ситуації в досліджуваній галузі, серед яких – розвиток рекреаційних можливостей парків, контроль впливу антропогенного навантаження на навколишнє середовище, регулювання стандартів якості та безпеки, а також збереження біорізноманіття місцевих екосистем. Практична значимість результатів дослідження полягає в можливості їх застосування в процесі розробки відповідних програм, що мають на меті підвищення ефективності функціонування міських парків, зростання показників їх рекреаційної значущості, а також формування стабільної екологічної паркової мережі в Україні

Ключові слова: зелені зони; стійка урбанізація; зміна клімату; розумні міста; оптимізація

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Recreation characteristics of the green zone forests of the Zhytomyr city

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Abstract. Recreation in forests is important for residents of cities, including Zhytomyr. The forests of the city's green zone require a comprehensive assessment to regulate the recreational use of state and municipal forests. In order to analyse the recreational indicators of the forests of the green zone of Zhytomyr, a comparative analysis of forest management data of landscape mensuration was carried out and compared with the results of our own field research. To analyse the recreational indicators, the forest management database, materials of previous field studies, as well as electronic mapping materials and a geographic information system were used. According to the forest management data, the spatial structure of the forest park area is far from optimal due to the small share of open and semi-open landscape types. The existing functional zoning in most areas does not correspond to the actual recreational use of the territory. There are areas with intensive visits that are not classified as forest parks and do not have landscape mensuration data, although they have a high level of improvement. In terms of walkability, sustainability, aesthetic and integrated assessment, the forest park areas demonstrate mostly mediocre results. The recreational digression of the vast majority of sites is insignificant. Some plots have the necessary indicators for a high additional assessment. The results of the field surveys confirmed the unreliability of some recreational indicators determined by forest management. The largest discrepancy was noted in the determination of walkability, additional and recreational values, which are significantly

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underestimated. In the most visited areas, the actual indicators of recreational digression and aesthetic assessment are lower than those in the forest management materials. Refinement of the data on recreational characteristics of the forest park zone areas allows updating the information on landscape mensuration and developing a comprehensive functional zoning of the territory of suburban forests in Zhytomyr. The results of the study will help state and municipal forestry enterprises to optimize the recreational exploitation of forests within the green zone of the city, rationalize the use of natural resources for recreational purposes, while ensuring environmental sustainability

Keywords: forest parks; landscape mensuration; recreational assessment; digression; sustainability; walkability

Introduction

In the modern world, urbanization is a typical process for the vast majority of countries. The sharp increase in the share of the urban population both abroad and in Ukraine is caused by both economic and social factors (Pauli *et al.*, 2019; Referowska-Chodak, 2019). The growing population of large cities poses challenges not only to improving the infrastructure of suburbs, but also to increasing the area of green space (Zhao *et al.*, 2020). Quite often, the reverse process is observed in large cities, which is a reduction in the area of green zone forests due to the increase in built-up areas at the expense of suburban forests. Due to the desire of numerous people to live in proximity to forests, the “city is constantly advancing on the forest” (Dragun, 2021).

For many large cities in Ukraine, recreation in suburban forests has already been studied. These are mostly cities that are geographically located in the Polissia, Forest-Steppe of Ukraine and the Ukrainian Carpathians. I.R. Kuzyk’s (2021) research focused on determining the recreational capacity of the city’s complex green zone and calculating the main parameters of intra-city recreational activities. However, these studies were not based on the assessment of landscape mensuration data. A comprehensive study of silvicultural, mensuration, and landscape-recreational indicators of recreational forests in the western part of Ukraine was conducted by N.F. Prykhodko *et al.* (2023). Similar studies were also conducted in the conditions of the Left-Bank Forest-Steppe of Ukraine (Musienko *et al.*, 2020). What these studies have in common is that forest management materials served as the basis for assessing the recreational capacity, developing functional zoning, and studying attendance. Yu.S. Miklush *et al.* (2019) studied recreation in forests, analysing only a specific recreational indicator or a group of them. For example, O.M. Romanets (2020) analysed the relationship between indicators of the aesthetic value of plantations and their taxonomic and phytocoenotic characteristics, which are determined during forest management, in particular, age, sanitary condition and stage of recreational digression, for the green zone of Kyiv. N.Y. Melnychuk & Y.V. Henyk (2019), in the urban ecosystem of Lviv, focused on the study of the relationship between recreational digression and external features of plant communities. However, none of the publications in Ukraine in recent years has analysed the relevance and correctness of forest management information on landscape mensuration.

A number of recreational indicators (landscape type, sustainability, additional assessment, integrated recreational assessment, walkability) are determined by software in forest management. Other indicators (digression, aesthetic assessment) are determined during forest management through direct site surveys and are quite dynamic, as they can be affected by any management measure, natural phenomenon on the site and by recreationists themselves. Therefore, these indicators hypothetically have the highest chances of not matching the forest management data.

The city of Zhytomyr is one of the largest settlements in Ukraine, with significant areas of suburban forests. No one has comprehensively studied the recreational performance of the city's green zone forests. The compilation of landscape mensuration data on the main forest users of the forest park zone would allow us to assess the reliability and relevance of recreational indicators and the existing functional zoning.

After a preliminary inspection of the territory of the green zone of Zhytomyr, doubts arose about the reliability of a number of indicators. This is what led to the analysis of landscape mensuration data and comparison of forest management data with our own field materials. In order to analyse the recreational indicators of the forests of the green zone of Zhytomyr, the following tasks were envisaged:

- compilation of landscape mensuration data by major forest users;
- determination of the area of forest areas with a high level of attendance within the forests of the city's green zone, which are not related to forest parks;
- determination of the reliability and relevance of forest management information in areas with a high level of public access.

Materials and Methods

The materials for the analysis of recreational indicators were forest management data on landscape mensuration of three forestry enterprises: Korosten Forestry and Hunting Enterprise, Berdychiv Forestry Enterprise, and subsidiary Puliny Forestry of the Agro-Industrial Complex (AIC). The survey was conducted in June-August 2023. The forest management information was obtained and analysed using the Ukrainian State Project Forest Management Manufacturing Association of the Production Association (PA) "Ukrderzhlisproekt" (n.d.) using SQL Server, "Forest Planner" (software solution for managing the forest fund of the enterprise) and Geoportal "Forests of Ukraine" (n.d.) in accordance with the current instructions (Instruction for forest management..., 2006). All areas of the forestry fund that belong to the green zone of Zhytomyr were taken into account. The database information was filtered by grouping the areas of the forest park zone plots by 7 main recreational indicators: landscape type, recreational digression, sustainability, walkability, aesthetic, supplementary and recreational values.

In order to verify the reliability of forest management data on landscape mensuration of forest owners of the Zhytomyr forest park zone, field studies were specially conducted at 20 sites using the same methods (Vozniak & Fukarevich, 2000) (Table 1).

Table 1. General characteristics of research objects

No sample plot	Forestry, No compartment and subcompartment	Coordinates	Mensuration characteristics of the site (stand composition, age, site conditions)	Feature
1	Levkiv, 16, 12	50.23236, 28.8681	100% birch, 57 years old, fresh poor	Landscaping elements
2	Levkiv, 17, 9	50.23446, 28.87315	100% pine, 114 years old, fresh fairly poor	Near the source of drinking water

Table 1, Continued

No sample plot	Forestry, No compartment and subcompartment	Coordinates	Mensuration characteristics of the site (stand composition, age, site conditions)	Feature
3	Levkiv, 16, 8	50.23341, 28.8618	100% pine, 79 years old, fresh fairly poor	There are berries
4	Zhytomyr, 13,13	50.26505, 28.86039	100% alder, 32 years old, wet fairly rich	There is a waterfall nearby
5	Levkiv, 87, 14	50.19222, 28.86381	100% pine, 64 years old, fresh fairly poor	Near the quarry
6	Stanyshivka, 20, 2	50.28695, 28.8658	100% spruce, 60 years old, fresh fairly rich	Recreational facility with amenities
7	Bohunia, 86, 1	50.28556, 28.59915	100% pine, 63 years old, fresh fairly poor	There is a monument
8	Bohunia, 74, 14	50.28077, 28.59777	100% pine, 102 years old, fresh fairly poor	Next to the building of the city
9	Bohunia, 75, 10	50.277, 28.58268	60% oak 40% pine, 109 years old, moist fairly rich	Near the sanatorium
10	Zhytomyr, 17,35	50.19572, 28.70804	50% pine 30% birch 10% acacia 10% willow, 28 years old, moist fairly poor	Landscaping elements, near the lake
11	Bohunia, 71, 2	50.29548, 28.63774	100% pine, 92 years old, fresh fairly rich	Near the quarry
12	Bohunia, 64, 9	50.29008, 28.60534	100% acacia, 70 years old, fresh fairly poor	Next to the quarry, landscaping elements
13	Korbutivka, 12, 19	50.24335, 28.60759	100% pine, 112 years old, fresh fairly rich	Near the pond
14	Korbutivka, 13, 10	50.23695, 28.58891	90% pine 10 % oak, 112 years old, fresh fairly rich	Next to the building of the city
15	Trigyria, 1, 4	50.21064, 28.36312	50% oak 50 % hornbeam, 188 years old, fresh fairly rich	Recreational facility with amenities
16	Trigyria, 6, 9	50.20095, 28.3863	70% pine 30 % oak, 168 years old, fresh fairly rich	There is a natural monument, next to the river
17	Trigyria, 6, 10	50.20284, 28.39031	1st storey 100% oak / 2nd 100 % hornbeam, 188 years old, fresh fairly rich	There is a monument
18	Zarichany, 10, 2	50.21893, 28.61791	70% pine 30 % oak, 132 years old, moist fairly rich	Existing landscaping elements, next to the river
19	Zarichany, 12, 2	50.22576, 28.6495	100% pine, 85 years old, fresh fairly rich	Next to the building of the city
20	Stanyshivka, 38, 5	50.18313, 28.70709	100% pine, 89 years old, fresh fairly poor	Existing landscaping elements, next to the river

Source: developed by authors

The study sites are popular among recreationalists and are representative of the area of the three enterprises and cover the entire suburban area of Zhytomyr.

The indicator of walkability was determined using the electronic mapping resources of Google and the Geoportal "Forests of Ukraine" (n.d.). Recreational digression was determined by determining the percentage of disturbed area to the total area of the allotment on linear transects that were laid out diagonally across the plots in two opposite directions. The research was carried out in compliance with all the standards approved by the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973).

Results and Discussion

The length of the forests of the green zone of Zhytomyr city from the west (extreme point – massifs north of the Buky (50.21158, 28.36038) to the east (extreme point – massifs south of the Kmytiv (50.28761, 28.89189) is about 38 km. From south to north, the length of suburban forests is about 23 km. The northernmost point (50.36228, 28.6701) is east of the Pischanka, the southernmost point (50.15887, 28.70331) north of the village Horodishche. The total area of the territory where the forest massifs of the forest park part of the green zone of the Zhytomyr city are located is about 87 thousand hectares. The forest coverage of this territory is about 53%.

As of 2023, the area of the forest park part of the green zone forests, where landscape mensuration has been completed, is 14.08 thousand hectares, of which almost 10.46 thousand hectares belong to the branch "Korosten Forestry and Hunting Enterprise", 2.29 thousand hectares belong to the branch "Berdychiv Forestry Enterprise" and 1.34 thousand ha – to the subsidiary "Pulyny AIC Forestry". It is worth noting that in addition to this territory, more than 2 thousand hectares of forests of other owners are used for recreational purposes both within the city and in the suburban zone. Also, significant areas of forests of different owners were discovered, in which it would be worthwhile to revise the purpose, taking into account their recreational load and location in relation to the Zhytomyr city. About 0.73 thousand ha of forest plantations were found within the "Korosten Forestry and Hunting Enterprise" (Trighirya Forestry, forestry part), 0.26 thousand ha in the "Korostyshiv Forestry Enterprise" (Korostyshiv Forestry, protective forests) and about 0.08 thousand ha in the subsidiary "Pulyny AIC Forestry" (Zhytomyr Forestry, forestry part).

According to forest management data, more than 14,000 hectares of the three forest owners were surveyed during the landscape mensuration in the forest park part of the green zone forests. The distribution of the forest fund of forest parks by landscape types indicates a significant predominance of closed types of space in all three enterprises (83-92%). Considering that the optimal share of closed landscapes for the region is 55-65%, it is necessary to state the need for further optimization of the spatial structure due to the increase of semi-open and open landscapes through landscape felling. Currently, the share of open spaces in the forest fund is 5-7% instead of the optimal 15-25%. The situation is similar with semi-open types of landscapes: their actual share is 3-10% against the optimal 15-25% (Table 2). The closest to the optimal spatial structure are the suburban forests owned by the "Berdychiv Forestry Enterprise" branch.

