UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4)

Засновник:
Національний університет біоресурсів і природокористування України

Рік заснування: 2010

Рекомендовано до друку та поширення
через мережу Інтернет Вченою радою
Національного університету біоресурсів і природокористування України
(протокол № 4 від 23 листопада 2022 р.)

Свідоцтво про державну реєстрацію
друкованого засобу масової інформації
серії КВ 25127-15067 ПР від 17 лютого 2022 р.

Журнал входить до переліку фахових видань України
Категорія «Б». Галузь наук – сільськогосподарські, технічні, біологічні,
спеціальність – 206 « Садово-паркове господарство»,
205 «Лісове господарство», 187 «Деревообробні і меблеві технології»,
101 «Екологія», 091 «Біологія»
(накази Міністерства освіти і науки України від 28 грудня 2019 року № 1643
та від 30 листопада 2021 року № 1290)

Журнал представлено у міжнародних наукометричних базах даних,
репозитаріях та пошукових системах: : Index Copernicus International,
Google Scholar, Національна бібліотека України
імені В. І. Вернадського, MIAR, BASE, AGRIS

Адреса редакції:
Національний університет біоресурсів і природокористування України
вул. Героїв Оборони, 15, м. Київ, Україна, 03041
E-mail: info@forestscience.com.ua
www: https://forestscience.com.ua/uk

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE
Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4)

Founder:
National University of Life and Environmental Sciences of Ukraine

Year of foundation: 2010

Recommended for printing and distribution
via the Internet by the Academic Council
of National University of Life and Environmental Sciences of Ukraine
(Minutes No. 4 of November 23, 2022)

Certificate of state registration
of the print media
Series KV No. 25127-15067 PR of February 17, 2022

The journal is included in the list of professional publications of Ukraine
Category "B". Agricultural, technical, biological, specialty – 206 "Horticulture", 205 "Forestry", 187 "Woodworking and furniture technologies", 101 "Ecology", 091 "Biology"
(orders of the Ministry of Education and Science of Ukraine of December 28, 2019, No. 1643 and of November 39, 2021, No. 1290)

The journal is presented international scientometric databases, repositories and scientific systems: : Index Copernicus International,
Google Scholar, Vernadsky National Library of Ukraine,
MIAR, BASE, AGRIS

Editors office address:
National University of Life and Environmental Sciences of Ukraine
03041, 10 Heroiv Oborony, Kyiv, Ukraine
E-mail: info@forestscience.com.ua
www: https://forestscience.com.ua/en

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en

Ukrainian Journal of Forest and Wood Science, 13(4)

Редакційна колегія

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4)

Editorial Board

ЗМІСТ

CONTENTS

Received: 15/10/2022; Revised: 01/12/2022; Accepted: 20/12/2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4), 6-15

UDC 712.254(477.411)
DOI: 10.31548/forest.13(4).2022.6-15

Current State of Parks in the Sviatoshynskyi District of Kyiv

Oksana Bahatska*, Olesia Pikhalo, Tetiana Levchenko

Education and Research Institute of Forestry and Landscape-Park Management
National University of Life and Environmental Sciences of Ukraine
03041, 19 Horikhuvatskyi Shliakh Str., Kyiv, Ukraine

Abstract. In the issue of Kyiv's greening strategy, an increase in the number of public parks in each district of the city was noted, but their expediency is not always substantiated. That is why the purpose of the study is to highlight the role of public parks in the urbanised environment and to analyse normative indicators. An analysis of the quantitative indicators of public plantings within the public parks of the Sviatoshynskyi district of Kyiv was carried out. The actual number of public parks, their areas, and the main results of the public park survey have been established. Based on field studies and cartographic materials parks are classified according to visual features. The sizes, areas, shapes, layout, and composition of the plantations at the experimental sites were determined. Classification by functions: transit, recreational, memorial, and by the time of creation. It was established that 70% of the district's parks are intended for short-term recreation, and the largest number of parks are located along the streets (39% of the total area of the district's parks). It was determined that the territories of public parks of the Sviatoshynskyi district occupy small areas (from 0.11 to 7.86 ha) and are evenly distributed throughout the district. In terms of shape, parks of a rectangular configuration predominate in the city – 35% by area, and in terms of appearance – parks of a small area (up to 0.5 ha). The composition of plantings is dominated by parks with a preference for deciduous species (40%). It was determined that according to the functional purpose, most of the parks perform the function of short-term recreation, and according to the time of creation, the majority of the parks were established in 2016-2020. The presented classification would allow to systematise the existing territories and developing the classification of the parks of the Sviatoshynskyi district of Kyiv

Keywords: classification of public parks, green spaces, plant assortment, urban ecosystems, hedges

Introduction

To ensure an optimal human living environment in megacities, an important issue is the creation of a holistic and continuous landscaping system. Urban green spaces include gardens, vegetation cover, and trees that contribute to ecosystem services [1]. Given the significant pace of development of large cities, which leads to the compaction of living space and reduction of green spaces, it is necessary to pay considerable attention to existing parks and territories where they can be created. Occupying a small area, the territories of parks within districts provide an important function for the establishment of an

Suggested Citation:
Bahatska, O., Pikhalo, O., & Levchenko, T. (2022). Current state of parks in the Sviatoshynskyi district of Kyiv. *Ukrainian Journal of Forest and Wood Science*, 13(4), 6-15.

**Corresponding author*

architectural and planning structure. In addition to recreational requirements, a park, as a small green space, must also meet aesthetic requirements, as these areas address the issues of interconnecting the environment and building exteriors, ensuring artistic and aesthetic potential, and a comfortable and cosy stay of visitors in a green space. The research paper by G. Kothencz, T. Blaschke highlighted studies related to the hypothesis of perceived and spatial indicators of urban parks and found that the role of urban green spaces is fundamental in human perception of objective indicators of the environment [2].

Urban green spaces differ in size, quality, amenities, and entertainment resources in terms of their use, maintenance, and design quality. According to J. Wu, Z. Feng, Y. Peng, Q. Liu, & Q. He, this heterogeneity is related to the requirement that parks meet local standards [3]. R. Zhang, S. Peng, F. Sun, L. Deng, & Y. Che proposed a classification of parks in terms of environmental justice (for groups of the population with different socio-economic status and racial/ethnic composition in different countries), which combines accessibility, quality, aesthetic features, recreation facilities, and amenities [4].

Given the important role of urban green spaces, researchers pay great attention to their study. The authors of [5], investigating the system of green spaces in more than 1,000 cities, point out that scientific publications are limited to individual cities and give contradictory results due to the use of various data sources and methods. The modern world is working to expand a large-scale project that includes a detailed survey of all green spaces in megacities and the creation of a publicly accessible geographic database that documents all types, species, their quantity, and distribution [6]. Researchers also study the possibility of identifying vegetation in the city from satellite images in the optical range in order to establish the condition of garden and park objects and point out the accuracy and necessity of research data [7]. It is satellite data that will be used to determine the green potential of the city's space. In addition to planning documentation on the list and areas of public facilities, the authors of [8] point out the need for research that will be based on maps and will be able to show the relationship between built-up areas and green spaces.

Since the 2000s, there has been a massive demolition of green spaces in cities and localities of Ukraine, as a result of which the area of green spaces has significantly decreased, in particular, in Kyiv (in 1968, 24 m^2/ resident, now – 16-18 m^2/resident) [9]. The standard indicator for the area of urban landscaping established by the World Health Organization is 50 m^2 of urban green spaces per resident, and the indicator of public green spaces for large cities is 21 m^2 per person [9; 10]. A common category of urban public spaces is mini-parks, which in most cases are intended for transit traffic or short-term recreation.

According to V.Yu. Yukhnovskyi, O.V. Zibtseva, in 1984 significantly larger areas of parks were recommended in Ukraine – from 0.5 to 3.0 hectares. At the same time, in practice, deviations from the standards were allowed: parks had an area from 0.1-0.2 and up to 4-5 hectares. For example, the size of parks in Georgia ranges from 0.2 to 2-3 hectares, while in Moldova parks have an area of up to 3 hectares. According to the researcher, a 25-fold decrease in the minimum area of public gardens (compared to 1984) left a loophole, whereby small areas of street greenery are transferred to the category of public green spaces, which allows improving the indicator of public green space provision [11].

S.V. Rogovskiy, N.V. Krupa, who studied the mini-parks on Kontraktova Square, proposed an algorithm for the reconstruction of plantings on the territory of the park, namely: assessment of inventory results, sanitary logging; establishment of future compositions and engineering preparation; planting of plants and qualified care [12].

The green spaces of Rivne, including public gardens, were investigated by N.V. Denisyuk and V.Y. Melnyk. It was concluded that the distribution of public green spaces within the city is uneven, which, according to the researchers, is conditioned by the heterogeneity of growth conditions and the human factor [13].

In the city of Kyiv, according to the "Kyivzelenbud" municipal association, there are currently 618 parks [14]. In recent years, there has been a tendency to allocate areas for new parks by the decision of the city council. The study of these territories would establish their compliance with the generally accepted concept of "park" and state construction standards and provide meaningful recommendations for identifying these territories.

The purpose of the study was to investigate and analyse the current state, identify, and classify parks in the Sviatoshynskyi district of Kyiv.

Materials and Methods

The object of research is the territory of 63 parks in the Sviatoshynskyi district of Kyiv. Table 1 provides information on the distribution of parks by the following criteria: address, area [15], year of establishment. For further classification and identification of experimental objects, each park was assigned an ordinal number.

Table 1. General characteristics of parks in the Sviatoshynskyi district of Kyiv

No.	Park name	Area, ha	Time of establishment
1	Park on Hnata Yury Str. and Lesia Kurbasa Ave.	0.67	2016
2	Park on Chaadayeva Str.	0.43	2016
3	Park on the corner of Lesia Kurbasa Ave. and H. Kosmosu Str.	1.32	2017
4	Park on the corner of Y. Kolasa Str. and R. Rollana Blv.	7.86	2017
5	Park on Tuluzy Str. 6-D	0.41	2017
6	Park on Korolyova Str.	1.17	2018
7	Park on V. Kuchera Str. (from the children's clinic to S. Sosninykh Str.)	0.5	2017
8	Park on Korolyova Str. (near "Smarahd" SE)	1.4	2016
9	Park on the corner of H. Barskoho Str. and Symyrenka Str.	0.86	2016
10	Park on Symyrenka Str. 22-24	2.4	2017
11	Park at the intersection of Kiltseva Road and Zodchykh Str. (along Vira lake)	3.7	2018
12	Park on Koltsova Ave. to Symyrenko juncture	0.16	2017
13	Park on Lesya Kurbasa Ave. near building No. 1-A	0.11	2017
14	Park along Korolyova Str. (adjacent to building No. 10 on Korolyova Str. and tram lines)	0.21	2017
15	Park between buildings No. 5-A and No. 7-A on Symyrenka Str.	0.95	2017
16	Park on Symyrenka Str. 13/1	0.25	2016
17	Park on Bulhakova Str. 12	0.23	2016
18	Park on Bulhakova Str. 9	0.37	2020
19	Park on Verkhovynna Str. 8-10	1.37	2017
20	Park on the corner of Peremohy Ave. and Kramskoho Str.	0.34	2017
21	Park near the administration on 97 Peremohy Ave.	1.91	2014
22	Park on Peremohy Ave. 117-119	1.24	2016
23	Park on Peremohy Ave. 121-123	0.46	2015
24	Park on the corner of Peremohy Ave. and Chornobylska Str.	1.15	2010
25	Park on Kiltseva Road	0.18	2015
26	Park on the corner of Lvivska Str, and Kramskoho Str.	0.21	2014
27	Park on Peremohy Str. 117 (near "Ekran" cinema theatre)	0.31	2012
28	Park on Verkhovynna Str. 80	0.46	2017
29	V. Stus Square (on the corner of Peremohy Ave. and Palladina Ave.)	1.06	2014
30	Park between Semashka Str. and Palladina Ave.	2.84	2019
31	Park on Kotelnikova Str. 26-32	3.15	2019
32	Park on Peremohy Ave. 131	0.77	2017
33	Park on Kramskoho Str. 10	1.3	2001
34	Park on Chornobylska Str. 12	0.65	2016
35	Park on Chornobylska Str. 4/56	0.46	2016
36	Park on Zhyvopysna Str. 12	0.17	2016
37	Park between Krasnova Str. and Semashka Str.	2.8	2017
38	Park near the monument to soldiers on Yefremova Str.	0.6	2018
39	Park on the corner of Yefremova Str. and Chornobylska Str. (near Afghanistan War Memorial)	0.2	2017
40	Park near School No. 304 on Pryluzhna Str.	0.81	2018
41	Park on Deputatska Str. 13-17	0.5	2017
42	Park between Palladina Ave. and buildings No. 87, 87-A and Vernadskoho Blvd.	0.52	2017
43	Park on Chornobylska Str. 24/26	1.01	2016

Table 1, Continued

No.	Park name	Area, ha	Time of establishment
44	Park on Pidlisna Str. 2	0.8	2018
45	Park on Bulakhovskoho Str. near buildings No. 40 and No. 42/43	0.35	2017
46	Park on Yefremova Str. near building No. 18	0.43	2018
47	Park on Pryluzhna Str. 2	0.78	2017
48	Park on Zodchykh Str. 36-38	0.42	2018
49	Park on Symyrenka Str. 27-29	0.53	2018
50	Park on Peremohy Ave. 144	0.4	2006
51	Park on Chornobylska 3	1.08	2017
52	Park on Peremohy Ave. 73-A	0.206	2018
53	Park on Irpinska Str. 63-A and F. Pushynoi Str. 44/50	0.8	2017
54	Park between buildings 7-A and 9-A on Tupoleva Str.	0.4	2017
55	Park between buildings No. 11 and 11-A on Tupoleva Str.	0.32	2006
56	Park between buildings No. 59 on Vernadskoho Blvd. and No. 2, 4 on Dobrokhotova Str.	0.4	2006
57	Park near buildings No. 8-A and 10 on Semashka Str.	0.8	2006
58	Park along buildings No. 81 and 85 on Vernadskoho Blvd.	0.6	2017
59	Park between buildings No. 11-D, 15-A, and 15-B on Tupoleva Str.	0.6	2019
60	Park between buildings No. 63-A and 71-A on Vernadskoho Blvd.	0.9	2017
61	Park on Naumova Str. 31-33	0.6	2018
62	Park on Rakhmaninova Str. 22	0.36	2018
63	Park on Lvivska Str. 3	1.8	2020

Source: [15]

Field studies were conducted during 2021-2022 using landscape and visual analysis. Research materials were obtained on the territory of the Sviatoshynskyi district of Kyiv by route and field survey of the park territories. A systematic approach and comparative analysis of factual material were applied. Regulatory data were analysed [16]. The species composition was determined using dendrological determinants [17; 18], and the species name – according to the international classification [19].

When processing the field survey materials, the analysis was used to summarise data on the area, configuration, and location of parks. The comparative method was used to group parks according to certain characteristics and summarise the information obtained based on professional literature and theoretical publications. General information about the objects of research was taken from literary sources [15], the year of creation of parks was specified from archival materials.

Results and Discussion

The park is an ordered and landscaped plot with an area of 0.02 ha to 2.0 ha, which is an element of architectural and artistic design of populated areas, intended for short-term recreation of the population [20].

According to modern standards [16], the park should occupy an area of 6 m^2 per person. According to regulatory data, green spaces should make up 65% of the total area of the park; paths, playgrounds, alleys – 30%; buildings and small architectural forms – 5% [16]. The elements of the arrangement of parks include small architectural forms: decorative fountains, active fountains, benches, and garden furniture [21]. The development of the classification of green spaces, in particular parks, is becoming increasingly important.

The Kyiv district under study is currently a cozy, albeit remote from the centre, residential area with excellent transportation and affordable housing. In this area there is a good transport interchange – there is a metro and a suburban railway station [14; 22].

According to their functional purpose, parks belong to public plantings, which, according to "Kyivzelenbud" municipal association in Sviatoshynskyi district, occupy 208.24 hectares [15], among them 6 parks with a total area of 59.42 hectares and 63 parks with an area of 59.42 hectares (Table 2).

Table 2. Registry of landscaping facilities of the public utility company for the maintenance of green spaces in the Sviatoshynskyi district as of 01.01.2020

Name	Value
Number of parks, units	63
Area, ha	59.4247
including the lawn, ha	48.8485
Trees, units	5,180
Bushes, units	11,768
Flower beds, m^2	1,815.6
Paths, m^2	32,066
Hedges, lm	1,613

Source: [15]

According to tabular data, a significant area within parks is occupied by lawns, more than 82%, the rest of the area is occupied by woody plants and paths (17) and a small percentage is accounted for by flower beds and hedges (0.5%). Considering the data for the Sviatoshynskyi district, it was established that public plantings cover an area of more than 208 hectares and account for less than 7 m^2 per inhabitant. That is why it is necessary to preserve existing plantings as much as possible, increase their area, and create new green spaces within the district.

According to field surveys and literature data [15], there are 63 parks in the Sviatoshynskyi district with a total area of 60.05 hectares, which is about 1% of the total area of the district. The area of parks is about 30% of all common plantings in this area of the city. In the course of research and field surveys, it was found that the submitted list of parks of the district is not exhaustive, since some green zones, under certain circumstances, have lost the status of a park, and some are only being established.

Parks located throughout the Sviatoshynskyi district have small areas from 0.11 to 7.86 ha. The smallest park is located on Lesya Kurbasa Ave. near building No. 1-A, and the largest – on the corner of Ya. Kolosa Str. and R. Rollana Blvd. It was established that the parks of the Sviatoshynskyi district with ordinal numbers 4, 10, 11, 30, 31, and 37 do not meet the established standards in terms of the area.

In the mid-19th century, there were no public gardens or landscaped parks for public use in Kyiv [21]. Parks of the Sviatoshynskyi district of Kyiv were created in 2006-2020 and can be divided into the latest and most modern ones by the time of creation. It was established that the majority of parks, namely 86%, were created in 2016-2020. According to Lviv researchers, most of the parks in Lviv were created in the second half of the 20th century, although a significant part of the parks can be considered new, which were created according to the developed projects in the context of city development plans [23].

Parks of the district perform several functions in accordance with their intended purpose and location, namely: for short-term recreation of citizens, transit, memorial function, for active recreation and sports (Table 3).

Table 3. Classification of parks in the Sviatoshynskyi district of Kyiv by functional purpose

Functional orientation of parks	Number of parks	Area, ha	Ordinal number of the park according to Table 1
Short-term recreation	44	48.26	2, 4-11, 13-15, 21, 23-25, 27, 30-37, 43-49, 52-63
Transit	13	8.24	1, 3, 12, 16-20, 22, 28, 40-42
Memorial	4	2.26	29, 38-39, 50
Sports	2	1.29	26, 51
Total	**63**	**60.05**	

Source: compiled by the authors

Thus, it was determined that 70% of the parks of the Sviatoshynskyi district are intended for short-term recreation, 21% – for transit traffic of pedestrians, 6% – memorial, and 3% – for active recreation and sports. The sports function is performed by two parks, namely: the park on the corner of Lvivska Str, and Kramskoho Str. (area 0.21 ha) and the park on Chornobylska Str., 3 (area 1.08 ha). The authors of this study suggest that the number of the latter category of parks should be increased within the district.

Parks of the Sviatoshynskyi district are classified according to four characteristics, which, accordingly, are divided into groups and subgroups in even more detail:

1. *by place of creation:*
- within the residential area;
- near administrative buildings;
- along linear structures;
- on the streets.

2. *by appearance:*
- by size (area): small (up to 0.5 ha), medium (0.5-1.0 ha), and large (over 1 ha);
- by shape: rectangular, triangular, elongated, irregular;
- by planning structure: regular, landscape;
- by the preferred composition of plantings: coniferous, deciduous, mixed;
- by the presence of flower beds and hedges.

3. *by functional purpose:*
- transit;
- short-term recreation;
- memorial.

4. *by creation time:*
- latest (2006-2015);
- modern (2016-2020).

The natural and geographical affiliation of parks directly affects the development of plant communities and the species composition of green spaces [23; 24]. Classification of parks by location and place of creation is given in Table 1. Most of them (27 parks out of 63) are located on the streets of the district, their area is 23.65 hectares, which is 39.0% of the total area of parks in the Sviatoshynskyi district. Such type of location is observed in all megacities of Ukraine, which is conditioned by the creation of small buffer zones between the roadway and the residential area.

In terms of appearance, parks differ in their shape and size (Table 4), the species composition, and the planning structure. In the Sviatoshynskyi district, small parks (up to 0.5 hectares) predominate – 27 objects with a total area of 9.0 hectares, which is 15% of the total area of parks in the district. The small size of public parks is conditioned by the fact that in dense neighbourhoods only a small area is allocated for green spaces.

Table 4. Classification of parks of Sviatoshynskyi district by various criteria

Classification attribute	Classification group/ subgroup	Ordinal number of the park according to Table 1	Number of parks	Area, ha
By location	between the residential areas	15, 18, 42-43, 45-46, 53-60	14	8.45
	near administrative buildings	21	1	1.91
	along roads/tram tracks	1, 3, 11-14, 19-20, 22-25, 27, 29-30, 32, 38, 50	18	16.89
	on the streets	2, 5-10, 16-17, 26, 28, 31, 33-37, 39-41, 44, 47-49, 61-63	27	23.65
By appearance	By size small	2, 5, 7, 12-14, 16-18, 20, 23, 25-28, 35-36, 39, 45-46, 48, 50, 52, 54-56, 62	27	8.13
	medium	1, 9, 15, 32, 34, 38, 40-42, 44, 47, 49, 53, 57-61	18	12.74
	large	3, 4, 6, 8, 10-11, 19, 21-22, 24, 29-31, 33, 37, 43, 51, 63	18	38.56
	By shape: triangular	8, 9, 18, 29, 38	5	3.92
	rectangular	3, 5, 14, 19-21, 23, 24, 26, 30-32, 36, 39-41, 44, 46, 50, 51, 54-56, 59, 60	25	21.15
	elongated	1, 4, 6, 7, 10-12, 22, 25, 27, 35, 42, 48, 52, 58, 63	16	22.20
	irregular shape	2, 13, 15-17, 33, 34, 37, 43, 45, 47, 49, 53, 57, 61, 62	16	11.95
	By the composition of plantings: deciduous	2, 5, 6, 8-11, 13-19, 25, 26, 30, 33, 37, 39, 41, 42, 46-49	29	24.57
	coniferous	22-24, 27, 31, 32, 34-36, 40, 43, 44, 50, 52, 53	15	12.31
	mixed	1, 3, 4, 7, 20-22, 28, 29, 45, 54-63	20	22.49
	By the presence of flower beds	9-11, 18, 20, 21, 24, 26, 29, 33-35, 37-40, 43, 44	18	20.63
	By the presence of hedges	4, 8, 14, 19, 21, 24, 26, 29-31, 33, 34, 48	13	23.53
By creation time	latest (2006-2015)	21, 23-27, 29, 33, 50, 55-57	12	8.50
	modern (2016-2020)	1-20, 22, 28, 30-32, 34-49, 51-54, 58-63	61	40.52

Source: compiled by the authors

The shape is dominated by rectangular parks, the total area of which is 21.0 hectares or 35% of the total area of parks in the Sviatoshynskyi district. Using GIS methods, when surveying urban areas, it was found that a high coefficient of green areas is associated with the creation of so-called "green wedges". With this method of gardening and careful care it is possible to adapt urban greenery to difficult urban conditions [25].

In contrast to Lviv parks, where mixed plantings predominate [23], Sviatoshynskyi district has 40% of parks (from the total area of the district's parks), with a total area of 24 hectares, which are dominated by deciduous plant species. The most common types of ornamental plants are: Norway maple (*Acer platanoides* L.), small-leaved linden (*Tilia cordata* L.), horse chestnut (*Aesculus hippocastanum* L.), black poplar (*Populus nigra* L.) black locust (*Robinia pseudoacacia* L.), mountain ash (*Sorbus aucuparia* L.), white poplar (*Populus alba* L.), silver birch (*Betula pendula* L.), white willow (*Salix alba* L.), southern catalpa (*Catalpa bignonioides* L.), Siberian peashrub (*Caragana arborescens* L.), white mulberry (*Morus alba* L.), cherry plum (*Prunus cerasifera `Pissardii`* L.), varnish tree (*Ailanthus altissima* L.), common beech (*Fagus sylvatica* L.), common hornbeam (*Carpinus betulus* L.), common oak (*Quercus robur* L.), common ash (*Fraxinus excelsior* L.), staghorn sumac (*Rhus typhina* L.), Chinese elm (*Ulmus parvifolia* L.), myrobalan plum (*Prunus divaricata* L.), eastern redbud (*Cercis canadensis* L.), London planetree (*Platanus × acerifolia* L.), common apricot (*Prunus armeniaca* L.), Japanese maple (*Acer palmatum* L.).

The size of plants determines the architectural and planning solution of such small areas of short-term recreation as parks [26; 27]. Among the types of plantings in parks, the most common are single plantings of Norway maple (*Acer platanoides* L.), mountain ash (*Sorbus aucuparia* L.), white willow (*Salix alba* L.), white mulberry (*Morus alba* L.), London planetree (*Platanus×acerifolia* L.), Scots pine (*Pinus sylvestris* L.), and common oak (*Quercus robur* L.). Such an assortment of plants is explained by the fact that parks were created within territories where plants were already planted, which were later left as single plantings or compositional accents on a certain territory.

Within the limits of row plantings, the most commonly used conifers are common spruce (*Picea abies* L.), from deciduous – Norway maple (*Acer platanoides* L.), white poplar (*Populus alba* L.), black poplar (*Populus nigra* L.), and small-leaved linden (*Tilia cordata* L.).

For group plantings, the most decorative range of plants is used. Usually these are plants or their cultivars which differ in special or characteristic decorative qualities: the colour and texture of the stem, the architectonics of the crown, the colour of the leaf surface in different seasons, flowering, etc. Among them, the most common are cherry plum (*Prunus cerasifera `Pissardii`*), blue spruce (*Picea pungens `Glauca`*), Japanese spiraea (*Spiraea japonica `Gold`*), savin juniper (*Juniperus sabina* L.), eastern redbud (*Cercis canadensis* L.), staghorn sumac (*Rhus typhina* L.), Japanese maple (*Acer palmatum* L.) etc.

Alley plantings, within parks, are most often created from Norway maple (*Acer platanoides* L.).

On 18 objects under study, which cover an area of 20.63 hectares and make up 32% of the total area of parks in the Sviatoshynskyi district, flower beds were observed, which are overwhelmingly created from annual flowers. Hedges were observed in 13 parks, which have an area of 23.53 hectares, which is 39% of the total area of parks in the Sviatoshynskyi district. It was also found that in the considered parks, hedges were created from common hornbeam (*Carpinus betulus* L.), common privet (*Ligustrum vulgare* L.), evergreen boxwood (*Buxus sempervirens* L.) and Siberian dogwood (*Cornus alba* L.)

Comparing the recommended areas of the territories of parks in Georgia, Moldova [11], and Ukraine [21; 23; 24], it is necessary to point out the difference in the minimum areas according to regulatory documents which allows identifying individual areas for public plantings, in particular in the Sviatoshynskyi district of Kyiv. According to H.Y. Hryn and Y.V. Henyk, Lviv's parks cover an area of 0.060-2.404 hectares and are dominated by small parks, which is similar to the parks of the Sviatoshynskyi district of Kyiv.

N.V Denysiuk distinguished 39 public gardens in Rivne with a total area of about 43 hectares. According to their location in urban areas, the parks of Rivne are divided into two groups: parks on squares and parks on streets [13]. Regarding the parks of Lviv, the researchers note that the most represented parks are located along the streets (47%) [23]. For the studied parks of Kyiv, a similar pattern has been established, which calls for further reflection on increasing the number of parks with a different location. The difference is that a significant number of parks in Lviv are located inside residential buildings, and in the Sviatoshynskyi district there are fewer parks with this location.

Analysing studies on the range of plants on the territory of parks [12; 13; 23] and comparing them with the findings of this study, there is an advantage of local dendroflora, considering the ecological and biological characteristics of plants. It is also necessary to increase the number of coniferous plants, hedges, and flower arrangements.

Considering the modern "classification of green spaces" or in some post-Soviet countries "classification of green areas", which have similar categories, the territories of parks are classified as public spaces. But the classification of parks is not a subject of discussion in modern scientific publications, since these parks are quite small in area, created on plots that are not used for construction, and do not have a special concept and architectural plan. But the main stage on the way to urban comfort is the planning of an effective system of urban improvement, including the development of a system of landscaping of the territory, and their classification by the level of landscaping [28]. Analysis of the classification of public parks allows systematising the generalised information on the studied territories and developing perspective plans for improving their organisation within the Sviatoshynskyi district of Kyiv.

Conclusions

Parks of the Sviatoshynskyi district and other green spaces of the city perform important environmental and nature protection functions, form a special microclimate, and provide a favourable human habitat.

Parks are classified according to the following criteria: appearance, location, functions, and time of creation. Classification features were divided into groups and subgroups, respectively.

According to the place of creation, the largest number of parks was found along streets and squares. In terms of shape, they are dominated by parks of rectangular shape and small area, up to 0.5 hectares, and the composition of plantings is deciduous. Parks of the Sviatoshynskyi district mainly perform several functions in accordance with their intended purpose. Most of the parks in the city perform transit and recreation functions and were created mainly in 2016-2020. Deciduous plant species predominate in the plantings of parks. In the last decade, the dendroflora of the objects under study has significantly expanded due to introduced and exotic plants. Among the types of plantings, the most represented are row and group plantings of trees and shrubs. The most common plant species are Norway maple (*Acer platanoides* L.), white poplar (*Populus alba* L.), black poplar (*Populus nigra* L.), small-leaved linden (*Tilia cordata* L.) black locust (*Robinia pseudoacacia* L.), horse chestnut (*Aesculus hippocastanum* L.), Scots pine (*Pinus sylvestris* L.), European box (*Buxus sempervirens* L.), European elderberry (*Sambucus nigra* L.), Siberian dogwood (*Cornus alba* L.), common privet (*Ligustrum vulgare* L.). About a third of parks have flower beds, and 13 parks (21%) have hedges.

The developed classification of city parks would allow more effectively to analyse the species, age, and spatial structures of plant communities in urban ecosystems, developing productive and aesthetically attractive green zones in an urbanised environment, and surveying the inventory of plantings of the complex green zone of the district.

Thus, after analysing the laws and regulations of Ukraine, it can be concluded that 6 parks of the Sviatoshynskyi district (ordinal numbers 4, 10, 11, 30, 31, 37) do not meet the established standards regarding the minimum area, and there is an insufficient number of sports-type parks. Further study will be aimed at the investigation of the features of park reconstruction, depending on the classification group.

References

[1] Abass, Z.I. (2021). Green spaces in residential communities: The potential for ecological and health. *IOP Conference Series: Earth and Environmental Science*, 779(1), article number 012011. doi: 10.1088/1755-1315/779/1/012011.

[2] Kothencz, G., & Blaschke, T. (2017). Urban parks: Visitors' perceptions versus spatial indicators. *Land Use Policy*, 64, 233-244. doi: 10.1016/j.landusepol.2017.02.012.

[3] Wu, J., Feng, Z., Peng, Y., Liu, Q., & He, Q. (2019). Neglected green street landscapes: A re-evaluation method of green justice. *Urban Forestry & Urban Greening*, 41, 344-353. doi: 10.1016/j.ufug.2019.05.004.

[4] Zhang, R., Peng, S., Sun, F., Deng, L., & Che, Y. (2022). Assessing the social equity of urban parks: An improved index integrating multiple quality dimensions and service accessibility. *Cities*, 129, article number 103839. doi: 10.1016/j.cities.2022.103839.

[5] Han, Y., He, J., Liu, D., Zhao, H., & Huang, J. (2022). Inequality in urban green provision: A comparative study of large cities throughout the world. *Sustainable Cities and Society*, 89, article number 104229. doi: 10.1016/j.scs.2022.104229.

[6] Aly, D., & Dimitrijevic, B. (2022). Public green space quantity and distribution in Cairo, Egypt. *Journal of Engineering and Applied Science*, 69, article number 15. doi: 10.1186/s44147-021-00067-z.

[7] Pasichnyk, N.A., Shvorov, S.A., Opryshko, O.A., Komarchuk, D.S., Dudnyk, A.O., & Bahatska, O. (2022). Urban agriculture – as a component of the concept of energy efficiency communities. *2022 IEEE 16th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering (TCSET)*, 2022, 319-324.

[8] Bulatović, S. (2023). Green infrastructure: Spatial Potentials of the Greening the City of Brčko. *Lecture Notes in Networks and Systems*, 529, 264-275.

[9] Ocheretnyy, V., Potapova, T., Kuz'mina, D., & Solohor, V. (2017). The modern trend of reducing the area of green spaces in the world. *Modern Technologies, Materials and Structures in Construction*, 2, 69-76.

[10] Official website of the Verkhovna Rada of Ukraine. Draft law on green spaces in cities and other settlements. (2015). Retrieved from http://w1.c1.rada.gov.ua/pls/zweb2/webproc4_1?pf3511=55455.

[11] Yukhnovskyi, V., & Zibtseva, O. (2018). Comparative analysis of classifications of plantations in settlements of Ukraine and post-Soviet countries. *Scientific works of the Forestry Academy of Sciences of Ukraine*, (16), 90-98.

[12] Rogovskiy, S.V., & Krupa, N.M. (2018). Current state of tree plantations on contract park in Kiev and the prospects for their reconstruction. *Scientific Bulletin of UNFU*, 28(7), 60-65. doi: 10.15421/40280713.

[13] Denisyuk, N., & Melnyk, V. (2019). The current of greening in the territory of the city of Rivne. *Biodiversity, Ecology and Experimental Biology*, 21, 21-30. doi: 10.34142/2708-583x.2019.21.03.

[14] Official website of the Municipal enterprise for the maintenance of green spaces of Svyatoshinsky district of Kyiv. (n.d.). Retrieved from http://svyatosh.kyivzelenbud.com.

[15] The list of parks and parks of the communal enterprise for the maintenance of green spaces of the Svyatoshyn district of the city of Kyiv. (2022). Retrieved from https://data.gov.ua/dataset/5efad67d-41a8-4744-8972-d1c5fe72918b?filter=all_time.

[16] State building regulations – all building regulations of Ukraine on the DBNU portal. (2022). Retrieved from https://dbn.co.ua/load/normativy/dbn/1.

[17] Kohno, M., Gordienko, V., Zakharenko, G., Kolesnychenko, O., Kuznetsov, S., Logginov, V., Pohorila, L., & Chupryna, P. (2001). *Dendroflora of Ukraine. Wild and cultivated trees and shrubs*. Kyiv: High school.

[18] Kohno, M.A., Trofymenko, N.M., & Parkhomenko, L.I. (2005). *Dendroflora of Ukraine. Wild and cultivated trees and bushes*. Kyiv: Fitosociotsentr.

[19] World Flora Online. (n.d.). Retrieved from http://www.worldfloraonline.org/.

[20] Order of Ministry of Construction, Architecture and Housing and Communal Services of Ukraine No.105 "On the Approval of Rules for the Maintenance of Green Spaces in Populated Areas of Ukraine". (2006, April). Retrieved from https://zakon.rada.gov.ua/laws/show/z0880-06#Text.

[21] Vasylenko, L.H. (2017). Parks of the historical part of Kyiv. *Suchasni Problemy Arkhitektury ta Mistobuduvannya*, 47, 26-30.

[22] Official website of the Svyatoshynska district state administration in the city of Kyiv. (n.d.). Retrieved from https://svyat.kyivcity.gov.ua.

[23] Hryn, H.Yu., & Genyk, Ya.V. (2020). Classification of public parks and their distribution in the integrated green zone of Lviv. *Scientific Bulletin of UNFU*, 30(2), 28-32. doi: 10.36930/40300205.

[24] Marchenko, A., & Oleshko, O. (2012). Analysis of the current state of the green areas of the square near Torgovy Ryady, Bila Tserkva. *Ahrobiolohiya*, 6(86), 131-134.

[25] Halecki, W., Stachura, T., Fudała, W., Stec, A., & Kuboń, S. (2022). Assessment and planning of green spaces in urban parks: A review. *Sustainable Cities and Society*, 88, article number 104280. doi: 10.1016/j.scs.2022.104280.

[26] Dudin, R.B. (2016). *Conservation, restoration and reconstruction of garden and park facilities*. Lviv: Manuscript.

[27] Pikhalo, O., & Marinyuk, D. (2018). Identification of the square "Gunski Krynytsi" in Kamyanets-Podilsky, Khmelnitsky region. *Scientific reports of NULES of Ukraine*, 2018(6), 1-9. doi: 10.31548/dopovidi2018.06.027.

[28] Zadorozhnya, I. (2021). Global practices of public administration in the sphere of blagoustra city. *Scientific Bulletin: State Administration*, 4(10), 38-49. doi: 10.33269/2618-0065-2021-4(10)-38-49.

Сучасний стан скверів Святошинського району м. Києва

Оксана Михайлівна Багацька,
Олеся Віталіївна Піхало, Тетяна Володимирівна Левченко

Навчально-науковий інститут лісового і садово-паркового господарства
Національний університет біоресурсів і природокористування України
03041, вул. Горіхуватський шлях, 19, м. Київ, Україна

Анотація. В питанні стратегії озеленення Києва, відмічено збільшення кількості скверів у кожному районі міста, проте їх доцільність не завжди обґрунтована. Саме тому метою статті було висвітлення ролі скверів в урбанізованому середовищі, аналіз нормативних показників. Польові дослідження проводилися упродовж 2021-22 рр. методом ландшафтно-візуального аналізу. У процесі наукового пошуку було застосовано теоретичні методи дослідження, методи аналізу, синтезу, порівняння, маршрутно-рекогносцирувальні, математичні, порівняльні методи та узагальнення отриманої інформації на основі фахової літератури й теоретичних публікацій. Проведений аналіз кількісних показників насаджень загального користування в межах скверів Святошинського району м. Києва. Встановлено фактичну кількість скверів, їх площ та основні результати досліджень скверів. Було складено повний перелік скверів із зазначенням площі, року створення і місця розташування в районі. За натурними дослідженнями та картографічними матеріалами класифіковано сквери за візуальними ознаками. Визначено розміри, площі, форми, планування та склад насаджень на дослідних об'єктах. Проведена класифікація за функціями: транзитні, відпочинкові, меморіальні, а також за часом створення. Встановлено, що 70 % скверів району призначені для короткочасного відпочинку, а за місцем створення найбільша кількість скверів розташованих вздовж вулиць (39 % загальної площі скверів району). Визначено, що території скверів Святошинського району займають невеликі площі (від 0,11 до 7,86 га) та розташовані рівномірно по всьому району. З'ясовано, що за формою у місті переважають сквери прямокутної конфігурації – 35 % за площею, а за зовнішнім виглядом – сквери малої площі (до 0,5 га). За складом насаджень домінують сквери з перевагою листяних видів (40 %). Визначено, що за функціональним призначенням більшість скверів виконують функцію короткочасного відпочинку, а за часом створення переважна частина скверів сформована в 2016-2020 рр. Подана класифікація дозволить систематизувати існуючі території та розробити номенклатуру скверів Святошинського району м. Києва

Ключові слова: класифікація скверів, зелені насадження, асортимент рослин, міські екосистеми, живоплоти

Received: 10/11/2022; Revised: 01/12/2022; Accepted: 16/12/2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4), 16-29

UDC 712.42/7.034
DOI: 10.31548/forest.13(4).2022.16-29

The Value of Protected Man-Made Parks of the Ukrainian Polissya of the Second Half of the 18th and Early 20th Centuries

Anzhela Dzyba*, Olena Kolesnichenko

Education and Research Institute of Forestry and Landscape-Park Management
National University of Life and Environmental Sciences of Ukraine
03041, 19 Horikhuvatskyi Shliakh Str., Kyiv, Ukraine

Abstract. For thousands of years, human activity has shaped the environment, changing it in accordance with utilitarian and functional requirements. As these requirements changed over time, so did the value that people associated with certain landscape features. Man-made parks created in the Ukrainian Polissya in the second half of the 17th – early 20th century are landscapes, the historical park environment, and modern adaptation of which to the modern functional purpose are valued by modern society and can be considered as ecosystem services of the park. The purpose of the study was to develop and test a methodology for assessing the values of man-made protected parks in the Ukrainian Polissya. The following research methods were used: field surveys (route), analytical, comparative and historic and systematic. To assess the level of ecosystem services provided by 32 parks located on the territory of the Ukrainian Polissya, a methodology was developed and tested that included 19 assessment categories, each of which contained several attributes (1-20). Assessment categories included utilitarian, environmental, educational, etc. Attributes were presented, but were not limited to the presence of a source and/or the presence of medicinal plants (within the utilitarian category), the presence of plantings that perform the functions of river protection and/or soil stabilisation (within the ecological category), and the presence of an educational path (in the educational category). Each attribute was assigned a score of 1 with a sum of values (up to a potential sum of 97), reflecting the level of ecosystem services provided by each individual park. By estimating the sum of values, parks were classified as high-value (sum of values from 70 to 97), medium-value (sum of values from 40 to 69), and low-value (sum of values below 40). Among the 32 parks surveyed, 31 (96.9%) parks were classified as medium-value (most with a sum of values in the range from 50 to 60), and one (3.1%) park was classified as low-value, while no park was classified as high-value. By identifying which of the 19 assessment categories (and attributes) are missing, it is possible to plan and implement improvements to increase the ecosystem services provided by individual parks. This methodology can be used to evaluate ecosystem services provided by man-made parks in Ukraine and around the world. Such an assessment would help preserving existing parks, saving them from destruction and development, thus preventing their transition to other types of land use. It would also increase the value of these unique multi-purpose landscape features in the future by transforming and expanding their cultural and social ecosystem services

Keywords: park-monuments of landscape art, protected areas, ecosystem services, history, transformation

Suggested Citation:
Dzyba, A., & Kolesnichenko, O. (2022). The Value of protected man-made parks of the Ukrainian Polissya of the second half of the 18th and early 20th centuries. *Ukrainian Journal of Forest and Wood Science*, 13(4), 16-29.

**Corresponding author*

Introduction

Historical sites that reflect national identity are the key to sustainable development. The historical heritage reflects the cultural code and identity of a particular region, city, or locality. Historical architecture and park environment form an idea of harmony and aesthetic tastes of many generations [1]. The park and garden are interconnected with the natural and architectural environment and with society. Different philosophical views have enriched the semantics of the landscape gardening styles over the centuries [2]. A historical garden according to the Florence Charter [3] is an architectural and park composition (the components are mainly plants that are in constant dynamics), which is of interest to the public from a historical or artistic standpoint. Parks can be considered not only as an object of biodiversity, but also as man-made architectural objects that use woody plants in the composition [4]. Countries that have well-established park and gardening traditions, such as the United Kingdom, the United States, France, etc., pay considerable attention to the preservation, restoration, and management of historical gardens. On the other hand, the lack of gardening culture and education leads to the degradation and loss of historical parks and gardens [5]. Researchers also conduct various studies in historical parks around the world. In Estonia, based on the inventory and analysis of the species composition of plantings of historical parks, the model for the composition of stands of trees in a historic park was developed [4]. Greece has developed methodological plans for the recognition and preservation of historical gardens and parks based on a comparative analysis of similar sites abroad and in Greece [5].

Protected parks of Ukrainian Polissya of the 18th-20th century attracted the attention of many researchers who studied them in various aspects. O.Yu. Klymenko [6] investigated the condition of the plantings of park-monument of landscape art (PMLA) Ivnytskyi. F.F. Markov conducted ecological, geographical, phytosociological, and taxonomic analysis of woody plants such PMLAs as Yulino, Park imeni Miklukho-Maklaia, Korostyshivskyi, and Vilkhivskyi [7]. In the work [8], the historical, cultural, and architectural significance of the Park imeni Miklukho-Maklaia is analysed. The study [9] highlights the history of the creation of the Tereshchenko family palace and park complexes (PMLA Yulino), and examines the current state of parks and their structure in landscape, taxonomic, and aesthetic aspects. In [10], the history of the creation of the Korostyshivskyi PMLA and the state of the park zone and its structure were investigated, and a taxonomic, landscape and aesthetic assessment was carried out. The study by A.M. Savoskina considers the historical aspect of the establishment of plantings and their condition in the Vozdvyzhenskyi and Kochubeivskyi PMLAs [11]. The study [12] examines the historical features and modern categorical structure of the network of man-made protected parks of the Ukrainian Polissya.

The authors of the above studies analysed the history of park establishment, their current state, taxonomic composition, and species composition of dendrosozoexotic species, and aesthetic evaluation, mostly in fragments in the regions of Ukrainian Polissya. However, in the Ukrainian Polissya there had been no comprehensive assessment of the value of parks-monuments of landscape art of the second half of the 17th century – early 20th century, which is currently relevant.

The purpose of the study is to develop and test a methodology for assessing the values of parks based on the generalisation of key features of 32 protected man-made historical parks of the Ukrainian Polissya.

Tasks: to conduct an inventory of 32 objects, of which 31 are man-made protected parks and complex natural monuments of the Ukrainian Polissya, to identify and explore preserved objects, structural elements of parks-monuments of landscape art, to develop a methodology and determine the value of the objects under study.

Materials and Methods

During 2014-2021, an inventory survey and comprehensive analysis of 31 park-monuments of landscape art (PMLA) and complex natural monument (CNM) (hereinafter – parks) of the Ukrainian Polissya of the second half of the 17th – early 20th centuries was carried out. PMLAs and CNM are located in the Polissya part (mixed forest zone) of seven regions. The largest number of PMLAs is concentrated in Zhytomyr (34.4%) and Chernihiv (21.9%) regions, 15.6% each in Rivne and Volyn regions, and one or two PMLAs each in Kyiv (3.1%), Sumy (6.3%) and Khmelnytskyi (3.1%) regions. Park and garden complexes differ in regional characteristics: park and garden complexes of Volyn and Kyiv regions, Northern Left Bank, which is associated with certain differences in the historical and social development of these lands and the features of natural landscapes of the localities based on which they were formed [13]. Analytical and systematic methods, and general scientific principles of historicism and chronological sequence have been applied.

The analysis of literary sources and iconographic material was carried out, with the involvement of museum materials of images of park-monuments of landscape art and complex natural monuments, which provided an idea of the development of parks in different periods and allowed tracing the nature of transformation over a long period of time. A visual full-scale survey (route method) of the territory of 32 parks was carried out, when structural elements of parks (types of woody plants, types of plantings, reservoirs, buildings, small architectural forms), composite axes, and planning structure were recorded in the field. The plant species were identified [14], and the species names were specified in accordance with the international classification [15]. The age structure of plantings was determined by mensurational descriptions and archival materials.

In order to develop the value assessment (value implies certain phenomena or objects that have material (economic), social, or cultural significance [16]) of man-made protected parks, the following methods were applied: classification of protected nature values [17], methodology for determining the dendrological value and level of preservation of landscape objects [18], assessment of unique trees [19], in accordance with the Florentine Charter, components of the architectural composition of historical parks: plan and relief; types of plantings, plant species, structural and decorative features; water elements [4], approaches to applying the design of landscape groups of plants and their medicinal properties [20], classification of ecosystem services [21], assessment of ecosystem services [21-23]. The study evaluated each value in points depending on the number of features found in parks (PMLA and CNM), and then, according to the classification of ecosystem services and classified them into four groups.

Results and Discussion

According to the chronology and stylistic features, L. Prybieha attributes the PMLAs created before the middle of the 18th century to the early period; in the last third of the 19th century – to the era of early classicism; in the first third of the 19th century – to the Empire style; from the middle of the 19th century to the beginning of the 20th century – to the period of romantic and eclectic trends in architecture and landscape gardening (in the organisation of the park environment, preference is given to refined plasticity and the creation of lyrical architectural and artistic images, monumentality is reduced) [14]. By size, the parks were grouped of authors into categories: small (up to 3 ha) – 6.2%, medium (from 3 to 10 ha) – 34.4%, large (from 10 to 25 ha) – 43.8%, and very large (from 25 ha) – 15.6 % (Table 1).

Table 1. Characteristics protected man-made parks of the Ukrainian Polissya

No.	Region	PMLA, CNM	Purpose	Area, ha	Creation period	Number of species	Types of plantings
17th century							
1	Rivne	CNM Volodymyretskyi park	castle*** palace*	3	17th, 1827	16	a; gr; s; st
2	Chernihiv	Lyzohubivskyi	estate*	22	end of 17th	21	a; gr; s; r; or
18th century							
3	Zhytomyr	Park imeni Kutuzova	fortress, palace***	5	2nd half of 18th	35	a; g; s; or
4	Zhytomyr	Ivnytskyi	estate***	14	2nd half of 18th	32	gr; s; r; st; rp
5	Zhytomyr	Kmytivskyi	estate*	9	2nd half of 18th	40	a; gr; s; rp; st, b
6	Sumy	Kochubeivskyi	estate*	22	2nd half of 18th	27	a; gr; s; rp; st
7	Volyn	Zdorovia	castle palace*	13.6	2nd half of 18th	44	a; gr; s; rp; h; or
8	Rivne	Tuchynskyi	residence***	10	end of 18th	35	a; gr; s; rp; g
9	Chernihiv	Stolnenskyi	estate***	12	end of 18th	39	a; gr; s; rp; h
10	Volyn	Liubeshivskyi	**	12	end of 18th	25	a; g; gr; s
19th century							
11	Rivne	Horodotskyi	***	8	1820	44	a; gr; s; r
12	Volyn	Makarevychivskyi	estate*	0.9	1839	14	a; gr; s; r
13	Zhytomyr	Dvoryshchanskyi	estate*	1.5	1840	20	gr; s; g; a

Table 1, Continued

No.	Region	PMLA, CNM	Purpose	Area, ha	Creation period	Number of species	Types of plantings
14	Zhytomyr	Korostyshivskyi	castle palace	12.9	1840	41	a; gr; s; r; st; r*
15	Zhytomyr	Ushomyrskyi	estate**	12.91	first half of 19th	55	a; gr; g, s; r; st; or
16	Zhytomyr	Park imeni Yu.Haharina	estate	36	end of the first half of 19th century	90	a; gr; s; r; st; h
17	Chernihiv	Miskyi sad	-	11.2	1850-1900	53	gr; s; r; st
18	Rivne	Oleksandriyskyi	estate***	5	1840-1870	22	a; gr; s; rp; r
19	Zhytomyr	Vilkhivskyi	palace**	11.2	mid-19th century, 1860	35	gr; s; rp; st
20	Volyn	Sadyba Lypynskoho	estate*	3	1882	26	gr; s; rp; b
21	Zhytomyr	Horodnytskyi	estate***	21	1880-1890	52	a; gr; s; rp; h
22	Zhytomyr	Park imeni Miklukho-Maklaia	-***	29.6348	1873-1886	66	a; g; gr; s; rp; st, h; or
23	Zhytomyr	Yulino	estate*	25	2nd half of 19th	36	a; g; s; rp; gr, or, st
24	Kyiv	Kopylivskyi	summer residence*	8	1888-1890	45	a; gr; s; rp; g; h
25	Chernihiv	Vahanytskyi	estate	6	1880-1900	42	a; gr; s; rp
26	Sumy	Vozdvyzhenskyi	estate**	45.9	1889	47	a; gr; s; rp; st
27	Chernihiv	Park imeni T.H. Shevchenka	-	10	end of 19th century	27	gr; s; rp
28	Khmelnytskyi	Polonskyi	estate**	37	2nd half of 19th	51	a; gr; g; s; rp; r
29	Volyn	Litynskyi	family estate***	8.4	end of 19th	37	a; gr; s; rp; or; r
30	Rivne	Zirnenskyi	summer residence***	17.2	late 19th 1896	50	a; gr; s; rp
early 20th century							
31	Chernihiv	Tupychivskyi	estate	3	1900-1905	22	a; gr; r
32	Chernihiv	Boldyna Hora	Saint Anthony cave comlpex*	6	1911	42	a; gr; s; rp; h

Note: * – estate building has been preserved; ** – partially preserved buildings for various purposes; *** – estate building is not preserved; a – alley; rp – row planting; s – solitary, gr – group; st – stands on an area >0.5 ha; g – grove; or – orchard; h – hedges; b – border; r – ring, *r – ring is not preserved
Source: compiled by the authors

It was found that 62.4% of PMLAs were established during the 19th century, 25 % – in the second half of the 18th century, and 6.3% – at the end of the 17th century and early 20th century. Natural factors influenced the creation of the architectural and artistic composition of palace and park ensembles. Until the middle of the 17th century, the protective properties of the area were an outstanding factor in choosing a site for a residence, the transformation of castle complexes into palace and park ensembles took place over time and gradually (Volodymyretskyi park). O.L. Mykhailyshyn noted that in Volhyn, the function of protection at a certain stage was performed by natural reservoirs, which were gradually included in the structure of palace and park ensembles as elements of a new aesthetic, water surfaces also had an economic and applied purpose [24].

During the 17th – 19th century, functional and compositional relationships of natural (woodlands) and anthropogenic (park part of residences) landscapes have become widespread, which is found in the Volodymyretskyi, Horodnytskyi, Kmytivskyi, Kochubeivskyi, Vozdvyzhenskyi, and Park imeni Kutuzova. In the 18th century, manor construction had its own characteristics. L. Prybieha notes that in the planning and spatial structure of parks, the palace was located on elevated terraces of the area and had a dominant position, the symmetrical composition of the park with the cour d'honneur open towards the entrance was emphasised by the main alley located on the same axis as the palace, which ensured regular planning of the pre-palace space and garden plantings. At the same time, the second part of the park, located behind the palace, opposite to the main entrance, was laid out freely, had a landscape character [13].

A similar planning and spatial structure of the park can be observed in the PMLA Ivnytskyi, founded in the second half of the 18th century in Ivnytsia village on the gentle left slope of the river, the owner of the town, Jozef Czarnecki, built a two-story stone palace, established a landscape park with a system of ponds with gateways. Nowadays, the entrance gate and *Fraxinus excelsior* L. on the left, the utility building, dilapidated defensive towers, and steps leading to the south-eastern tower remain. Behind the entrance gate, a little further on, there is a clearing, probably a cour d'honneur that was in front of the palace, it has the shape of a circle with a diameter of 100 m, around which century-old trees grow in an row planting with three specimens of *Tilia cordata* Mill., two specimens of *Carpinus betulus* L. At the end of the 19th century, a greenhouse parterre was built behind the palace with *Citrus limon* L. Osbeck and *Citrus×aurantium* L. in containers, *Picea abies* Karst. were planted as single plantings (1914), some have survived to this day.

In the second half of the 18th century, the type of rural estate with the corresponding establishment of parks (Kmytivsky, Kochubeivskyi) also spread. Baroque parks were not widespread – among the studied sites is the well-known Liubeshivskyi PMLA. The Baroque residence was built by the Great Lithuanian Hetman M. Vyshnevetskyi on the site of a wooden palace that burned down during the Great Northern War; a park was established around the palace. J. Mniszech, having inherited the residence after the Vyshnevetskyi family, sold it in 1754 to J. Czarnecki, who built a brick wall and created a moat, on the western side of the palace – an entrance gate, the entrance to which was closed by a suspension bridge. In the first half of the 19th century, the palace had an Italian-style garden with stalls, alleys, and lawns. O.L. Mykhailyshyn notes that the imitation of the traditions of Western European landscape art in Volyn was embodied in the arrangement of baroque gardens of the Italian type, baroque gardens of the French type in their traditional form did not become widespread, only the front parterre was used. In the second half of the 18th century, the English theory of landscape-style parks began to be applied, where the structural elements were a garden for walking, a menagerie, and an orchard.

In Volyn, there were ceremonial, melancholic parks, and parks in which water was the main element. Other types: rustic, pastoral, and intimidating were represented by separate semantic sections (P. Giżycki distinguishes six types of landscape parks) [24]. In the Ukrainian Polissya, 84.4% of the studied objects have reservoirs or water bodies, where six principles of arrangement of garden compositions with water elements were revealed: single-faced (PMLAs Liubeshivskyi, Tuchynskyi, Park imeni Kutuzova, Dvoryshchanskyi, Lyzohubivskyi, Stolnenskyi, Kochubeivskyi, Kmytivskyi, Oleksandriyskyi), double-faced (Horodnytskyi), island (Horodnytskyi, Zdorovia), combined (river and lake PMLAs Horodnytskyi, Korostyshivskyi, river and fountain PMLA Park imeni Yu. Haharina, river and pond system of PMLAs Ushomyrskyi, Ivnytskyi, Park imeni Miklukho-Maklaia), man-made reservoirs (PMLAs Zdorovia, Yulino, Vahanytskyi, Miskyi sad, Zirnenskyi, CNM Volodymyretskyi park, in PMLAs Kopylivskyi and Sadyba Lypynskoho, reservoirs have not been preserved). Of the 27 protected historical parks, 62.3% were created along the river banks [25].

During the 19th century, intensive construction of new park complexes began in the Ukrainian Polissya, with 62.5% of the studied parks being established. This period is characterised by landscape parks, some of them included fruit orchards, which were located either in the entrance part (PMLA Litynskyi), or in remote parts, next to the walking part of the park and delimited by alleys with *Carpinus betulus* L. (PMLA Ushomyrskyi), *Tilia cordata* Mill. (PMLA Vozdvyzhenskyi), *Ulmus laevis* Pall. and *Aesculus hippocastanum* L. (PMLA Lyzohubivskyi). In Park imeni Kutuzova, an orchard was created in the 1950s on an area of 3 hectares, now there are: *Prunus cerasus* L., *Prunus avium* L., *Prunus cerasifera* Ehrh., *Pyrus pyraster* (L.) Burgsd., *Juglans regia* L., *Malus domestica* Borkh.

At the end of the 19th – beginning of the 20th century, summer residences were created and parks were arranged around them (PMLAs Kopylivskyi, Zirnenskyi, Kmytivskyi). In 1888, the Kopylivsky family built a summer wooden residence (cottage) in Nordic or National Romantic architectural style around the manor house, and a rose garden was arranged. Alleys of large-sized plants with *Picea abies* Karst. (in 2018, the trees died) and with *Tilia cordata* Mill. were arranged (the paths of the alleys were sprinkled with sea sand); a pond was dug. Evelina Sumovska (Bohdanovych), the owner of the Kmytivskyi estate, inherited the house (built at the turn of the 19th and 20th centuries) as a summer residence after her marriage. Over time, Anna-Maria and Evelina Sumovsky build the villa for winter living, where they stayed until 1917 [26].

During the first half of the twentieth century, some of the historical park complexes underwent a devastating transformation (Park imeni Kutuzova, Park imeni Miklukho-Maklaia, Dvoryshchanskyi, Sadyba Lypynskoho). Since the 1950s, certain measures have been taken to restore the plantings of PMLAs Kmytivskyi, Park imeni Kutuzova, Ivnytskyi, Dvoryshchanskyi, Korostyshevskyi, Park imeni Yu. Haharina, Boldyna Hora, but the preservation of characteristic vegetation and historical landscape structure was rather neglected.

L. Pribega [13] divided PMLAs into two groups: the first group includes historical parks or gardens (aesthetic features are determined primarily by the unique biological properties of the presented plant species), such a group can include Park imeni Yu. Haharina, Park imeni Miklukho-Maklaia, Ushomyrskyi, Vozdvyzhenskyi, Litynskyi. The second group – estate and park complexes (ensemble) – any set of separate or interconnected structures, their architecture and consistency with the landscape is of particular historical, artistic, scientific, social, or ethnological value [3]). The planning and spatial organisation of palace and park complexes has a special creative idea, where park buildings and the palace are placed as a compositional dominant of the entire ensemble. These include – CNM Volodymyretskyi park, PMLAs Sadyba Lypynskoho, Polonskyi, Lyzohubivskyi, Kochubeivskyi, Zdorovia, Horodotskyi, Korostyshivskyi, Kopylivskyi, Dvorishchanskyi, and Yulino. According to the authors, it is necessary to single out another group of parks that have preserved compositional dominants, but park buildings and the palace have not been preserved. This group is proposed to include: PMLAs Horodnytskyi, Ivnytskyi, Stolnenskyi, Liubeshivskyi, Oleksandriyskyi, Tupychivskyi.

According to the authors' methodology for assessing parks, it is proposed to introduce 19 values, with a total maximum score of 97 points, which can provide such ecosystem services (ES) as security, regulating, cultural and social, and supportive (Table 2). The distribution of parks by value is as follows: low-value – up to 40 points, medium-value – 40-70 points, high-value – from 70 to 97 points. Based on the results of a scoring of the values of parks, their features and ways to optimise these objects will become clear. Since most of the values for which the assessment was conducted relate to cultural and social services of the ecosystem, accordingly, it will be possible to identify in which parks they are presented more fully and ways to increase them for parks where such values are poorly developed. Evaluating the utilitarian value that supply services provide will help identify the parks with the highest representation. The ecological and maintenance value of regulating and supporting ecosystem services, respectively, is typical for all parks.

Table 2. Assessment of the values of man-made protected parks

ES*	Value	Maximum number of points	Signs
1	Utilitarian	4	availability: water sources (1 point), resources for further use (fruits and seeds of rare species (1 point)), medicinal raw materials (1 point), genetic resources (1 point)
2	Ecological	4	plantings of the park perform a water-regulating (1 point), soil-protective (1 point) function, create a comfortable microclimate (1 point), plantings are habitats for entomophages, insectivorous species, pollinating insects (1 point)
3	Museum	3	presence of a museum on the territory of the park (3 points), it is possible to create a museum on the territory of the park (2 points), it is not possible to create a museum on the territory of the park (0 points)
3	Historical and cultural	9	preservation of cultural monuments together with their environment (1 point), preservation of cultural landscapes (1 point), remains of ancient settlements (1 point), remains of ramparts (1 point), religious graves (1 point), entrance gate (1 point), defence tower (1 point), bridge (1 point), shooting gallery (1 point)
3	Spiritual (religious)	5	presence of a church or cathedral on the territory of the park (3 points), near but outside the park (2 points), absence, but the park is a place of spirituality (2 points)
3	Scientific	3	the park is subordinate to an institution where research can be conducted (1 point); the park has objects (rare plants, animals, birds, etc.) for conducting research (1 point); the ability to study natural processes (1 point).
3	Educational	4	organised ecological trail (3 points), developed and potentially possible organisation of an ecological trail (2 points), there is no possibility of organising an ecological trail (0 points); the park is a place of visual knowledge (1 point).