Table 2. Distribution of areas of forest parks in Zhytomyr by types of landscapes, ha

Type of landscape	Forest owner		
	"Berdychiv Forestry Enterprise"	"Pulyny APC Forestry"	"Korosten Forestry and Hunting Enterprise"
Open spaces without trees	135.8	38.8	405.4
Open spaces with single trees	11.3	30.2	331.7
Open spaces with evenly spaced trees	6.7	-	-

Table 2, Continued

Type of landscape	Forest owner		
	"Berdychiv Forestry Enterprise"	"Pulyny APC Forestry"	"Korosten Forestry and Hunting Enterprise"
Closed spaces – tree stands of horizontal closure	1890.1	1229	8674.5
Semi-open spaces with uneven placement of trees	59.7	19.6	11.9
Semi-open spaces with an even distribution of trees	167	23.9	276.2

Source: developed by authors basing on Ukrainian State Project Forest Management Manufacturing Association of the Production Association "Ukrderzhlisproekt" (n.d)

The distribution of areas according to the stages of recreational digression according to forest management data indicates that the territory within the boundaries of all three enterprises in the vast majority belongs to class 1, which actually identifies the integrity and minimal disturbance of the areas from the actions of recreationists and forest users.

Of the 5 classes of recreational digression in forest parks of the Zhytomyr city, only I-III were detected by forest management (Table 3).

Table 3. Distribution of areas of Zhytomyr forest parks by stages of recreational digression, ha

Stage of recreational digression	Forest owner		
	"Berdychiv Forestry Enterprise"	"Pulyny APC Forestry"	"Korosten Forestry and Hunting Enterprise"
1st stage	2081.1	1272.5	9678
2nd stage	66.6	-	199.4
3rd stage	4.7	-	0.1
Total	2152.4	1272.5	9877.5

Source: developed by authors basing on Ukrainian State Project Forest Management Manufacturing Association of the Production Association "Ukrderzhlisproekt" (n.d)

In the forests of the subsidiary "Pulyny AIC Forestry" no areas with a share of paths and trampled areas of more than 5% were found, and in the rest of the enterprises these areas are scarce ("Berdychiv Forestry Enterprise" branch – 2%, "Korosten Forestry and Hunting Enterprise" branch – 3%). In our opinion, these data will need to be revised, since during the field surveys, several areas were found that have a significant disturbance of the above-ground cover (over 30%), which corresponds to the lower classes of digression.

In contrast to digression, the resistance of forest areas to recreational loads is determined programmatically based on indicators of forest vegetation conditions, the dominant species and category of areas. The predominance of pine and oak forests in the forest stock of suburban forests in fresh and moist fairly poor and fairly rich site conditions (Siruk *et al.*, 2020) led to relatively high and average indicators of resistance, which is confirmed by the fact that the largest areas belong to the 2 and 3 classes of sustainability (Table 4).

Table 4. Distribution of areas of forest parks in the Zhytomyr city by sustainability classes, ha

Sustainability classes	Forest owner		
	"Berdychiv Forestry Enterprise"	"Pulyny APC Forestry"	"Korosten Forestry and Hunting Enterprise"
1st class	1.6	-	224.8
2nd class	1815.3	336.6	4684.1
3rd class	198.4	765.9	4116.1
4th class	132.5	161.4	768.3
5th class	4.6	8.6	84.2
Total	2152.4	1272.5	9877.5

Source: developed by authors basing on Ukrainian State Project Forest Management Manufacturing Association of the Production Association "Ukrderzhlisproekt" (n.d)

The highest sustainability indicators on average were noted in the "Berdychiv Forestry Enterprise" branch – 2.2 class, the lowest – in the subsidiary "Pulyny AIC Forestry" – 2.9 class. Regarding the adequacy of the values of the distribution of areas according to the walkability indicator, which is also determined by forest management by software, there are certain doubts in the data of the distribution of areas for two enterprises. The walkability is determined by the distance of sites from public roads, health facilities, and settlements (Vozniak *et al.*, 2000). During the processing of cartographic materials, it was found that a significant part of the plots of the "Pulyny AIC Forestry" and the "Korosten Forestry and Hunting Enterprise" branch is located in the immediate vicinity of these objects, corresponding to the 1-2 classes of walkability. However, as it is possible to see from Table 5, no plots were found for the 1st and 2nd classes of walkability by forest management within the boundaries of the two mentioned enterprises. This creates an additional need to check the adequacy of the determination of the walkability indicator in general for the suburban forests of Zhytomyr.

Table 5. Distribution of areas of forest parks in Zhytomyr by classes of walkability, ha

Walkability classes	Forest owner		
	"Berdychiv Forestry Enterprise"	"Pulyny APC Forestry"	"Korosten Forestry and Hunting Enterprise"
1st class	961.8	-	-
2nd class	1038.6	-	-
3rd class	152	1272.5	9120.9
4th class	-	-	-
5th class	-	-	756.6
Total	2152.4	1272.5	9877.5

Source: developed by authors basing on Ukrainian State Project Forest Management Manufacturing Association of the Production Association "Ukrderzhlisproekt" (n.d)

According to the aesthetic assessment, which is determined by forest management automatically based on the values of the composition of plantations, age and forest site conditions with correction in nature conditions, the forest parks of Zhytomyr city generally show average results. Areas of the 2nd and 3rd classes of aesthetic assessment predominate (Table 6).

Table 6. Distribution of areas of forest parks in the city of Zhytomyr by classes of aesthetic assessment, ha

Aesthetic assessment classes	Forest owner		
	"Berdychiv Forestry Enterprise"	"Pulyny APC Forestry"	"Korosten Forestry and Hunting Enterprise"
1st class	60.8	15.6	501.8
2nd class	841.1	612.6	5872.4
3rd class	1002	323.9	2578.7
4th class	302.7	223.2	587.1
5th class	79.1	166.2	337.5

Source: developed by authors basing on Ukrainian State Project Forest Management Manufacturing Association of the Production Association "Ukrderzhlisproekt" (n.d)

This is due, firstly, to the predominance of fresh and moist edatopes, secondly, to the dominance of older age groups of forests, and thirdly, to the predominance of the most widespread species of the region in the stands. The highest average class of aesthetic assessment turned out to be in the branch "Korosten Forestry and Hunting Enterprise" – 2.4, and the lowest in "Pulyny AIC Forestry" – 2.9.

Additional assessment is another important recreational indicator. This indicator characterizes the presence of features in the areas that can attract the attention of vacationers. According to forest management data, the indicators of additional assessment in the suburban forests of Zhytomyr are quite low, which is confirmed by the small areas of plots with the presence of noteworthy monuments (Table 7).

Table 7. Distribution of areas of forest parks in Zhytomyr according to indicators of additional assessment, ha

Indicators of additional assessment	Forest owner		
	"Berdychiv Forestry Enterprise"	"Pulyny APC Forestry"	"Korosten Forestry and Hunting Enterprise"
The presence of only noteworthy monuments and landscaping elements	-	-	-
The presence of only noteworthy sights	1.9	-	12.3
The presence of only landscaping elements	-	-	-
Amateur berry picking is possible	182.7	-	165.9
Lack of monuments, landscaping elements and berry trees	1967.7	1272.5	9699.3
Total	2152.3	1272.5	9877.5

Source: developed by authors basing on Ukrainian State Project Forest Management Manufacturing Association of the Production Association "Ukrderzhlisproekt" (n.d)

The "Pulyny AIC Forestry" has the lowest additional assessment of all possible. In the rest of the enterprises, the additional recreational characteristic is slightly higher. There are also doubts about the reliability of the forest management data used to determine the indicators of additional assessment, since only in the territory of the forest park zone of the "Korosten Forestry and Hunting Enterprise" branch there are at least three recreational facilities with a high level of improvement ("Lisovychok" and "Uzlisia" in Stanyshiv forestry, "Dibrova" in Tryhirske Forestry), which is not reflected in the forest management materials. In addition, there are at least three well-equipped modern recreational sites located in the forestry part of the green zone forests, but they do not have a description of recreational indicators: "Prolisok" in Bereziv Forestry, "Kitove Ozero" in Levkiv Forestry (branch of "Korosten Forestry and Hunting Enterprise" and a recreation centre near Perlyavka village in Zhytomyr Forestry ("Pulyny AIC Forestry").

The recreational assessment is an integrated indicator that summarises the level of aesthetics, accessibility, landscaping and availability of additional facilities.

According to the forest management data, the forest fund of the "Berdychiv Forestry Enterprise" branch has the highest recreational score – 1.7 points, significantly lower than the "Korosten Forestry and Hunting Enterprise" branch – 2.1 points and the "Pulyny AIC Forestry" – 2.3 points.The latter did not have a single site with a high recreational score (Table 8).

Table 8. Distribution of areas of forest parks in Zhytomyr according to recreational assessment, ha

Recreational assessment	Forest owner		
	"Berdychiv Forestry Enterprise"	"Pulyny APC Forestry"	"Korosten Forestry and Hunting Enterprise"
High	775.5	-	497
Average	1329.6	942.6	7564.8
Low	47.3	329.9	1815.7
Total	2152.4	1272.5	9877.5

Source: developed by authors basing on Ukrainian State Project Forest Management Manufacturing Association of the Production Association "Ukrderzhlisproekt" (n.d)

Given that the components of the integrated recreational assessment include three indicators, two of which (walkability and additional assessment) are unreliable according to forest management data, it was assumed that the final indicator could be significantly underestimated for the Korosten Forestry and Hunting Enterprise and the Pulyny AIC Forestry. A comparison of the recreational characteristics obtained as a result of field research on 20 research plots with forest management data revealed certain discrepancies (Table 9).

Table 9. Data of landscape mensuration on experimental sites (own data/forest management)

№ SP*	Type of landscape	Sustainability	Digression	Aesthetic assessment	Walkability	Additional assessment	Recreational assessment
1	semi-open/ closed	4/4	3/1	2/3	1/3	3/5	1/2
2	semi-open/ semi-open	3/3	4/1	3/2	1/3	5/5	2/2
3	closed/ closed	3/3	1/2	2/2	1/3	4/5	1/1
4	closed/ closed	4/4	1/1	5/5	3/3	2/5	2/3
5	closed/ closed	3/4	2/1	2/3	1/3	5/5	1/2

Table 9, Continued

№ SP*	Type of landscape	Sustainability	Digression	Aesthetic assessment	Walkability	Additional assessment	Recreational assessment
6	closed/ closed	3/3	5/1	2/2	1/3	3/5	1/2
7	closed/ closed	3/3	1/1	4/2	1/3	5/5	2/2
8	closed/ closed	3/3	2/1	3/2	1/3	5/5	2/2
9	closed/ closed	2/2	2/1	3/2	1/3	5/5	2/2
10	closed/ closed	2/2	2/1	3/4	1/3	3/5	1/3
11	closed/ closed	2/2	2/1	3/2	1/3	5/5	2/2
12	closed/ closed	3/3	2/1	2/2	1/3	3/5	1/2
13	semi-open/ semi-open	2/2	1/1	2/2	1/1	5/5	1/1
14	semi-open/ semi-open	2/2	2/1	2/4	1/1	5/5	1/2
15	closed/ closed	2/3	2/1	1/1	1/5	1/5	1/2
16	closed/ closed	2/2	2/1	1/1	1/3	2/5	1/2
17	closed/ closed	2/3	2/1	3/3	1/5	3/5	1/3
18	closed/ closed	3/2	2/1	2/3	1/3	1/5	1/2
19	closed/ closed	2/2	1/1	3/3	1/3	5/5	2/2
20	closed/ closed	3/3	3/1	2/2	1/3	3/5	1/2
Difference, %	5	9.1	90.5	20.0	66.7	20.0	50.0

***Note:** SP – sample plot
Source: developed by authors

When determining all 7 recreational indicators, discrepancies with forest management data were noted, which are associated with both the dynamics of individual indicators and software errors in landscape mensuration. The smallest discrepancy was found in determining the landscape type, where only one research plot (sample plot No. 1) was reduced below the closed landscape type limit due to selective sanitary felling. In addition, minor deviations (4 test plots) were noted in determining the indicator of resistance to recreational loads. The difference between the average scores was 20 per cent in the aesthetic assessment, with a difference in data at 10 sites. The aesthetic assessment based on forest management data is generally overestimated. This indicator was adjusted during the field surveys. Taking into account the presence of garbage or clutter in 5 plots lowered this indicator, and the noted attractive features (forest edges, groups of trees) allowed for higher scores in the other 5 plots.

When comparing the average scores of the supplementary assessment, the difference is also insignificant – 20%, but at 11 of the 20 sites, features were identified that allowed for a significant increase in this indicator by 1-4 points during field surveys. In determining the additional score, none of the plots were assessed for berry picking or for the presence of amenities and attractions, which significantly underestimated this recreational indicator. Significant differences were found when determining the digression of the plots. Since the sites surveyed mostly had high rates of visitation, 16 out of 20 sites had a disturbance index that was 1-3 points higher than the forest management data. The biggest mistakes were made by the forest management when establishing the walkability indicator. This indicator was correctly determined only in 3 out of 20 sites, and the underestimation of the indicator was mostly significant – by 2-4 points. A significant difference in the data of the 3 recreational indicators (walkability, aesthetic and additional assessment) significantly affected the integrated recreational assessment. At 13 of the 20 study sites, this indicator was underestimated by 1 grade.

The data analysed in this article confirm the findings of many scientists that landscape inventory materials are the basis for assessing the recreational potential of green zone forests (Edwards *et al.*, 2012). However, as the comparative analysis of recreational indicators in the research plots has shown, some of the forest management data may not be true and need to be corrected. Some scientists do not use landscape mensuration data at all when assessing the recreational functions of a complex green area of a city. For example, I.R. Kuzyk (2021), while conducting research on recreation in the green zone of Ternopil, calculated the main parameters of short, medium and long-distance suburban recreational activities and the recreational capacity of forests in the forest park part without taking into account these forest management data. N.F. Prykhodko *et al.* (2023) concluded that forestry and landscape recreation indicators should be taken as a basis for planning measures for the recreational and health development of an enterprise, taking into account the preferences of the enterprise. In this case, the authors used forest management data from 2012. The analysis of recreational indicators in this article was carried out using 2017 data, but their comparison with 2011 data indicates the identity and lack of dynamics for the parameters determined in the field, which calls into question the correctness of updating forest management information on recreation. The observations made during the field research confirmed that the improvement of individual sites can dramatically change the recreational use of the territory. Scientists from the Ukrainian Research Institute of Forestry and Agroforestry S.I. Musienko *et al.* (2020) believe that the priority should be to improve recreational areas in order to improve aesthetic properties and prevent negative environmental changes in forest ecosystems that would optimise recreational forest use.

As a confirmation of the effectiveness of the current methodology for determining and adjusting the aesthetic assessment used in the field research, O.M. Romanets (2020) concluded that the stage of recreational digression and the aesthetic value of plantations are interdependent. Plantations with better aesthetic qualities are more frequently visited by recreationists and are more heavily impacted, which eventually leads to a deterioration in their sanitary condition, a decrease in species diversity, and a decrease in aesthetic value. Studies of digression at the research sites located near water bodies (SP 5, 10, 11, 16) confirmed the conclusions of both domestic and foreign scientists that the negative effects of recreational nature management are exacerbated by seasonality and the concentration of recreationists in the most developed park plantations (Olsson, 2013; Melnychuk & Henyk, 2019). The studies of pyrogenic properties of green zone forests by P. van Lierop *et al.* (2015) and C. Ayala-Azcárraga *et al.* (2019), the results of which should be taken into account in the future when studying the sustainability of plantations. According to the current methods, the parameter of stand stability is regulated only by the predominant species, type of forest vegetation conditions and age of the stand. This does not take into account the components of plantations that affect their pyrogenic properties.

One of the key recreational indicators on which the recreational use of suburban forests largely depends is walkability. This indicator in Ukraine needs to be seriously revised, as modern transport proposals have changed significantly. If earlier public transport and cars were considered as transport, now the use of bicycles, ATVs and other off-road vehicles has become very popular. Interesting is the research of Finnish scientists on assessing walkability using the Zonation software (Jalkanen *et al.*, 2020). The approach of these scientists determined the establishment of zones of high recreational potential in different parts of the study area. This allows for the systematic integration of accessibility measures based on travel time by different means of transport.

Conclusions

The conducted geospatial analysis of the studied territory allows us to state that the suburban forests of Zhytomyr are located on the territory of about 87 thousand hectares. The forest cover of this territory is about 53%. Only a little more than 14 thousand hectares of forests are classified as forest parks. On an area of about 1,000 hectares of forests, it would be worth changing the protection category of the sites from the forestry part of the green zone and protective forests to forest parks, due to the high level of recreational use of this area and the need to take measures to optimise recreational use. The owners of suburban forests in Zhytomyr are state-owned and municipal forestry enterprises (88% of the area). About 12% of the area within the city's suburban forests and plantations belong to other owners.

The analysis of recreational indicators revealed the need to further optimise the spatial structure by increasing semi-open and open landscapes through landscape felling of about 30% of the area of closed landscape types. The territory of the forest park zone of Zhytomyr is undisturbed, as evidenced by the prevalence of the 1st class of recreational digression in the vast majority of areas. Resistance of the areas to recreational loads and aesthetic assessment are average. Walkability according to forest management data is mostly average (class 3). The additional assessment is low, with only about 2% of the site areas having features (class 1-4). The integrated recreational assessment of the vast majority of sites is average.

The results of preliminary field studies to determine recreational indicators in the most visited areas showed the unreliability of the programme definition of such indicators as walkability, additional assessment and recreational assessment. A significant underestimation of the results was noted for these indicators. When comparing the values of recreational digression and aesthetic assessment, significant discrepancies were also found between the forest management indicators and our own field studies. On the plots located near populated areas, the presence of garbage was mostly detected, which reduces the aesthetic assessment. In areas with landscaping elements, the actual recreational digression rates are much lower compared to the forest management data. In some cases, the level of soil surface disturbance reaches 70%. It is the results of the digression study that are key and determine the further prospects for studying the level of attendance of the forest park area in Zhytomyr and developing a plan for the functional zoning of the territory.

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Conflict of Interest

None.

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Рекреаційна характеристика лісів зеленої зони міста Житомира

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Анотація. Рекреація у лісах має важливе значення для мешканців міст, включаючи м. Житомир. Ліси зеленої зони міста потребують проведення комплексної оцінки для врегулювання рекреаційного користування лісами державної та комунальної власності. З метою проведення аналізу рекреаційних показників лісів зеленої зони м. Житомира було проведено порівняльний аналіз лісовпорядних даних ландшафтної таксації та співставлення із результатами власних польових досліджень. Для аналізу рекреаційних показників були використані база даних лісовпорядкування, матеріали попередніх польових досліджень, а також електронні картографічні матеріали та географічна інформаційна система. За даними лісовпорядкування просторова структура ділянок лісопаркової зони далека від оптимальної за рахунок малої частки відкритих і напіввідкритих типів ландшафтів. Наявне функціональне зонування на більшості ділянок не відповідає реальному рекреаційному використанню території. Наявні ділянки з інтенсивним відвідуванням, які не відноситься до лісопарків і не мають даних ландшафтної таксації, хоча мають високий рівень благоустрою. За показниками пішохідної доступності, стійкості, естетичної та інтегрованої оцінки ділянки лісопаркової зони демонструють здебільшого посередні показники. Рекреаційна дигресія переважної більшості ділянок незначна. Невелика кількість ділянок має необхідні показники для високої додаткової оцінки. Результати польових досліджень підтвердили недостовірність деяких рекреаційних показників, визначених лісовпорядкуванням. Найбільша невідповідність даних відмічена при визначенні пішохідної доступності, додаткової та рекреаційна оцінка, які суттєво занижені. У найбільш відвідуваних ділянках реальні показники рекреаційної дегресії та естетична оцінка є нижчими ніж у лісовпорядних матеріалах. Уточнення даних рекреаційної характеристики ділянок лісопаркової зони дозволяє актуалізувати інформацію по ландшафтній таксації та розробити комплексне функціональне зонування території приміських лісів м. Житомира. Результати дослідження допоможуть державним та комунальним лісогосподарським підприємствам оптимізувати рекреаційну експлуатацію лісів у межах зеленої зони міста, раціоналізувати використання природних ресурсів для рекреаційних цілей, забезпечуючи при цьому екологічну стійкість

Ключові слова: лісопарки; ландшафтна таксація; рекреаційна оцінка; дигресія; стійкість; пішохідна доступність

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Current increment of ecosystem services in permanent sample plots within the forest stands of the Feofania park-monument

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Abstract. Despite the fact that forests in nature conservation areas are of mature and over-mature age, they have a leading role in the production of ecosystem services, in particular in ensuring biodiversity. In the typical sense, at the mature and over-mature age of stands, the growth of live biomass and carbon sequestration almost stops, and the death of trees leads to a negative change in the stock. The purpose of the study is to substantiate the ability of over-mature forests to accumulate live biomass under the condition of the formation of multi-tiered and different-age stands. The research was conducted on four permanent sample plots of the Feofania park-monument, which were established in 2016 and 2017. The method of approximate mensuration was used to study the current growth of ecosystem services. The method of dendrochronology was used to analyse annual rings. The age range of experimental stands is between 80 and 180 years. Experimental stands of all sample plots are characterized by high-level productivity, compared to model data on the productivity of stands in Ukraine and the European part of Eurasia. According to the results of the research, it was established that the biggest current increment of ecosystem services is formed in the uneven-aged stand with the centuries-old common oak trees of the overstory. The results of the research can be used in practice for the management of nature conservation areas and improvement of the management of over-mature forests

Keywords: live biomass; carbon; energy; oxygen production; age; relative stocking; site index

Introduction

Forest ecosystems are able to produce ecosystem services on the territory of the environmental fund, provided that a balanced approach to nature management is observed. The main goal of forestry is to ensure the continuity of the functioning of forest ecosystems and maximise the number and productivity of ecosystem services. At the mature age of plantations, the increment of live biomass and carbon sequestration almost stops, and the death of trees leads to a negative change in the stock.

The concept of ecosystem services is an active area of interdisciplinary research involving representatives of natural and socio-economic sciences (Braat & de Groot, 2012), and the situation in this field is changing very rapidly. Today, there are many interpretations of the concepts of “environmental services”, “ecosystem services” and related “ecological functions”, “ecosystem functions”. It also traces the uncertainty in the methods and approaches used to assess the economic potential of resources as a powerful lever of economic management. In global understanding, one of the latest constructive papers in the field of ecosystem service identification was the study by T. Brown *et al.* (2007). They highlighted ecosystem benefits and ecosystem services. The benefits group has included non-renewable goods (rocks, minerals, fossil fuels) and those that are restored (animals, plants, water, air, soil, recreation, aesthetics). Forest biomass is an essential indicator for monitoring the Earth’s ecosystems and climate. D. Schepaschenko *et al.* (2019) prove that this is an important contribution to greenhouse gas accounting, assessment of carbon loss and forest degradation, evaluation of renewable energy potential and development of climate change mitigation policies. Patterns of carbon sequestration in forest ecosystem components reflect the accumulative potential of forest biomass in the context of anthropogenic environmental transformation (Bilous *et al.*, 2019). In the study of strategic guidelines for ecosystem services in wetlands, E.V. Mishenin & N.V. Degtyar (2016) presented a decomposition of wetland ecosystem services management strategies detailed on the following features: general and dominant strategies, strategies on how to achieve the goal of managing ecosystem services, strategies on the nature of the behaviour of wetland ecosystem services management entities, and target strategies on the capacity of such services. O.R. Pelyukh & L.D. Zahvoyska (2017), considering methodological approaches to estimating the cost of forest ecosystem services, established that the method of the selective experiment allows for assessment of the marginal utility of individual attributes of forest ecosystems that have the properties of public benefits. This estimate can be presented in various units of measurement, in particular, in monetary terms. Investigating the causes of deforestation in the tropics, using high-resolution maps and increased sample sizes, has helped to better identify the key factors leading to deforestation. This has been confirmed by the study carried out by the researchers J.C. Laso Bayas *et al.* (2022).

Forest loss risk management is a priority for forest conservation and enhancement and increasing the current production of ecosystem services. The analysis of scientific papers and practical measures that determine the process of formation of the concept of ecosystem services shows that there is no clear unity of understanding of the mechanisms of its practical implementation and development tools. The purpose of the study was to substantiate the ability of over-mature plantations to increase live biomass and sequestrate carbon under the condition of forming multi canopy layers and uneven-aged stands.

Materials and Methods

Experimental studies were conducted on four permanent sample plots in the period from 2016 to 2021, which are situated within the territory of the Feofania park-monument, a nationally substantial landscape art park located on a portion of an elevated forest-steppe plateau that borders with the Polissya region of Ukraine. In accordance with the geo-botanical zoning, the territory of the park belongs to the Podilsk-Serednioprydniprovska province. The relief is formed by valley-girder, hilly, dissected ravines. The soil cover is mostly represented by Grey podzolic, forest, sod-podzolic, and Meadow-swamp types (United Nations Framework Convention ..., 1996). According to the floral classification, the forest stands of the tract belong to the association *Galeobdoloni luteae-Carpinetum* (Goncharenko *et al.*, 2013).

The research consisted of quantitative and qualitative assessment of the bio-production process in forest ecosystems, accounting of quantitative parameters of ecosystem services, verification, interpretation, and practical application of mathematical models and information support for quantitative assessment of forest ecosystem services, and determination of the social and economic significance of ecosystem functions of forest phytocenoses for sustainable development of forest stands were studied in Ukraine by Ya.P. Didukh & U.M. Alioshkina (2007), R.D. Vasylyshyn, (2013), M. Matsala *et al.* (2021) and others.

During the study, the Convention on Biological Diversity (1992) standards were observed. Observing permanent sample plots (Fig. 1) and collecting forest inventory data were realized ed in accordance with SOU 02.02-37-476:2006. “Sample plots for forest management planning. Method of creating” (2006). All permanent sample plots were homogeneous in terms of structure and parameters and experienced minimal forest management impact.

Figure 2 shows a general diagram of the ecosystem services assessment methodology that was used to achieve the study goal. Assessment of ecosystem services was conducted by direct measurement of the diameter of trees of the permanent sample plots at a height of 1.3 m, height of trees, crown length and their geographical coordinates.