Table 2, Continued

ES*	Value	Maximum number of points	Signs
3	Ethical (moral)	3	park plantings as a valuable example of a human-made environment by previous generations, which has the right to exist. Where the morality of kindness and beauty is laid down, as a result, a humane attitude to nature and people (3 points).
3	Educational (patriotic)	3	the park located within cities and towns is an example of a human-made environment and processes that occur in it, there is a possibility to raise children in contact with nature (3 points), the park is located outside of settlements, is an example of a human-made environment and processes that occur in it, there is a possibility to raise children in contact with nature (2 points), the park is located in the depths of the forest there is no opportunity to raise children in contact with nature (1 point)
3	Aesthetic	3	elements: plantings, reservoirs, buildings (3 points), a combination of two elements including the remains of buildings (2 points), one element (1 point)
3	Health and recreation	7	availability of a recreation environment (plantings (1 point), reservoirs (1 point)), stadium (1 point), playgrounds (1 point), recreation areas (1 point), theater (1 point), lawn (1 point)
3	Unperceived	1	a value that is not yet realised by a person, but potentially exists (1 point)
3	Reference	20	availability of reference plantings (alley; row planting; solitary, group; array; grove; orchard; hedge; borders; ring) (1 point is given for each reference type of plantings), preservation of the planning structure (1 point), composite axes (1 point); available main elements of the estate: complex of buildings (1 point), building (1 point), natural reservoirs (river, lake, pond) (1 point), man-made water systems (pond, cascade or pond system, fountain or cascade of fountains) (1 point), island (1 point), gazebo (1 point), lawn (1 point)
3-4	Collectable (taxonomic)	3	availability of 100 taxa (3 points), 50 to 100 taxa (2 points), and up to 50 taxa (1 point) in the park's plantings collection
3-4	Dendrorarity	3	availability of rare woody plants in the collection in % of the total number: 90 to 100% (3 points), from 50 to 90% (2 points), less than 50% of rare plants (1 point)
3-4	Planting types	9	old (100-200 years) and centuries-old (200- 800 years) plantings: alleys (1 point), groups (1 point), solitary (1 point), row plantings (1 point), mixed and pure stands on an area > 0.5 ha (1 point); unique plantings (ring) (1 point), moulded plants (1 point), orchard (1 point), typical plantings: mixed and pure stands on an area > 0.5 ha, groves, groups, alleys, row plantings, solitary, hedges, borders (1 point).
3-4	Unique trees	5	ancient trees (trunk circumference is significant) (1 point), veteran trees that have experienced various harsh living conditions, as a result of accelerating ageing and the appearance of signs of old age, regardless of their age (1 point); notable (significant) trees (very large mature trees, stand out locally, larger than other trees around them (1 point); champion trees – the tallest or those that have the largest trunk circumference among trees of a certain species in a particular region (1 point); heritage trees (outstanding) correspond to any of the above descriptions, are of particular cultural or historical interest (1 point).
3-4	Therapeutic plant communities	5	place for restoring human health (5 points in total) (stimulating the five senses of visitors: vision (1 point), hearing (1 point), touch (1 point), smell (1 point), taste (1 point)
4	Support	3	air quality (1 point), noise reduction (1 point), environmental impact on the development of living organisms (1 point)
	Total	97	

Note: if there are several characteristics of the same value criterion, their number is summed up. *Ecosystem services (ES): 1 – security (supply), 2 – regulating, 3 – cultural and social, 4 – supporting
Source: compiled by the authors

Next, the study considers the significance of some key values. Each epoch influences people's worldview and forms their new historical consciousness due to changing economic, political and socio-cultural changes. In turn, each epoch, the political structure of states, and their economic development are created not by their own efforts, but in accordance with certain laws. Understanding of the processes that are taking place depends on awareness of the epochs of human development in the relationship of times. The establishment of historical parks is the impact of man on the environment, the impact of nature on man, the perception of nature by man and his actions in connection with this perception. The study and preservation of park-monuments of landscape art is possible in the absence of ideological approaches that harm their development. Under Soviet rule, due to ideology, some of the estates (buildings) were destroyed (PMLA Zirnenskyi, Ivnytskyi, Stolnenskyi, Korostyshivskyi, Vilkhivskyi). This deprived humanity of important components of universal culture, which is no longer possible to study, because it is completely destroyed.

A positive result in the knowledge of culture can be achieved only in a combination of the study of material and non-material (spiritual) culture. Museums play a significant role in studying historical, cultural and natural heritage in their totality. Therefore, their value is obvious. Museums are found on the territory or nearby in seven PMLAs (Lyzohubivskyi, Zirnenskyi, Sadyba Lypynskoho, Kochubeivskyi, Horodotskyi, Korostyshivskyi, and Kmytivskyi (outside the park) (Table 3). The museum's mission is to study, preserve, and broadcast historical, cultural, and natural heritage to future generations. Heritage is the social experience of generations that the museum preserves and transmits from the past through the present to the future. Therefore, the assessment of museum value is important, and the creation of new museums on the territory of the PMLA or outside of them will contribute to social memory.

Table 3. Assessment of the value of man-made protected parks in Ukrainian Polissya

CNM, PMLA	Value																			
	Utilitarian	**Ecological**	**Museum**	**Historical and cultural**	**Spiritual (religious)**	**Scientific**	**Educational**	**Ethical (moral)**	**Educational (patriotic)**	**Aesthetic**	**Health and recreation**	**Unperceived**	**Reference**	**Collectable (taxonomic)**	**Dendrorarity**	**Planting types**	**Unique trees**	**Therapeutic plant communities**	**Support**	**Total**
ES	1	2	3	3	3	3	3	3	3	3	3	3	3	3-4	3-4	3-4	3-4	3-4	4	
CNM Volodymyretskyi park	1	4	2	3	4	2	3	3	3	3	5	1	5	1	2	4	3	4	3	56
Lyzohubivskyi	2	4	3	2	4	2	3	3	3	3	3	1	6	1	2	5	3	5	3	58
Park imeni Kutuzova	2	4	0	2	2	2	1	3	3	2	3	1	2	1	2	4	2	5	3	44
Ivnytskyi	2	4	2	3	2	3	3	3	3	2	3	1	7	1	3	5	2	5	3	57
Kmytivskyi	1	4	3	1	2	2	1	3	3	3	4	1	3	1	2	6	1	4	3	48
Kochubeivskyi	2	4	3	1	2	2	3	3	3	3	6	1	6	1	3	5	2	4	3	57
Zdorovia	2	4	2	4	4	2	3	3	3	3	3	1	8	1	2	6	2	5	3	61
Tuchynskyi	2	4	0	1	2	2	3	3	3	2	5	1	7	1	2	5	3	4	3	53
Stolnenskyi	2	4	2	1	2	2	3	3	3	2	6	1	4	1	2	5	2	4	3	52
Liubeshivskyi	2	4	2	2	4	2	3	3	3	3	6	1	4	1	3	4	3	4	3	57
Horodotskyi	2	4	3	3	5	2	1	3	3	3	3	1	5	2	2	4	3	5	3	57
Makarevychivskyi	1	4	2	1	2	2	1	3	3	2	2	1	4	1	2	4	2	5	3	45
Dvoryshchanskyi	1	4	2	1	2	2	3	3	3	3	2	1	4	1	2	4	2	4	3	47
Korostyshivskyi	1	4	3	3	5	2	3	3	3	2	5	1	4	1	2	7	2	4	3	58
Ushomyrskyi	2	4	2	1	2	2	3	3	3	3	7	1	8	2	2	6	3	5	3	62
Park imeni Yu. Haharina	2	4	2	1	2	3	3	3	3	2	7	1	4	2	2	6	2	5	3	57
Miskyi sad	1	4	0	1	2	2	3	3	3	2	6	1	1	2	2	4	1	5	3	46
Oleksandriyskyi	2	4	0	1	4	2	3	3	3	1	5	1	6	1	3	5	4	4	3	55
Vilkhivskyi	2	4	2	2	2	2	3	3	3	3	4	1	3	1	2	4	1	5	3	50

Table 2, Continued

CNM, PMLA	Value																			
	Utilitarian	Ecological	Museum	Historical and cultural	Spiritual (religious)	Scientific	Educational	Ethical (moral)	Educational (patriotic)	Aesthetic	Health and recreation	Unperceived	Reference	Collectable (taxonomic)	Dendrorarity	Planting types	Unique trees	Therapeutic plant communities	Support	Total
Horodnytskyi	2	4	2	1	2	3	3	3	3	2	5	1	5	1	2	5	1	5	3	53
Park imeni Miklukho-Maklaia	3	4	2	1	2	2	3	3	3	2	7	1	10	2	2	8	2	5	3	65
Yulino	2	4	2	1	2	2	3	3	3	3	4	1	7	1	2	7	2	5	3	57
Kopylivskyi	1	4	2	2	2	2	3	3	3	3	5	1	5	1	2	6	3	5	3	56
Vahanytskyi	2	4	2	1	4	2	3	3	3	3	3	1	7	1	2	4	3	5	3	56
Vozdvyzhenskyi	2	4	2	1	5	2	3	3	3	3	4	1	8	1	2	5	3	5	3	60
Park imeni T.H. Shevchenka	1	4	0	1	4	1	1	3	3	2	2	1	1	1	2	3	2	4	3	39
Polonskyi	2	4	2	1	4	3	3	3	3	3	4	1	8	2	2	6	2	5	3	61
Litynskyi	2	4	0	1	2	2	3	3	3	1	3	1	8	1	2	6	3	5	3	53
Zirnenskyi	2	4	3	1	2	3	3	3	3	2	3	1	8	2	2	4	3	5	3	57
Tupychivskyi	1	4	2	1	2	2	3	3	3	3	1	1	2	1	3	3	1	4	3	43
Boldyna Hora	1	4	3	1	5	1	3	3	3	3	2	1	1	1	2	5	1	5	3	48

Source: compiled by the authors

L. Prybieha noted that the historical and cultural value of an ensemble or complex is determined by the compositional integrity and artistic level of the entire territorial and spatial objects and an integrated system of layers reflecting historical stages of development [13]. The planning structure of ensembles, complexes, and estates was influenced by the characteristic features of the corresponding landscapes and such components as reservoirs, hills, and slopes. According to the assessment proposed by the authors, the historical and cultural value was attributed to: the preservation of cultural monuments together with their environment, the preservation of cultural landscapes, the remains of ancient settlements, the remains of ramparts, religious burials, entrance gates, defensive rowers, bridges in the studied parks and their components, the authors partially agree with the researcher. Reservoirs, according to the authors' method, are classified as signs of health and recreational value.

Study [27] showed that spending time in nature restores and heals psychological, physical, and emotional aspects of a person, promotes the development of social relationships, and has the greatest impact on the human spirit, giving a sense of connection, vibration and awe. Time in nature can be transformative, turning negative emotions into positive ones that lead to joy, gratitude, and compassion. In addition, it is a free and affordable way to foster spiritual well-being [27]. Thus, spiritual value is obvious, because PMLA is the place where a person can heal and receive spiritual well-being. The presence of a church or cathedral on the territory of a park or nearby can enhance the spiritual value. In the 18th-19th centuries, the construction of the church and the palace took place almost simultaneously, and then the park was built, so the church was an integral part of some palace and park complexes (CNMs Volodymyretskyi park, Zdorovia, Liubeshivskyi, Oleksandriyskyi).

According to the authors, the reference value is very important, which is represented by: various types of reference plantings (alley; row planting; solitary, group; array; grove; orchard; hedges; borders; ring), preservation of the planning structure, compositional axes, the main elements of the estate are: a complex of buildings, a building, natural reservoirs (river, lake, pond), man-made water bodies (man-made pond, cascade or pond system, fountain or cascade of fountains), an island, gazebo, lawn (Table 2). That is, all the structural components that can be used as an example for the reconstruction of parks of a certain period. Antique reference alleys are most represented in the PMLAs Ushomyrskyi, Litynskyi, Lyzohubivskyi, Liubeshivskyi, and Yulino they are created from *Pinus sylvestris* L., *Carpinus betulus* L., *Tilia cordata* Mill., *Acer platanoides* L., *Aesculus hippocastanum* L., *Picea abies* Karst. No less interesting is the ring plantation type, which occurs only in PMLAs Litynskyi (with *Picea abies* Karst., *Tilia cordata* Mill.), Polonskyi (double ring with *Carpinus betulus* L. and a low hedge with *Ligustrum vulgare* L.), Oleksandriyskyi (with *Fraxinus excelsior* L. and *Fraxinus angustifolia* Vahl.), grew in the middle of the 20th century in PMLA Korostyshivskyi (with *Populus nigra* var. *italica* Münchh.), however, it has not been preserved. As reference stands with *Pinus sylvestris* L., *Quercus robur* L. on an area of >0.5 ha and an orchard are available at the PMLA Vozdvizhenskyi.

The park environment is able to provide a pleasant, healthy, and comfortable atmosphere for people of all ages and has a positive impact on human health [28]. A person perceives external information through the five senses (sight, hearing, touch, smell, and taste). The theory of the five senses provides an opportunity to understand the therapeutic effect of plant communities [20]. Therapeutic plant groups have the following signs of value: leaf colour, crown architectonics, creating light and shadow from plants (stimulate vision), phytoncidal and aromatic plants (stimulate the sense of smell), deciduous plants that add the sound of rustling leaves, edible plants (affect the taste buds), long-lasting plants with different textures (diversify the sense of touch). All of the above signs have a positive effect on strengthening a person's physical and mental health. Assessment of the value of therapeutic plant communities in PMLA will help identify shortcomings in plantings, and will help in selecting plants to improve the design and complement certain groups of sensory plants. Species diversity and stable plant communities are a reliable basis for PMLA, which will influence the ecological state of the park's plantings and ensure the diversity of therapeutic plant landscapes. The design of therapeutic plant communities is extremely important. They can improve the park environment, provide a comfortable and pleasant stay, and also increase its value in terms of aesthetics. The authors also agree with the opinion of researchers [23] that with the increase in urbanised areas and the decrease in human contact with nature around the world, the question of preserving and expanding access to the natural environment arises. In addition, the compaction of the urban environment, which causes air pollution and noise pollution, can be buffered by parks where citizens can spend leisure time [20]. Plantings in parks reduce the temperature in summer, mitigate the effects of heat islands, increase the comfort of recreation conditions, and indirectly affect human health. Staying in the PMLA can affect a person's cognitive functioning, emotional well-being, and other aspects of mental health, which increases the value of parks and expands eco-friendly services. Mental health benefits are usually accompanied by benefits from other ecosystem services and can be considered as "concomitant benefits" for other services [28].

Based on the analysis of values, it was revealed that 30 PMLAs and CNMs have an average value ranging from 40 to 70 points: 22.6% of parks have a value of 40-50 points, 61.3% – 50-60 points, 12.9% – 60-65 points (PMLAs Vozdvyzhenski, Polonskyi, Zdorovia, Ushomyrskyi, Park imeni Miklukho-Maklaia) (Table 3). The last five PMLAs that received the most points are to some extent reference ones, which retain plantings, planning structure, and most of the components of parks. The remaining 24 PMLAs and CNMs require careful analysis to diversify the components of parks, increase their attractiveness, and understand their area of development. When supplementing plantings (to create therapeutic plant communities) in PMLAs, it is important to consider the basic needs of communities, adopt a holistic view, and use natural types of woody and herbaceous plants to achieve sustainable development of parks and local ecosystems.

Park imeni T.H. Shevchenka has a low score, which indicates that the cultural and social services of the ecosystem are not high in the PMLA, which is conditioned by the history of its creation. In the 18th century, the Holy Trinity and St. George churches were built on the site of the park, around which a system of burials was established. In the 19th century, the park had the Trinity cemetery with the city garden and the St. George cemetery [29]. A mass grave of several hundred people who died in the Second World War has been built near the city stadium. In a separate part, a place for burials was left in the direction of ravines, which began to be developed as a Soviet burial site in the 1930s.

Currently, considerable attention is paid by researchers around the world to assessing different values at both the regional, local, and global levels, with different approaches being used. A special place is occupied by assessing the value of nature and eco-forest services, which are key to human mental health. G.N. Bratman et al. developed a conceptual model to preserve and expand the assessment of ecosystem services to include mental health. The model can be used to assess where green spaces or better access to nature can improve a person's mental health, and where certain infrastructure, building placement, and other land use decisions can negatively affect it [28]. R.P. Remme et al. proposed a spatial model that can be used in decision-making to guide and inform numerous groups of stakeholders, considering individual approaches to a particular territory. The researchers suggest that integrating a natural-oriented physical activity model as a tool for evaluating ecosystem services can help take into account the many values of preserving and improving the natural environment [30]. Z. Ouyang et al. developed an indicator of the gross product of the ecosystem, which summarises the importance of the contribution of nature to the economic activity of the country. This indicator can be used in making decisions about investing in the conservation of ecosystem assets to ensure the provision of ecosystem services through transregional compensation payments [31]. A.S.M.G. Kibria et al. evaluated Cambodia's Veun Sai-Siem Pang National Park, which is significant in terms of biodiversity value and little known to the international community, and found that the area under study is a base of valuable knowledge about natural resources, has cultural significance for indigenous peoples, and is part of one of the most important eco-regions in the world. At the same time, it has numerous threats (illegal logging, poaching, public pressure, and corruption). Assessment of ecosystem services will provide an opportunity to promote sustainable park management [32]. G. Moradi et al. studied the recreational value of Baharan Park in Maybod, and a logit model was used to determine the effective factors of visitors' willingness to pay for park protection and improvement The willingness to pay for ecosystem services indicates the high importance of the park [33]. Assessment of recreational ecosystem services in protected areas, namely, in botanical gardens, as noted by C. Funsten et al., can promote the development and optimisation of potential ecosystem services that botanical gardens are designed to provide, such as demonstration and training, and planning various activities can increase social well-being and improve inclusivity. C. Funsten et al. examined respondents' satisfaction with a questionnaire at the Zagara Plant Festival in the Botanical Garden of the University of Palermo in Sicily (Italy) and found that the festival met the relevant needs of visitors to outdoor social events. Therefore, one of the management decisions, according to the researchers, can be the creation of special events in protected areas to improve the well-being of people [34]. Raising awareness of the value of natural resources [32] will encourage policy-makers to adopt a sustainable development approach rather than a popular short-term economic benefit.

Conclusions

Based on the generalised features, an assessment of 19 values was developed and tested in 32 parks that were created over three centuries. Man-made parks of the Ukrainian Polissya are an integral element of estates of the second half of the 17^{th} – early 20^{th} centuries, which had local characteristics and aesthetic individuality. Their spatial frame is represented by a characteristic relief, reservoirs, historically formed layout, buildings and structures with more than 100-year-old plantings (mixed and pure stands on an area >0.5 ha, groves, alleys, groups, rings, solitary, row plantings, fruit orchards). It was revealed that 6.3% of parks were established in the late 17^{th} century and early 20^{th} century, in the second half of the 18^{th} century – 25%, and in the 19^{th} century – 62.4%. They differ in area: up to 3 hectares – 6.2 %, from 3 to 10 hectares – 34.4 %, from 10 to 25 hectares – 43.8%, and over 25 hectares – 15.6 %.

Based on the assessment of 19 values (total number of points 97), it was found that 31 parks have an average value score ranging from 40 to 70 points. The average value with the number of points from 60 to 65 is given to the park-monuments of landscape art Vozdvyzhenskyi, Polonskyi, Zdorovia, Ushomyrskyi, and Park imeni Miklukho-Maklaia, which are the best preserved and have different structural components, in turn, they provide the most diverse cultural and social ecosystem services. Therefore, it is necessary to continue to ensure the further preservation of the considered parks as a valuable historically inherited environment that can provide ecosystem services such as cultural and social, security, regulating, and maintenance.

The findings can be used to preserve the existing components, and maintain the historical and artistic image of the park environment by restoring plantings during reconstruction. The proposed method of value assessment can be applied to determine the values of man-made protected parks, including those that do not have a protected status both in Ukraine and in other countries of the world. The results obtained can be used to guide research on expanding the provision of cultural and social ecosystem services.

References

[1] Honcharova, K. (2018). In search of new approaches to the preservation of cultural heritage: private-public partnership. Retrieved from https://uccs.org.ua/detsentralizatsiia/statti/u-poshukakh-novykh-pidkhodiv-do-zberezhennia-kulturnoi-spadshchyny-pryvatno-hromadske-parterstvo.

[2] Kuznetsov, S. (2021). *Park science*. Kyiv: NAKKKiM.

[3] The Florence Charter. International Charter for the Historic Gardens. (1982, December). Retrieved from https://www.icomos.org/images/DOCUMENTS/Charters/gardens_e.pdf.

[4] Nutt, N., & Kubjas, A. (2020). The model of trees for the restoration of historical manor parks in Estonia. *Tourism Geographies*, 17, 22-29. doi: 10.22616/j.landarchart.2020.17.03.

[5] Athanasiadou, E. (2019). Historic gardens and parks worldwide and in Greece: Principles of acknowledgement, conservation, restoration and management. *Heritage*, 2(4), 2678-2690. doi: 10.3390/heritage2040165.

[6] Klymenko, Yu.O. (2009). Planting of ancient parks-monuments of landscape art of the Zhytomyr region. *Scientific Bulletin of UNFU*, 19(7), 28-37.

[7] Markov, F.F., Shvets, M.V., Pitsil, A.O., & Gurkova, M.S. (2020). Comprehensive assessment of heritage parks' plantations of Zhytomyr Region, Ukraine. *Forestry Ideas*, 26(2(60)), 528-539.

[8] Markov, F. (2012). Miklouho-Maclay park-the object of historical, cultural and architectural heritage. In *Annual 18th International Scientific Conference Proceedings "Research for Rural Development"* (pp. 148-151). Jelgava: Latvia University of Agriculture.

[9] Markov, F.F., & Terelya, I.P. (2019). Features of creation and current state of the Tereshchenko family palace and park complexes in Zhytomyr Region, Ukraine. *Forestry Ideas*, 25(1(57)), 182-195.

[10] Markov, F. (2014). Comprehensive assessment of Korostyshev park, the Monument of Landscape art, Zhytomyr district, Ukraine. *Forestry Ideas*, 20(1), 111-117.

[11] Savoskina, A.M. (2016). Formation of the modern state of plantings of parks-monuments of landscape art in the Polissy part of the Sumy region. Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine, 238, 195-200.

[12] Savoskina, A.M. (2015). The history of the formation and current state of the network of parks-monuments of landscape art of the Ukrainian Polissia. *Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine*, 219, 255-261.

[13] Prybieha, L. (2015). *Architectural heritage of Ukraine: Monument preservation aspect*. Kyiv: Institute of Cultural Studies of the National Academy of Arts of Ukraine.

[14] Spohn, M., & Spohn, R. (2011). *Kosmos-Baumführer Europa*. Stuttgart: Kosmos.

[15] WFO. (2022). Word Flora Online Published on the Internet. (n.d). Retrieved from http://www.worldfloraonline.org/classification.

[16] Perha, T.Yu. (2019). Ecological values of modern civilization. In *The value dimension of the development of civilizations and globalization* (pp. 89-97). Kyiv: State Institution "Institute of World History of the National Academy of Sciences of Ukraine".

[17] Boreiko, V.E. (1996). On the values of protected nature. Zapovidna on the right in Ukraine. *Reserve Business in the Ukraine*, 2, 7-10.

[18] Hatalska, N. (2015). The method of determining the dendrological value and the level of preservation of landscape objects on the example of parks-monuments of horticultural art in the territory of the central Dnieper upland region. *Scientific Bulletin of UNFU*, 25(6), 36-43.

[19] Dzyba, AA (2021). Unique trees of protected areas of Ukrainian Polissya. *Scientific Bulletin of UNFU*, 31(6), 16-25. doi: 10.36930/40310602.

[20] He, M., Wang, Y., Wang, W.J., & Xie, Z. (2022). Therapeutic plant landscape design of urban forest parks based on the Five Senses Theory: A case study of Stanley Park in Canada. *International Journal of Geoheritage and Parks*, 10(1), 97-112. doi: 10.1016/j.ijgeop.2022.02.004.

[21] Vasyliuk, O., & Ilminska, L. (2020). *Ecosystem services*. Rzhyshchiv: BF Biodiversity Protection Fund of Ukraine.

[22] Solovii, I. (2006). Assessment of ecosystem services provided by the forests of Ukraine and proposals for payment mechanisms for ecosystem services. Retrieved from https://d2ouvy59p0dg6k.cloudfront.net/downloads/evaluation_of_forest_ecosystem_services_and_proposals_on_pes_mechanisms.pdf.

[23] Sarukhán, J., & Whyte, A. (Eds.). (2005). *Ecosystems and human well-being: Biodiversity synthesis*. Washington: Island Press.

[24] Mykhailyshyn, O.L. (1999). Ensembles of the Volyn region parks and palaces in the second half of the 18th-19th centuries (background, trends, patterns of architectural development). (Doctoral thesis, Academy of Fine Arts and Architecture, Kyiv, Ukraine).

[25] Dzyba, A.A (2022). Water elements of the landscape in protected man-made parks of the Ukrainian Polissya. *Scientific Bulletin of UNFU*, 32(5), 19-27. doi: 10.36930/40320107.

[26] Mokrytskyi, H.P. (2019). The Olizarov-Sumovsky estate with a villa in the village of Kmytiv: Historical and architectural research. Zhytomyr – 1135. *Scientific Collection "Great Volyn"*, 59, 379-391.

[27] Schauer, B., Koch, K., Lemieux, L., & Willey, K. (2016). How immersion in nature impacts the human spirit: A phenomenological study. Retrieved from https://sophia.stkate.edu/ma_hhs/8.

[28] Bratman, G.N., Anderson, C.B., Berman, M.G., Cochran, B., de Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J.J., Hartig, T., Kahn, P.H.Jr., Kuo, M., Lawler, J.J., Levin, P.S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., Scarlett, L., Smith, J.R., van den Bosch, M., Wheeler, B.W., White, M.P., Zheng, H., & Daily, G.C. (2019). Nature and mental health: An ecosystem service perspective. *Science Advances*, 5(7), article nunber eaax0903. doi: 10.1126/sciadv.aax0903.

[29] Domotskyi, B. (2016). Novgorod-Siversky choice: A park or a cemetery? *Chernihivshchyna*, 26(583). Retrieved from https://m.gorod.cn.ua/news_73857.html.

[30] Remme, R.P., Frumkin, H., Guerry, A.D., King, A.C., Mandle, L., Sarabu, C., Bratman, G.N., Giles-Corti, B., Hamel, P., Han, B., Hicks, J.L., James, P., Lawler, J.J., Lindahl, T., Liu, H., Lu, Y., Oosterbroek, B., Paudel, B., Sallis, J.F., Schipperijn, J., Sosič, R., de Vries, S., Wheeler, B.W., Wood, S.A., Wu, T., & Daily, G.C. (2021). An ecosystem service perspective on urban nature, physical activity, and health. *Proceedings of the National Academy of Sciences of the United States of America*, 118(22), article number e2018472118. doi: 10.1073/pnas.2018472118.

[31] Ouyang, Z., Song, C., Zheng, H., Polasky, S., Xiao, Y., Bateman, I.J., Liu, J., Ruckelshaus, M., Shi, F., Xiao, Y., Xu, W., Zou, Z., & Daily, G.C. (2020). Using gross ecosystem product (GEP) to value nature in decision making. *Proceedings of the National Academy of Sciences of the United States of America*, 117(25), 14593-14601. doi: 10.1073/pnas.1911439117.

[32] Kibria, A.S.M.G., Behie, A., Costanza, R., Groves, C., & Farrell, T. (2017). The value of ecosystem services obtained from the protected forest of Cambodia: The case of Veun Sai-Siem Pang National Park. *Ecosystem Services*, 26(A), 27-36. doi: 10.1016/j.ecoser.2017.05.008.

[33] Moradi, G., Dehghan Benadkuki, F., Fayazi, M.N., & Operajuneghani, E. (2022). Estimating recreational value of greenspace and park using contingent valuation method (Case study: Baharan Park, Meybod city). *Journal of Environmental Studies*, 48(1), 35-53. doi: 10.22059/jes.2022.334903.1008257.

[34] Funsten, C., Di Franco, C., Borsellino, V., Surano, N., Asciuto, A., & Schimmenti, E. (2022). The recreational value of botanic garden events: A case study of the Zagara plant fair in Palermo, Italy. *Journal of Outdoor Recreation and Tourism*, 39, article number100565. doi: 10.1016/j.jort.2022.100565.

Цінність заповідних штучно-створених парків Українського Полісся другої половини XVII початку XX століть

Анжела Андріївна Дзиба, Олена Валеріївна Колесніченко

Навчально-науковий інститут лісового і садово-паркового господарства
Національний університет біоресурсів і природокористування України
03041, вул. Горіхуватський шлях, 19, м. Київ, Україна

Анотація. Протягом тисячоліть діяльність людини формувала навколишнє середовище, змінюючи його відповідно до утилітарних і функціональних вимог. Оскільки ці вимоги змінювалися з часом, змінювалася й цінність, яку люди пов'язували з певними особливостями ландшафту. Рукотворні парки, створені на українському Поліссі у другій половині XVII – на початку XX століття, являють собою ландшафти, історичне паркове середовище та сучасна адаптація яких до сучасного функціонального призначення цінуються сучасним суспільством і можуть розглядатися як екосистемні послуги парку. Метою дослідження було розробити та апробувати методику оцінки цінностей заповідних штучно-створених парків Українського Полісся. Застосовано методи дослідження: натурних обстежень (маршрутний), аналітичний, порівняльно-історичний, систематизації. Для оцінки рівня екосистемних послуг, які надають 32 парки, що розташовані на території Українського Полісся, було розроблено та апробовано методику, яка використовувала 19 категорій оцінки, кожна з яких містить кілька атрибутів (1-20). Категорії оцінювання включали утилітарну, екологічну, освітню та інші. Атрибути були представлені, але не обмежувались наявністю джерела та/або наявністю лікарських рослин (в межах утилітарної категорії), наявністю насаджень, що виконують функції захисту річок та/або стабілізації ґрунтів (в межах екологічної категорії), та наявністю навчальної стежки (в освітній категорії). Кожному атрибуту було присвоєно значення 1 із сумою значень (до потенційної суми 97), що відображає рівень екосистемних послуг, що надаються кожним окремим парком. Оцінюючи суму цінностей, парки були класифіковані як високоцінні (сума цінностей від 70 до 97), середньоцінні (сума цінностей від 40 до 69) і низькоцінні (сума цінностей нижче 40). Серед 32 досліджених парків 31 (96,9 %) парк був віднесений до середньоцінних (більшість із сумою значень у межах від 50 до 60), а один (3,1 %) парк – до низькоцінних, тоді як жоден парк не був віднесений до високоцінних. Визначивши, яких із 19 категорій оцінки (та атрибутів) бракує, можна планувати та впроваджувати вдосконалення для збільшення екосистемних послуг, що надаються окремими парками. Ця методика може бути використана для оцінки екосистемних послуг, які надають штучно-створені парки, в Україні та світі. Така оцінка допомогла б зберегти існуючі парки, врятувавши їх від знищення, а їх територію – від забудови, таким чином запобігаючи їх перехід в інші види землекористування. Це також дозволить підвищити цінність цих унікальних багатоцільових ландшафтних особливостей у майбутньому шляхом урізноманитнення та розширення їх культурних і соціальних екосистемних послуг

Ключові слова: парки-пам'ятки садово-паркового мистецтва, охоронні території, екосистемні послуги, історія, трансформація

Received: 30/09/2022; Revised: 24/10/2022; Accepted: 10/12/2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4), 30-40

UDC 712.254:582(477.41)
DOI: 10.31548/forest.13(4).2022.30-40

Dendroflora in Spatial Planning Compositions of Children's Squares in Vyshhorod Town

Olha Zibtseva[1*], Olena Troshkina[2], Olena Olkhovska[3]

[1]National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

[2]National Academy of Fine Arts and Architecture
04053, 20 Voznesensky Uzviz Str., Kyiv, Ukraine

[3]Kyiv National University of Construction and Architecture
03680, 31 Povitroflotskyi Ave., Kyiv, Ukraine

Abstract. Various groups of urban residents, including children, need to ensure a high-quality environment. One of the important features of urban plantings is their biodiversity, which is often low in the territories of children's facilities. The purpose of the study is to identify spatial planning solutions and assess the species composition of tree plantations on the territory of six newly created children's parks of the small historical city of Vyshhorod, Kyiv Oblast, which is located near the capital and is marked by positive demographic dynamics. The initial data were obtained as a result of the authors' inventory survey of vegetation in these parks. The spatial planning composition of the dendroflora of these parks is also analysed using a visual method. Based on the obtained data, the level of biodiversity of tree stands in parks under study was estimated: the available number of taxa, Menhinick's richness and diversity index, and the Berger-Parker abundance index were compared. On the territory of these parks, a total of 70 taxa of woody and shrubby plants were identified, among which introduced species predominate. More than half of the identified taxa are found only in one of the parks. The most common types represented on the territory of most children's parks are the following: *Spiraea vanhouttei, Juglans regia, Physocarpus opulifolius*. Cluster analysis revealed groups of parks with a similar assortment of woody plants, and, accordingly, similar biodiversity indicators. The relationship between the assortment of plants and the general spatial solution of parks is traced. It was concluded that the selection of the species composition of woody plants for children's parks should be more thorough, and it is also advisable not to exceed the recommended 10% share of one species in the composition of plantings. The use of "thorny" species that are not recommended for children's territories is quite balanced and rational. The use of the findings in urban planning would help create a multifunctional eco-balanced children's space and increase the sustainability of urban ecosystems

Keywords: richness index, diversity index, dominance index, native woody plants, spatial planning composition

Introduction

Urban landscaping is shaped by the historical and current decisions of a wide range of people and is able to maintain high levels of plant diversity [1], which is an important condition for creating healthy, useful, and sustainable urban plantings [2]. The high biodiversity of woody plants increases not only the

Suggested Citation:
Zibtseva, O., Troshkina, O., & Olkhovska, O. (2022). Dendroflora in spatial planning compositions of children's squares in Vyshhorod town. *Ukrainian Journal of Forest and Wood Science*, 13(4), 30-40.