Figure 1. Location of embedded permanent sample plots
Source: Google satellite image in the background

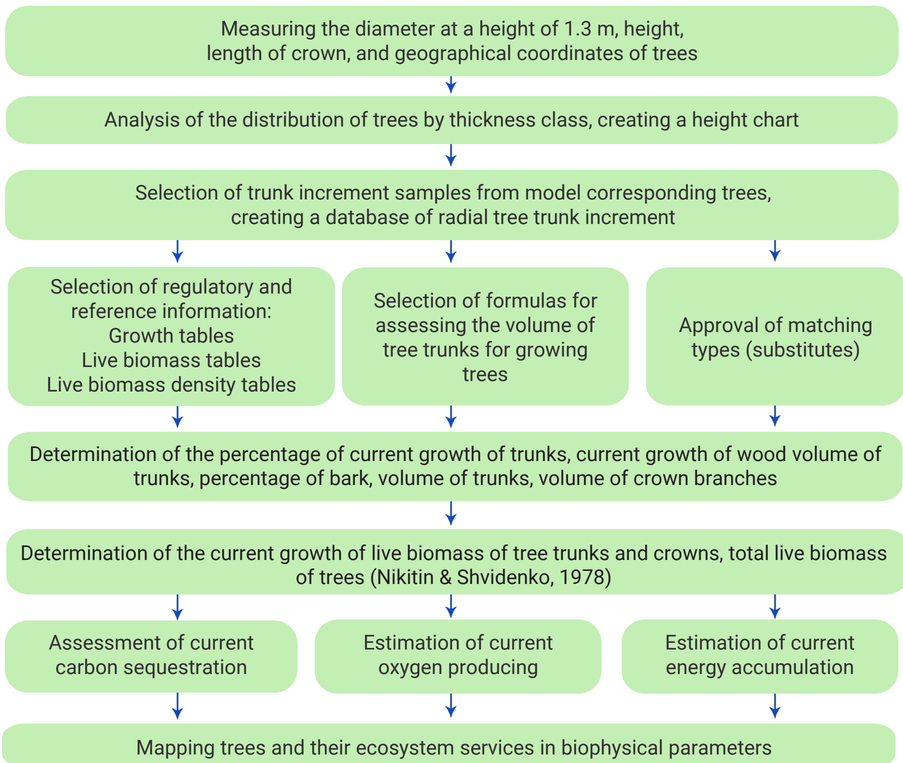

Figure 2. Scheme of methodology for evaluating ecosystem services of trees
Source: compiled by A. Bilous

Then, the analysis of the distribution of trees by thickness degrees and construction of a height curve was conducted. The next step involved sampling trunk growth from model matching trees and creating a database of radial tree trunk growth. The selection of regulatory reference information involved the use of growth tables, live biomass tables, and density tables (Lakyda *et al.*, 2011). Subsequently, the volume of trunks for growing trees was determined.

The percentage of current increment of trunks, current increment in the volume of wood trunks, percentage of bark, volume of trunks, and volume of crown branches was determined to fully assess the ecosystem services of forest stands of the research object, which allowed determining the intensity of current increment of live biomass of trunks and crowns of trees, and the total live biomass of trees. Subsequently, the main parameters of ecosystem services were evaluated: total carbon of trees and current carbon increment, total amount of oxygen released and its current annual producing, total amount of stored energy and current energy accumulation. The final stage was the mapping of trees and their ecosystem services in biophysical parameters.

Results and Discussion

During the period of laying sample plots, the structure of forest stands by their vital state was analysed (Table 1).

Table 1. Distribution of trees on permanent sample plots by their vital state (2016-2021), pcs

Number of the permanent sample plots	Condition of trees	CABE	ACPL	QURO	TICO	ULLE	ROPS	FREX
2016								
1	Live	-	142	98	1	2	5	-
	Dead	-	6	6	-	-	-	-
2	Live	215	36	33	23	-	-	-
	Dead	2	-	5	-	-	-	-
2017								
3	Live	181	8	7	6	10	1	-
	Dead	1	-	-	-	-	-	-
4	Live	57	73	63	9	1	-	1
	Dead	8	2	8	4	-	-	-
2019								
1	Live	-	139	86	1	2	5	-
	Dead	-	9	18	-	-	-	-
2	Live	208	36	31	23	-	-	-
	Dead	9	-	7	-	-	-	-
3	Live	172	8	7	6	10	1	-
	Dead	10	-	-	-	-	-	-
4	Live	55	71	60	8	1	-	1
	Dead	10	4	11	5	-	-	-
2020								
1	Live	-	139	79	1	2	5	-
	Dead	-	9	25	-	-	-	-
2	Live	207	36	31	23	-	-	-
	Dead	10	-	7	-	-	-	-
3	Live	167	8	7	6	10	1	-
	Dead	15	-	-	-		-	-

Table 1, Continued

Number of the permanent sample plots	Condition of trees	CABE	ACPL	QURO	TICO	ULLE	ROPS	FREX
2020								
4	Live	51	69	57	6	1	-	1
	Dead	14	6	14	7	-	-	-
2021								
1	Live	-	138	73	1	2	5	-
	Dead	-	10	31	-	-	-	-
2	Live	204	35	31	23	-	-	-
	Dead	13	1	7	-	-	-	-
3	Live	162	7	7	5	10	1	-
	Dead	20	1	-	1	-	-	-
4	Live	50	68	57	5	1	-	1
	Dead	15	7	14	8	-	-	-

Note: CABE – Common Hornbeam, ACPL – Sycamore Maple, QURO – Common Oak, TICO – Small-leaved Linden, ULLE – European White Elm, ROPS – Black Locust, FREX – Common Ash
Source: compiled by the authors

Each permanent sample plots (PSP) is represented by typical broad-leaved tree species and is formed by the following composition according to its species structure:

- PSP No. 1 (2016) (the total of counted trees is 260, of these, dead trees – 2.3% Maple, 2.3% Oak), area – 0.51 ha) – Sycamore Maple (ACPL) – 54.6% Common Oak (QURO) – 37.7%, Black Locust (ROPS) – 1.9%, Small-Leaved Linden (TICO) – 0.4%, European White Elm (ULLE) – 0.8%;
- PSP No. 2 (2016) (the total of counted trees is 314 units, of these, dead trees – 0.6% Hornbeam, 1.6% Oak, area – 0.88 ha) – Sycamore Maple (ACPL) – 11.5%, Common Hornbeam (CABE) – 68.5%, Common Oak (QURO) – 10.5%, Small-Leaved Linden (TICO) – 7.3%;
- PSP No. 3 (2017) (the total of registered trees is 214 units, of these, dead trees – 0.5% Hornbeam, area – 0.44 ha) – Sycamore Maple (ACPL) – 3.7%, Common Hornbeam (CABE) – 84.6%, Common Oak (QURO) – 3.3%, Black Locust (ROPS) – 0.5%, Small-Leaved Linden (TICO) – 2.8%, European White Elm (ULLE) – 4,6%;
- PSP No. 4 (2017) (the total of counted trees is 226 units, of which dead trees – 3.5% Hornbeam, 3.5% Oak, 0.9% Maple, 1.8% Linden, area – 0.29 ha) – Sycamore Maple (ACPL) – 32.3%, Common Hornbeam (CABE) – 25.2%, Common Oak (QURO) – 27.9%, Small-Leaved Linden (TICO) – 4.0%, European White Elm (ULLE) – 0.5%, Common Ash (FREX) – 0.4%.

The largest number of the four PSP examined is represented by Maple, Hornbeam, and Oak trees. The density of stands for PSP was – PSP No. 1 – 510 trees per ha, PSP No. 2 – 357 trees per ha, PSP No. 3 – 486 trees per ha, PSP No. 4 – 779 trees per ha.

In the first PSP, the number of live Maple trees decreased by 2.8%, Oak – by 25.5%. The living condition of Black Locust, Ash, and Linden remained unchanged, and the share of dead Oak and Maple units was already 11.9% and 3.8% of the total number of trees, respectively. According to the vital state of plantations, the structure of the second PSP is formed with an advantage of Hornbeam – 204 trees. The number of dead trees increased to 13 trees, which is 4.1%. Among dead trees, the number of Oak and Maple trees also increased, their share is 2.2% and 0.3% of the total number of trees in the PSP, respectively. The largest amount of dead wood in the third PSP was formed by Hornbeam (9.3%) and Maple and Linden (0.5%). The fourth PSP according to the dynamics of dead trees formation is characterised by an increase in the share of dead Hornbeam and Oak trees, which is 6.6% and 6.2% of the total number of trees in the PSP, and the share of Linden and Maple – 3.5% and 3.1%.

Based on the results of measurements, sampling of tree increment on PSP, and considering the intensity of growth and development of forest stands, the current increment of ecosystem services for each growing tree was estimated. General parameters of current live biomass increment, carbon sequestration, energy storage, and oxygen production are shown in Table 2.

Table 2. Current increment of ecosystem services at PSP No. 1 (2016-2021)

Species of trees	Parameter			
	current live biomass increment, $t \cdot ha^{-1} \cdot yr^{-1}$	current carbon sequestration, $t \cdot ha^{-1} \cdot yr^{-1}$	current energy storage, $GJ \cdot ha^{-1} \cdot yr^{-1}$	current oxygen producing, $t \cdot ha^{-1} \cdot yr^{-1}$
ROPS	0.25	0.12	4.4	0.35
ULLE	0.01	0.01	0.2	0.01
QURO	2.17	1.09	38.9	3.04
ACPL	0.91	0.46	16.3	1.28
TICO	0.01	0.004	0.1	0.01
Total	**3.35**	**1.67**	**59.9**	**4.69**

Source: compiled by the authors

The total live biomass of the stand of the first trial area, considering the trunk of the bark, bark, branches, leaves, roots, green forest floor, and understorey, was 3.35 $t \cdot ha^{-1}$ yr^{-1} the first PSP. The current increase in carbon for the specified period in the study on PSP was 1.67 $t \cdot ha^{-1}$ yr^{-1}.

The sustainability of the ecosystem of urban Oak stands, due to structural diversity, should become an important tool for protecting the remains of old forests. Human exposure can contribute to tree size differentiation, dead wood formation, and biodiversity maintenance, but will threaten forest stands in large cities in the long run (Morozyuk, 2009). In the current increment in total carbon, Oak stands account for the largest share – 1.09 $t \cdot ha^{-1}$ yr^{-1}, and the smallest on Linden stands – 0.004 $t \cdot ha^{-1}$ yr^{-1}. These indicators closely correlate with the results of the study of the structure of this plantation, which confirms that the main share of them in the first PSP is formed from Oak trees and, accordingly, its plantations have the largest share of sequestrated carbon.

During the growth and development of forest stands in the first PSP, the largest share of current carbon sequestration (Fig. 3) formed from Oak stands – 64.9%. Maple accounts for 27.2%, and the lowest growth rate is observed in Linden trees – 0.2%.

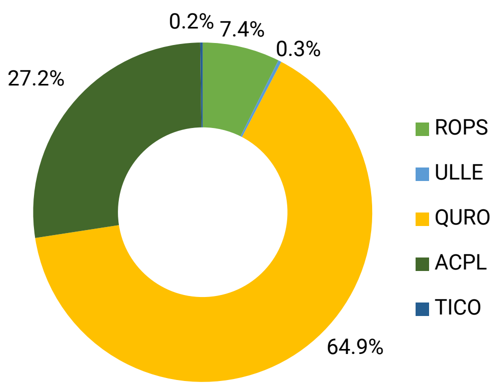

Figure 3. Structure of carbon sequestration by species composition of PSP No. 1 (2016-2021)
Source: compiled by the authors

Parameters of the current increment of ecosystem services of the second PSP (Table 3) are characterised by the formation of the main share due to Common Oak trees.

Table 3. Current increment of ecosystem services at PSP No. 2 (2016-2021)

Species	Parameter			
	current live biomass increment, t·ha^{-1}·yr^{-1}	**current carbon sequestration, t·ha^{-1}·yr^{-1}**	**current energy storage, GJ·ha^{-1}·yr^{-1}**	**current oxygen producing, t·ha^{-1}·yr^{-1}**
CABE	1.23	0.61	21.9	1.72
QURO	3.34	1.67	59.7	4.68
ACPL	0.78	0.39	14.0	1.09
TICO	0.41	0.20	7.3	0.57
Total	**5.75**	**2.88**	**102.9**	**8.06**

Source: compiled by the authors

The current increase in live biomass during the research period was 5.75 t·ha^{-1}·yr^{-1}, and the share of the total number accounted for by Oak trees was 58%. The current increase in carbon, which is formed mainly Oak trees, was 2.88 t·ha^{-1}·yr^{-1} for the study period. Among all the species that form the second PSP in terms of ecosystem services, compared to other species, the lowest growth rate is characteristic of Linden.

The overwhelming proportion of current carbon sequestration (Fig. 4) in the second PSP, was formed from Oak trees, which amounted to almost 58.1%. Hornbeam trees account for 21.3%, and Maple trees – 13.6%. A smaller proportion is formed by Linden trees.

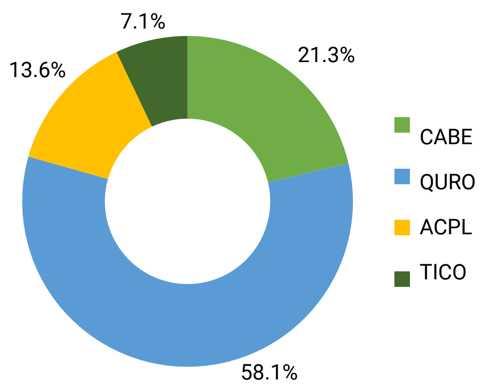

Figure 4. Structure of carbon sequestration by species composition of PSP No. 2 (2016-2021)
Source: compiled by the authors

In the course of investigating the parameters of ecosystem services (Table 4) of the third trial area, it was established that the total current increment of live biomass was 4.78 t·ha^{-1}·yr^{-1}, and the increase in carbon – 2.39 t·ha^{-1}·yr^{-1}. Among the trees that make up the third PSP, Hornbeam and Oak trees can be distinguished by the predominant values of ecosystem services – 3.88 t·ha^{-1}·yr^{-1}, respectively and 2.39 t·ha^{-1}·yr^{-1}.

As noted above, in the third PSP, Hornbeam and Oak are the main trees that have formed the largest share of ecosystem services (Fig. 5).

Table 4. Current increment of ecosystem services PSP No. 3 (2017-2021)

Species	Parameter			
	current live biomass increment, t·ha^{-1}·yr^{-1}	current carbon sequestration, t·ha^{-1}·yr^{-1}	current energy storage, GJ·ha^{-1}·yr^{-1}	current oxygen producing, t·ha^{-1}·yr^{-1}
ROPS	0.02	0.01	0.4	0.03
ULLE	0.18	0.09	3.2	0.25
CABE	2.77	1.39	49.6	3.88
QURO	1.71	0.85	30.5	2.39
ACPL	0.03	0.02	0.6	0.05
TICO	0.07	0.03	1.2	0.1
Total	**4.78**	**2.39**	**85.5**	**6.70**

Source: compiled by the authors

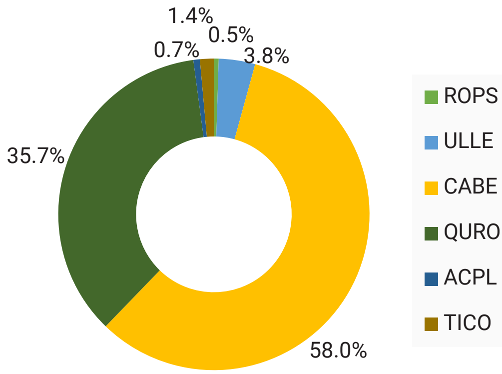

Figure 5. Structure of carbon sequestration by species composition of PSP No. 3 (2017-2021)
Source: compiled by the authors

Thus, carbon sequestration, as one of the determining parameters of ecosystem services, mainly belongs to Hornbeam – 58.0% and Oak – 35.7%, and the smallest share to – Maple – 0.7%.

The fourth PSP, according to the examined growth parameters, is characterized by the following values: the total current increase in live biomass was 3.31 t·ha^{-1}·yr^{-1}, carbon – 1.65 t·ha^{-1}yr^{-1} and oxygen 4.63 t·ha^{-1}·yr^{-1} (Table 5).

Table 5. Current increase in indicators of ecosystem services PSP No. 4 (2017-2021

Species	Parameter			
	current live biomass increment, t·ha^{-1}·yr^{-1}	current carbon sequestration, t·ha^{-1}·yr^{-1}	current energy storage, GJ·ha^{-1}·yr^{-1}	current oxygen producing, t·ha^{-1}·yr^{-1}
ULLE	0.001	0.001	0.03	0.002
CABE	0.2	0.1	3.6	0.28
QURO	2.37	1.19	42.4	3.32
ACPL	0.61	0.30	10.9	0.85
TICO	0.06	0.03	1.0	0.08
FREX	0.07	0.04	1.3	0.1
Total	**3.31**	**1.65**	**59.2**	**4.63**

Source: compiled by the authors

The highest share among the species that PSP No. 4 belongs to Oak – 72% and the minimum – to Elm. In terms of the increase in carbon sequestration, the advantage here belongs to Oak plantations – 71.7% (Fig. 6). The rest is formed from Maple – 18.1%, Hornbeam – 6.1%, and Ash – 2.1%. The minimum increment belongs to Elm – 0.06%.

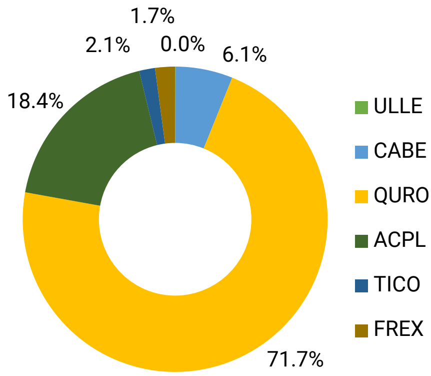

Figure 6. Structure of carbon sequestration by species composition of PSP No. 4 (2017-2021)
Source: compiled by the authors

Thus, among the permanent sample plots, the current increment of ecosystem services parameters was most intense in the second permanent sample plots, and among the trees forming the studied plantations, the Common Oak prevailed in growth.

The study of biological productivity involves, first of all, establishing the biological potential of tree species in different growing conditions, which is expressed by the annual production of live biomass, drawing up appropriate criteria for the components of live biomass, productivity maps, etc. (Petrenko, 2002). The results of the investigation of permanent sample plots highlight the dynamics of biophysical parameters of ecosystem services, the assessment of which is based on the study of the bio-productivity of stands. The list of services provided by forest stands, in particular, the nature reserve fund, is much larger than presented in the study and requires a comprehensive approach to their assessment and consideration in the environmental management economy. For example, in the paper of D.C. Donato *et al.* (2012), it is noted that ecosystem services, such as pollution filtration and carbon sequestration, are difficult to replace, and the deterioration of environmental quality due to the loss of ecosystem services is now one of the biggest threats to society and business.

It is important to note that, according to the results given in the study by O.V. Morozyuk (2009), in terms of the scale of production and, especially, the duration of carbon sequestration in trees, forests are recognised as the most reliable system for preventing the greenhouse effect, which is relevant for urban forests in conditions of intense atmospheric pollution from moving and stationary sources.

Given that forest ecosystems serve as the main terrestrial carbon dioxide absorber (Vyshenska, 2014; Prokopuk & Netsvetov, 2016), forestry is one of the main factors that can substantially affect its balance and circulation (Pasternak & Buksha, 2004). This should also be considered when planning forestry activities plantations, which substantially affect the growth and development of stands, and therefore the intensity of carbon storage. It is necessary to consider the fact that much younger stands on PSP No. 1 and No. 4 have a substantially lower current increment of live biomass, compared to older stands on PSP No. 2 and No. 3, which may be due to the lack of economic logging for the formation of plantations, since this is the forest fund of a nature protection object.

Each forest plot produces a different amount of ecosystem services, depending on the species composition, spatial distribution, and other forest stand parameters. As a result of the study by T. Häyhä *et al.* (2015), the annual volume of ecosystem services produced by alpine forest ecosystems was established and their monetary equivalent was determined. Thus, alpine forests annually produce ecosystem services in the amount of 300 to 6100 €·ha^{-1}·yr^{-1}, which is about 820 €·ha^{-1}·yr^{-1} (Grotti *et al.*, 2019). For the development of objects of the nature reserve fund, it is important in the future to move from evaluating ecosystem services in Biophysical terms to determining the cost indicators of the benefits that forests produce for people.

Comparison of the obtained results of the study on all PSP (PSP) with the data of the tables of bioproductivity of Oak stands, according to P. Lakyda *et al.* (2006) and A. Shvidenko *et al.* (2008) indicates a substantially greater current increment of ecosystem services for stands across all PSP compared to regulatory reference data. Notably, the vast majority of theoretical models of live biomass dynamics in plantings over 110-120 years will have a negative value of the current live biomass increment parameters, since the drop in such plantations will prevail over the growth of trees. That is why Figure 7 shows the data obtained by P. Lakyda *et al.* (2006) and A. Shvidenko *et al.* (2008) in negative trends for PSP No. 2 and No. 3.

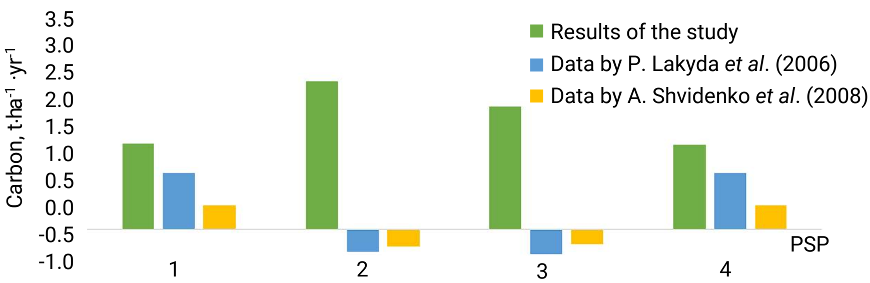

Figure 7. Comparison of data on current carbon sequestration of stands of PSPs (1 – PSP No. 1, 2 – PSP No. 2, 3 – PSP No. 3, 4 – PSP No. 4)

Source: compiled by the authors according to P. Lakyda *et al.* (2006) and A. Shvidenko *et al*. (2008)

Thus, stands on all PSP are characterized by high productivity of ecosystem services compared with the regulatory data on the bio-productivity of stands in Ukraine and the European part of Eurasia. The most substantial feature of trial stands in PSP No. 2 and 3 is the substantially higher productivity of 180-year-old stands, compared to modal stands of the same age and site index.

Conclusions

The establishment of regularities of the main processes of growth and development of forests depends on the study of the main forest stand parameters on permanent sample plots. The implementation of successive stages of performing forest measurements in the field and combining them with existing models or standards fully allows for assessing the increment of ecosystem services of forest stands.

Assessment of biophysical parameters of ecosystem services allows for identifying the ecological significance of forest stands of objects of the nature reserve fund, which in the future may potentially have economic significance, which is especially important within urban ecosystems.

Studies have shown that forest stands with 180-year-old Oak trees in the overstory have a high level of production of ecosystem services, in particular, carbon sequestration and oxygen production. In two PSP, old Common Oak trees are key to carbon storage, and the current carbon sequestration is conducted by younger trees of the midstory of plantations.

As part of the study, a justification was added for the advantages of plantations many-layed, uneven-aged and diverse in species structure for producing ecosystem services, which is primarily important for the arrangement and management of forest stands within the nature reserves. It is important to expand the network of permanent sample plots, conduct systematic comprehensive case studies, and check the existing regulatory and reference support for trees and stands of the main forest-forming species of Ukraine.

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Conflict of Interest

The authors declare no conflict of interest.

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Поточний приріст екосистемних послуг на постійних пробних площах у деревостанах парку-пам’ятки «Феофанія»

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Анотація. Незважаючи на те, що ліси на природоохоронних територіях переважно є стиглими та перестиглими, вони мають провідну роль у продукуванні екосистемних послуг, зокрема у підтримці біорізноманіття. У класичному розумінні, у стиглому та перестиглому віці деревостанів приріст живої біомаси та поглинання вуглецю насаджень майже припиняється, а відпад дерев призводить до негативної зміни запасу. Мета дослідження – обґрунтувати здатність перестиглих лісів накопичувати фітомасу за умови формування багатоярусних та різновікових насаджень. Дослідження було проведено на чотирьох постійних пробних площах парку-пам’ятки «Феофанія», закладених у 2016 та 2017 роках. Для вивчення поточного приросту екосистемних послуг використано метод наближених таксацій. Для аналізу річних кілець використано метод дендрохронології. Віковий діапазон дослідних насаджень – від 80 до 180 років. Дослідні насадження всіх пробних ділянок характеризуються високим рівнем продуктивності порівняно з модельними даними про продуктивність насаджень України та Європейської частини Євразії. За результатами досліджень встановлено, що найбільший поточний приріст екосистемних послуг формується в різновіковому насадженні з багатовіковими деревами дуба звичайного у верхньому ярусі. Результати досліджень можуть бути використані на практиці для управління природоохоронними територіями та вдосконалення проектування переформування насаджень

Ключові слова: фітомаса; вуглець; енергія; киснепродуктивність; вік; відносна повнота; клас бонітету

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Post-aseptic adaptation and *ex vitro* propagation of Ukrainian cultivars of *Paulownia* Sieb. et Zucc.

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Abstract. Plantation forestry using highly productive and fast-growing plants involves the use of high-quality improved planting material for genetic constancy, which is solved by microclonal reproduction. However, the high survival rate and stability of plants obtained *in vitro* are realised as a result of post-aseptic adaptation of regenerants. Therefore, the research aims to improve the

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survival techniques of paulownia regenerants of the Ukrainian varieties "Feniks" and "Enerdzhy" *ex vitro*. The study was conducted in December 2021 on the Ukrainian paulownia varieties "Feniks" and "Enerdzhy", cultivar "Feniks". The survival rate, development of regenerants, and their damage by facultative saprophytic pathogens differed on substrates of organic (Eco Plus, La Flora, Jiffy, coconut peat, cotton wool) and mineral (vermiculite, perlite, sand) origin. The biological products "Rise P" and "Prestop" proved to be effective for the control of pathogenic microorganisms on substrates of organic origin. The technological feasibility of using perlite substrate is substantiated. The pathophysiology of *ex vitro* regenerants of paulownia under Fusarium is described. The thickness of the films used for sheltering influenced the regeneration, engraftment, microbial damage, and temperature of the wet chambers. Growing regenerants with covering films of different thicknesses showed a high survival rate in the variants with stretch films of 10 and 23 μm thickness. In the case of using polyethene films with thicknesses of 60, 80 and 100 μm, a sharp increase in temperature was observed, which was 48, 53 and 65^{0}C, respectively. At these high temperatures, most of the regenerants died, after which they were colonised by facultative saprophytes, and the tissues were completely macerated within two days. The optimal ratio of juvenility reduction and the acquisition of adaptive traits is characteristic of the second, third and fourth generation *ex vitro*. The expediency of propagation by stem cuttings up to the fourth generation, which preserves the regenerative ability of shoot cuttings, was substantiated. The practical results of the research are a protocol for growing paulownia plants *in vitro* and *ex vitro* on different types of substrates for use by institutions engaged in paulownia propagation.