*Corresponding author

aesthetic appeal of territories [3], but also, most importantly, reduces the vulnerability of plantings to the influence of many factors, in particular, pests, diseases, and climate change [4]. However, despite the wide variety of trees in the natural world and the wide possibilities of its use in the development of urban environments, a rather limited number of species predominate in urban plantings [5]. Therefore, green spaces have limited potential to support biodiversity, in particular, low levels of biodiversity are typical for public places [6]. They are used to create spatial and planning compositions of landscape objects that become too utilitarian, similar to each other, uninteresting, and low in aesthetics [7].

In general, space in cities is limited, and the establishment of green spaces depends on the understanding of the preferences of urban residents [8]. At the same time, it is important to ensure a high-quality environment for various groups of citizens, of which about a third are children. However, despite the fact that children are frequent users of urban green spaces, the design of space for children is determined by adults, which leads to landscapes that limit the daily life of urban children and negatively affect their development [9]. It is noted that school territories formed by adult priorities are often devoid of biodiversity [10]. Currently, children spend less time in their natural environment, which affects their mental and physical health [11].

The historic city of Vyshhorod is located 20 km northwest of the Ukrainian capital Kyiv. Now it is a modern town on the banks of the Dnipro River, which is rapidly developing and has positive demographic dynamics. However, after the complete destruction of the town park in the central part of the town in the 1990s (as evidenced by the 1990 town master plan) and the construction of high-rise buildings, there are now very few public green spaces. There are virtually no parks in the town. Instead, new, mainly children's parks were created in the central part of the town , six of which are the subject of this study.

According to the available master plans of the 1970s-1990s, the species composition of woody plants in small towns of the region was quite limited and consisted mainly of up to 12 species. Among the most common types were: *Acer negundo*, *Robinia pseudoacacia*, *Aesculus hippocastanum*, *Acer saccharinum*, *Populus pyramidalis* (introduced species are now common in most Ukrainian cities). In addition, such native species as *Tilia cordata*, *Populus nigra*, *Betula pendula*, *Alnus glutinosa*, *Sorbus aucuparia*, *Pinus sylvestris*, and also *Salix alba*, *S. caprea*, *Quercus robur*, *Ulmus minor*, *Fraxinus excelsior*, *Picea abies* were also common in small town green spaces. Among the wide range of woody plants recommended for long-term urban gardening by these master plans, introduced species prevailed.

The purpose of the study is to assess the biodiversity and spatial planning compositions of green spaces in urban children's parks of the small historical city of Vyshhorod, Kyiv Oblast, which is characterised by demographically positive trends. This study provides currently almost non-existent data on the quality of green spaces in small towns, in particular, those important public facilities that are intended for children's recreation.

Literature Review

The growth of urbanisation and the processes of transformation of natural ecosystems drew attention to the issues of optimisation of the urban environment, where the main role belongs to urban plant communities, which, subject to rational organisation, significantly affect the most important indicators of environmental quality. At the same time, a scientifically based selection of woody plant species that are resistant to urban environment conditions is an important requirement for ensuring the high efficiency and longevity of urban green spaces being created. An important indicator of the quality of green spaces is considered to be their species diversity, which should guarantee resistance to anthropic and any other load [12].

Biodiversity in cities is of fundamental importance for human health and well-being, and provides a wide range of essential ecosystem services. Nevertheless, it is often perceived as a minor addition, although, the consideration of the requirements of biodiversity allows developing a strategic and thoughtful design with its increase in mind [13]. Urban design with biodiversity in mind is a protocol for creating urban areas that benefit local species and ecosystems.

A number of researchers recommend "liberal use" of woody plants, in which individual species in urban green spaces should not exceed 10% of the total number of trees. When planning a green space, it is recommended to preserve native species and increase the diversity of introduced species [14], which should help increase the stability and decorative nature of plantings [15], and to effectively resist recreational stress – increase the share of shrubs, in particular, in the form of hedges. It was found that park visitors prefer plant communities with large species richness and the absence of shrubs [16]. At the same time, there is an opinion that the introduction of new species negatively affects the biodiversity of native species [17], which, as a result of the invasion of non-native species, faces serious threats to the ecological balance [18], since invasive species not only reduce natural biodiversity, but also change key ecological processes and destroy the natural ecosystem of parks.

Despite the fact that many urban parks have been created in the world, there is little knowledge about the composition and diversity of trees: there is evidence that more ornamental and exotic trees are used in new parks and that the diversity of trees is affected by the size and age of the park. Urban parks of the same age and landscape design have similar communities of species, and with rapid urbanisation, the homogenisation of park trees is increasing. According to [19], the composition of park trees is now shifted towards alien species, and the species richness of new parks is noticeably higher; however, the diversity index between new and old parks is not statistically significant. The share of individual tree species is more than 10%, which did not comply with the "10/20/30 rule of thumb". It is established that urban parks are characterised by a simple structure and low variety of plantings, which can be influenced by landscape architects [20]. As a rule, single exotic trees and trees with high decorativeness serve as compositional accents, dominants of the space of a landscape object. In the case of big parks, there can be quite a few such dominants, while in mini-parks, as a rule, there are single trees or bushes. Accordingly, such a composition is primitive and limited, with a clear selection of the centre, but without consideration of other compositional means (such as rhythm and meter, contrast and nuance, symmetry and asymmetry, etc.) [21].

The trees allow urban parks to perform various conservation and decorative functions and provide residents with the opportunity to be closer to nature [22]. Communication with nature is a multidimensional psychological construct that becomes an important predictor of both mental well-being and environmental behaviour [23]. It is important to enable children to connect with nature for their personal development, physical and mental health, and as interactions with nature increasingly occur in urban settings, it is important to identify ways in which children can be encouraged to connect with nature. Interaction with natural components improves psychological, emotional, and social health [24]. The ability to have access to green spaces on a daily basis allows children to benefit from socialising with nature, promotes physical and mental health, offers children aesthetic experiences and opportunities for recovery, and develops a positive attitude to nature in adult life.

Notably, the psychological needs of a person, along with many others, include the need for creative self-realisation and self-expression, development and self-knowledge, which is closely related to the needs in art, religion, philosophy, and is a component of human cultural needs. However, before a person "grows up" to art, religion, and philosophy, from the first years of life they satisfy this need through play. Its action is so strong, and its significance is so great, that growing up, a person continues to play and this process continues throughout life and affects all areas without exception [7; 25].

Children's willingness to play and interact with nature is affected by the quality of urban green spaces. There is currently little research on the impact of the natural environment on children's learning and development [26], although, it has been determined that the natural landscape can meet the needs of children in a diverse play environment. It was found that a high level of tree cover corresponds to the maximum development of emotional and behavioural regulatory skills in schoolchildren [27]. Green spaces can increase children's levels of physical activity, which requires understanding how to create spaces that encourage attendance and activity [28]. That is why it is necessary to pay more attention to children's needs for green spaces when planning new residential areas.

The function of playing in a landscape object, even if it is small in area and size, can be provided by a scenario approach to solving the spatial planning composition of green spaces. The child's interest in the very space of the park is ensured by well-placed exotic elements – accents of the composition and the planning structure of the object itself. The child, as well as the accompanying adult, should be constantly wandering: "what is next, up ahead, and on the other track?" [21; 29].

Studies [30] have shown the effectiveness of playgrounds in terms of physical activity and inefficiency in terms of the natural aspect. Sensory, emotional, and aesthetic experiences with nature are valuable for children, and direct contact with nature is of paramount importance for deepening children's interest in biodiversity [31]. The similarity of knowledge about plants was found by children from the same type of socio-cultural environment [32]: children from rural areas were more aware of biodiversity and local species, and most of the plants known to children belonged to exotic, in particular edible, medicinal, and much less to decorative ones.

Pocket parks also play an important role in providing access to nature [33]. In general, these are places where children can interact with other people and engage in physical activity in a natural environment [34], and visiting parks improves children's social, mental, and physical health. Designing a children's park or pocket park requires consideration of their cognitive function, which, together with the function of the game, based on a scenario approach to the overall composition of the object, "works" for the development and self-knowledge of the child.

Materials and Methods

An inventory assessment of green spaces in the town has never been performed, so field studies were conducted by the authors in 2016-2018. Field research covered six newly created children's squares in the central part of the town, which were marked by numbers: 1 – "Children's Park" on Shkilna Street; 2 – square near the Centre for Children's Creativity; 3 – square on Symonenko Street ("ABVG-deyka"); 4 – square on Shevchenko Avenue (near the city administration building); 5 – square between multi-storey residential buildings near Mazepa Street; 6 – square near Mazepa Avenue, 24. The species composition and age structure of plantings, their taxation specifications, condition and decorative nature in the context of species were determined [35]. According to preliminary studies, public green spaces in Vyshhorod are represented only by squares, in which 54 species and forms of woody and shrubby plants are identified, among which 78% are introduced species [36]. A very high participation rate is characteristic for *Thuja occidentalis* L. and *Aesculus hyppocastanum* L.; high – for *Thuja occidentalis*, *Acer platanoides* L., *Ulmus scabra* Mill., *Tilia cordata* Mill. As a rule, the basis of old parks was made up of older trees of several native species, to which decorative introduced species were added over time, the share of which is now about 55%. Young trees are represented mainly by decorative forms of conifers. Critical species in the old parks of the city centre are *Thuja occidentalis* (20.6 %), *Aesculus hyppocastanum* (18.3 %).

The easiest way to characterise the richness of a community is to use the number of identified taxa (usually species). To assess the diversity of biological communities, various indices are used – numerical indicators that are calculated based on the number of taxa in the community and the number of individuals in different taxa. In this case, diversity includes two components: richness (number of taxa) and alignment (relative diversity of taxa). One of the simplest diversity indices that does not include the relative number of taxa is Menhinick's index, which uses only the number of identified taxa and the total number of individuals. It is recommended to use Menhinick's index to compare communities of different sizes, although, in the case of this index, a decrease in the sample size leads to an overestimation of the diversity.

The analysis of plantings of six squares was carried out based on data from the sub-tree inventory survey of their territories conducted by the authors in previous years. Based on these data, the simplest generally accepted biodiversity indicators were determined for the green spaces of each of the squares [35], for the calculation of which only the number of identified taxa and the total number of plant individuals are estimated, and the number of plant specimens of the most numerous species: Menhinick's richness and diversity index, and Berger-Parker dominance index were used by the authors in previous studies. Cluster analysis in the Statistica 10 environment was used to process the results obtained. The planning structure is provided for larger and more interesting objects 1, 4, and 6.

Results and Discussion

The selection of woody plants for the arrangement of children's facilities has a number of specific requirements, while the richness of green spaces created is traditionally considered mainly as an educational, incentive, and not an environmentally stabilising factor.

The rapid development of the city since the beginning of the 21st century is accompanied by changes in landscaping, primarily in relation to public green spaces – new squares appear. In the central part of the town, where the lack of recreational space is particularly noticeable due to the destruction of the former square with an area of 9 hectares, a number of mostly children's squares are arranged, most of which are marked by a small area (about 0.1 hectares) and young plantings of mainly introduced ornamental woody plants.

On the territory of the largest newly created square 1 (on Shkilna Str.), which is called Children's Park (Fig. 1, object No. 1 in Table 1), located between two educational institutions for children: a lyceum and a gymnasium, the maximum number of studied objects is calculated – 265 specimens of trees and shrubs of 21 types and shapes, including such exotic ones as *Aesculus carnea 'Briotti', Physocarpus opulifolius f. Diablo, Ginkgo biloba* L., *Catalpa bignonioides* Walt., *Potentilla fruticosa 'Elizabeth*. The number of trees per 1 hectare (as in most of the city parks under study) exceeds the optimal value by 1.5 times.

Figure 1. Location of the newly created square (2) (object No. 1) between the lyceum (1) and gymnasium (3), the allocated research area – 1.08 ha

Source: [37]

The most quantitatively represented plant species in the square are *Spiraea vanhouttei* and *Acer platanoides f. Globosum*, however, the share of participation of the latter does not exceed 10% of the total number of specimens of woody plants and other existing taxa. The square performs mainly a transit function, which is determined by its location between residential buildings and two educational institutions. The planning structure is linear and symmetrical, with a clearly defined centre – a round platform that is scaled and repeated in the rest of the square. There is a general randomness and dispersion of vegetation and the absence of plant groups in the central part of the square. Along the paths, to emphasise the linear structure, there could be rhythmically placed plantings, single or group, which are currently absent. The functional purpose of each part of the square is not clearly defined. The object needs to improve its spatial planning composition.

On the territory of square No. 2, 16 species of woody plants were found, and on the territory of square No. 3 (near the Symonenko Str.) – 23 species and forms of woody and shrubby plants, including such rare ones as *Catalpa bignonioides*, *Juniperus squamata* Lamb., *J. squamata f. Blue Swede*, *Corylus colurna* L., *Magnolia soulangeana* Soul.-Bod., *Rhus typhina*, *Physocarpus opulifolius f. Diablo*. In terms of participation, only *Spiraea vanhouttei* and *Cornus alba* L. exceed the 10% critical threshold.

24 species of woody plants were identified on the territory of square No. 4 near the administration building in the town centre (Fig. 2). The square has a well-thought-out spatial and planning composition. Most of the territory is reserved for a children's playground. Outdoor structures are located on the territory: cafe, kiosk. The square has several functional areas, which is convenient for people of different age groups to use, given its location in the central part of the town. A children's playground in the middle of the lawn, oriented towards the town centre, is clearly highlighted. Dense green spaces frame the territory and serve as a backdrop for playground equipment. Excessive independence of functional zones in terms of spatial planning can be considered a disadvantage.

Figure 2. Square near the administration building in the town centre (object No. 4)

Source: [37]

The smallest number of taxa (12) and the minimum total number of woody plant specimens (36) were found on the territory of a small square No. 5 (between multi-storey residential buildings near Mazepa Str.). On the territory of square No. 6 (Fig. 3) 29 species and forms of woody and shrubby plants were identified, where the participation rate does not exceed 10%, and the number of specimens of native species is only 8.6%.

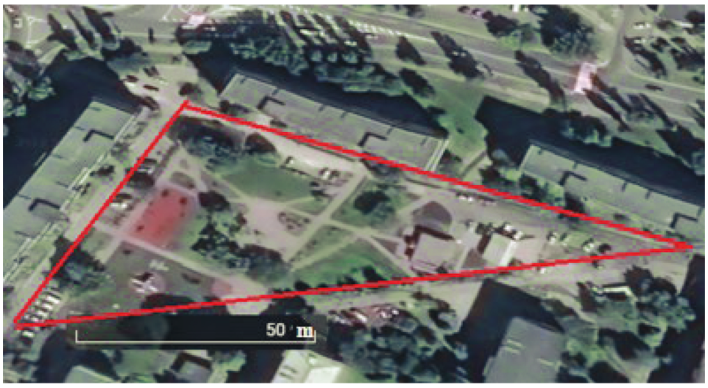


Figure 3. Square near residential buildings near Mazepa Ave., 24 (object No. 6)
Source: [37]

Square No. 6 is the most interesting in terms of composition. The territory in the form of a large triangle is highlighted by the geometric structure, and the theme of the triangle is repeated in all its parts. There is a harmonious attitude of open areas to green spaces; thoughtfulness of the composition from the standpoint of its scenario construction. The alternation of closed and open parts of the spatial planning composition creates the effect of surprise during the movement of visitors. An increase in the number of group plantings would highlight clear functional zones in the square, considering the needs of all residents of nearby buildings. In total, from 12 to 29 species and forms of woody plants are represented on the territory of each of the squares under study. The best indicators are in squares No. 4 (near the city administration building) and No. 6 (near multi-storey residential buildings, also located in the central multi-storey part of the town).

Table 1. Indicators of dendroflora diversity in children's squares in Vyshhorod

Indicators	Squares					
	1	2	3	4	5	6
Number of species	21	16	23	24	12	29
Total number of plants	265	166	169	98	36	141
Indexes: richness	0.08	0.1	0.14	0.24	0.33	0.21
diversity	1.29	1.24	1.77	2.42	2	2.44
domination	0.5	0.33	0.41	0.13	0.36	0.12

Source: compiled by the authors

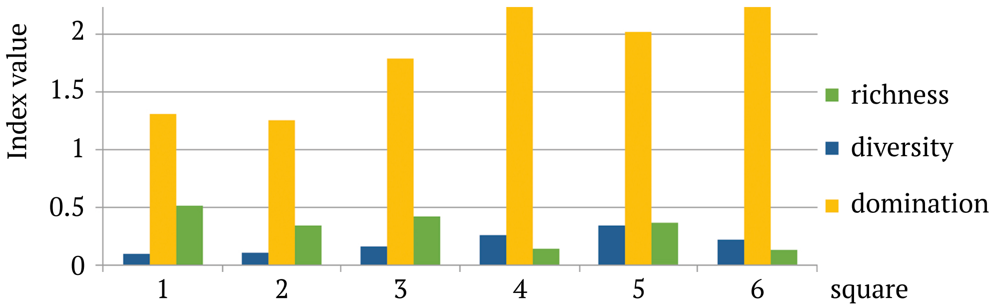


Figure 4. Biodiversity indicators of tree plantations in 6 children's squares
Source: compiled by the authors

It is the tree plantings of these two newly created squaress that are characterised by relatively better indicators: higher indices of richness, diversity, and a lower index of dominance. Thus, on the territory of square No. 1 (the largest, so-called Children's Park), half of the plantings are represented by one specie. In total, on the territory of four squares under study, the most common type is *Spiraea* × *vanhouttei* (Briot) Zabel. The share of native species among their total number is only 16.7 to 39.1% in the plantings of various squares. *Syringa vulgaris* L. and *Acer platanoides* L. are widespread Introduced species predominate on the territory of all squares. The introduced ornamental species include: *Ginkgo biloba* L., *Catalpa bignonioides* Walter, *Liriodendron tulipifera* L., *Rhus typhina* L., *Kolkwitzia amabilis* Graebn., garden forms of *Juniperus* L. and *Picea* A. Dietr., and beautifully blooming shrubs. In addition, contrary to existing recommendations, both thorny and strongly fragrant and allergenic plants are represented on the territories of children's squares. Interestingly, local dendrologists explain the presence of thorny plants by introducing "vandal-proof" gardening.

The species that would have been represented in all 6 squares under study were not identified. On the territory of 5 of the 6 experimental squares there are two common types: *Spiraea* × *vanhouttei* and *Cornus alba f. varigata*; on the territory of 4 parks – there are also two common species: *Juglans regi*a L. and *Physocarpus opulifolius* (L.) Maxim. *'Diabolo'*. On the territory of half of the experimental squares, 12 taxa are represented, in particular, Juniperus sabina L. and its decorative forms, decorative forms of *Malus, Rosa rugosa* Thunb., *Philadelphus coronarius* L., *Berberis thunbergii*, *Syringa vulgaris*, *Weigela florida* (Bunge) A.DC., *Catalpa bignonioides*, *Acer platanoides* L.; 16 species are found in only two squares, and more than half – 38 species – occur only on the territory of one of the children's squares. According to the cluster analysis of the available assortment of tree species on the territory of the children's squares, they can be grouped into three clusters (Fig. 5).

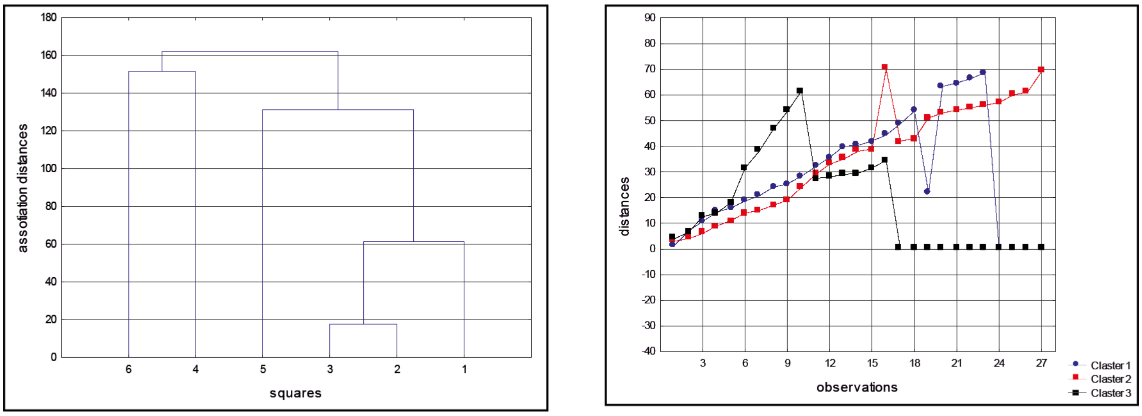


Figure 5. Diagram of cluster analysis of the assortment of woody plants on the territory of the squares under study (a) and their association (b)

The first cluster includes squares No. 4 and No. 6 (with similar, relatively better characteristics in terms of biodiversity indicators); the second – square No. 5 (a small square with a minimum number of plant species and specimens), and the third – squares No. 1, 2, 3 (with lower biodiversity indicators and the dominance of several species represented on their territories).

Despite the fact that clustering was carried out only considering the presence (or absence) of taxa of woody plants on the territory of squares, the resulting cluster association clearly shows the similarity of plant communities of squares in terms of biodiversity indicators. At the same time, biodiversity indicators did not depend on the size of square area, on the total number of plant specimens, but were completely determined by the preferences and decisions of their designers and builders.

Given the mostly small areas of squares, which is conditioned by the dense urban fabric in the central part of Vyshhorod, all of them have regular planning and perform the task of reducing the radius of accessibility from residential areas to "islands of nature". In compositional terms, most of the green spaces in the territories of the studied landscape objects are placed randomly, without much thought for the establishment of their spatial and planning composition and require appropriate adjustment. To compare indicators of biodiversity on the territory of different objects, researchers often use the Shannon and Simpson indices [35]. However, it was determined that the Berger-Parker dominance index for sanitary protection zones of industrial enterprises in Zaporizhzhya [38] ranged from 0.21-0.78 compared to 0.14-0.28 in children's squares under study. At the same time, in the territories of three schools in Vyshhorod [39], according to the authors' calculations, tree plantings had similar, but slightly better indicators: the richness index also ranged widely: from 0.08 to 0.46; the diversity index was slightly higher: from 1.49 to 3.32; the dominance index was not so pronounced, it ranged from 0.14 to 0.28.

Notably, when designing the parks, the designers considered only the aesthetic aspect and, to a certain extent, the utilitarian one. But the environmental component was neglected. The selection of the species composition of newly established squares was determined by the available wide range of plants of the local garden centre (mainly by introduced species) according to the physiological principle and the limit of the total cost of work on creating the object. However, the high proportion of introduced plants in green spaces will contribute to the interest of children from childhood in the biodiversity of tree species, which is one of the signs of stable development of territories.

Children in modern society lose touch with nature and green plants [40-42], which, in particular, playgrounds are designed to prevent. Researchers suggest that trees are important elements of healthy child communities [43] that should be integrated at various scales, from landscaping around homes, schools, and kindergartens to connected systems of urban paths, parks, and public gardens. In parks, children can interact with other people and engage in physical activity in a natural environment. Therefore, their attendance can improve children's social, mental, and physical health [34]. However, among the characteristics that facilitate visits to children's squares, the only ones that can be noted in the studied facilities are the presence of young trees that do not currently form shaded areas and do not facilitate physical activity, and the presence of open space, which is mostly insufficient for active recreation. In addition, the small size of squares does not contribute to social interaction. The authors of this study suggest that designers should provide for and consider the functions of the created territories in order to help children lead an active healthy lifestyle.

Similar to English researchers [28], the authors also suggest that it is necessary to pay more attention to children's needs regarding the quantity and quality of green spaces when planning residential areas and considering measures to increase children's physical activity.

According to a number of researchers [42], a negative anthropic impact on vegetation on the territory of children's squares and playgrounds was observed during a third of children's playtime. As a result, half of all existing trees and shrubs were damaged on the plots. However, given that the squares under study are visited mainly by mothers with preschool children and have limited opportunities for physical activity in their territories due to small areas, the problem of vandalism is not relevant here.

Conclusions

During the inventory survey of tree stands of newly established children's squares in Vyshhorod, a total of 70 taxa of woody and shrubby plants were identified, among which introduced species predominated. More than half of the identified taxa occurred only in one of the squares under study. The most common types represented on the territory of most children's squares were the following: *Juglans regia*, *Spiraea × vanhouttei*, *Cornus alba f. varigata*, *Physocarpus opulifolius*.

Using cluster analysis, the squares were divided into three clusters according to the available assortment of woody plants, and, accordingly, similar biodiversity indicators.

The study suggests that the selection of the species composition of woody plants for creating children's squares should be more detailed. At the same time, it is advisable not to exceed the recommended 10% share of each used species in the total composition of plantings of each of the created squares. Instead, the use of "thorny" species that were not previously recommended for landscaping children's facilities can be quite balanced and rational. The presence of evergreen coniferous plants on the territory of squares will help increase the aesthetic assessment of the environment and the importance of cultural ecosystems and services throughout the year.

Careful selection of the assortment in accordance with well-thought-out spatial planning compositions would create landscape objects that would not only improve the aesthetics of the urban environment but also positively influence the perception and psychological state of visitors. The establishment of the square space with the help of vegetation should include the needs of visitors, especially children, in development, self-realisation, and knowledge in a playful way. Carefully thought-out arrangements and selected plant species composition can help implement these ideas.

The authors consider it necessary to create larger children's parks, which would encourage children to engage in physical activity and promote their health. In the future, it is planned to continue studying the biodiversity of woody plants in Ukrainian towns, in particular, green spaces of limited use: on the territory of hospital and school institutions, industrial enterprises, etc., and compare the results obtained by category of objects.

References

[1] Alvey, A.A. (2006). Promoting and preserving biodiversityin the urban forest. *Urban Forestry & Urban Greening*, 5(4), 195-201. doi: 10.1016/j.ufug.2006.09.003.

[2] Hilbert, D.R., Koeser, A.K., & Northrop, R.J. (2020). Urban tree selection for diversity. *University of Florida. Florida's Urban Forest Diversity. Increasing Urban Tree Diversity*, ENH1325, 1-5. doi: 10.13140/RG.2.2.25297.97122.

[3] Kiester, A.R. (1997). Aesthetics of Biological Diversity. *Human Ecology Review*, 3(2), 151-157.

[4] Roloff, A., Korn, S., & Gillner, S. (2009). The Climate-Species-Matrix to select tree species for urban habitats considering climate change. *Urban Forestry & Urban Greening*, 8(4), 295-308. doi: 10.1016/j.ufug.2009.08.002.

[5] Hilbert, D.R., Koeser, A.K., Andreu, M., Hansen, G., Roman, L.A., Thetford, M., & Thompson, G.L. (2022). Conceptualizing the human drivers of low tree diversity in planted urban landscapes. *Preprints*, 2022, article number 2022080517. doi: 10.20944/preprints202208.0517.v1.

[6] Roberts, M., Glenk, K., & McVittie, A. (2022). Urban residents value multi-functional urban greenspaces. *Urban Forestry & Urban Greening*, 74, article number 127681. doi: 10.1016/j.ufug.2022.127681.

[7] Troshkina, O.A. (2013). The function of play in architecture, as a manifestation of a natural human need. In *Ukraine: acquisition of architectural heritage, Proceedings of the 5th All-Ukrainian Scientific Conference "Weinghort Readings"* (pp. 209-217). Poltava: Divosvit.

[8] Castelli, K.R., Silva, A.M., & Dunning, J.B. (2021). Improving the biodiversity in urban green spaces: A nature based approach. *Ecological Engineering*, 173, article number 106398. doi: 10.1016/j.ecoleng.2021.106398.

[9] Shu, X., Mesimäki, M., Kotze, D.J., Wales, M., Xie, L., Benicke, R., & Lehvävirta, S. (2022). Needs and expectations of German and Chinese children for livable urban green spaces revealed by the method of empathy-based stories. *Urban Forestry & Urban Greening*, 68, article number 127476. doi: 10.1016/j.ufug.2022.127476.

[10] Lindemann-Matthies, P., & Köhler, K. (2019). Naturalized versus traditional school grounds: Which elements do students prefer and why? *Urban Forestry & Urban Greening*, 46, article number 126475. doi: 10.1016/j.ufug.2019.126475.

[11] Baró, F., Camacho, D.A., Pérez Del Pulgar, C., Triguero-Mas, M., & Anguelovski, I. (2021). School greening: Right or privilege? Examining urban nature within and around primary schools through an equity lens. *Landscape and Urban Planning*, 208, article number 104019. doi: 10.1016/j.landurbplan.2020.104019.

[12] Matus, S.A., Levina, H.M., Karpyuk, T.S., & Denischyk, O.Yu. (2019). A basic study of the state and directions of the development of Ukraine's environmental policy and the prospects for strengthening the participation of civil society organizations in the development and implementation of environmentally friendly policies (period: 2018 - January 2019). (2019). Retrieved from https://www.irf.ua/wp-content/uploads/2019/12/baseline-research_report_publishing-dec-2019.pdf.

[13] Kirk, H., Garrard, G.E., Croeser, T., Backstrom, A., Berthon, K., Furlong, C., Hurley J., Thomas, F., Webb, A., & Bekessy, S.A. (2021). Building biodiversity into the urban fabric: A case study in applying Biodiversity Sensitive Urban Design (BSUD). *Urban Forestry & Urban Greening*, 62, article number 127176. doi: 10.1016/j.ufug.2021.127176.

[14] Liu, J., & Slik, F. (2022). Are street trees friendly to biodiversity? *Landscape and Urban Planning*, 218, article number 104304. doi: 10.1016/j.landurbplan.2021.104304.

[15] Himes, A., Puettmann, K., & Muraca, B. (2020). Trade-offs between ecosystem services along gradients of tree species diversity and values. *Ecosystem Services*, 44, article number 101133. doi: 10.1016/j.ecoser.2020.101133.

[16] Tomitaka, M., Uchihara, S., Goto, A., & Sasaki, T. (2021). Species richness and flower color diversity determine aesthetic preferences of natural-park and urban-park visitors for plant communities. *Environmental and Sustainability Indicators*, 11, article number 100130. doi: 10.1016/j.indic.2021.100130.