Keywords: explant; regenerant; rhizogenesis; survival; juvenility

Introduction

Modern rapid development of society is impossible without the development and implementation of the latest technologies. In particular, in forestry, this means the introduction of plantation technologies for growing fast-growing valuable species, varieties, and clones of plants, i.e., the transition from extensive to intensive forestry methods (Kaletnik *et al.*, 2021). At the same time, climate change and the ever-growing demand for timber necessitate the urgent creation of high-performance fast-growing plantations from tree species that are adapted to new conditions, resistant to pathogens and climatic stress, and have valuable wood. These requirements are met by hybrid varieties, clones of *Paulownia*. The plant is resistant to high temperatures in summer and low temperatures in winter, and it grows rapidly and develops well. Ukraine has developed varieties that meet the requirements of the State Register of plants suitable for distribution in Ukraine (2023).

V. Matskevych *et al.* (2019) determined that microclonal propagation and post-apoptotic adaptation methods are used for the rapid introduction of Ukrainian paulownia varieties into production. *In vitro*, under heterotrophic nutrition and conventional methods of microclonal propagation using exogenous sources of hydrocarbons and hormones, plant objects reach a juvenile state. Juvenilisation is valuable because it increases the regeneration potential. However, according to A. Podhaietskiy *et al.* (2020), at the stage of adaptation, regenerated plants in this state are vulnerable to adverse *ex-vitro* non-static conditions.

The adaptation of regenerated plants *in vitro* to conditions "outside the glass" (*ex vitro*) is called post-applied adaptation. At this stage, technological methods should be aimed at a gradual, stress-free transition of different levels of endogenous regulation of plant growth and development from organelles and cells to the organismal level. Under such conditions, mixotrophic nutrition with a predominance of heterotrophic plant objects will be transformed into autotrophic nutrition through the activation of photoassimilating systems. V. Matskevych *et al.* (2019) noted that the water exchange system is also reformatted, including the balance between absorption and transpiration. Therefore, after aseptic cultivation, *in vitro*, plants must undergo a post-aseptic "reset", i.e. post-aseptic adaptation.

M. Abbasi *et al.* (2020) show great potential for renewable energy production in Iran, as scientists have substantiated favourable conditions for growing paulownia in an area of about 160,000 km^2. On the other hand, the results of the calculations show that the use of the Z-score reduces the error of weather forecasts by 8%, so the assessment of land suitability can be carried out more accurately. As a result, this robust method can prevent loss of agricultural productivity due to the selection of unsuitable locations.

The research of M. Jakubowski (2022), conducted on paulownia hybrids, showed significant differences in the growth dynamics of individual clones in their response to local environmental and climatic conditions. For example, the yield of dry biomass in the second year of cultivation ranges from 1.5 t/ha to 14 t/ha. This diversity is manifested not only in growth characteristics but also in wood properties and possibilities of its use (Magar *et al.*, 2016; Pożoga *et al.*, 2019).

The water productivity of paulownia and poplar in Kyrgyzstan was studied by N. Thevs *et al.* (2021). These studies were conducted to identify the possibility of additional load on water resources of the introduced paulownia (*Paulownia tomentosa* × *fortunei*) compared to three-year-old poplar (*Populus deltoides* × *nigra*) plants. Poplar increased stem biomass by 5.4 kg with an average water consumption of 4.18 l/day (water productivity 6.79 g/l). The stem biomass of paulownia increased by 4.8 kg at an average flow rate of 2.36 l/day (water productivity 11.90 g/l). Therefore, N. Thevs *et al.* (2021) concluded that the reproduction of paulownia will not put more pressure on the water resources of Central Asia than poplar. This refutes the negative feedback that paulownia is an invasive species and has a negative impact on other tree species.

Biotechnological production of planting material takes more than half of both labour and material resources. Therefore, it is necessary to develop technological methods for using plants *in vitro* only as mother plants for their further propagation using less costly methods in post-aseptic conditions of closed ground. To grow paulownia planting material for industrial purposes, it is necessary to develop technological methods of paulownia propagation as a result of post-aseptic adaptation. Since *in vitro* production is highly costly in the whole technological process, it is important to improve the adaptation of regenerants to *ex vitro* conditions.

The research aims to develop technological methods for simultaneous post-aseptic adaptation and propagation of Ukrainian paulownia varieties based on the results of morphophysiological studies.

Materials and Methods

The research was carried out on the Ukrainian varieties of paulownia "Feniks" and "Enerdzhy". The "Feniks" variety is characterised by fast growth rates and large leaves up to 1.0 m in diameter. The "Enerdzhy" variety has a slightly slower growth rate, but it is characterised by higher winter hardiness (24-26°C) and slightly denser wood. The explants used were cuttings harvested in December 2021 at the Plant Biotechnology Research Laboratory of

Bila Tserkva National Agrarian University. The age of the mother trees used for the study was 6-8 years. Shoots were taken in the middle part of the tree on the south side. The cuttings were taken only from healthy shoots and cut early in the morning to ensure the maximum amount of moisture in them. For each of the varieties, 360 shoot cuttings were taken. Cutting explants were cultivated *in vitro* according to the generally accepted methodology on Murashige and Skoog medium (Japan), which contains salts and a mixture of vitamins (Matskevych *et al.*, 2019). This medium is widely used for growing plant tissues. It has proven to be effective in the culture of tissues derived from monocots and dicots. This medium was developed to support callus and cell growth in suspension culture and regeneration of shoots and seedlings from explants (Kushnir & Sarnatska, 2005). Cuttings explants were cultivated *in vitro* for up to 30 days in containers with a total volume of 250 ml (Fig. 1). Then they were transplanted into closed-ground conditions on artificial substrates: peat, perlite, vermiculite, etc.

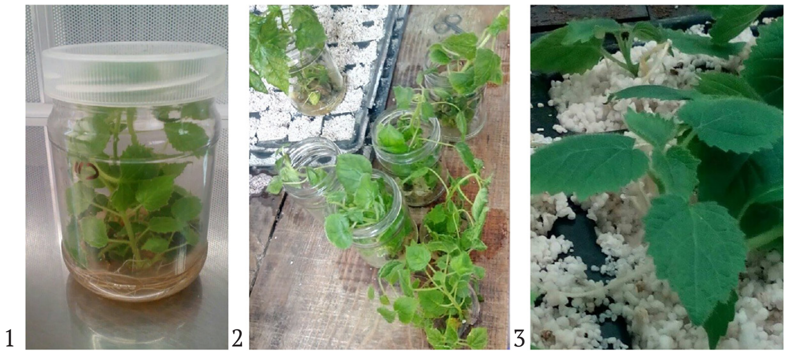


Figure 1. Cultivation of paulownia *in vitro* and *ex vitro* in research
Note: 1 – *in vitro* plant; 2 – planting *in vitro* plants in cassettes with substrate; 3 – *ex vitro* regenerant
Source: authors' photo

The mineral part of the Murashige and Skoog (MS) medium was added to the substrates. Cuttings were carried out for six generations *ex vitro* using the overlay method. Adapted plants *in vitro*, from which cuttings were taken for the first green cuttings, were conditionally considered as "generation 0". For successful adaptation of paulownia plants *in vitro*, their survival rate was analysed on the following substrates: universal substrate Eco Plus (produced in Ukraine), substrate LaFlora KKS-2 (produced in Latvia), peat loose substrate Jiffy, Jiffy tablets (produced in Estonia), coconut substrate Grond Meester UNI (produced in Sri Lanka), cotton wool, vermiculite, perlite, sand (produced in Ukraine).

Since it is necessary to maintain a turgid state in green cuttings to preserve moisture, they were planted in a humid chamber. For the first two weeks, the chamber was covered with a film lid. In the third week, the lid was gradually lifted to reduce the humidity from 95% to 65%. The temperature in the wet chambers was maintained at 24°C during cultivation. The chambers were ventilated twice a day for 15-20 minutes.

After rooting of green cuttings and regeneration of plants from them, they were re-cut or transplanted into cassettes with 500 ml cells, which were used for planting in the field or for sale. To combat pathogenic organisms (facultative saprophytes), two types of preparations were selected – "Rise P" (manufactured by Lallemand Plant Care SAS, France) and "Prestop" (Verdera OY, Finland), which were used to treat the substrate. The *Bacillus amyloliquefaciens* IT45 bacteria contained in "Rise P" were isolated from natural soils and selected by researchers from hundreds of other PGPR bacterial strains due to their agronomic properties: colonisation of the rhizosphere, secretion of compounds that are beneficial for the growth and nutrition of the host plant. The "Rise P" product is available as a wettable powder and provides benefits for a variety of crops.

"Prestop" is a biological fungicide for the control of fungal pathogens, in particular: grey rot (*Botrytissp.*), didymella (*Mycosphaerella*), fusarium, and Rhizoctonia. Clothianidin is an active ingredient from the neonicotinoid class that is systemically distributed throughout the plant and provides long-term protection against pests - for more than 30 days. The product has been tested for safety in the EU (Baibakova *et al.*, 2019). The biological products "Rise P" and "Prestop" were applied by spraying the substrate and plants in cassettes. The concentration of the solutions was 0.01%.

Organic substrates based on peat and coconut can be food not only for plants but also for undesirable organisms: saprophytic and pathogenic fungi, and insect larvae. In particular, peat substrates and coconut substrates were characterised by the colonisation of larvae of the mushroom mosquito *Mycetophilidae*, identified by the results of analyses carried out by the State Institution "Volyn Regional Phytosanitary Laboratory". Therefore, for plant objects, an additional measure was the use of Aktara (manufactured by Syngenta, Switzerland).

Plants were grown for two weeks in a humid chamber with 4 replications throughout the experiment. This is partly in line with the use of sugar-free medium technology (Photoautotrophic Micropropagation) or the New Micropropagation and Transplant Production System. These methods involve the absence of exogenous sources of carbohydrates, but instead intensify their synthesis by photoassimilation and affect photosynthesis simultaneously by increasing the light intensity (11,000 lx or more) and increasing the CO_2 content in the air (Kozai *et al.*, 2005). Wet chambers for *in vitro* plant adaptation are characterised by different volumes both in the root zone and in the air space around the plants. Among the most commonly used in production, two types were selected: 1 – micro-greenhouse cassette; and 2 – hydroponic trough with a lid (Fig. 2). Their dimensions are 140×60×8 cm (0.0192 m^3) and 100×60×20 cm (0.12 m^3), respectively.

Figure 2. Wet chamber – hydroponic trough with lid

Source: authors' photo

In the first variant, 60 planting cells were placed in 0.0192 m^3, which was an average of 0.00032 m^3 per cell. In the second variant, 150 cells (2.5 cassettes of 60 cells each) were placed in a volume of 0.12 m^3, which averaged 0.0008 m^3. That is, the volume per plant with the same area was 2.5 times larger (0.0008/0.00032 = 2.5). To study the effect of the wet chamber coating material, thin films with a thickness of 10-100 microns were used. The study was conducted following the requirements of the Convention on Biological Diversity (1992).

The mean biometric values X, their error m and correlation analysis were calculated using the Statistica 8.0 software package. The reliability of the difference in the mean values of the obtained data was assessed by the Student's t-test (Oghirko & Galayko 2017). The series of studies was conducted using the "step-by-step" principle. Its essence was that a series of consecutive experiments were carried out with regenerants that had better growth rates and were involved in the next stage of research, i.e., the variant of the previous experiment was the control in the next one.

Results and Discussion

Under *in vitro* conditions, regenerants develop a special anatomical structure that requires post-applied adaptation. This includes the creation of moist chambers with a gradual controlled decrease in air humidity and a moisture-absorbing and at the same time breathable substrate, which helps to develop the root system. More than 20 types of substrates and various combinations are used in indoor conditions (Matskevych *et al.*, 2019; Podhaietskiy *et al.*, 2020). The analysis of plant survival on different substrates (Table 1) showed that sand is not a technologically acceptable substrate for adaptation of both *in vitro* plants (0 generation) and for planting green cuttings of the 2nd generation. The survival rate on sand was only 2-7% higher than the least significant difference ($NIR_{0.5}$).