[17] Ali, S.M., & Malik, R.N. (2010). Vegetation communities of urban open spaces: Green belts and parks in Islamabad city. *Pakistan Journal of Botany*, 42(2), 1031-1039.

[18] Dutta, W., Basuthakur, P., & Ray, P. (2021). Gardening the menace! *Environmental and Sustainability Indicators*, 12, article number 100148. doi: 10.1016/j.indic.2021.100148.
[19] Xie, C. (2018). Tree diversity in urban parks of Dublin, Ireland. *Fresenius Environmental Bulletin*, 27(12A), 8695-8708.
[20] Chang, C.-R., Chen, M.-C., & Su, M.-H. (2021). Natural versus human drivers of plant diversity in urban parks and the anthropogenic species-area hypotheses. *Landscape and Urban Planning*, 208, article number 104023. doi: 10.1016/j.landurbplan.2020.104023.
[21] Troshkina, O.A. (2019). Experience of using the scenario approach in course design of the park. *Problems of the Development of the Urban Environment*, 1(22), 149-160.
[22] Wang, S., & Zhang, H. (2022). Tree composition and diversity in relation to urban park history in Hong Kong, China. *Urban Forestry & Urban Greening*, 67, article number 127430. doi: 10.1016/j.ufug.2021.127430.
[23] Harvey, C., Hallam, J., Richardson, M., & Wells, R. (2020). The good things children notice in nature: An extended framework for reconnecting children with nature. *Urban Forestry & Urban Greening*, 49, article number 126573. doi: 10.1016/j.ufug.2019.126573.
[24] Child, M.F. (2021). Wildness, infinity and freedom. *Ecological Economics*, 186, article number 107055. doi: 10.1016/j.ecolecon.2021.107055.
[25] Olkhovska, O.V. (2020). Revitalization of the urban environment by means of landscape design. *Problems of the Development of the Urban Environment*, 2(25), 116-121.
[26] Fjørtoft, I., & Sageie, J. (2000). The natural environment as a playground for children. *Landscape and Urban Planning*, 48(1-2), 83-97. doi: 10.1016/S0169-2046(00)00045-1.
[27] Scott, J.T., Kilmer, R.P., Wang, C., Cook, J.R., & Haber, M.G. (2018). Natural environments near schools: Potential benefits for socio-emotional and behavioral development in early childhood. *American Journal of Community Psychology*, 62(3-4), 419-432. doi: 10.1002/ajcp.12272.
[28] Mears, M., Brindley, P., Baxter, I., Maheswaran, R., & Jorgensen, A. (2020). Neighbourhood greenspace influences on childhood obesity in Sheffield, UK. *Pediatric Obesity*, 15(7), article number e12629. doi: 10.1111/ijpo.12629.
[29] Gamaliya, K.M., & Olkhovska, O.V. (2017). Historical prerequisites for the formation and development of garden and park ensembles of Ukraine. *History of Science and Technology*, 10, 138-144.
[30] Ristianti, N.S., & Widjajanti, R. (2020). The effectiveness of inclusive playground usage for children through behavior-setting approach in Tembalang, Semarang city. *IOP Conference Series: Earth and Environmental Science*, 592(1), article number 012027. doi: 10.1088/1755-1315/592/1/012027.
[31] Matos, S., Silva, A.R., Sousa, D., Picanço, A.R., Amorim, I., Ashby, S., Gabriel, R., & Arroz, A.M. (2022). Cultural probes for environmental education: Designing learning materials to engage children and teenagers with local biodiversity. *PLOS ONE*, 17(2), article number e0262853. doi: 10.1371/journal.pone.0262853.
[32] Eyssartier, C., Margutti, L., & Lozada, M. (2017). Plant knowledge in children who inhabit diverse socio-ecological environments in northwestern Patagonia. *Journal of Ethnobiology*, 37(1), 81-96. doi: 10.2993/0278-0771-37.1.81.
[33] Balai Kerishnan, P., & Maruthaveeran, S. (2021). Factors contributing to the usage of pocket parks – A review of the evidence. *Urban Forestry & Urban Greening*, 58, article number 126985. doi: 10.1016/j.ufug.2021.126985.
[34] Veitch, J., Flowers, E., Ball, K., Deforche, B., & Timperio, A. (2020). Exploring children's views on important park features: A qualitative study using walk-along interviews. *International Journal of Environmental Research and Public Health*, 17(13), article number 4625. doi: 10.3390/ijerph17134625.
[35] Zibtseva, O. (2022). Tree species biodiversity in small Ukrainian towns. *Ekológia (Bratislava)*, 41(2), 161-171. doi: 10.2478/eko-2022-0017.
[36] Zibtseva, O. (2021). Tree species diversity in two small cities of Kyiv region, Ukraine. *AgroLife Scientific Journal*, 10(2), 218-227.
[37] Google Earth. (n.d.). Retrieved from https://earth.google.com.
[38] Sklyarenko, A.V., & Bessonova V.P. (2019). Species diversity of tree plantations in industrial enterprise protective zones (Zaporizhzhya, Ukraine). *Acta Biologica Sibirica*, 5(1), 167-174. doi: 10.14258/abs.v5.i1.5495.
[39] Zibtseva O.V. (2018). Species composition, condition and decorativeness of tree plantations of educational institutions. *Scientific bulletin of the National Forestry University of Ukraine. Series: Forestry and decorative horticulture*, 28(3), 22-26.

[40] Borah, D., Biswajit, D., Sumpam, T., Abhaya, P.D., & Khapugin, A.A. (2020). Assessment of woody species diversity and composition along a disturbance gradient in Behali reserve forest of Biswanath District, Assam, India. *Ecological Questions*, 32(1), 1-25. doi: 10.12775/EQ.2021.009.

[41] Lakicevic, M., Reynolds, K.M., Orlovic, S., & Kolarov, R. (2022). Measuring dendrofloristic diversity in urban parks in Novi Sad (Serbia). *Trees, Forests and People*, 8, article number 100239. doi: 10.1016/j.tfp.2022.100239.

[42] Browning, M.H.E.M., Marion, J.L., & Gregoire, T.G. (2013). Sustainably connecting children with nature – an exploratory study of nature play area visitor impacts and their management. *Landscape and Urban Planning*, 119, 104-112. doi: 10.1016/j.landurbplan.2013.07.004.

[43] Chawla, L. (2015). Benefits of nature contact for children. *Journal of Planning Literature*, 30(4), 433-452. doi: 10.1177/0885412215595441.

Дендрофлора в просторово-планувальних композиціях дитячих скверів м. Вишгорода

Ольга Василівна Зібцева[1], Олена Анатоліївна Трошкіна[2], Олена Владиславівна Ольховська[3]

[1]Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

[2]Національна академія образотворчого мистецтва і архітектури
04053, вул. Вознесенський узвіз, 20, м. Київ, Україна

[3]Київський національний університет будівництва і архітектури
03680, Повітрофлотський проспект, 31, м. Київ, Україна

Анотація. Забезпечення якісного довкілля потребують різні групи міських жителів, зокрема діти. Однією з важливих ознак міських насаджень є їхнє біорізноманіття, яке часто є низьким на територіях дитячих закладів. Мета дослідження – виявити просторово-планувальні рішення та оцінити видовий склад деревних насаджень на території шести новостворених дитячих скверів малого історичного міста Вишгорода Київської області, розташованого неподалік столиці, і яке відзначається позитивною демографічною динамікою. Вихідні дані були отримані в результаті проведеної авторами інвентаризації зелених насаджень цих скверів. Також візуальним методом проаналізовано просторово-планувальну композицію дендрофлори цих скверів. За отриманими даними було оцінено рівень біорізноманіття деревних насаджень дослідних скверів: порівняно наявну кількість таксонів, індекси багатства і різноманіття Менхініка, індекс домінування Бергера-Паркера. На території цих скверів загалом виявлено 70 таксонів деревних і кущових рослин, серед яких переважають інтродуценти. Понад половини виявлених таксонів трапляються лише на одному зі скверів. Найпоширенішими, представленими на території більшості дитячих скверів, є такі види, як *Spiraea vanhouttei, Juglans regia, Physocarpus opulifolius*. За допомогою кластерного аналізу виявлено групи скверів з подібним асортиментом деревних рослин, і, відповідно, подібними показниками біорізноманіття. Прослідковано взаємозв'язок асортименту рослин із загально-просторовим рішенням скверів. Автори дійшли висновку, що добір видового складу деревних рослин для дитячих скверів має бути ретельнішим, також доцільно не перевищувати рекомендовану 10 %-ву частку одного виду в складі насаджень. Використання не рекомендованих для дитячих територій «колючих» видів є доволі виваженим і раціональним. Врахування результатів досліджень у міському плануванні сприятиме створенню багатофункціонального екозбалансованого дитячого простору та підвищенню стійкості урбоекосистем

Ключові слова: індекс багатства, індекс різноманіття, індекс домінування, аборигенні деревні рослини, просторово-планувальна композиція

Received: 21/09/2022; Revised: 18/10/2022; Accepted: 01/12/2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4), 41-51

UDC 630*231(477.41/.42)
DOI: 10.31548/forest.13(4).2022.41-51

Natural Afforestation of the Fallows in the Western Polissya

Ivan Kimeichuk[1*], Oleksandr Kaidyk[2]

[1]Bila Tserkva National Agrarian University
09117, 8/1 Soborna Sq., Bila Tserkva, Ukraine

[2]National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony, Kyiv, Ukraine

Abstract. One of the main tasks of forestry in Ukraine is to increase forest cover – it can be partially solved by the development of low-productive agricultural land, in particular, fallows, on which self-sown forest is already growing or just appearing, since the expanded reproduction of forests is relevant for Ukraine, considering ecological and forestry transformations of fallows conditioned by their natural afforestation. The main goal was to evaluate the success of natural renewal on fallows in the region under study, to identify factors influencing the course of natural afforestation and tree conservation depending on the location of the plot relative to the forest border and the distance to it. General scientific, forestry and taxation, reconnaissance, forestry and ecological, and geobotanics methods were used to investigate natural renewal at fallows. Office study of materials was carried out using mathematical statistics. As a result of a detailed investigation of the natural settlement of forest tree species on abandoned fields of Western Polissya, it was found that in coniferous and subor conditions, the plots are mostly wooded with pine, as well as birch and alder. In most of the test plots, the renewal was satisfactory (according to the Nesterov scale). The number of self-seeding of tree species in the test plots was not uniform and ranged from 1.2-13.1 thous. units/ha depending on forest site types, species composition, undergrowth size, the abundance of living ground cover, and the degree of sodding of the site and clogging with weeds and grass, which ranged from 20 to 90%. The occurrence of natural renewal is also not uniform: from 19 to 100%. The spread of tree species occurred mainly from forest stands located to the west, northwest, and north of the fallows. The findings of the study are extremely important for employees of the forest industry, and can also be used by territorial communities in improving land management, establishing landscape parks, etc.

Keywords: natural renewal, live ground cover, Drude abundance scale, forestry potential, self-seeding

Introduction

One of the most important tasks for the forestry sector of Ukraine is to increase forest cover and bring it to the optimal level. In part, the problem of low forest cover in Ukraine can be solved by developing low-productive agricultural land, in particular, fallows where self-sown forest grows or appears [1]. In Ukraine, there are about 5 million hectares of land that is not suitable for efficient agricultural use, in particular, 2 million hectares require afforestation in the coming years [2]. Only in the Rivne region, according to [3], there are 7,087.3 hectares of fallows, the afforestation of which would allow increasing the forest cover of Ukraine, but this is impossible, since they are registered as the land of shareholders.

Suggested Citation:
Kimeichuk, I., & Kaidyk, O. (2022). Natural afforestation of the fallows in the Western Polissya. *Ukrainian Journal of Forest and Wood Science*, 13(4), 41-51.

*Corresponding author

Given the need to increase the forest cover of Ukraine, the President initiated the Green Country environmental project and issued Decree No. 228/2021 of 07.06.2021 "On some measures to preserve and reproduce forests" [4], which aims to increase the total forest area by 1 million hectares in 10 years and carry out large-scale reforestation in the next three years (plant 1 billion new trees). This, in turn, requires foresters to attract all opportunities and available economic, environmental, and social resources.

Within the framework of the Green Country project, self-sown forests are of great importance, the transfer of which to the subordination of state forestry enterprises with the subsequent implementation of forestry measures in them can ensure an increase in forest cover. Notably, granting self-sown forests the status of a state forest fund is an extremely relevant and important issue today and is not easy from a legal standpoint.

Every year, the area of unsuitable and degraded land, including fallows, increases, and therefore, research into this problem may gain resonance and change attitudes toward self-seeding forests.

Special attention should also be paid to the more complete use of the bioecological potential of forested areas, in particular, the presence of natural renewal, which takes place both in designated and non-designated areas adjacent to forest stands. A characteristic feature of such areas is indirect signs of forest ecosystems, especially in areas adjacent to the northern border of forest cenoses. In such areas, there is often a successful natural renewal of not only pioneer species – birch, aspen, willow, but also pine, spruce, pear, etc. The success of the appearance of natural renewal in such areas depends on many factors: the composition of adjacent tree stands, the frequency of fruiting (seed bearing), the yield of seeds, their ability to move on the area, soil fertility, grass vegetation, etc. As a rule, in the coniferous and subor forest site types in low and more humid areas with indirect signs of forest ecosystems, renewal occurs with silver birch, and in elevated and drier areas – with Scots pine.

The use of natural forestry potential in afforestation of areas with indirect features of forest ecosystems will not only reduce the cost of expanded forest reproduction, but also contribute to improving their biological sustainability. Forests of natural origin are more resistant to adverse factors than artificial ones. Self-seeding forests often combine woodlands that have been separated by fields or pastures.

Nowadays, there is a need to increase the biological stability of plantings and prevent deterioration of their condition in the future, and for this, it is advisable to adjust the current priorities of afforestation in the direction of their greening. In forest development based on the principles of ecological-oriented forestry, integration processes have a significant impact on forest ecosystems, which have significantly intensified since independence, and mainly the ecological significance of the state's forests and the focus on sustainable forestry development [5; 6]. The relevance of the study is conditioned by the importance for Ukraine of expanded forest reproduction and the major significance of ecological and forestry transformations of fallows due to their natural afforestation, and the establishment of biologically stable pine stands.

The purpose of the study was to assess the process of natural afforestation of fallows in Western Polissya and suggest ways to improve afforestation in the region under study with the involvement of areas where afforestation occurred independently, without human participation.

Literature Review

Since 1990, from 5 to 8.5 million hectares of arable land have been withdrawn from cultivation in Ukraine and subsequently converted into fallows [7]. Spontaneous overgrowth of old arable lands goes through various stages of secondary succession towards the meadow-type phytocenoses and the development of forest vegetation, which at the final stages of formation are close to natural phytocoenoses in terms of their systematic structure. For almost a quarter of the 21^{st} century, it was possible to observe an increase in the area of fallows on the territory of Polissya, which were at various stages of autogenic succession – from weed to forest [8; 9]. This makes them a unique testing ground for studying the dynamics of ecosystems under various edaphic conditions under the influence of various external factors [10]. The process of natural afforestation of such fields continues to this day [1].

Notably, in 2022, the Verkhovna Rada of Ukraine adopted the Law [11], which provides for changes to the legislation on the conservation of self-sown forests (natural renewal on non-wooded lands). Now fallows have certain guarantees at the legislative level and are assigned to permanent forest owners.

Solving the problem of biodiversity protection, rational use and restoration of natural vegetation in modern conditions of constantly increasing anthropogenic impact on the environment requires a thorough investigation of the current state of the flora of artificially changed territories in general and dendroflora in particular [12].

Afforestation of low-productive and degraded land is inextricably linked to improving the ecological situation, increasing forest productivity and forest cover, and additional production of a significant amount of wood [3]. Natural landscapes often have less social and agricultural benefits than the local forests and agricultural systems they replace, especially when non-native species dominate succession processes. Agroforestry systems that combine native and foreign culturally important plants represent a potential pathway to increase the social and environmental benefits of unused agricultural land. The results of such studies indicate that fallows have a high potential for recovery through agricultural reclamation [13].

The authors of [14] argue that the process of natural restoration is complex and depends on a number of environmental factors, namely: thickness of the litter, density and closeness of herbaceous plants, vegetation layer, and abundance of fruiting (seed years). The most abundant natural renewal occurs in areas with only weak competition from terrestrial vegetation. The type of forest cultivation system does not significantly affect the amount of natural renewal, but it can be recommended to increase the success of natural renewal by scarifying the soil when using manual seeding to improve germination on the site. This allows increasing the amount of reliable self-seeding and undergrowth by 80%. To protect and preserve vulnerable 1-2-year-old undergrowth and self-seeding of Scots pine, it is necessary to remove weeds and unwanted woody vegetation. Ultimately, the right combination of these measures and their timely implementation will ensure high quality of natural renewal of Scots pine [14].

The intensification of agriculture poses a serious threat to natural biodiversity and related environmental services. Conservation or restoration of semi-natural habitats (forests and fallows) is used to counteract the negative impact of agricultural intensification [15].

M.M. Bilous [16; 17] investigated afforestation of fallows and the influence of grass vegetation on them, plant growth on poor old arable land, and L. Boletus [18] – the role of fallows in preserving the rare fauna that inhabits them. Interesting are the studies by L.P. Lysohor et al. [19-21], who proposed ways to attract fallows as renewable elements of the eco-network, and researchers [22-24], which found recovery sites characterised by significant cenotic diversity [25] and the presence of sozologically valuable species [26-28], and the influence of afforestation of agricultural soils and the species composition of trees on changes in the physical characteristics of the soil [29].

Foreign researchers pay great attention to the study of fallows in terms of the impact of land use changes on the amount of vegetation [30-32], increasing ecosystem functions [33-35], and soil restoration and succession changes [36-38], which are only gaining relevance.

Materials and Methods

The objects of the study were naturally wooded areas on fallows that were located near the woodlands of three forestry enterprises: state enterprise (SE) "Dubrovytsa forestry enterprise (FE)", SE "Sarny FE" and SE "Berezne FE" of the Rivne Regional Department of Forestry and Hunting (RDFH). The research period was 2020-2022.

During the study of natural renewal on fallows, the following methods were applied: general scientific: observation, analysis, synthesis, generalisation, comparison; forestry and taxation – for establishing test plots to determine the taxational specifications of growing stock and investigate the natural afforestation of non-forest lands by tree species; reconnaissance – for finding and establishing test areas on the ground; forestry and ecological – for studying forest and biological characteristics of plantings; comparative ecology – for describing grasses and grass vegetation; methods of geobotanics – for determining forest live cover (FLC) and plant species; modelling, mathematical statistics, and the advanced Microsoft Excel software suite – for processing and analysing experimental materials.

Temporary test areas (TTA) were established according to SOU 02.02-37-476 2006 [39]. Natural regeneration was studied at the discount areas, which were placed evenly over the test site. Their number was 3 units at different distances from the forest border (50, 100, and 150 m). Undergrowth was recorded in a special listing sheet, where the name of the tree species, the number of the temporary trial area (number of the discount area), and the number, height of the undergrowth, and occurrence were indicated.

According to the height, the undergrowth was divided into: small – the height of the undergrowth was up to 0.5 m; medium – 0.51-1.5 m; large – more than 1.5 m [40]. By density, the following were distinguished: sparse undergrowth – up to 3 thous. units/ha; medium density – from 3 to 8; dense – from 8 to 13; very dense – more than 13 thous. units/ha. By occurrence: uniform – occurrence is more than 65%; uneven – from 40 to 65%; group – if the in groups contain at least 10 units of small or 5 units of medium and large specimens of viable and closed undergrowth [40].

The size of discount areas was set depending on the density and height of the undergrowth: if the undergrowth was small and dense, then the size of the discount area was 4 m^2; if the undergrowth was medium in height and density, then the size of the discount area was 10 m^2; if the undergrowth was large and sparse, then the size of the discount area was 20 m^2 [41].

When processing field materials, only viable undergrowth was included in the calculations. Renewal assessment and assistance measures were determined for each test area. First, for each sample, the total amount of viable undergrowth was summed up for all discount areas, after which it was recalculated per 1 ha using the equation:

$$N = n\frac{10000}{p}, \quad (1)$$

where N – the number of undergrowth per 1 ha, units/ha; n – the number of undergrowth on all discount areas, units; p – area of all accounting platforms, m^2.

After determining the total number of undergrowth, its height group was established according to the following principles: the undergrowth is considered small if specimens up to 0.5 m high make up more than 2/3 of the total number; the undergrowth is considered large if specimens over 1.5 m high make up more than 1/3 of the total number; in other cases, the undergrowth is considered medium-sized.

After the predominant group of undergrowth heights on the area was established, the undergrowth of other height groups was transferred to the predominant group of heights according to the corresponding conversion coefficients (Table 1) [42].

Table 1. Coefficients of conversion of undergrowth of different height groups to the predominant one

Predominant group of undergrowth heights	Transfer coefficients for undergrowth height groups		
	large	**medium**	**small**
large	1.0	0.8	0.5
medium	1.25	1.0	0.625
small	2.0	1.6	1.0

When describing the forest live cover, the species composition and abundance of undergrowth were determined according to the method of G.M. Vysotskyi, modified by the authors [42].

The distribution of forest live cover is determined using the Drude abundance scale:

Soc – plants cover more than 3/4 of the area; Cop^1 – plants cover from 1/2 to 3/4 of the area; Cop^2 – plants cover from 1/4 to 1/2 of the area; Cop^3 – plants cover from 1/20 to 1/4 of the area; Sp – plants cover less than 1/20 of the soil surface, but are still significantly widespread; Sol – plants occur singly; Un – only one specimen was found.

To calculate and assess the success of natural renewal on fallows, 45 discount areas were established on 15 temporary test areas (3 plots on each test area). Discount area dimensions – 10 m^2 each, since the medium-sized undergrowth prevailed. Samples were taken in plots adjacent to different forest site types. The influence of forest live cover on the soil and the state of natural renewal on fallows were also analysed.

After counting renewal trees according to the V.G. Nesterov scale, the success of natural regeneration of trees in the test areas was assessed according to the scale of M.M. Gorshenin, A.I. Shvydenko, modified by V.M. Maurer and I.V. Kimeichuk [42; 43].

Results and Discussion

The region under study contains quite a lot of land that is not used for its intended purpose, and where the forest environment is fully formed, that is, these are full-fledged stands, although they are located on the lands of shareholders or reserve lands. Temporary test areas were established in these areas (Fig. 1).

Figure 1. General view of natural renewal of Scots pine on fallows

The authors analysed the features of afforestation of fallows depending on the side of the forest border abutment; taxation specifications of undergrowth and its age structure were established; the influence of forest live cover on afforestation of plots was investigated; proposals for afforestation of land unsuitable for agricultural use were developed. A summary of the characteristics of forest live cover and natural renewal in test areas, and recommended measures to promote natural renewal are given in Table 2.

Table 2. Characteristics of natural renewal of tree species on fallows

TTA No.	Basic tree species	Assessment of FLC abundance according to the Drude abundance scale	Undergrowth size category	Number of natural seeding, thous. units/ha	Occurrence, %	Assessment of renewal success	Recommended measures to promote natural renewal
1	pine	Cop^3	Medium	3.0	50	satisfactory	Additional sowing or partial planting of seedlings/saplings
2	pine	Cop^2	Medium	4.1	60	satisfactory	Additional sowing or partial planting of seedlings/saplings
3	pine	Cop^2	Medium	11.6	100	good	Not required
4	pine	Cop^2	Medium	4.4	65	satisfactory	Partial planting of seedlings/saplings
5	pine	Cop^2	Small	13.1	100	good	Not required
6	pine	Soc	Small	5.6	39	insufficient	Additional sowing or partial planting of seedlings/saplings
7	pine	Soc	Small	2.9	19	bad	Planting by seedlings/saplings
8	birch	Cop^2	Large	2.6	65	satisfactory	Not required
9	alder	Cop^3	Medium	4.1	65	satisfactory	Partial planting of seedlings/saplings
10	alder	Cop^3	Medium	3.3	65	satisfactory	Partial planting of seedlings/saplings
11	birch	Cop^2	Large	1.8	39	insufficient	Partial planting of seedlings/saplings
12	birch	Cop^3	Large	2.5	65	satisfactory	Not required
13	pine	Soc	Large	1.2	40	insufficient	Planting of seedlings/saplings
14	pine	Cop^2	Medium	4.6	65	satisfactory	Additional sowing of seeds
15	pine	Sor^4	Small	11.3	100	good	Not required

Source: compiled by the authors

Data from Table 1 show that in 8 of the 15 test areas, the natural renewal of tree species was satisfactory (according to the Nesterov scale); in three areas – good and insufficient (unsatisfactory); in one – bad. The number of self-seeding tree species on test areas is not uniform and varied: for pine – in the range from 1.2 thous. units/ha (TTA No. 13 – large pine) up to 13.1 thous. units/ha (TTA No. 5 – small pine); for birch (only large undergrowth) – from 1.8 thous. units/ha (TTA No. 11) up to 2.6 thous. units/ha (TTA No. 8); for alder – medium undergrowth in the amount of 3.3-4.1 thous. units/ha (TTA No. 9-10). The settlement of tree species occurred mainly from forest stands located to the west, northwest, and north of the fallows. Factors that influenced the distribution of tree species and their development (type of forest stand conditions, distance to the forest border, seed years) also affected their number and occurrence, which is also not the same: from 19% (TTA No. 7) to 100% (TTA No. 3, 5, 15).

Fallow lands that have not been used for their intended purpose for a long time have a significant degree of sodding and infestation with weeds and grass. At the test sites, the grass cover occupied from 20% (TTA No. 15) to 90% (TTA No. 7) of the area. Severe sodding of certain areas (TTA No. 6, 7, 11, 13) complicated the process of natural renewal by tree species. Young trees often compete fiercely for nutrients and moisture on poor soil.

To investigate the taxation specifications of natural renewal on fallows, 4 temporary test areas were established in areas where the forest border was adjacent from different parts of the world (Table 3).

Table 3. Success of the natural renewal of pine trees depending on the connection of the forest border to the site and its taxation specifications

Side of the forest border adjacent to the plot	FST*	Distance to the forest border, m	Taxation specifications of natural pine renewal									
			number of plants, units/ ha	height, m			diameter, cm			increment, cm		
				min	max	χ**	min	max	χ	min	max	χ
North	B_2	50	11,450	2.70	6.35	4.44	1.25	11.75	4.46	23	89	47
		100	5,750	2.12	6.73	4.19	1.25	11.00	4.71	21	85	47
		150	3,150	1.47	7.08	2.96	1.00	10.00	3.85	22	88	45
South	B_3	50	9,450	0.76	7.53	3.43	1.25	9.50	2.94	17	98	57
		100	4,250	1.00	2.30	2.63	1.25	8.25	3.22	15	82	55
		150	1,500	0.50	2.53	1.38	0.40	2.75	2.63	13	71	37
West	A_2	50	9,850	1.50	7.00	3.61	1.00	11.25	5.10	16	75	44
		100	5,050	1.70	6.93	2.63	1.00	13.75	3.79	19	81	52
		150	2,550	1.45	4.95	3.16	1.00	9.00	3.90	24	84	50
East	A_3	50	11,700	0.10	10.55	2.39	0.10	11.50	2.46	5	103	39
		100	6,800	0.20	6.25	1.80	0.20	10.50	1.72	10	85	42
		150	1,400	0.10	3.40	0.96	0.10	4.50	1.00	9	55	22

Note: * FST – forest site type; **χ – arithmetic mean

As can be seen from Table 3, as the distance from the forest border increases, the biometric indicators of undergrowth decrease. They are highest in trees in areas where the forest border is adjacent to the north and west and which are located in fresh coniferous and subor conditions. According to the number of new trees, there are areas with the forest borders in the north and east. Pine trees aged 1 to 8 years and older were found in the test areas (Table 4) with different percentages by age groups, depending on the side of the forest border abutment and distance from it.

Table 4. Distribution of natural renewal of pine trees by age depending on the distance to the forest border and the side of its abutment

Side of the forest border adjacent to the plot	Age structure of renewal (%) depending on the distance to the forest border (m)								
	50			100			150		
	<3 years	4-8 years	≥9	<3 years	4-8 years	≥ 9	<3 years	4-8 years	≥9
North	0	26	74	0	31	69	3	48	49
South	6	85	9	1	90	9	7	93	0
West	0	64	36	4	65	31	0	70	30
East	59	8	33	76	10	14	79	21	0

Source: compiled by the authors

As can be seen from the data in Table 4, on the fallows to which the forest adjoins from the south and west, the largest 4-8-year natural renewal of pine in all test areas, slightly less than the older 9 years and very few young shoots and 1-3-year renewal. If the forest is adjacent from the north, new trees at the age of 9 years and older prevail, and young trees at the age of 1-3 years are detected only at a distance of 150 m from the forest border. In the area where the forest border was adjacent to the east, the age structure of renewal is radically different – 1-3-year-old prevails (from 59 to 79%), and at a distance of 150 m from the forest, there is no renewal aged 9 years and older.

A forest environment has already been established in the areas under study, so a number of forestry measures should be implemented to form a full-fledged forest stand, similar to the indigenous one in these conditions. This can be mineralisation or tillage with furrows or strips with or without sowing seeds of the necessary tree species. Attention should be paid to the mineralisation of the soil in strips after 2-3 m. In areas with intensive sodding, it is better to cultivate the soil with furrows with a PKL-70 plough to a depth of 20-25 cm or strips (PKL-70+KLB-1.7). In areas adjacent to the pine forest, in low-yielding years, it is advisable to plant pine seeds with manual seed drills in places where there is no natural renewal, but before that it is necessary to loosen the soil with heavy harrows. Using the natural forestry potential of such plots (in particular, natural renewal, which is intensively appearing on the lands of shareholders and reserves that have been in a state of fallow for a significant time) in order to increase forest cover will save a significant amount of money and allow creating new forests that will be biologically sustainable, more productive, with better biodiversity, and better adapted to climate change.

A number of forestry measures should be implemented on self-forested fallows to establish a full-fledged forest stand. This can be mineralisation of the soil in strips after 2-3 m or cultivation of the soil with furrows or strips with or without planting the necessary tree species, depending on the success of natural renewal on the site.

State authorities should simplify the scheme of transferring agricultural land that is not being used for its intended purpose and is empty, on which spontaneous forests have already settled, and where only forest service can carry out forestry activities and care for them professionally. By comparing the findings of this study with the results of other researchers in the same area, it was found that the natural afforestation of fallow lands is generally satisfactory, but the predominant in the plantings of Chernihiv Polissya are mostly secondary tree species, such as birch, aspen, alder [17]. Natural plantings of seed origin on fallows have uneven crown closure.

The species composition of the dendroflora of the fallow lands of the Pridnestrovian Podillya includes 52 species of woody and shrubby plants [44], which is explained by the richness of forest conditions in the region. The researchers also claim that the establishment of anthropogenic ecotones is observed over time between forest areas and fallows, provided that they are very close.

According to M.M. Bilous [16; 17] on fallows in the conditions of Chernihiv Polissya, the silver birch is better restored naturally, its seeds spread up to 300 m from the forest border, while the seeds of Scots pine reach up to 200 m, but the researcher states that a relatively satisfactory renewal of pine occurs in a 100-metre strip near the forest, and birch – at 160 metres. At a distance of up to 100 m from the mother plant, the amount of self-seeding of pine trees was 1-5 thous. units/ha, which is 2-5 times less compared to the results of this study (4.3-11.7 thous. units/ha). At a distance of 100-150 m, the amount of self-seeding of pine trees decreases sharply, but the same dependence remains: 0.4-1 thous. units/ha [17] against 1.5-4.5 thous. units/ha.

Somewhat similar results were obtained by V.A. Zakharchuk45] in Zhytomyr region. According to the researcher, only 6-8-year-old self-seeding of Scots pine was found in the amount of 2.4 thous. units/ha at a distance of up to 50 m from the forest border, 2.2 thous. units/ha – up to 100 m, and 2.1 thous. units/ha – at a distance of up to 150 m, i.e., there is a slight decrease in the amount of self-seeding with increasing distance from the forest border. Such data differ significantly from the findings of this study, according to which the number of self-seeding at a distance of up to 50 m is 4-8 times greater than the number at a distance of 100-150 m and almost at each of the intervals there is an undergrowth aged from 1 to 9 years or more, although 4-8-year-old self-seeding prevails in all areas.

Other researchers [46] also state the fact that the amount of self-seeding depends on the distance to the forest borders. Thus, the largest number of young trees was observed at a distance of 20 m from the forest border. Self-seeding on this test area is characterised by the highest (compared to others) average age, that is, at first it appeared closer to the forest border, and every year it occupied more and more area. A characteristic feature of its distribution on fallows is a pronounced grouping. The area of the plot between the self-seeding groups practically does not contain woody plants of natural origin, but only isolated specimens are found.

Similar results were obtained by other researchers [47], who considered the state of afforestation of fallow lands and the species composition of forest live cover. Their results confirm that the species composition of forest live cover, especially ruderants and protants, competes with young trees and strong sodding worsens their condition and biometric indicators (height, diameter, and growth of the current year).

M. Malashevskyi, O. Malashevska [48] investigated the processes of natural afforestation of fallow lands and their subordination and recommended, as in the previous studies, special measures to promote natural renewal, which would ensure its relatively rapid closure and increase the area of mixed plantings of natural origin, resistant to negative climatic and other factors.

Conclusions

Natural renewal on fallow lands that are not used in agriculture occurs with the main and accompanying tree species, in particular, pine, birch, and alder, but not always evenly and in sufficient quantities.

The number of pine renewal ranged from 1.2 thous. units/ha (large undergrowth) to 13.1 thous. units/ha (small undergrowth); birches – from 1.8 thous. units/ha to 2.6 thous. units/ha (only large undergrowth); alders – from 3.3 to 4.1 thous. units/ha (medium undergrowth). The number and occurrence (spread) of forest renewal is affected by: forest site type, distance to the forest border, seed years, amount of forest live cover, and the degree of soil sodding.

Fallow lands that have not been used for their intended purpose for a long time have a significant degree of sodding at the sites under study, the grass covered from 20 to 90% of the area. Severe sodding of certain areas has complicated the process of natural renewal by tree species in these areas.

Natural renewal on abandoned fields (fallows) mainly occurs in areas adjacent to forest on the north and west sides. At the same time, this renewal is also characterised by better average biometric indicators, which decrease with increasing distance from the forest wall.

On the fallow areas, to which the forest adjoins from the south and west, there is the largest number of 4-8-year-old natural renewal of pine trees, somewhat less of older than 9 years, and very few 1-3-year-old trees. If the forest is adjacent from the north, new trees at the age of 9 years and older prevail, and young trees at the age of 1-3 years are detected only at a distance of 150 m from the forest border. In the area where the forest border was adjacent to the east, 1-3 year-old undergrowth prevails, and at a distance of 150 metres from the forest there are no trees aged 9 years and older.

A characteristic feature of self-forested fallow lands are indirect signs of forest ecosystems. It is established that the success of natural renewal is influenced by: composition of the adjacent forest stand, frequency of its seed bearing/fruiting, yield, the ability of seeds to move to large areas, soil fertility, contamination, etc.

The next studies are intended to investigate the process of successive changes in the fallow areas, the NPK content in the soil, the range of forest live cover (silvants, pratants, ruderants), and expand the network of test areas in other forest site types on the fallow land that was not covered by this study.

References

[1] Radko, R.P. (2019). *It is possible to increase the forest cover of Ukraine for free at the expense of forests without a "registration"*. Retrieved from https://www.openforest.org.ua/123710/.

[2] Oniskiv, M.I., Sbytna, M.V., & Sandul, T.R. (2003). To the issue of afforestation of the poor sandy lands of Polissia. *Scientific Bulletin of NAU*, 61, 54-61.

[3] Kimeishik, I.V., Radko, R.P., Khryk, V.M., Levandovska, S.M., Sokolenko, K.I., & Rabko, S.V. (2021). Assessment of forest crops created on the dependent lands of Rivne region. *Agrobiology. Bila Tserkva*, 2, 84-94.

[4] Decree of the President of Ukraine No. 228/2021 "On Some Measures to Preserve and Reproduce Forests". (June, 2021). Retrieved from https://zakon.rada.gov.ua/laws/show/228/2021#Text.

[5] Maurer, V.M., & Kaidyk, O.Yu. (2016). *Eco-adaptive reproduction of forests*. Kyiv: RVV NUBiP of Ukraine.

[6] Kimeichuk, I.V., & Kaidyk, O.Yu. (2022). Natural and artificial afforestation of fallow lands of the Volyn Polissia. In *International scientific conference* (pp. 113-117). Riga: Baltija Publishing.

[7] Saiko, V.F. (2000). (Ed.) *Removal of unproductive lands from intensive cultivation and their rational use*. Kyiv: Agricultural Science.

[8] Kuchma, M.D., Landin, V.P., Khaurdinova, G.O., & Zibtsev, S.V. (2012). Changes in ecological characteristics of fallow soils under the influence of afforestation. *ScientificReports of NUBiP of Ukraine*, 2(31). Retrieved from https://nd.nubip.edu.ua/2012_2/12kmd.pdf.

[9] Khaurdinova, G.O. (2010). Ecological features of succession in pine plantations on old arable lands. *Agroecological Journal*, 1, 79-81.

[10] Khom'iak, I.V. (2018). Dynamics of flora of fallow ecosystems of Ukrainian Polissia. *Science Rise: Biological Science*, 1(10), 8-3.

[11] Law of Ukraine No. 2321-IX "On Amendments to Certain Legislative Acts of Ukraine Regarding Forest Conservation". (June, 2022). Retrieved from https://zakon.rada.gov.ua/laws/show/2321-20.

[12] Ivanytskyi, R.S. (2011). *Reproduction and formation of forest stands with the participation of Scots pine in the conditions of North-Western Podillia* (Doctoral thesis, Ukrainian National Forestry University, Lviv, Ukraine).

[13] Hastings, Z., Ticktin, T., Wong, M., Kukea-Shultz, J.K., & Bremer, L.L. (2022). Non-native fallows hold high potential for restoration through agroforestry in a Pacific Island ecosystem. *Agriculture, Ecosystems and Environment*, 342, article number 108214. doi: 10.1016/j.agee.2022.108214.

[14] Lavnyy, V., Spathelf, P., Kravchuk, R., Vytseha, R., & Yakhnytskyy, V. (2022). Silvicultural options to promote natural regeneration of Scots pine (*Pinus sylvestris* L.) in Western Ukrainian Forests. *Journal of Forensic Sciences*, 68, 298-310.

[15] Yang, L., Zeng, Y., Xu, L., Li, M., Wang, H., Zou, Y., & Lu, Y. (2022). Perennial woodlands benefit parasitoid diversity, but annual flowering fallows enhance parasitism of wheat aphids in an agricultural landscape. *Agriculture, Ecosystems and Environment*, 340, article number 108184. doi: 10.1016/j.agee.2022.108184.

[16] Bilous, M.M. (2012). The species composition of forest crops on the agricultural lands of Eastern Polissia. *Scientific Reports of NUBiP of Ukraine*, 7(36), 1-7.

[17] Bilous, M.M. (2006). Natural regeneration of forest plantations on lands unsuitable for agricultural production in Chernihiv Polissia. *Scientific reports of NAU*, Vol. 2(3), 1-5.

[18] Borovyk, L. (2012). The role of wetlands in the preservation of rare phytodiversity. In *Collection of Science Proceedings "Dynamics of Biodiversity 2012"* (pp. 55-58). Luhansk: Publishing House "Taras Shevchenko LNU".

[19] Lysohor, L.P., Bagrikova, N.O., & Krasova O.O. (2016). Fallen lands as promising regenerating elements of the eco-network of the Right Bank Steppe of the Dnieper region. *Ukrainian Botanical Journa*l, 73(2), 116-125.

[20] Pasha, S.V., Behera, M.D., Mahawar, S.K., Barik, S.K., & Joshi, S.R. (2020). Assessment of shifting cultivation fallows in Northeastern India using Landsat imageries. *Tropical Ecology*, 61(1), 65-75. doi: 10.1007/s42965-020-00062-0.

[21] Satyanandam, T., Babu, K., Rosaiah, G., & Vijayalakshmi, M. (2021). Production of exopolysaccharide and hydrogen cyanide by rhizobium strains isolated from Vigna mungo cultivated in rice fallows. *Research Journal of Biotechnology*, 16(9), 162-167.

[22] Wietzke, A., Albert, K., Bergmeier, E., Sutcliffe, L.M.E., van Waveren, C.-S., & Leuschner, C. (2020). "Flower strips, conservation field margins and falls promote the arable flora in intensively farmed landscapes: Results of a 4-year study". *Agriculture, Ecosystems and Environment*, 304, article number 107142. doi: 10.1016/j.agee.2020.107142.

[23] Zhao, L., Waldner, F., Scarth, P., Mack, B., & Hochman, Z. (2020). Combining fractional cover images with one-class classifiers enables near real-time monitoring of fallows in the Northern Grains region of Australia. *Remote Sensing*, 12(8), article number 1337. doi: 10.3390/RS12081337.

[24] Zhao, Z., Zhao, Z., Fu, B., Wu, D., Wang, J., & Tang, W. (2021). Available heavy metal concentrations and their influencing factors in cropland and fallows of different age in tropical area. *Polish Journal of Environmental Studies*, 30(2), 1935-1942. doi: 10.15244/pjoes/126372.

[25] Wietzke, A., Albert, K., Bergmeier, E., Sutcliffe, L.M.E., van Waveren, C.-S., & Leuschner, C. (2020). Corrigendum to "Flower strips, conservation field margins and fallows promote the arable flora in intensively farmed landscapes: Results of a 4-year study". *Agriculture, Ecosystems and Environment*, 315, article number 107357. doi: 10.1016/j.agee.2020.107142.

[26] Musokwa, M., & Mafongoya, P.L. (2021). Effects of improved pigeonpea fallows on biological and physical soil properties and their relationship with maize yield. *Agroforestry Systems*, 95(2), 443-457. doi: 10.1007/s10457-021-00598-7.

[27] Musokwa, M., Mafongoya, P.L., & Chirwa, P.W. (2020). Monitoring of soil water content in maize rotated with pigeonpea fallows in south Africa Terms and conditions. *Water (Switzerland)*, 12(10), article number 2761. doi: 10.3390/w12102761.

[28] Naik, B.S.S.S., Murthy, K.R., & Rupesh T. (2021). Comparative response of sorghum genotypes to varied levels of nitrogen in rice-fallows of North Coastal Region of Andhra Pradesh. *Journal of Environmental Biology*, 41(6), 1710-1718. doi: 10.22438/JEB/41/6/SI-259.

[29] Vopravil, J., Podrázský, V., Khel, T., Holubík, O., & Vacek, S. (2014). Effect of afforestation of agricultural soils and tree species composition on soil physical characteristics changes. *Ekológia (Bratislava)*, 33(1), 67-80. doi: 10.2478/eko-2014-0008.

[30] Satyanandam, T. Rosaiah, G., Babu, K., & Vijayalakshmi, M. (2020). Preliminary Characterization of Rhizobial Strains isolated from the root nodules of Vigna mungo cultivated in rice fallows. *Research Journal of Biotechnology*, 15(11), 64-71.

[31] Singh, S.L., & Sahoo, U.K. (2021). Tree species composition, diversity and soil organic carbon stock in homegardens and shifting. cultivation fallows of Mizoram. Northeast India. *Vegetos*, 34(1), 220-228. doi: 10.1007/s42535-021-00194-1.

[32] Velasco-Murguía, A., del Castillo, R.F., Rös, M., & Rivera-García, R. (2021). Successional pathways of post-milpa fallows in Oaxaca. *Mexico Forest Ecology and Management*, 500(1), aricle number 119644. doi: 10.1016/j.foreco.2021.119644.
[33] Kher, V., & Dutta, S. (2021). Rangelands and crop fallows can supplement but not replace protected grasslands in sustaining Thar Desert's avifauna during the dry season. *Journal of Arid Environments*, 195, article number 104623. doi: 10.1016/j.jaridenv.2021.104623.
[34] Mamuye, M., Nebiyu, A., Elias, E., & Berecha, G. (2020). Short-term improved fallows of Tephrosia vogelii and Cajanus cajan enhanced maize productivity and soil chemical properties of a degraded fallow land in Southwestern Ethiopia. *Agroforestry Systems*, 94(5), 1681-1691. doi: 10.1007/s10457-020-00485-7.
[35] Mpanda, M., Kashindye, A., Aynekulu, E., Jonas, E., Rosenstock, T.S., & Giliba, R.A. (2021). Forests, farms, and fallows: The dynamics of tree cover transition in the southern part of the uluguru mountains. *Tanzania. Land*, 10(6), article number 571. doi: 10.3390/land10060571.
[36] Filimonova, D.A., Solovev, S.V., Bezborodova, A.N., & Miller, G.F. (2020). The degree of restoration of the soil properties developed under the fallows in the early stages of succession. *E3S Web of Conferences*, 224, article number 04025. doi: 10.1051/e3sconf/202022404025.
[37] Gautam, P., Lal, B., Panda, B.B., Bihari, P., Chatterjee, D., Singh, T., Nayak, P.K., & Nayak, A.K. (2021). Alteration in agronomic practices to utilize rice fallows for higher system productivity and sustainability. *Field Crops Research*, 260, article number 108005. doi: 10.1016/j.fcr.2020.108005.
[38] Jacobson, M., & Ham, C. (2020). The (un)broken promise of agroforestry: a case study of improved fallows in Zambia. *Environment, Development and Sustainabilit*, 22(8), 8247-8260. doi: 10.1007/s10668-019-00564-5.
[39] SOU 02.02-37-476:2006 (2006). *Trial forest management areas*. Laying method. Kyiv: Ministry of Agrarian Policy of Ukraine.
[40] Svyridenko, V.E., Babich, O.G., & Kyrychok, L.S. (2008). *Forestr*y. Kyiv: Aristei.
[41] Order of the State Forestry Committee of Ukraine No. 260 "Instructions on Design, Technical Acceptance, Accounting and Quality Assessment of Forestry Objects". (2010, August). Retrieved from http://zakon4.rada.gov.ua/laws/show/z1046-10.
[42] Maurer, V.M., & Kimeichuk, I.V. (2020). Dynamics of the number and state of natural regeneration of Scots pine on clearcut areas in the conditions of oak forests on fresh, relatively rich soils of Kyiv Polissya. *Ukrainian Journal of Forest and Wood Science*, 11(1), 45-54. doi: 10.31548/forest2020.01.045.
[43] Svyrydenko, B.Ye., & Shvydenko, A.Y. (1995). *Forestry*. Kyiv: Agricultural Education.
[44] Parpan, V.I., & Oliinyk, M.P. (2013). Natural restoration of tree species on the fallows of Pre-Dnister Podillia. *Scientific bulletin of NLTU of Ukraine*, 23.14, 8-15.
[45] Zakharchuk, V.A. (2017). The influence of ecological factors on the restoration of forest ecosystems on the fallows of Zhytomyr Polissia. *Agroecological Journal*, 4, 117-122.
[46] Kychyliuk, O.V., & Kaidyk, O.Yu. (2011). Forestation from position ecological orientalised forestry. *Scientific bulletin of NUBiP of Ukraine*, 164(1), 182-189.
[47] Holubík, O., Podrázský, V., Vopravil, J., Khel, T., & Remeš, J. (2014). Effect of agricultural lands afforestation and tree species composition on the soil reaction, total organic carbon and nitrogen content in the uppermost mineral soil profile. *Soil and Water Research*, 9, 192-200.
[48] Malashevskyi, M., & Malashevska, O. (2022). Land consolidation considering natural afforestation. *Geomatics and Environmental Engineering*, 16(2), 5-19. doi: 10.7494/geom.2022.16.2.5.

Природне заліснення перелогових земель Західного Полісся

Іван Васильович Кімейчук[1], Олександр Юрійович Кайдик[2]

[1]Білоцерківський національний аграрний університет
09117, Соборна площа, 8/1, м. Біла Церква, Україна

[2]Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Анотація. Одне із головних завдань лісового господарства України – підвищення лісистості – частково може бути вирішене освоєнням низькопродуктивних сільськогосподарських угідь, зокрема перелогів, на яких уже зростає чи тільки з'являється самосійний ліс, оскільки актуальним для нашої держави є розширене відтворення лісів з урахуванням еколого-лісівничих трансформацій перелогових земель, внаслідок їх природного заліснення. Основною метою було оцінити успішність природного поновлення на перелогових землях в регіоні досліджень, виявити фактори впливу на перебіг природного заліснення і збереження дерев залежно від розташування ділянки відносно стіни лісу та відстані до неї. Для дослідження природного поновлення на перелогах використано загальнонаукові, лісівничо-таксаційні, рекогносцирувальні, лісівничо-екологічні, геоботанічні методи. Камеральну обробку матеріалів здійснено методом математичної статистики. У результаті детального вивчення природного заселення лісових деревних видів на перелогових землях Західного Полісся, встановлено, що у борових і суборових умовах ділянки заліснюються здебільшого сосною, а також березою і вільхою. На більшості пробних площ поновлення виявилося задовільним (за шкалою Нестерова). Кількість самосіву деревних видів на пробних площах не однорідна і коливалася в межах від 1,2-13,1 тис. шт./га залежно від типу лісорослинних умов, виду деревних рослин, категорії крупності підросту, рясності живого надґрунтового покриву і ступеню задерніння ділянки та засмічення бур'янами і трав'яними рослинами, який на об'єктах коливався від 20 до 90 %. Трапляння природного поновлення також неоднакове: від 19 до 100 %. Заселення деревними видами відбувалося здебільшого від насаджень, розташованих із західної, північно-західної та північної сторін від перелогів. Результати дослідження є надзвичайно важливими для працівників лісової галузі, а також можуть бути використані територіальними громадами в удосконаленні землеустрою, закладенні ландшафтних парків тощо

Ключові слова: природне поновлення, живий надґрунтовий покрив, шкала Друде, лісівничий потенціал, самосів

Received: 04/10/2022; Revised: 19/11/2022; Accepted: 15/12/2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4), 52-63

UDC 81.1:57.085:547.587.2
DOI: 10.31548/forest.13(4).2022.52-63

Gallic Acid as a Non-Specific Regulator of Phenol Synthesis and Growth of Regenerate Plants of *Corylus avellana* (L.) H. Karst. and *Salix alba* L. *in vitro*

Artur Likhanov*, Andrii Klyuvadenko, Oleksandr Subin, Mariia Shevchuk, Mariia Dubchak

National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony, Kyiv, Ukraine

Abstract. Gallic acid is found in plant tissues in free form, as well as in the composition of complex esters and hydrolysed tannins. These phenolic compounds have significant antioxidant activity and protect plant cells from damage by free radicals. In the conditions of stress that occurs during the introduction of plants into *in vitro* culture, the vast majority of explants are characterised by an intensive synthesis of phenols, which quickly oxidise, polymerise, block the explants' nutrition pathways, and cause tissue necrosis. The addition of gallic acid in millimolar concentrations to the nutrient medium reduces the risk of autointoxication of tissues by secondary metabolic products. The purpose of this study was to investigate the effect of exogenous gallic acid on organogenesis and phenolic synthesis of *Salix alba* and *Corylus avellana* plants *in vitro*. For this purpose, the study used methods of tissue and organ culture *in vitro*, spectrophotometric determination of total phenols and flavonoids in leaves, methods of dispersion and nonparametric analysis. It was established that gallic acid at a concentration of 1 mmol·l^{-1} in the composition of the DKW nutrient medium caused the awakening of dormant buds, stimulated the growth of shoots, and also promoted the branching of stems, the development and growth of lateral roots of *Salix alba in vitro*. It also inhibited the synthesis of phenols in *Corylus avellana* plants of the varieties 'Tonda Romana', 'Tonda Gentile Dele Lange', 'Barcelona', while contributing to an increase in the content of phenolic compounds in the leaves of the varieties 'Tonda Di Giffoni', 'Mortarella', and 'Epsilon'. It was established that the varieties recommended for fruiting have a higher content of phenolic compounds ('Tonda Gentile Dele Lange' and 'Tonda Di Giffoni') compared to pollinator varieties ('Mortarella'). Therefore, exogenous gallic acid at a concentration of 1 mmol·l^{-1} has the properties of a non-specific regulator of phenol synthesis in regenerating plants of hazel (*Corylus avellana*), which is relevant for plants with a high content of phenols, especially at the stage of their introduction into *in vitro* culture

Keywords: development, hydroxybenzoic acid, organogenesis, phenolic compounds, flavonoids, nutrient medium

Introduction

A unique property of plants is the ability to synthesise a wide range of organic compounds that belong to the class of secondary metabolites (SM) [1]. The vast majority of SMs exhibit specific bioactivity that supports the physiological stability and viability of the plant organism [2-4]. These organic compounds, which are quite diverse in structure and chemical properties, protect plant cells and tissues from stress factors in conditions of excess or lack of moisture, light, organ injury, heavy metals and xenobiotics [5; 6],

Suggested Citation:
Likhanov, A., Klyuvadenko, A., Subin, O., Shevchuk, M., & Dubchak, M. (2022). Galic acid as a non-specific regulator of phenol synthesis and growth of regenerate plants of *Corylus avellana* (L.) H. Karst. and *Salix alba* L. *in vitro*. *Ukrainian Journal of Forest and Wood Science*, 12(3), 52-63.

*Corresponding author

as well as pathogens – phytoviruses, mycoplasmas, pathogenic bacteria, fungi, and phytophages [7-9]. At the same time, SMs serve as attractants for pollinating insects [10]. Tannins and flavonoids protect tissues and organs from the harmful effects of ultraviolet light [11], increase drought resistance [12], and provide root protection, especially in acidic soils [13].

SM are responsible for the interaction of plants with the natural environment at the individual, population, and ecosystem levels [10; 14]. At the same time, the current vision of secondary plant metabolism is not limited only to the functionality of protective mechanisms and adaptive responses. It is believed that individual products of SM are components of regulatory molecular programmes that positively affect plant growth and development [15; 16]. Transcription factors are associated with secondary synthesis due to complex regulatory networks that control the processes of metabolite generation [16]. Some products of secondary metabolism actively affect the course of plant growth and development [17]. In particular, polyphenols and flavonoids regulate the polar transport of phytohormones through tissues [18-20].

Phenol carboxylic acids: vanillic, syringic, ferulic, salicylic, and gallic acids, even in low concentrations, affect the development of plant tissues and organs in *in vitro* conditions [21; 22]. Phenol carboxylic acids containing 4-oxy and 3-methoxy groups stimulate the growth of shoots of essential oil rose [23]. It is shown that hydroxybenzoic (vanillic, syringic, gallic) and hydroxycinnamic (p-coumaric, caffeic, ferulic) acids in the nutrient medium (concentration of $1 mm \cdot L^{-1}$) in the area of contact with living tissues initiate callusogenesis [23]. Vanillic acid in the nutrient medium increases the activity of phenylpropanoid synthesis. At the same time, an increase in the number of hydroxyl groups in the molecular structure of hydroxybenzoic acids (gallic acid), on the contrary, slows down the synthesis of total phenols and catechins.

Gallic acid (GA) is found in plant tissues in free form (Figure 1), but mainly in the composition of esters and hydrolysed tannins (gallotannins).

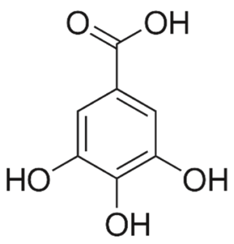


Figure 1. Structural formula of gallic (3,4,5-trihydroxybenzoic) acid

Tannins have high antioxidant activity and protect cell membranes and other intracellular structures from free radical damage, especially under stressful conditions [12]. Although in some plant species (*Populus tremula* L., *Salix alba* L.) the synthesis of phenolic compounds in response to injury slightly increases [24; 25]. This creates prerequisites for the successful introduction of primary explants into the *in vitro culture*. For other species (*Quercus robur* L., *Corylus avellana* (L.) H.Karst.), on the contrary, it is characterised by intensive synthesis of hydrolysed tannins and other polyphenols, which are able to chelate metals and participate in redox reactions [26; 27]. GA complexes, as the main component of gallotannins, with iron ions have antibacterial activity [28]. Due to the polymerisation of condensed tannins, the nutrition of explants is difficult, which over time can cause tissue necrosis. Slowing down the accumulation and release of phenols at the sites of tissue damage to donor plants is critical. Therefore, at the first stages of the introduction into *in vitro* culture of plants with active polyphenol synthesis, the addition of GA to the nutrient medium would be appropriate to reduce the risk of tissue autointoxication due to active oxidation under traumatic stress conditions.

The purpose of this study was to investigate the effect of GA on organogenesis and phenolic synthesis of *Salix alba* and *Corylus avellana* in plant tissue culture in the aspect of reducing autointoxication of explant tissues by polyphenol oxidation products.

Materials and Methods

Studies were conducted on *Salix alba* regenerant plants and 6 varieties of hazel (varieties of Italian selection – 'Tonda Romana' (Lazio), 'Tonda Di Giffoni', 'Mortarella' (Campania) [29], 'Tonda Gentile Dele Lange' and varieties of North American selection – 'Barcelona', 'Epsilon'. A wild form *Corylus avellana* was used as a reference object.

Apical buds from 1-2 annual hazel plants (*Corylus avellana* L.) (container culture) and willows (*Salix alba* L.) were used as primary explants.

70% ethanol (30-60 seconds) and 0.1% mercury chloride ($HgCl_2$) solution with an exposure of 7-8 minutes were used to obtain an aseptic culture, which provided 80% of sterile and viable material.

Explant were cultivated on a modified Driver-Kuniyuki walnut medium (DKW) [30] with the addition of 2.5-5.0 $mg \cdot l^{-1}$ BAP (6-benzylaminopurine), 100-200 $mg \cdot l^{-1}$ Fe-EDDHA, 30 $g \cdot l^{-1}$ sucrose, and 6 $g \cdot l^{-1}$ agar at 5.8-6.0 pH (control). To investigate the effect of trihydroxybenzoic acid (GA) on explant morphogenesis, it was added to a nutrient medium at a concentration of 1 mmol·l^{-1}. All experiments on the morphogenesis of hazel and willow tissues and organs *in vitro* were conducted in a controlled climate room with 16-hour lighting (2.5-3.0 klx), at a temperature of +26.0°C. The cultivation period – 30-45 days. Determination of the total content of phenolic compounds and flavonoids in the leaves of regenerant plants was performed 14 days after cultivation.

Methods for quantitative determination of total phenols and flavonoids. Extraction of polyphenols from macerated plant tissues was performed with cold methyl alcohol (80%). The volume ratio of solvent to raw mass of leaves was 1/10 (v/v). The total content of phenols in the leaves was determined using spectrophotometry with Folin-Ciocalteu reagent [31]. The calibration graph was plotted using gallic acid. The flavonoid content was determined spectrophotometrically at λ=419 nm. 250 µl of methanol (80%), 200 µl of 0.1 mol aluminium chloride ($AlCl_3$), and 300 µl of 1 mol sodium acetate (CH_3COONa) were added to 50 µl of the obtained ethanol extract of the leaves. The calibration graph was constructed using quercetin (Sigma, Germany). Repeatability of measurements n=4.

Biochemical profiling of solutions of iron and GA chelate complex. The separation of substances was performed by high-performance thin-layer chromatography (HPTLC) on cellulose plates (Merck) in solvent systems: ethyl acetate–formic acid–acetic acid–water (v/v/v/v – 5:1:1:2) and n-butanol–acetic acid–water (v/v/v – 3:1.2:0.8). The resulting chromatograms were treated with 0.5% NP reagent in ethyl acetate, followed by heating at 90°C for 1 min. GA was detected on the chromatogram in ultraviolet light (λ_{max}= 365 nm). The Rf (retention factor) values of individual compounds were determined photodensitometrically using the Sorbfil TLC Videodensitometer computer programme.

Method of statistical data processing. The measurement results are presented as the average value ± standard error (x±SE). The significance of the difference ($p<0.05$) between the obtained data was determined by variance analysis (one-way ANOVA) using Tukeys post-hoc test in the XLSTAT software suite [Addinsoft Inc., USA, 2010]. The principle component analysis (PCA) was performed in the XLSTAT.

Results and Discussion

According to the findings, GA as part of the DKW nutrient medium (NM) actively awakened dormant buds and stimulated the growth of shoots of *Salix alba* L. *in vitro*. At a concentration of 1 mmol·l-1, hydroxybenzoic acid stimulated the awakening of lateral buds, caused branching of stems, development and growth of lateral roots (Fig. 2).

a b

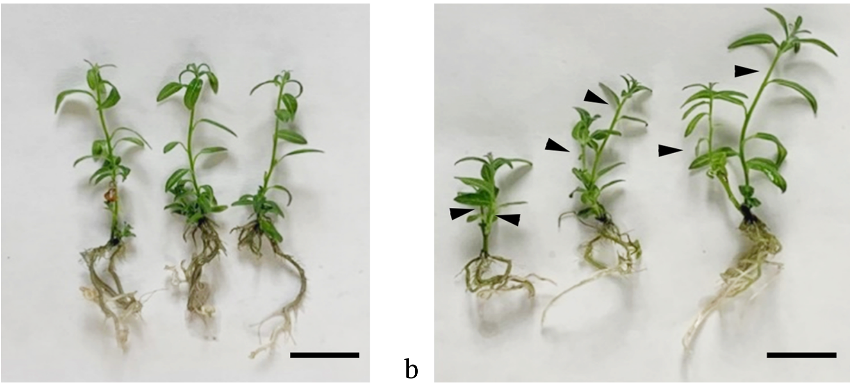
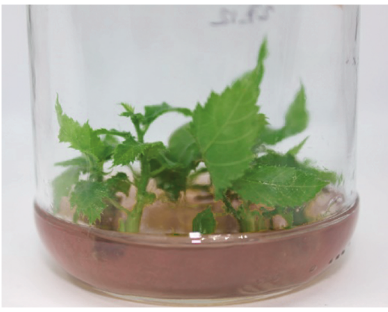


Figure 2. *Salix alba* regenerant plants, which are grown in the following conditions: *in vitro* on the basic (a) and modified gallic acid (b) DKW nutrient medium; scale bar – 10 mm

However, during the experiment, a difference was found in the individual sensitivity of regenerant plants to free GA. Thus, some plants showed signs of suppressed growth, while the morphometric parameters of others (the length of shoots and lateral roots, the length and width of leaf blades) exceeded the control by 1.3-1.5 times. This fact may indicate the ability of free GA, or in combination with metal ions, to influence plant morphogenesis. The variability of growth processes indicates a non-specific nature of *Salix alba* regenerant plant reactions to non-hormonal stimuli of 3,4,5-trihydroxybenzoic acid, which is of scientific and practical interest from the standpoint of identifying genotypes that are particularly sensitive to GA.

The role of GA and other hydroxybenzoic and hydroxycinnamic acids in the regulation of physiological processes is quite complex and multi-vector. GA is a part of hydrolysed tannins, has a high antioxidant potential, and is able to chelate metal ions [32; 33]. In the experiment, it contributed to a decrease in the effect of apical plant dominance conditioned by the vertical gradient of auxin concentration. The development of lateral roots and lateral shoots is usually associated with changes in the transport and distribution of phytohormone in tissues. Differences in organogenesis and features in stem alkalinisation indicate that this hydroxybenzoic acid acts on explants not locally, at the point of contact with the medium, but systemically. This suggests that it not only enters the tissues with NM, but is also transported through the tissues.