Table 1. *In vitro* survival of paulownia plants and green cuttings, %

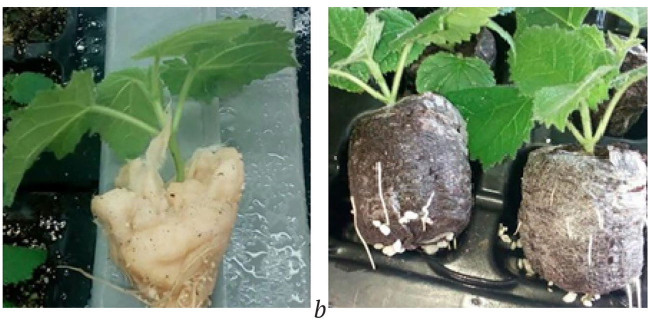
Substrate	"Feniks" Variety		"Enerdzhy" Variety	
	***in vitro* plants**	**second-generation**	***in vitro* plants**	**second-generation**
Eco Plus	19	61	16	59
La Flora	35	73	22	64
Jiffy	44	72	41	66
Jiffy pills	69	71	56	65
Coconut peat	33	72	27	71
Cotton wool	51	72	60	69
Vermiculite	49	75	42	66
Perlite	64	84	61	71
Sand	7	11	6	8
$HIP_{0.5}$	5	4	5	6

Source: compiled by the authors

The decrease in the survival rate of "Feniks" plants *in vitro* on different substrates was distributed in the following order: Jiffy pills, perlite, cotton wool and vermiculite, which was 69%, 64%, 51% and 49%, respectively. The *in vitro* survival of "Enerdzhy" plants in descending order was recorded in perlite (61%), cotton wool (60%), Jiffy tablets (56%) and vermiculite (42%); the second-generation plants of this variety had the best survival in perlite (71%) and coconut peat wool (69%), followed by vermiculite and Jiffy loose peat (66%). Green cuttings regenerated 3-6 adventitious roots in the second week (Fig. 3).

Figure 3. Root formation in green cuttings of second-generation paulownia *ex vitro*
Source: authors' photo

In vitro, the survival rate of plants compared to green cuttings of the 2nd generation was lower in both varieties of paulownia. This is due to both anatomical features (condition of stomata, structure of integumentary tissues) and the time regime for restarting trophic and hormonal determinants. Among the peat substrates compared, Jiffy pills were the best in terms of survival rates. On this substrate, plants of the "Feniks" variety *in vitro* survived in the amount of 69%, and of the "Enerdzhy" variety – 56%. These figures were higher than when the same Jiffy substrate was used, but not in the format of tablets with a mesh, but simply poured into cassette cells. In addition to the properties of the substrate itself, greater aeration of the root zone affected the plant organisms (Fig. 4). In green cuttings of the 2nd generation, the survival rate was higher, but this substrate was inferior to perlite in terms of survival rate in both varieties.



a *b*

Figure 4. Development of second-generation paulownia regenerants on different substrates
Note: *a* – Jiffy pills; *b* – cotton wool
Source: authors' photo

It should be noted that in addition to the influence on the presence of air, water, and the specifics of nutrient retention, substrates have different colours, and therefore different absorption of light energy and heating. Among the substrates compared, perlite and cotton wool had a white colour. The biological characteristics of the varieties also had an impact on their survival and regeneration. The "Feniks" variety had higher survival rates than the "Enerdzhy" variety. This pattern was typical for regenerants of all generations in subsequent experiments. On peat substrates, in addition to lower survival rates, both cuttings and regenerated plants were affected by fungal pathogens that cause diseases such as Fusarium and blackleg (Table 2, Fig. 5). Damage and damage rate increased with increasing temperature above 24°C, increasing humidity and decreasing time of ventilation of wet chambers.

Table 2. Affection of plants on different substrates by fungal pathogens, %

Substrate	"Feniks" Variety		"Enerdzhy" Variety	
	***in vitro* plants**	**of the second-generation**	***in vitro* plants**	**of the second-generation**
Eco Plus	63	31	74	39
LaFlora	45	33	22	34
Jiffy	14	12	21	27
Jiffy pills	19	17	16	15
Coconut peat	29	13	37	19
Vermiculite	0	0	0	0
Perlite	0	0	0	0
Cotton wool	0	0	0	0
Sand	100	79	100	94
$HIP_{0.5}$	5	4	5	6

Source: compiled by the authors

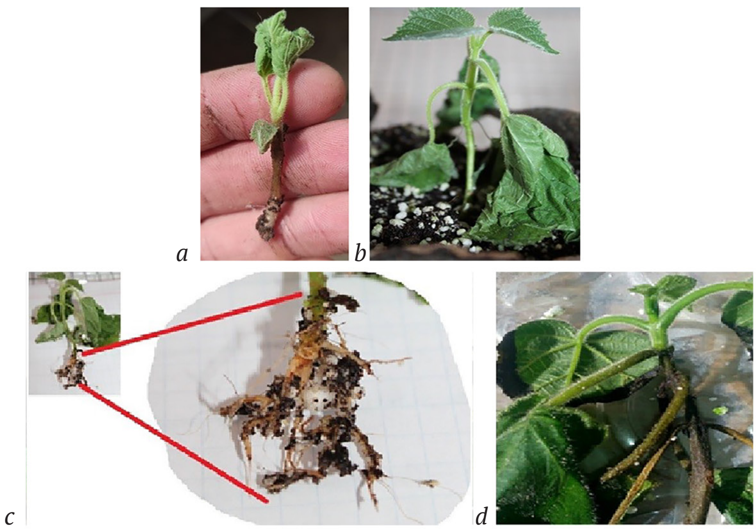


Figure 5. Damage of green cuttings and regenerated plants of "Enerdzhy" on peat substrate
Note: *a* – the first symptoms of wilting of the cutting; *b* – the first symptoms of wilting of the regenerate; *c* – the affected root system of the regenerate; *d* – stem necrosis
Source: authors' photo

In the case of Fusarium infection, the symptoms appear on the lower part of the shoots. The lower leaves are the first to wilt and droop due to vascular occlusion. According to observations, this wilting feature is what distinguishes infection with this fungus from wilting caused by moisture deficiency. Affected plants have a smaller root system, yellow brown in colour. Root hairs are the first to die, followed by small peripheral roots. In the case of a lack of water in the substrate, the upper leaves wither first due to loss of turgor. Young organs are more susceptible to dehydration. With a slight moisture deficit, the root system remained unchanged in size and colour. Regenerants without signs of damage grown on perlite substrate are shown in Figure 6. The root is white, and the lateral roots "grow" into the perlite particles. After 15 days, a well-developed root system, growing and intertwining in the cell of the cassette, holds all the perlite and does not lose its shape when transplanted into larger containers.

a  *b*

Figure 6. Condition of regenerated "Enerdzhy" plants on perlite substrate
Note: *a* – healthy white root system; *b* – root growth in the cassette cell
Source: authors' photo

In addition to purely pathogenic organisms, facultative saprophytes were also colonised on substrates of organic origin (Fig. 7). They had no direct impact on the regenerants in the studies conducted. However, over time, in cases of death of these microorganisms, the regenerants were inhibited. In particular, the height of plants and the percentage of survival decreased. To combat them, the trial established the effectiveness of "Rise P" and "Prestop" preparations. The effectiveness of the preparations was found to be both preventive and therapeutic.

Figure 7. Use of "Rise P" and "Prestop" for the control of facultative saprophytes
Source: authors' photo

Thus, the use of peat substrates and coconut substrate was inferior to vermiculite and perlite in terms of survival rate and was a favourable environment for the development of facultative saprophytes, pathogenic fungi and insects. Therefore, perlite substrates were used for further research. The use of perlite changes the strategy of controlling facultative heterotrophic parasites that are unable to develop on mineral substrates. Table 3 shows the survival rate and growth rates of regenerants in wet chambers of different volumes.

Table 3. *In vitro* survival and height of regenerants in wet chambers on the 15th day of cultivation

Wet chamber variant	"Feniks" Variety		"Enerdzhy" Variety	
	the survival rate of regenerants, %.	increase in shoot height, mm	the survival rate of regenerants, %.	increase in shoot height, mm
1 (40×60×8 cm)	61	56	49	37
2 (100×60×20 cm)	78	75	63	43

Source: compiled by the authors

The effect of chamber volume on the survival rate of both cultivars under the same conditions was found. In the case of the "Feniks" variety, the number of regenerants that survived increased from 61 to 78% with increasing chamber volume. In the "Enerdzhy" variety, the number of regenerated plants that took root increased from 49 to 63%. The stem growth rate, i.e. the difference in the height of the regenerant before planting and the height on the day of the survey, also increased.

The better survival rate with a larger air volume is due to greater gas exchange, and less temperature and humidity fluctuations. When comparing the varieties, the "Feniks" variety had a higher survival rate and shoot growth compared to the "Enerdzhy" variety. To adapt the cassette greenhouses to a larger volume on the farm, they were modified by replacing them with arcs with film material. This allows for an increase in the volume of air above the plants. And later, hydroponic troughs are used both in experiments and in production conditions (Suryawanshi, 2021).

Influence of the covering material of the wet chamber. To reduce the dehydration of plant objects in wet chambers, it is necessary to seal them. In particular, covering the top of the chamber with transparent lids that transmit light well and ensure humidity maintenance. The effectiveness of different films on post-septic adaptation was compared (Table 4). In the control, in the absence of the film, all regenerants died from dehydration.

Table 4. *In vitro* survival and height of regenerants in wet chambers on the 15th day of cultivation

Wet chamber variant	"Feniks" Variety		"Enerdzhy" Variety	
	of regenerated plants survived, %.	increase in shoot height, mm	of regenerated plants survived, %.	increase in shoot height, mm
Control without film	0	0	0	0
Transparent stretch film 10 μm	79	56	63	39
Transparent stretch film 23 μm	78	55	63	37
Polyethylene film 60 μm	41	59	21	33
Polyethylene film 80 μm	33	38	18	11
Polyethene film 100 μm	9	27	5	12
$HIP_{0.5}$	4	5	4	3

Source: compiled by the authors

The covering material compared (different types of film) differed primarily in thickness. Depending on the variant, this indicator ranged from 10 to 100 microns. When using stretch films with a thickness of 10 and 23 microns, the temperature increased from 22 to 26 and 27°C. A sharp increase in temperature was observed in the variants with thicknesses of 60, 80 and 100 μm (Fig. 8).

Despite the high heat resistance of paulownia, the use of films and, accordingly, chambers with a temperature of 48°C and higher led to significant losses among tender plants *in vitro* (Fig. 9).

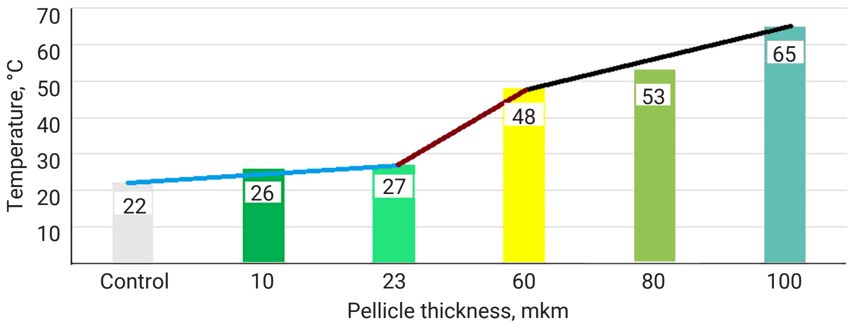
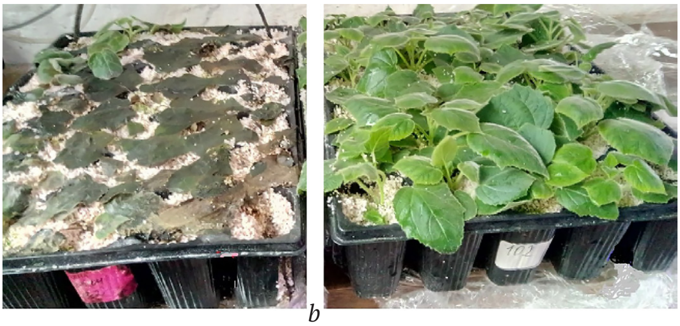


Figure 8. Wet chamber temperature at different film thicknesses
Source: compiled by the authors

1 2

Figure 9. Damage of plants *in vitro* by high temperatures and colonisation by thermophilic bacteria on the variant "Polyethylene film 80 μm"
Note: 1 – general view of greenhouse cassettes; 2 – maceration of damaged regenerant tissue
Source: authors' photo

Studies by A. Ivanyuk *et al.* (2019) on the effect of variable temperature on the germination of *Paulownia tomentosa* Steud. seeds also showed that lowering the temperature causes a decrease in germination energy, laboratory, and absolute seed germination, and increases the average seed dormancy. Therefore, it is important to find the optimal temperature regime for growing regenerants. At high temperatures, most regenerants died. The dead plant objects were colonised by facultative saprophytes, in particular thermophilic bacteria. Regenerants that were more adapted, including *ex vitro* plants of the third generation, also died (Fig. 10). The plant tissues were observed to be completely macerated within two days.



a *b*

Figure 10. Damage of *ex vitro* plants of the 3rd generation of "Feniks" cultivar by high temperatures and colonisation by thermophilic bacteria on variants
Note: 1 – polyethylene film 80 µm; 2 – transparent stretch film 23 µm
Source: authors' photo

An attempt to reduce the temperature in the room where the wet chambers with a film thickness of 60-100 µm were located led to an excessive increase in humidity in the chambers and the formation of a significant amount of dew condensation. There was no difference in the change in chamber humidity between films with thicknesses of 10 and 23 µm. However, the thicker film was observed to be denser under production conditions. As a result, its service life was extended from 1 month with a thickness of 10 µm to 4 months with a thickness of 23 µm. Czech researchers J. Kadlec *et al.* (2021) concluded that simple soil cover is the most effective protection of the root system from frost when growing paulownia in the open field. At the same time, a nonwoven bandage is the best protection for the aboveground parts of the plants.