A similar process was observed in an experiment with different varieties of hazel (*Corylus avellana* L.). At the initial stages of cultivation of GA as part of DKW NM contributed to the awakening of lateral buds and the growth of regenerant plants compared to the control (Fig. 3).


a

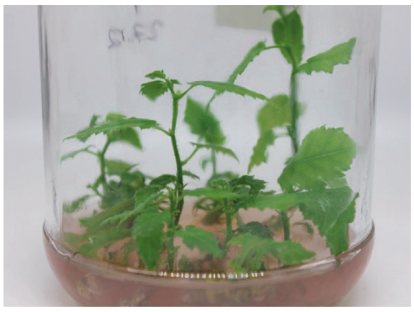

b

Figure 3. *Corylus avellana* regenerant plants of 'Tonda Romana' varieties on basic (a) and gallic acid-modified (b) DKW nutrient medium

However, over time, the difference between the growth rate indicators in the control and experimental groups of plants was levelled. The index of the ratio of leaf width to its length, and the total surface area of leaf blades, decreased on the modified medium with GC. This may indicate a slowdown in the proliferation of marginal meristem cells. Regarding the synthesis of polyphenols, it was found that according to the reaction to GA, the hazel varieties under study were divided into two groups. In the first (varieties 'Tonda Romana', 'Tonda Gentile Dele Lange', 'Barcelona') – GK, in comparison with the control, slowed down the synthesis of phenols; varieties of the second group ('Tonda Di Giffoni', 'Mortarella', 'Epsilon') – with the addition of exogenous hydroxybenzoic acid, increased the synthesis of polyphenols (Table 1). Interestingly, the distribution in these groups coincided with the complementarity of varieties for pollination. Thus, the Italian early-maturing variety 'Tonda Gentile Dele Lange' is pollinated by a larger calibre variety 'Tonda Romana', and the early, rather frost-resistant Italian variety 'Tonda Di Giffoni' is the main one for fruiting, and another Italian variety 'Mortarella' is recommended to be used as a pollinator. The 'Barcelona' variety, selected by the University of Oregon (USA), is an early and frost-resistant variety. Another variety of the same selection – 'Epsilon' is recommended as a pollinator.

Table 1. Effect of exogenous gallic acid on the content and ratio of polyphenols in leaves of *Corylus avellana* in vitro (x±SE; n=4)

Type/variety	NM	PH	FL	PH/FL
Wild form	Control	36.5±2.19	8.6±0.69	4.3
	GA	32.1±1.93	4.5±0.36*	7.1
'Tonda Romana'	Control	40.8±3.45	6.9±0.55	5.9
	GA	37.2±2.23	4.9±0.39*	7.6
'Tonda Gentile Dele Lange'	Control	62.8±3.77	6.4±0.51	9.8
	GA	45.8±4.15*	4.5±1.36*	10.2
'Mortarella'	Control	26.2±1.57	5.1±0.40	5.2
	GA	43.4±2.61*	5.6±0.45	7.8

Table 1, Continued

Type/variety	NM	PH	FL	PH/FL
'Tonda Di Giffoni'	Control	40.0±2.80	6.0±0.78	6.6
	GA	44.8±3.19	8.0±1.64*	5.6
'Barcelona'	Control	36.1±2.17	6.5±0.52	5.5
	GA	26.4±1.59*	4.1±0.33*	6.4
'Epsilon'	Control	26.6±1.60	5.4±0.43	5.0
	GA	47.0±2.82*	5.2±0.42	9.0

Note: PH – phenolic compounds, FL – flavonoids, PH/FL – ratio, GA – gallic acid, * – the difference with the control is significant ($p<0.05$)

Notably, the varieties recommended for fruiting have a higher content of phenolic compounds ('Tonda Gentile Dele Lange' and 'Tonda Di Giffoni'), compared to pollinating varieties ('Mortarella'). In general, Italian varieties, in comparison with the varieties of the selection centre of the University of Oregon (USA), are characterised by a higher content of phenolic compounds in the leaves. As for flavonoids, GA significantly increased their content in the leaves of only Italian varieties 'Tonda Di Giffoni' and 'Mortarella', which are usually recommended as a complementary pair. In *Corylus avellana* plants (classical species form) the flavonoid content decreases by 1.9, and in varieties 'Tonda Romana', 'Tonda Gentile Dele Lange' and 'Barcelona' – by almost 1.5 times. Thus, GA at a concentration of 1 mmol·L^{-1} can influence plant morphogenesis, stimulate cell proliferation, and accelerate or inhibit phenylpropanoid synthesis. At the same time, its regulatory effect is not specific and depends on the characteristics of the plant genotype.

Based on the results of PCA analysis, which are represented in the coordinates F1 and F2 of the main components of the *Corylus avellana* regenerant plants in terms of the content of phenols in the leaves, it was shown that the central position with the lowest contribution to the total variance is occupied by the varieties 'Tonda Romana', 'Tonda Di Giffoni' and 'Barcelona' (Fig. 4a).

These varieties are close to each other in terms of the intensity of accumulation of phenolic compounds and occupy an intermediate position between the high-phenolic variety 'Tonda Gentile Dele Lange' and the low-phenolic 'Epsilon' and 'Mortarella'. Accordingly, these varieties had the greatest contribution to the overall variance (F1 axis), which mainly determines the content of total phenols in the leaves (Table 2).

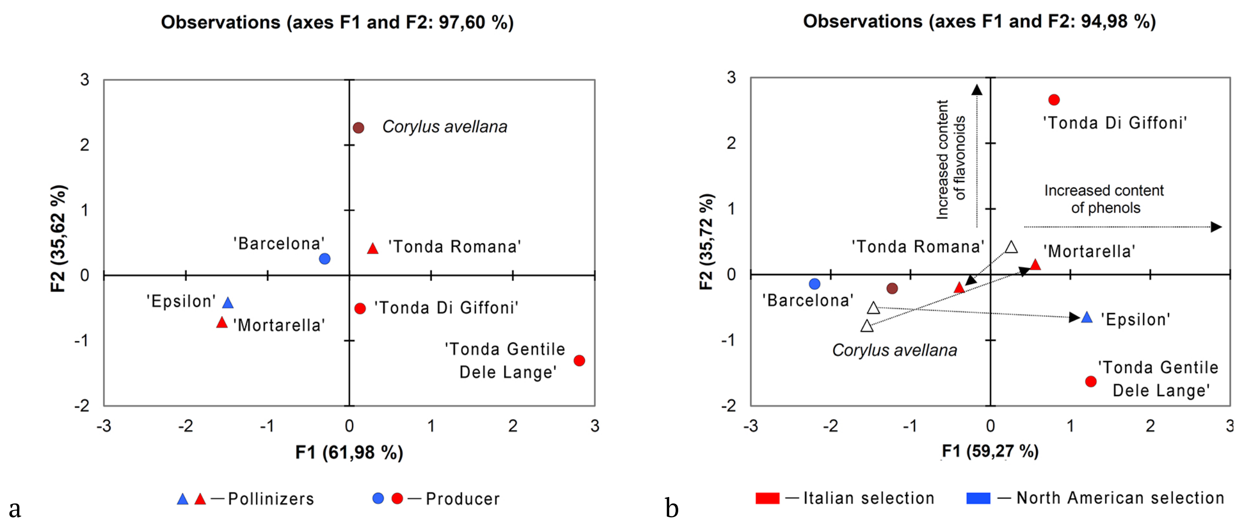


Figure 4. The results of PCA analysis of Italian and North American varieties of *Corylus avellana* under conditions of cultivation on basic (a) and gallic acid-modified (b) nutrient media

Table 2. Introduction of *Corylus avellana* species and varieties to the total variance (%) according to the results of PCA analysis of plant phenolic compounds i*n vitro*

Variety	F1	F2	F3
		Basic DKW	
Corylus avellana	0.1	**68.4**	**37.8**
'Tonda Romana'	0.6	2.4	0.0
'Tonda Gentile Dele Lange'	**60.8**	**22.8**	**9.6**
'Barcelona'	0.7	0.9	0.0
'Tonda Di Giffoni'	0.1	3.4	1.3
'Mortarella'	**18.6**	6.7	1.5
'Epsilon'	**17.0**	2.3	0.6
		A modified DKW with GA ($1mmol \cdot l^{-1}$)	
Corylus avellana	**12.1**	0.6	3.4
'Tonda Romana'	1.2	0.5	0.3
'Tonda Gentil Dele Lange'	**12.7**	**35.4**	0.2
'Barcelona'	**38.9**	0.3	**9.1**
'Tonda Di Giffoni'	5.1	**94.3**	2.9
'Mortarella'	2.5	0.3	3.2
'Epsilon'	**11.6**	5.5	**5.3**

The relatively high content of flavonoids in the leaves was typical for *Corylus avellana* plants (wild form) in plant tissue culture. The wild form of regenerant plants had the greatest contribution to the overall dispersion (F2 axis), which explains their distant position from the group of varieties along the second main component (Fig. 4a). At the same time, the flavonoid content decreased by 1.9 times in natural regenerant plants on GA-modified NM. A similar effect was observed in varieties 'Tonda Romana', 'Tonda Gentile Dele Lange' and 'Barcelona'. However, GA almost did not affect the amount of flavonoids in the leaves of the 'Epsilon' and 'Tonda Di Giffoni' varieties, which also indicates a non-specific nature of the action of 3,4,5-trihydroxybenzoic acid. In the coordinates of the main components, after the addition of GA, the wild form among the group of varieties moved down along the F2 axis (a decrease in the content of flavonoids in the leaves) and slightly less along the F1 axis (due to a decrease in the content of polyphenols) (Fig. 4b), the movement of some varieties in the coordinates of the main components under the influence of GC is shown by arrows). A more noticeable decrease in the content of phenols compared to the control group of plants was observed only in the 'Tonda Gentile Dele Lange' variety, which was also noted for the largest contribution to the overall variance (Table 2).

The revealed feature of the action of hydroxybenzoic acid may be related to the variety-specific sensitivity of plants to it by type: dose – effect. In the case of isothermal conditions and a regular photoperiod (16 hours), its effect on phenylpropanoid and flavonoid synthesis depended on the NM composition, GA concentration, and pH of the medium. It is known that GA can form coordination complexes with metal ions, which depend on the acidity of the medium [33]. Accordingly, under the conditions of adding GA to the NM composition, the mobility and availability of trace elements for plants may vary. In a slightly alkaline medium, a stable Fe^{3+} ion complex is combined by three coordination bonds with gallic acid, and in a slightly acidic medium, it gradually dissociates with the transition to bis-coordination [34]. In the pH range from 3.52 to 5.50, GA interacts with Fe^{2+} ions in the ratio of 1:1 [28].

In this experiment, a chelated form of iron (Fe-EDDHA) was added to NM, which is more stable and accessible to hazel plants compared to Fe-EDTA [35]. Iron in the form of Fe-EDTA at pH 5.7 is photooxidised to form iron oxide [36], which causes acute deficiency of an extremely important element for hazel explants [35; 37]. The system of phenolic synthesis enzymes is very sensitive to iron ion deficiency [38]. Their lack, for example, activates the synthesis of coumarin, which is released by the roots of some plants with the participation of a transporter protein. As a result, an organometallic complex with a physiologically accessible form of iron is formed.

It is known that the equilibrium constant of the complex Fe^{2+} with GA (log(K)~7) [39] is significantly less than the equilibrium constant of its binding to Fe^{3+} ions (log(K)~34) [40]. This indicates that under the conditions of adding GA to the nutrient medium, the stability of the chelate complex Fe-EDDHA (log(K)~35.09) should be maintained. However, for different volume ratios of aqueous solutions Fe-EDDHA and GA, certain interactions occur between the components, which is determined by the adsorption spectra of light energy (Fig. 5a).

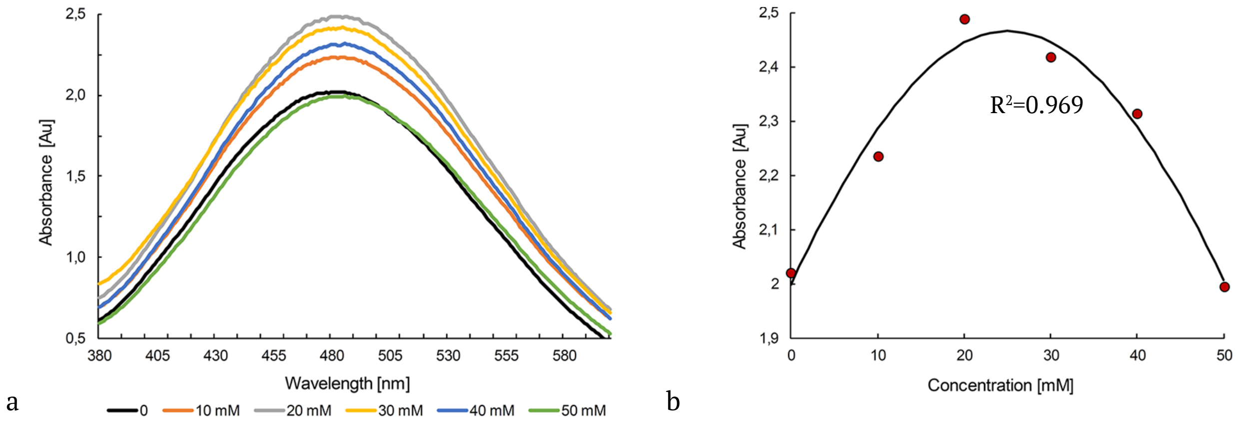


Figure 5. Light energy absorption spectra of the chelated form of iron (10 mmol Fe-EDDHA): a – at different wavelengths after adding a gallic acid solution; b – at the maximum absorption (λ_{max}=480 nm) with the addition of gallic acid

When adding 10 mmol GA solution to chelated iron, the light absorption index (λ_{max}= 480 nm) the resulting solution reached its maximum volume ratio (v/v) – 1:2. With a further increase in the volume fraction of GA, the absorption of the solution gradually decreased (Figure 5b). A possible explanation for the detected effect is the partial protonation of EDDHA in solution, which creates prerequisites for the competition of GA for coordination bonds with iron ions. After reaching a certain equilibrium, the interaction of hydroxybenzoic acid with the chelate complex slows down.

The stability of Fe-EDDHA in an aqueous solution was confirmed by chromatography (Fig. 6). At the same time, in the case of chromatographic separation of a 10 mmol aqueous solution of iron chelate, two products were detected (Fig. 6a). The EDDHA ligand is known to exist in three forms. Of these, the ortho- and ortho-isomer EDDHA has the best complexing ability, which has six binding sites and forms stable chelates [32]. Two peaks on the chromatogram probably correspond to Fe(III)-rac-o,o-EDHHA (Rf~0.50) and Fe(III)-meso-o,o-EDHHA (Rf~0.55), which are the main components in the chelate complex [41]. The stability coefficients of these isomers are 35.86 and 34.15, respectively [42]. When the GA solution was added, the peak area of one of the metal chelate isomers with a retention factor (Rf~0.55) on chromatography initially increased, and when the volume fraction of GA increased, it decreased until it almost completely disappeared (Figs. 6c-6f), which is consistent with spectrophotometry data (Fig. 5b). Considering that equilibrium constant of meso Fe-(o,o)EDDHA is very close to the Fe^{3+} complex with GA, it interacted with the latter when added to the iron chelate, as observed in the densitograms. The total area of the main peaks on the densitogram for the introduction of GA into the Fe-EDDHA solution in a volume ratio of 1:2 first increased, and then gradually decreased with an increase in the volume fraction of hydroxybenzoic acid. Under other chromatography conditions, the chelate complex and GA were separated differently (Fig. 6b). This revealed a direct relationship between the increase in the Fe-EDDHA retention factor (Rf~0.90 to 0.93) and the volume fraction of hydroxybenzoic acid. This also confirms that under such conditions, GA affects the coordination complexes of at least one of the iron chelate isomers.

At low concentrations in plant tissues, GA accelerates the desoxydation of Fe^{3+} to Fe^{2+}. Divalent iron is more accessible to plants, but under stress, cells actively synthesise H_2O_2, and in the presence of Fe^{2+}, the Fenton reaction (catalytic decomposition of hydrogen peroxide by iron ions to form a hydroxyl radical) is triggered [26]. Under such conditions, GA is able to reduce energy barriers and accelerate the oxidation of organic compounds [43]. In addition, as a result of desoxydation of Fe^{3+} to Fe^{2+}, GA is converted to a semiquinone radical, which can then be reduced by Fe^{3+} ions to biologically active quinones [44; 45]. In the presence of oxygen, semiquinone is oxidised to form a superoxide anion radical that has mutagenic

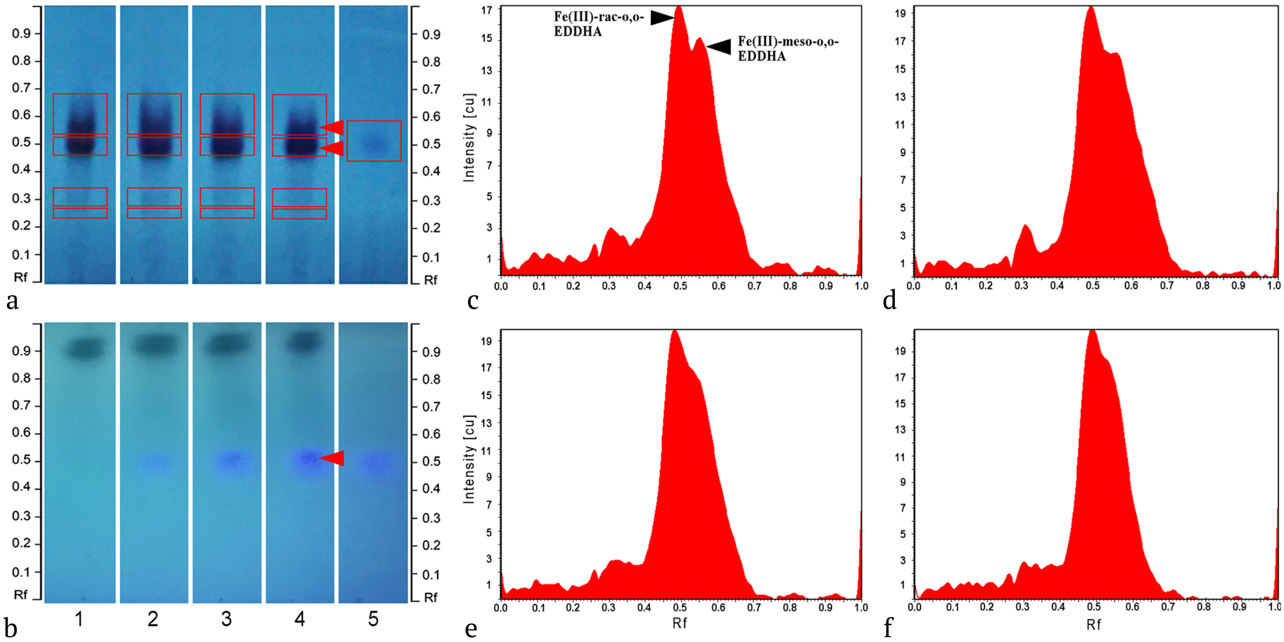


Figure 5. Chromatograms (a-b) and densitograms (c-f) of solutions: 1, (c) – 10 mmol Fe-EDDHA, for adding gallic acid solution to iron chelate: 2, (d) – 10 mmol, 3, (e) – 20 mmol, 4, (f) – 30 mmol, 5, (d) – 10 mmol gallic acid; arrows on chromatograms show GA (a) and Fe-EDDHA forms (b)

activity [46]. In living cells, a general increase in the concentration of free radicals causes oxidative stress due to the establishment of oxidised proteins, lipids, and biopolymers [47]. Thus, at the GA concentration of 10^{-5}-10^{-3} mol, an order of magnitude higher than that used in this experiment (10^{-6} mol), the processes of *Cucumis sativus* L. seed germination and seedling growth are suppressed [48]. In addition, it is known that hydrolysed tannins, which include GA, form chelates with metal ions depending on their valence, ionic radius, and polarity coefficient, which directly affects the physiological availability of elements for plants. In polycationic solutions, which also include nutrient media, metals with a higher valence and a larger ionic radius are primarily chelated [32]. Thus, by the presence of Fe^{3+} and Fe^{2+} ions in the medium under conditions of competitive complexation, chelation occurs mainly with a trivalent iron ion, which is conditioned by a higher stability constant of the complex. Chelates with Cu^{2+} can also form quite quickly. With macro- and microelements Zn^{2+}, Mg^{2+}, Sa^{2+}, and K^{+}, this process may be somewhat slower. With the addition of Fe-EDDHA to the NM, not only iron ions but also the ligand itself, which is capable of chelating other trace elements inside the tissues, enter the tissues of *Corylus avellana* plants [49].

The formation of gallic acid chelate complexes with metal ions can significantly affect the mobility of trace elements in the nutrient medium and their bioavailability, which determines the physiological state of plants. In addition, the concentration of trihydroxybenzoic acid used in the experiment is not sufficient for the complete chelation of existing metal ions. Therefore, the vast majority of macro- and microelement salts in the nutrient medium remained relatively unchanged.

The study found that exogenous GA increased the morphometric parameters of the leaf plate, shoots, and roots. Similar results were obtained on *Oryza sativa* L. plants, where an increase in shoots and roots was observed by 1.28 and 2.05 times, respectively, under the action of GA (60 μg/ml) in relation to the control [50]. According to cold stress, GA had a positive effect on plant growth indicators of *Glycine max* (L.) Merr. [51]. Based on the results obtained by A. Singh et al. [50] during the treatment of *Oryza sativa* with GA, the total level of phenolic compounds increased by 1.31 times compared to the control. A similar effect was observed in *Lepidium sativum* L. plants. Exogenous gallic acid not only increased the total content of phenolic compounds (by 19%) and antioxidant activity (46%), but also increased plant resistance to salt stress [52]. GA and its derivatives have been shown to increase plant resistance to low positive temperatures and drought [53], and reduce the toxic effect of copper on *Zea mays* L. [54]. In callus tissues of *Solanum lycopersicum* L. after the introduction of GA into NM, the concentration of phenols and flavonoids increased by 1.6 and 1.8 times, respectively [55], which indicates a significant effect of GA on the phenolic synthesis of the plant. However, in this study, the response of regenerant plants to exogenous GA was significantly different. Thus, in half of the 6 *Corylus avellana* varieties under study, the phenol content in the leaves also increased. At the same time, in the wild form and other varieties, on the contrary, it decreased. This may indicate the species- and variety-specific sensitivity of these plants to GA and its concentration. Thus, when treated with 10 mmol ferulic, coumaric, and vanillic acids, seed germination and seedling growth of *Chenopodium album* L., *Solanum nigrum* L., *Amaranthus retroflexus* L. were almost completely suppressed The effect of GA on these plant species was insignificant and depended on the concentration of hydroxybenzoic acid. Thus, for *Chenopodium album* and *Solanum nigrum*, the optimal concentration for growth was 0.01 mmol, for *Amaranthus retroflexus* – 0.1 mmol. Other oxybenzoic acids showed both growth-stimulating and inhibiting effects on different species [56].

Based on the results of assessing the general condition of regenerant plants of *Salix alba* and *Corylus avellana* in the *in vitro* conditions, there were no signs of suppressed growth, abnormal stem development, or leaf pigmentation disorders. According to physiological indicators, the presence of 1 $mmol{\cdot}L^{-1}$ GA in NM is mainly regulatory in nature. Variety-specific and individual sensitivity of plants to exogenous GA are primarily conditioned by the redox status of regenerant plants, which determines the direction of metabolism, in particular, associated with morphogenesis, transport of active forms of phytohormones, and other processes in which 3,4,5-trihydroxybenzoic acid and its chelated complexes with metals directly or indirectly participate.

Conclusions

The presence in the nutrient medium of individual phenolcarboxylic acid, which is part of hydrolysed tannins as one of the main components, even in micromolar concentrations can significantly affect the functionality of plant tissues. Exogenous gallic acid at a concentration of 10^{-6} mol as part of the DKW nutrient medium (pH 6.0) contributed to the branching of stems, the development and growth of lateral roots of *Salix alba* L. regenerant plants. In *Corylus avellana* L. regenerant plants, gallic acid caused an increase in the total number and elongation of internodes. Availability in nutrient medium composition of gallic acid and chelate complex Fe-EDDHA did not cause pigmentation disorders in willow and hazel leaves. Given that equilibrium constant of meso Fe-(o,o)-EDDHA as one of the main isomers of the chelate complex is very close to the equilibrium constant of the ion complex Fe^{3+} with gallic acid, the latter is able to interact with the iron chelate isomer and affect its physiological activity and accessibility for plants. This hydroxybenzoic acid caused a decrease in the total content of phenolic compounds, in particular flavonoids, in the leaves of *Corylus avellana* regenerant plants, which is especially important for plants at the stage of their introduction into plant tissue culture. Special attention should be paid to the fact that the phenolic synthesis of the studied hazel varieties of Italian and North American selection for gallic acid had varietal differences, which confirms its non-specific regulatory properties, which may be related to its ability to interact with the corresponding isoenzymes. Given the ability of gallic acid to form chelated complexes with other trace elements, it remains an open question in what form it enters explants and is subsequently transported in tissues. Further studies of the specificity of the effect of gallic acid on plant phenolic synthesis would provide a better understanding of its role in secondary metabolism, and determine the range of functional possibilities for its practical application in plant biotechnology.

References

[1] Harborne, D. (1985). *Introduction to ecological biochemistry*. moscow: Mir.

[2] Chen, L.C., Wang, S.L., Wang, P., & Kong, C.H. (2014). Autoinhibition and soil allelochemical (cyclic dipeptide) levels in replanted Chinese fir (*Cunninghamia lanceolata*) plantations. *Plant Soil*, 374, 793-801.

[3] Dayan, F.E., & Duke, S.O. (2014). Natural compounds as next-generation herbicides. *Plant Physiol*, 166, 1090-1105.

[4] Lattanzio, V., Cardinali, A., Ruta, C., Fortunato, I.M., Lattanzio, V.M.T., Linsalata, V., & Cicco, N. (2009). Relationship of secondary metabolism to growth in oregano (*Origanum vulgare* L.) shoot cultures under nutritional stress. *Environmental and Experimental Botany*, 65, 54-62.

[5] Meinzer, F.C., Wisdom, C.S., Gonzalez-Coloma, A., Rundel, P.W., & Shultz, L.M. (1990). Effects of leaf resin on stomatal behaviour and gas exchange of *Larrea tridentata* (DC.). *Cover of Functional Ecology*, 4, 579-584.

[6] Lattanzio, V., Lattanzio, V.M.T., & Cardinali, A. (2006). Role of phenolics in the resistance mechanisms of plants against fungal pathogens and insects. *Phytochemistry: Advances in Research*, 3, 23-67.

[7] Caretto, S., Linsalata, V., Colella, G., Mita, G., & Lattanzio, V. (2015). Carbon fluxes between primary metabolism and phenolic pathway in plant tissues under stress. *International Journal of Molecular Sciences*, 16, 26378-26394.

[8] El-Nagar, A., Elzaawely, A.A., Taha, N.A., & Nehela, Y. (2020). The antifungal activity of gallic acid and its derivatives against *Alternaria solani*, the causal agent of tomato early blight. *Agronomy*, 10(9), article number 1402. doi: 10.3390/agronomy10091402.

[9] Fiehn, O. (2002). Metabolomics – the link between genotypes and phenotypes. *Plant Molecular Biology*, 48, 155-171.

[10] Rhoades, D.F. (1979). Evolution of plant chemical defense against herbivores. In *Herbivores: Their interaction with secondary plant metabolites*. (pp. 3-54). New York: Academic Press.

[11] Les, D.H., & Sheridan, D.J. (1990). Biochemical heterophylly and flavonoid evolution in North American Potamogeton (Potamogetonaceae). *American Journal of Botany*, 77, 453-465.

[12] Pizzi, A., & Cameron, F.A. (1986). Flavonoid tannins – structural wood components for droughtresistance mechanisms of plants. *Wood Science and Technology*, 20, 119-124.

[13] Kimura, M., & Wada, H. (1989). Tannins in mangrove tree roots and their role in the root environment. *Soil Science & Plant Nutrition*, 35, 101-108.

[14] Seigler, D.S. (1977). Primary roles for secondary compounds. *Biochemical Systematics and Ecology*, 5, 195-199.

[15] Tarchevsky, I.A. (2002). *Signaling systems of plant cells*. moscow: Nauka.

[16] Broun, P. (2005). Transcriptional control of flavonoid biosynthesis: A complex network of conserved regulators involved in multiple aspects of differentiation in Arabidopsis. C*urrent Opinion in Plant Biology*, 8(3), 272-279.

[17] Doberski, J. (1986). Simple phenolic compounds and the growth of plants: A short review. *Journal of Biological Education*, 20, 96-98.

[18] Graña, E., Costas-Gil, A., Longueira, S., Celeiro, M., Teijeira, M., Reigosa, M.J, & Sánchez-Moreiras, A.M. (2017). Auxin-like effects of the natural coumarin scopoletin on Arabidopsis cell structure and morphology. *Journal of Plant Physiology*, 218, 45-55.

[19] Brown, D.E., Rashotte, A.M., Murphy, A.S., Normanly, J., Tague, B.W., Peer, W.A., Taiz, L., Muday, G.K. (2001). Flavonoids act as negative regulators of auxin transport in vivo in Arabidopsis. *Plant Physiol*, 26(2), 924-535.

[20] Jacobs, M., & Rubery, P.H. (1988). Naturally occurring auxin transport regulators. *Science*, 241, 346-349.

[21] Subin, O.V., Melnychuk, M.D., Likhanov, A.F., & Klyachenko, O.L. (2016). Effect of salicylic acid on the organogenesis of garden strawberry plants (*Fragaria ananassa* Duch.) *in vitro* culture. *Physiology of Plants and Genetics*, 48(1), 26-33.

[22] Likhanov, A.F., Sereda, O.V., Klyachenko, O.L., & Melnychuk, M.D. (2018). Influence of hydroxy-cinnamic and oxybenzoic acids on synthesis of plastid pigments and fenolic compounds in the leaves of common grape vine (*Vitis vinifera*) *in vitro*. *Plant Physiology and Genetics*, 50(4), 331-343. doi: 10.15407/frg2018.04.331.

[23] Oliinyk, O.O., Likhanov, A.F., & Melnychuk, M.D. (2017). Effect of oxycinnamic and oxybenzoic acids on metabolism and regeneration processes in explants of rose ethereal *in vitro* culture. *Biological systems*, 9(1), 33-38.

[24] Bilous, S.Yu. (2012). Peculiarities of callusogenesis of *Populus tremula* L. in *in vitro* culture. *Scientific bulletin of NLTU of Ukraine*, 22.10, 19-25.

[25] Chornobrov, O.Yu. (2020). Analysis of the application of biotechnology in obtaining high-quality planting material of plants of the *Salicaceae* Mirb family *in vitro* to create bioenergy plantations. *Ukrainian Journal of Forestry and Wood Science*, 11(4), 60-68.

[26] Chu, W., Kwan, C.Y., Chan, K.H., & Chong, C. (2004). An unconventional approach to studying the reaction kinetics of the Fenton's oxidation of 2,4-dichlorophenoxyacetic acid. *Chemosphere*, 57, 1165-1171. doi: 10.1016/j.chemosphere.2004.07.047.

[27] Hynes, M.J., & Ó Coinceanainn, M. (2001). The kinetics and mechanisms of the reaction of iron(III) with gallic acid, gallic acid methyl ester and catechin. *Journal of Inorganic Biochemistry*, 85(2-3), 131-142. doi: 10.1016/s0162-0134(01)00205-7.