Effect of the number of generations of green cuttings donors on explant regeneration. Cultivation of artificial nutrient media with a high content of stimulatory hormones, in particular, cytokinins, causes the effect of juvenilisation. Changes in juvenility over several successive passages and post-appliance adaptation affect several indicators during regeneration: explant survival, biometric dimensions of regenerated vegetative organs (stem, leaf, root), which was also confirmed by V. Matskevych *et al.* (2019), A. Podhaietskiy *et al.* (2020).

Survival rate. Tests on the "Feniks" and "Enerdzhy" varieties revealed that *in vitro* survival rates of 64 and 61% were observed, respectively (Table 5, Fig. 11). Moreover, the survival rate of "Feniks" increased up to the third-generation *ex vitro*. In the "Enerdzhy" variety, growth is observed up to the second generation. In the sixth generation, the survival rate decreased to 36% in "Feniks" and 32% in "Enerdzhy".

Table 5. Regeneration rates and parameters of vegetative organs of green cuttings of paulownia *ex vitro* on the 15th day of cultivation depending on generation

Indicator	Generation							Pearson's correlation coefficient
	0*	1	2	3	4	5	6	
"Feniks" Variety								
Survival rate,	64	78	84	92	72	48	36	0.75
Shoot height, mm	51	68	77	74	71	62	56	0.78
Leaf blade diameter, mm	22	58	93	97	89	84	72	0.62
Root system length, mm	26	41	67	61	54	31	16	0.88

Table 5, Continued

Indicator	Generation							Pearson's correlation coefficient
	0*	1	2	3	4	5	6	
"Enerdzhy" Variety								
Survival rate,	61	66	71	65	60	49	32	0.78
Shoot height, mm	43	55	69	66	58	51	38	0.92
Leaf blade diameter, mm	17	37	51	49	46	31	27	0.77
Root system length, mm	13	22	29	21	17	12	9	0.85

Note: * "Generation 0 - in *vitro plants*"
Source: compiled by the authors

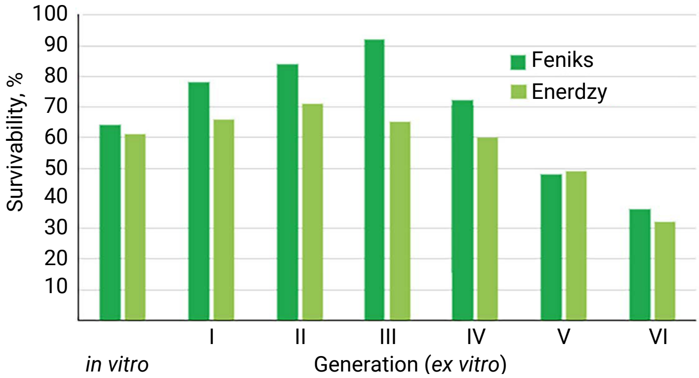


Figure 11. Explants survival rate in different generations of green cuttings donors, %
Source: compiled by the authors

Studies have shown that an increase in survival rate is associated with improved adaptation of plants to *ex vitro* conditions. A decrease in survival is associated with a gradual loss of juvenility. Thus, the optimal ratio of juvenility reduction and the acquisition of adaptive traits is characteristic of the second, third and fourth *ex vitro* generations. In this physiological state, two centres of the body's hormonal axis are actively functioning in regenerants: 1 – the apical meristem as the centre of auxin synthesis; 2 – the root meristem as the centre of cytokinin synthesis. With each subsequent passage, with the loss of juvenility and approaching the generative period of ontogeny, the activity of stimulatory hormones decreases (Keara & Wigge, 2014; Podhaietskiy *et al.*, 2020).

Size of vegetative organs. With each subsequent generation, not only the survival rate but also the size of the vegetative organs, including the stem, changed. The size of the root system was in natural correlation with the size of photoassimilating organs (Table 5). At the stage of adaptation of two species of Paulownia (*Paulownia hybrid* and *Paulownia tomentosa*), M. Mohamad *et al.* (2021) used peat and sand in different proportions as a soil mixture. The results showed that paulownia seedlings successfully survived (100%) in a soil mixture containing peat and sand (1:2, volume/volume). The highest values of seedling height and number of leaves/seedlings were recorded in this mixture. It was found that one of the signs of the loss of juvenility by plants is an increase in the size of the teeth on the leaf blades. A clearer sign of cuttings unsuitable for grafting was the formation of a void in the middle of the stem, which is characteristic of the fourth and older generations (Fig. 12).

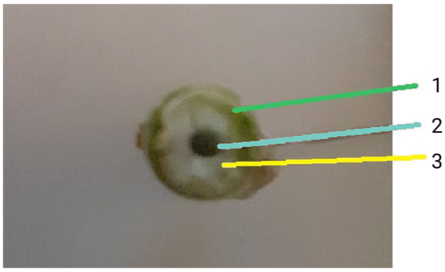


Figure 12. Stem void formation in 5th generation regenerants of "Feniks" cultivar
Note: 1 – cambium, cortex; 2 – parenchyma; 3 – cavity
Source: authors' photo

By studying the cell morphology and anatomical composition of green paulownia wood (a hybridisation of *Paulownia elongata* × *Paulownia fotunei* and tropical *Paulownia* spp.) as a raw material for the woodworking industry, N. San *et al*. (2016) found that the physical and mechanical properties of 3-year-old green paulownia have the same properties as 7-11-year-old *P. fortunei*. This confirms the optimal age of paulownia plants for cuttings.

Seedlings of different physiological ages. The loss of juvenility and intervention in the plant organism by cutting a part of the shoot changed the physiological age of both explants and their donors. Cutting of cuttings of the next generation from mother plants showed that shoot buds of mother plants formed the next order of branches, from which cuttings can also be harvested.

The induction of *in vitro* organogenesis of different explants originating from short-term stored seeds of *Paulownia elongata* and long-term stored seeds of *Paulownia elongata* x *fortunei* was studied by V. Gyuleva (2010). The nodal segments of three-month-old plants germinated from seeds under controlled conditions were used as primary explants. After induction of shoots and growth on Murashige and Skoog medium enriched with 0.3 mg/l 6-benzylaminopurine (BAP), isolated nodal and leaf segments were used for the active propagation stage. Of the different concentrations of BAP tested for propagation, the best effect was observed in a medium with 1.0 mg/l for nodal segments as explants of both species. The growth regulator Thidiazuron at a dose of 10 mg/l had a similar effect on the regeneration capacity of leaf segments grown on MS medium. These concentrations provoked the best effects related to the multiplication ratio, the average length of the newly formed bud and the overall shoot morphology. A 100% rooting rate *in vitro* and 90% adaptation to greenhouse conditions of the studied plants were achieved.

The ontogeny of the organism as a whole, organogenesis, histogenesis, and cell development occur in clear systemic correlations. In particular, one organ influences another. This is one of the determinants of the activation of certain genes or combinations of genes during the life cycle. For example, the branches of one tree are of different quality not only in terms of calendar but also in terms of physiological age. It is believed that the higher the order of branches, the older they are physiologically, despite their lower calendar age. There is a theory of physiological age in plant physiology. The physiological age of a branch of a certain order is the sum of the calendar ages of the branches of the previous branching, of which this branch is a continuation (Dolzhitska & Panchuk 2010). Considering this circumstance, a technique has been developed that allows inducing flower buds in three-month-old paulownia seedlings (Fig. 13). Such plants can be useful for ornamental gardening and breeding purposes.

Figure 13. Biological clock effect – laying flower buds in three-month-old seedlings
Source: authors' photo

This method is based on cutting off the tops of branches of one order to stimulate the growth of branches of the next order. In this way, branching is stimulated, which is typical for three- or four-year-old plants. It is at this biological age that paulownia begins to lay flower buds. Thus, the Ukrainian varieties of Paulownia "Feniks" and "Enerdzhy" adapt well to selected environments of organic and mineral origin. However, the best results were obtained on vermiculite, perlite, and cotton wool substrates, where the regenerants were not affected. The post-aseptic adaptation of regenerants in closed ground conditions using different types of covering material showed the effectiveness of using stretch films with a thickness of 10 and 23 µm, which form the optimal temperature regime.

Conclusions

The studies of post-applied adaptation of Ukrainian paulownia varieties "Feniks" and "Enerdzhy" revealed different effects of organic and mineral substrates on the survival rate, development of regenerants, and their damage by facultative saprophytic pathogens. On peat substrates with lower survival rates, cuttings and regenerated plants were affected by fungal pathogens such as Fusarium and blackleg, and their harmfulness and damage rate increased with increasing temperature above 24°C, increasing humidity and decreasing the time of ventilation of wet chambers. The biological characteristics of the varieties also influenced their survival and regeneration. Regenerants of the "Feniks" variety had higher indicated indicators compared to the "Enerdzhy" variety in all generations. Plant survival ranged from 64 to 81% depending on the variety and generation of regenerants. These values were higher than when the same Jiffy substrate was used, but not in the format of tablets with a mesh, but simply poured into cassette cells. The number of regenerants that took root increased with the increase in the volume of cassette cells. On the perlite substrate, regenerants were not affected by Fusarium. Biological products "Rise P" and "Prestop" proved to be effective for the control of pathogenic microorganisms on substrates of organic origin.

The coating material used in the form of polyethene and stretch films differed in thickness and, depending on the variant, ranged from 10 to 100 microns. When using stretch films with thicknesses of 10 and 23 microns, the temperature increased from 22 to 27°C.

A sharp increase in temperature was observed under polyethene films with thicknesses of 60, 80 and 100 microns, which were 48, 53 and 65°C, respectively. At these high temperatures, most of the regenerants died, after which they were colonised by facultative saprophytes, in particular thermophilic bacteria. It was found that plant tissues were completely macerated within two days. The obtained results of the research will allow us to identify the optimal varieties of paulownia and select a substrate that allows us to obtain the maximum survival rate and yield of healthy planting material for use in plantation forestry of forestry enterprises of the State Enterprise "Forests of Ukraine".

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None.

Conflict of Interest

None.

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Постасептична адаптація та розмноження українських сортів *Paulownia* Sieb. et Zucc. *ex vitro*

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Анотація. Плантаційне лісовирощування з використанням високопродуктивних і швидкорослих рослин передбачає застосування високоякісного оздоровленого садивного матеріалу генетичної константності, що вирішується міклоклональним розмноженням. Проте висока приживлюваність і стійкість рослин, отриманих *in vitro*, реалізується в результаті постасептичної адаптації регенерантів. Тому вдосконалення прийомів приживлюваності регенерантів павловнії українських сортів ‘Feniks’ і ‘Enerdzhy’ *ex vitro* стало метою цієї роботи. Дослідження поводилось в грудні 2021 року на українських сортах павловнії ‘Feniks’ і ‘Enerdzhy’. Сорту ‘Feniks’. Приживлюваність, розвиток регенерантів, їх пошкодження факультативними сапрофітними патогенними мікроорганізмами різнилися на субстратах органічного (Eco Plus, La Flora, Jiffy, кокосовий торф, бавовняна вата) та мінерального (вермикуліт, перліт, пісок) походження. Для контролю патогенних мікроорганізмів на субстратах органічного походження ефективними виявилися біопрепарати ‘Rise P’ та ‘Prestop’. Обґрунтовано технологічну доцільність застосування перлітового субстрату. Описано патофізіологію регенерантів павловнії *ex vitro* при фузаріозі. На показники регенерації, приживлювання, ураження мікроорганізмами, температуру вологих камер впливала товщина плівок, які використовувалися для укриття. Вирощування регенерантів з покривними плівками різної товщини показало високу їх приживлюваність у варіантах із стреч плівок товщиною 10 і 23 мкм. У випадку застосування поліетиленових плівок товщиною 60, 80 і 100 мкм, відмічене різке зростання температури, що становило 48, 53 і 65°C відповідно. За цих високих температур більшість регенерантів гинули, після чого заселялися факультативними сапрофітами, і тканини повністю мацерувалися упродовж двох діб. Оптимальне співвідношення зниження ювенільності і набуття пристосувальних ознак властиве другому, третьому та четвертому поколінню ex vitro. Обґрунтовано доцільність розмноження стебловими живцями до четвертого покоління, за яких зберігається регенераційна здатність пагонових живців. Практичними результатами досліджень є створений протокол вирощування рослин павловнії *in vitro* та *ex vitro* на різних видах субстрату для використання установами, які займаються розмноженням павловнії

Ключові слова: експлант; регенерант; ризогенез; приживлюваність; ювенільність

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