[28] Frešer, F., Hostnik, G., Tošović, J., & Bren, U. (2021). Dependence of the Fe(II)-gallic acid coordination compound formation constant on the pH. *Foods*, 10, article number 2689. doi: 10.3390/foods10112689.

[29] Bacchetta, L., Aramini, M., & Bernardini, C. (2008). *In vitro* propagation of traditional Italian Hazelnut cultivars as a tool for the valorization and conservation of local genetic resources. *Hortscience*, 43(2), 562-566.

[30] Driver, J., & Kuniyuki, A. (1984). *In vitro* propagation of Paradox walnut rootstock. *HortScience*, 19, 507-509.

[31] Mamdouh, D. (2021). Genetic stability, phenolic, flavonoid, ferulic acid contents, and antioxidant activity of micropropagated *Lycium schweinfurthii* plants. *Plants*, 10(10), article number 2089. doi: 10.3390/plants10102089.

[32] Wang, J., Wang, Y., Wang, F., & Jiang, J. (2008). Behavior of tannins in germanium recovery by tannin process. *Hydrometallurgy*, 93(3-4), 140-142. doi: 10.1016/j.hydromet.2008.03.006.

[33] Fazary, A.E., Taha, M., & Ju, Y.H. (2009). Iron complexation studies of gallic acid. *Journal of Chemical & Engineering Data*, 54, 35-42.

[34] Liu, F., He, X., Chen, H., Zhang, J., Zhang, H., & Wang, Z. (2015). Gram-scale synthesis of coordination polymer nanodots with renal clearance properties for cancer theranostic applications. *Nature Communications*, 6(1), article number 8003. doi: 10.1038/ncomms9003.

[35] Garrison, W., Dale, A., & Saxena, P.K. (2013). Improved shoot multiplication and development in hybrid hazelnut nodal cultures by ethylenediamine di-2-hydroxy-phenylacetic acid (Fe-EDDHA). *Canadian Journal of Plant Science*, 93, 511-521. doi: 10.4141/CJPS2012-218.

[36] Hangarter, R.P., & Stasinopoulos, T.C. (1991). Effect of Fe-catalyzed photo oxidation of EDTA on root growth in plant culture media. *Plant Physiol*, 96, 843-847.

[37] Sandoval Prando, M.A., Chiavazza, P., Faggio, A., & Contessa, C. (2014). Effect of coconut water and growth regulator supplements on *in vitro* propagation of *Corylus avellana* L. *Scientia Horticulturae*, 171, 91-94. doi: 10.1016/j.scienta.2014.03.052.

[38] Lan, P., Li, W., Wen, T.-N., Shiau, J.-Y., Wu, Y.-C., Lin, W., & Schmidt, W. (2011). iTRAQ protein profile analysis of Arabidopsis roots reveals new aspects critical for Fe homeostasis. *Plant Physiol*, 155, 821-834.

[39] Powell, H., & Taylor, M. (1982). Interactions of iron(II) and iron(III) with gallic acid and its homologues – a potentiometric and spectrophotometric study. *Australian Journal of Chemistry*, 35, 739-756.

[40] Strlic, M., Radovic, T., Kolar, J., & Pihlar, B. (2002). Anti- and prooxidative properties of gallic acid in Fenton-type systems. *Journal of Agricultural and Food Chemistry*, 50, 6313-6317.

[41] Klem-Marciniak, E., Huculak-Mączka, M., Marecka, K., Hoffmann, K., & Hoffmann, J. (2021). Chemical stability of the fertilizer chelates Fe-EDDHA and Fe-EDDHSA over Time. *Molecules*, 26, article number 1933. doi: 10.3390/molecules26071933.

[42] Yunta, F., García-Marco, S., Lucena, J.J., Gómez-Gallego, M., Alcázar, R., & Sierra, M.A. (2003). Chelating agents related to ethylenediamine Bis(2-hydroxyphenyl)acetic Acid (EDDHA): Synthesis, characterization, and equilibrium studies of the free ligands and their Mg^{2+}, Ca^{2+}, Cu^{2+}, and Fe^{3+}Chelates. *Inorganic Chemistry*, 42(17), 5412-5421. doi: 10.1021/ic034333j.

[43] Tabelini, C.H.B., Lima, J.P.P., & Aguiar, A. (2021). Gallic acid influence on azo dyes oxidation by Fenton processes. *Environmental Technology*, 3.475, 1-11. doi: 10.1080/09593330.2021.1921855.

[44] Dong, H., Sans, C., Li, W., & Qiang, Z. (2016). Promoted discoloration of methyl orange in H2O2/ Fe(III) Fenton system: Effects of gallic acid on iron cycling. *Separation and Purification Technology*, 171, 144-150. doi: 10.1016/j.seppur.2016.07.033.

[45] Christoforidis, K.C., Vasiliadou, I.A., Louloudi, M., & Deligiannakis, Y. (2018). Gallic acid mediated oxidation of pentachlorophenol by the Fenton reaction under mild oxidative conditions. *Journal of Chemical Technology & Biotechnology*, 93, 1601-1610. doi: 10. 1002/jctb.5529.

[46] Chesis, P.L., Levin, D.E., Smith, M.T., Ernster, L., & Ames, B.N. (1984). Mutagenicity of quinones: Pathways of metabolic activation and detoxification. *Proceedings of the National Academy of Sciences*, 81, 1696-1700.

[47] Moskalenko, N.I., Komarovska-Porokhniavets, O.Z., Iskiv, O.P., & Stadnytska, N.E. (2008). Biological and pharmacological aspects of quinones. *Bulletin of the National Lviv Polytechnic University*, 609, 124-130.

[48] Muzaffar, S., Ali, B., & Wani, N.A. (2012). Effect of catechol, gallic acid and pyrogallic acid on the germination, seedling growth and the level of endogenous phenolics in cucumber (*Cucumis sativus* L.). *International Journal of Life Sciences Biotechnology and Pharma Research*, 1(3), 50-55.

[49] Bienfait, H.F., Garcia-Mina, J., & Zamareño, A.M. (2004). Distribution and secondary effects of EDDHA in some vegetable species. *Soil Science and Plant Nutrition*, 50(7), 1103-1110. doi: 10.1080/00380768.2004.10408581.

[50] Singh, A., Gupta, R., & Pandey, R. (2017). Exogenous application of rutin and gallic acid regulate antioxidants and alleviate reactive oxygen generation in *Oryza sativa* L. *Physiology and Molecular Biology of Plants*, 23(2), 301-309. doi: 10.1007/s12298-017-0430-2.

[51] Ozfidan-Konakci, C., Yildiztugay, E., Yildiztugay, A., & Kucukoduk, M. (2019). Cold stress in soybean (*Glycine max* L.) roots: Exogenous gallic acid promotes water status and increases antioxidant activities. *Botanica Serbica*, 43, 59-71. doi: 10.2298/BOTSERB1901059O.
[52] Babaei, M., Shabani, L., & Hashemi-Sahraki, Sh. (2022). Improving the efects of salt stress by β-carotene and gallic acid using increasing antioxidant activity and regulating ion uptake in *Lepidium sativum* L. *Botanical Studies*, 63(1), article number 22. doi: 10.1186/s40529-022-00352-x.
[53] Senaratna, T., Merritt, D., Dixon, K., Bunn, E., Touchell, D., & Sivasithamparam, K. (2003). Benzoic acid may act as the functional group in salicylic acid and derivatives in the induction of multiple stress tolerance in plants. *Plant Growth Regulation*, 39, 77-81.
[54] Yetissin, F., & Kurt, F. (2020). Gallic acid (GA) alleviating copper (Cu) toxicity in maize (*Zea mays* L.) seedlings. *International Journal of Phytoremediation*, 22(4), 420-426. doi: 10.1080/15226514.2019.1667953.
[55] Farghaly, F.A., Salam, H.Kh., Hamada, A.M., & Radi, A.A. (2021) The role of benzoic acid, gallic acid and salicylic acid in protecting tomato callus cells from excessive boron stress. *Scientia Horticulturae*, 278, 1-11. doi: 10.1016/j.scienta.2020.109867.
[56] Reigosa, M.J., Souto, X.C., & Gonz, L. (1999) Effect of phenolic compounds on the germination of six weeds species. *Plant Growth Regulation*, 28, 83-88.

Галова кислота як неспецифічний регулятор фенольного синтезу і росту рослин-регенерантів *Corylus avellana* (L.) H.Karst. та *Salix alba* L. *in vitro*

Артур Федорович Ліханов, Андрій Андрійович Клюваденко, Олександр Володимирович Субін, Марія Олександрівна Шевчук, Марія Юріївна Дубчак

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Анотація. Галова кислота міститься у рослинних тканинах у вільній формі, а також у складі складних ефірів та гідролізованих танінів. Ці фенольні сполуки мають значну антиоксидантну активність і захищають клітини рослин від пошкодження вільними радикалами. В умовах стресу, який виникає під час введення рослин в культуру in vitro, для переважної більшості експлантатів характерним є інтенсивний синтез фенолів, які швидко окислюються, полімеризуються, блокують шляхи живлення експлантатів і викликають некротизацію тканин. Додавання галової кислоти у мілімолярних концентраціях до складу живильного середовища зменшує ризики автоінтоксикації тканин продуктами вторинного метаболізму. Метою даної роботи було дослідити вплив екзогенної галової кислоти на органогенез і фенольний синтез рослин *Salix alba* і *Corylus avellana* в умовах *in vitro*. Для цього використовували методи культури тканин і органів *in vitro*, спектрофотометричного визначення у листках загальних фенолів і флавоноїдів, методи дисперсійного і непараметричного аналізу. Встановлено, що галова кислота в концентрації 1 мМ·л$^{-1}$ у складі живильного середовища Драйвера-Куньюки (DKW) викликала пробудження сплячих бруньок, стимулювала ріст пагонів, сприяла галуженню стебел, а також розвитку і росту бічних коренів *Salix alba* в культурі *in vitro*. Фенолкарбонова кислота гальмувала синтез фенолів у рослин *Corylus avellana* сортів 'Тонда Романа', 'Тонда Гентіль Делє Ланге', 'Барселона', водночас сприяла підвищенню вмісту фенольних сполук у листках сортів ‹Тонда Ді Джифоні›, 'Мортарелла', 'Епсилон'. Встановлено, що рекомендований у якості запилювача сорт 'Мортарелла' містить у листках менше фенольних сполук ніж сорти для плодоношення ('Тонда Гентіль Делє Ланге' і 'Тонда Ді Джиффоні'). Отже екзогенна галова кислота в концентрації 1 мМ·л$^{-1}$ має властивості неспецифічного регулятора фенольного синтезу у рослин-регенерантів ліщини (*Corylus avellana*). Вона знижує негативні наслідки автоінтоксикації тканин продуктами окислення поліфенолів, що актуально для рослин з високим вмістом фенольних сполук особливо на етапі їх введення в культуру *in vitro*. Чутливість рослин-регенерантів до 3,4,5-тригідроксибензойної кислоти має практичне значення в аспекті виявлення генотипів з потенційно активним ростом

Ключові слова: розвиток, гідроксибензойна кислота, органогенез, феноли, флавоноїди, живильне середовище

Received: 09/09/2022; Revised: 23/10/2022; Accepted: 14/12/2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4), 64-73

UDC 630*27:631.895:635.921
DOI: 10.31548/forest.13(4).2022.64-73

Optimisation of Substrate Composition and Level of Mineral Nutrition as the Basis of Improving the Production of Decorative Plants in Container Culture

Victor Maurer*, Andrii Pinchuk

Education and Research Institute of Forestry and Landscape-Park Management
National University of Life and Environmental Sciences of Ukraine
03041, 19 Horikhuvatskyi Shliakh Str., Kyiv, Ukraine

Abstract. The current significant increase in the volume of growing ornamental seedlings in container culture in tree nurseries is conditioned by a number of significant advantages of planting material with an uninjured root system. At the same time, the agricultural technology for the production of such seedlings in container culture is much more complicated, compared to the traditional one. First of all, this is conditioned by growing them in a space limited by the size of containers and using an artificially prepared substrate. The purpose of the study was to conduct biotesting of three modifications of the substrate composition for the container culture of *Spiraea japonica* 'Goldflame', *Tamarix tetrandra* Pall. ex Bieb., *Forsythia ovate* Nakai and different doses of starter fertilisers "Nitroamofoska" and "Plantacote". The study used both general scientific methods of analysis, synthesis, and active experimentation, as well as applied research methods such as biometric, phenological, soil, and agrochemical. Studies have established the presence of species-specific reactions of experimental plants with different fastidiousness to soil conditions, to the composition of the substrate and the types and doses of starter fertiliser used in container culture. A conclusion was made regarding the increase in the profitability of their cultivation due to the use of cheaper local components for the preparation of the substrate. The conducted studies showed a number of advantages of using organo-mineral slow-release fertilisers in container culture as a starter, in particular, "Plantacote" at a dose of 2.5-5.0 $g \cdot l^{-1}$. That the mass production of decorative planting material with a closed root system should be preceded by research on establishing species-specific reactions of cultivated plants to cultivation conditions, which are the basis for optimising the composition of the substrate and the level of mineral nutrition of cultivated plants in order to increase the efficiency of the production of decorative seedlings in container culture. The obtained results will be useful for producers of planting material and the scientific community working towards the development of container culture of ornamental plants

Keywords: rooted cuttings, cutting seedlings, decorative planting material with a closed root system, substrate, substrate components, starter fertiliser

Suggested Citation:
Maurer, V., & Pinchuk, A. (2022). Optimisation of substrate composition and level of mineral nutrition as the basis of improving the production of decorative plants in container culture. *Ukrainian Journal of Forest and Wood Science*, 13(4), 64-73.

*Corresponding author

Introduction

A significant increase in recent years in the production of ornamental seedlings in container culture in nurseries is conditioned by a number of significant advantages of planting material with an uninjured root system, the main one of which is its 100% survival rate and the possibility of using it almost throughout the year [1-3].

At the same time, the agricultural technology of production of ornamental seedlings with a closed root system in container culture is more complex than traditional and therefore requires more care and professionalism [2; 4]. First of all, this is due to growing them in a space limited by the size of containers and using an artificially prepared substrate. The latter, considering the species-specific biological features of cultivated plants, is extremely important, since the water and physical properties of the substrate and the content of nutrients in it must meet the requirements of container culture [5-7]. In this context, the use of optimised substrate compositions and the use of highly effective modern fertilisers with regard to the biological characteristics of cultivated plants can be considered as a powerful lever for improving container culture and increasing its profitability [8-10].

Research on growing plants of the genera *Spiraea, Tamarix, Forsythia* in container culture, considering local conditions, mainly concerned the problems of optimizing mineral nutrition, substrate pH and substrate components for plant growth and development.

K.M. Stanton and M.V. Mickelbart investigated the effect of substrate pH in container culture of *Spiraea alba* and *Spiraea tomentosa* on the physiological state of plants and the level of mineral nutrition [5]. Researchers from Canada investigated the effects of various fertilisers and determined the best feeding system *Spiraea·bumalda* 'Goldmound' when grown in containers [11]. M.Z. Alam et al. studied the effect of various methods on the growth of *Forsythia x intermedia* 'Spring Glory' in container culture and the leaching of nutrients into the environment [12]. During the cultivation of *Tamarix chinensis* plants in containers, the reaction of plants to changes in soil salinity, increased stress resistance, and the dynamics of the physical and biochemical characteristics of the studied plants were investigated [7]. Romanian scientists have conducted research on the cultivation of *Tamarix tetrandra* and other species in container culture to replace peat in the substrate with alternative substrate components [13].

This determines the relevance of research on optimising the composition of the substrate and the use of various doses of conventional and modern starter fertilisers for the production of ornamental seedlings in container culture, considering their species-specific features, using the example of *Spiraea japonica* 'Goldflame', *Tamarix tetrandra* Pall. ex Bieb. and *Forsythia ovate* Nakai.

The purpose of the study was to develop scientifically based recommendations for improving the production of cuttings of experimental plants with a closed root system at the expense of optimisation of substrate composition of the container culture substrate and using scientifically based doses of starter fertiliser.

The main objectives of the study were:

– to identify species-specific responses of experimental plants with different requirements to soil conditions in container culture to the substrate composition and the use of types and doses of starting fertiliser;

– to establish the possibility of improving the production of ornamental seedlings with a closed root system in container culture according to their species-specific reactions to the composition of the substrate and the starting fertiliser used.

– to develop scientifically based proposals for improving the efficiency of growing seedlings of experimental plants with a closed root system by optimising the composition of the substrate and the level of their mineral nutrition.

Materials and Methods

The research programme provided for testing (biotesting) of three modifications of the substrate composition for container culture of *Spiraea japonica* 'Goldflame', *Tamarix tetrandra* Pall. ex Bieb., *Forsythia ovate* Nakai and various doses of starter fertilisers (traditional "Nitroamofoska" (NPK) and modern organo-mineral slow-release fertiliser "Plantacote").

With the help of general scientific and applied research methods: active experiment, analysis and synthesis, phenological, agrochemical, soil, and biometric – an assessment of the physiological state of experimental plants, their development, and growth parameters was carried out, and the conclusions were formulated based on the results obtained.

The research was conducted during 2019-2020. An experiment to investigate the influence of modern mineral fertilisers and substrate composition on the state and growth of container culture of experimental plants was conducted at the container culture training and research nursery of the Department of Forest Reproduction and Forest Reclamation of the National University of Life and Environmental

Sciences of Ukraine. In the experiment, the starting material was stem cuttings rooted in the course of studies on the effectiveness of using growth substances to activate rhizogenesis [14-16].

Cuttings were planted in 2-litre containers with three modifications of the substrate composition, for the preparation of which four components were used: peat, sand, humus layer of grey forest soil, and sawdust compost, in the following ratios: the first option – 2:1:1:1, the second – 1:1:2:1, and the third – 2:1:2:1. Each option, with the predominance of certain components, represented one of the following modifications of the substrate composition: peat (the first option), soil (the second), peat and soil (the third).

In the experiment to optimise the composition of the substrate and the level of mineral nutrition of experimental plants, five variants of the starting fertiliser were tested, which was applied in containers simultaneously with the planting of rooted cuttings: control (without fertilisation), traditional mineral fertiliser "Nitroamofoska" (5 g/l of substrate), and three variants with different doses of organo-mineral slow-release fertiliser "Plantacote": the minimum (half of the dose recommended by the manufacturer – or 2.5 g/l of substrate), recommended (5 g/l) and maximum dose, increased by one and a half times, compared to the one specified by the manufacturer (7.5 g/l of substrate).

The influence of various modifications of the substrate composition and fertiliser doses tested in the experiment on the container culture of experimental plants was determined by the survival rate of rooted cuttings, the safety of cuttings seedlings, the results of biotesting their condition and the intensity of growth in height.

The survival rate of rooted cuttings was determined 5 months after planting them in containers, and the safety of cuttings seedlings was determined by the proportion of viable experimental plants – in the spring of the following year after their "conservation" for the winter was completed.

The condition of seedlings was determined monthly based on the results of their visual assessment. In the process of evaluation, experimental plants were divided into 4 categories: excellent condition, satisfactory, unsatisfactory, and non-viable. The first category included individuals without signs of weakening or damage, with a rich colour of the photosynthetic apparatus; the second – plants with weakened turgor, less saturated leaf colour and minor lesions and injuries; the third – seedlings with significant lesions and signs of drying out; the fourth – plants without signs of viability ("drop-off").

The height of seedlings in containers was measured with an accuracy of 0.1 cm with a frequency of once a month, starting with planting rooted cuttings in containers with tested modifications of the substrate composition.

Results and Discussion

In accordance with the goal, when conducting experimental studies, plants with different attitudes to soil conditions were used. The response of plants to soil conditions is determined by the ability of woody plants to obtain the necessary nutrients from the soil in sufficient quantities. Tree species with high fastidiousness grow successfully only on fertile soils, while low-demand species with high fastidiousness can also grow on poor soils. The reasons for the differences in the fastidiousness of woody plants to soil conditions have not been definitively established. The main factors that determine these differences include the size of the active surface of the root system. Woody species with a powerful, well-developed root system are able to receive nutrients from a large volume of soil, and therefore, can grow on poor soils with a low content of nutrients [17]. But species with a less powerful root system are not able to provide themselves with nutrients in similar conditions, and therefore, are considered more demanding on soil fertility. On poor soils, most tree species form a more developed root system than on rich ones. This also applies to a container crop with an artificially prepared substrate with different content of mineral nutrition elements available to plants. In this regard, the experiment used tree species with different demands on soil conditions: *Spiraea japonica* 'Goldflame', *Tamarix tetrandra* Pall. ex Bieb., *Forsythia ovate* Nakai [18].

For *Spiraea japonica* 'Goldflame' moist, loose, fertile soils are the most optimal. On acidic and medium-acidic soils, the colour of the leaves of spiraea becomes brighter.

Tamarix tetrandra Pall. ex Bieb. can grow in the poorest soils. It is drought-resistant, sometimes suffers from high humidity, is very light-loving and does not tolerate shading. Tamarix can withstand gas and dust in the air and high soil salinity.

Forsythia ovate Nakai is quite demanding for soil fertility and is a drought-resistant plant. It develops better in well-drained, humus-rich, fresh soils, but does not tolerate excessive moisture.

The efficiency of production of ornamental seedlings of container culture in conditions of limited size of containers, first of all, depends on the quality of the substrate and the level of mineral nutrition of plants [4; 19; 20].

The study of the species-specific reaction of experimental plants to the quality of the substrate was carried out on the example of three modifications of the substrate, in which the basic components were the most commonly used components in the practice of seedling: peat, sand, humus layer of grey forest soil, and sawdust compost. The results of studies of the survival rate of rooted cuttings, the safety of cuttings seedlings, the measurement of the height of experimental plants and visual assessment of their condition by external signs are given in Table 1.

Table 1. Main characteristics of cuttings of experimental plants in container culture depending on the modification of the substrate composition and the type and dose of starting fertiliser

Substrate options	**Starter fertiliser options**	**Percentage of experimental plants by state, %**				**Status Index**	**Survival rate of cuttings, %**	**Seedling safety, %**
		Excellent	**Good**	**Satisfactory**	**Drop-off**			
1	2	3	4	5	6	7	8	9
Spiraea japonica* 'Goldflame' *seedlings								
1 – peat	Control	25	17	16	42	**2.3**	**75**	**58**
	NPK (5 $g \cdot l^{-1}$)	33	33	17	17	**2.8**	**92**	**83**
	Plantacote (2.5 $g \cdot l^{-1}$)	42	42	8	8	**3.2**	**100**	**92**
	Plantacote (5 $g \cdot l^{-1}$)	33	42	17	8	**3.0**	**92**	**92**
	Plantacote (7.5 $g \cdot l^{-1}$)	17	33	25	25	**2.4**	**83**	**75**
2 – soil	Control	17	17	16	50	**2.0**	**83**	**50**
	NPK (5 $g \cdot l^{-1}$)	25	25	25	25	**2.5**	**92**	**75**
	Plantacote (2.5 $g \cdot l^{-1}$)	25	33	25	17	**2.8**	**92**	**92**
	Plantacote (5 $g \cdot l^{-1}$)	17	42	25	16	**2.6**	**92**	**83**
	Plantacote (7.5 $g \cdot l^{-1}$)	17	16	42	25	**2.3**	**75**	**75**
3 – peat and soil	Control	17	25	16	42	**2.2**	**92**	**58**
	NPK (5 $g \cdot l^{-1}$)	34	33	25	8	**3.0**	**100**	**92**
	Plantacote (2.5 $g \cdot l^{-1}$)	42	42	8	8	**3.3**	**92**	**92**
	Plantacote (5 $g \cdot l^{-1}$)	42	33	17	8	**3.1**	**100**	**92**
	Plantacote (7.5 $g \cdot l^{-1}$)	17	33	33	17	**2.5**	**92**	**83**
Tamarix tetrandra* Pall. ex Bieb. *seedlings								
1 – peat	Control	-	40	20	40	**2.0**	**96**	**92**
	NPK (5 $g \cdot l^{-1}$)	60	-	-	40	**2.8**	**100**	**92**
	Plantacote (2.5 $g \cdot l^{-1}$)	80	20	-	-	**3.8**	**100**	**100**
	Plantacote (5 $g \cdot l^{-1}$)	-	80	-	20	**2.6**	**100**	**96**
	Plantacote (7.5 $g \cdot l^{-1}$)	40	60	-	-	**3.4**	**100**	**100**
2 – soil	Control	-	20	20	60	**1.6**	**96**	**88**
	NPK (5 $g \cdot l^{-1}$)	20	20	20	40	**2.2**	**96**	**92**
	Plantacote (2.5 $g \cdot l^{-1}$)	-	60	20	20	**2.4**	**96**	**96**
	Plantacote (5 $g \cdot l^{-1}$)	60	40	-	-	**3.6**	**100**	**100**
	Plantacote (7.5 $g \cdot l^{-1}$)	20	40	20	20	**2.6**	**100**	**96**
3 – peat and soil	Control	-	60	-	40	**2.2**	**96**	**92**
	NPK (5 $g \cdot l^{-1}$)	60	20	-	20	**3.2**	**100**	**96**
	Plantacote (2.5 $g \cdot l^{-1}$)	60	-	40	-	**3.2**	**100**	**100**
	Plantacote (5 $g \cdot l^{-1}$)	100	-	-	-	**4.0**	**100**	**100**
	Plantacote (7.5 $g \cdot l^{-1}$)	80	20	-	-	**3.8**	**100**	**100**

Table 1, Continued

1	2	3	4	5	6	7	8	9
Forsythia ovate* Nakai *seedlings								
1 – peat	Control	10	20	20	50	**1.9**	**75**	**50**
	NPK (5 g·l-1)	30	30	20	20	**2.7**	**80**	**60**
	Plantacote (2.5 g·l-1)	40	20	10	30	**2.7**	**85**	**55**
	Plantacote (5 g·l-1)	50	20	10	20	**3.0**	**93**	**70**
	Plantacote (7.5 g·l-1)	10	20	10	60	**1.8**	**73**	**50**
2 – soil	Control	40	20	20	20	**2.8**	**87**	**70**
	NPK (5 g·l-1)	60	20	10	10	**3.3**	**93**	**85**
	Plantacote (2.5 g·l-1)	50	20	20	10	**3.1**	**88**	**80**
	Plantacote (5 g·l-1)	70	15	5	10	**3.5**	**95**	**90**
	Plantacote (7.5 g·l-1)	40	20	20	20	**2.8**	**86**	**75**
3 – peat and soil	Control	40	20	20	20	**2.8**	**87**	**73**
	NPK (5 g·l-1)	50	20	10	20	**3.0**	**88**	**75**
	Plantacote (2.5 g·l-1)	40	30	20	10	**3.0**	**93**	**78**
	Plantacote (5 g·l-1)	60	20	5	15	**3.3**	**94**	**85**
	Plantacote (7.5 g·l-1)	40	20	10	30	**2.7**	**86**	**70**

Source: compiled by the authors

Studies have established that the highest (92-100%) survival rate of rooted cuttings planted in containers and their safety (92%) after the "conservation" of *Spiraea japonica* 'Goldflame' cuttings for the winter, was in containers with peat and soil modification of the substrate composition (Option 3) and the use of traditional Nitroamofoska fertiliser and modern long-acting Plantacote fertiliser with minimum (2.5 g·l-1) and recommended by the manufacturer (5 g·l-1) doses. The lowest (75%) survival rate of rooted spiraea cuttings was in containers on a peat substrate (Option 1 of the composition modification), and the safety (50%) of seedlings – with a soil-based mixture (Option 1) in control (without applying starting fertiliser) plants. The findings show that, in addition to the composition of the substrate, the level of mineral nutrition significantly affects the survival and preservation of cuttings of *Spiraea japonica* 'Goldflame' (Fig. 1).

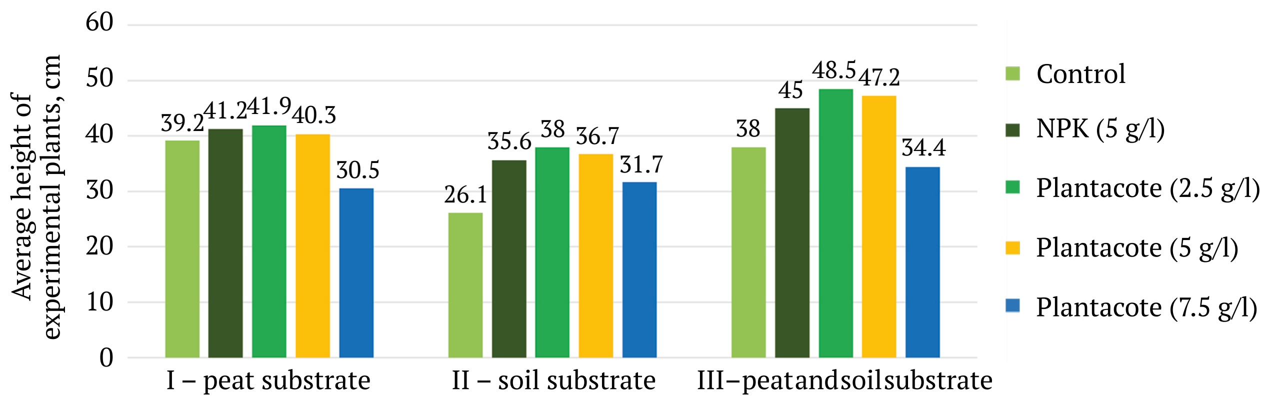


Figure 1. Height of *Spiraea japonica* 'Goldflame' cuttings, depending on the modification of the substrate composition and the type and dose of starting fertiliser

Source: compiled by the authors

The positive effect of "Plantacote" fertiliser has been established by M.J. Clark and Y. Zheng when growing *Spiraea·bumalda* 'Goldmound' variety in a container culture. Researchers have found that the best results were observed at a dose of 3.0-6.0 g of nitrogen per container. Moreover, it was revealed that an increase in the dose of "Plantacote" and "Osmocote Plus" fertilisers did not lead to an improvement in the condition of plants and changes in their morphormetric indicators [11]. In this study, an increase in the dose of application of "Plantacote" fertiliser to 7.5 g·l-1 has led to a deterioration in the condition of plants and, depending on the substrate, to a decrease in their survival rate. This trend was also observed when growing *Tamarix tetrandra* Pall. ex Bieb., *Forsythia ovate* Nakai plants in contained culture. The research conducted by M.J. Clark and Y. Zheng and the authors of this study, which provides data on plant condition assessment, timing and dose of fertiliser application, allows producers to select slow-release fertiliser rates to achieve production goals.

K.M. Stanton and M.V. Mickelbart found that the growth and development of *Spiraea alba* and *Spiraea tomentosa* plants is affected by changes in the level of mineral nutrition. At the same time, changes in the pH of the substrate significantly correlate with the absorption of mineral substances. It was found that increasing the pH of the substrate to 7.0 negatively affects plant growth and nutrient concentration. Due to the fact that most ornamental plants are grown on special substrates with long-acting fertilisers, further research is needed, taking into account the specific features of the grown plants [5]. According to experimental data, it was found that the high (96% and above) and maximum (100 %) survival rate of rooted cuttings of *Tamarix tetrandra* Pall. ex Bieb. was observed in containers with all tested variants of modifications of substrate compositions. The study suggests that it is conditioned by not high fastidiousness of this variety to soil conditions.

At the same time, tamarix seedlings were highly preserved in containers with peat and soil modification of the substrate and the starting organo-mineral slow-release fertiliser "Plantacote" with minimum (2.5 $g \cdot l^{-1}$) and maximum (7.5 $g \cdot l^{-1}$) doses. As in the experiment with spirea, the lowest survival rate (96%) and safety (88%) of cuttings of *Tamarix tetrandra* Pall. ex Bieb. seedlings was under control (without fertilisation) of the soil modification of the substrate composition (Fig. 2).

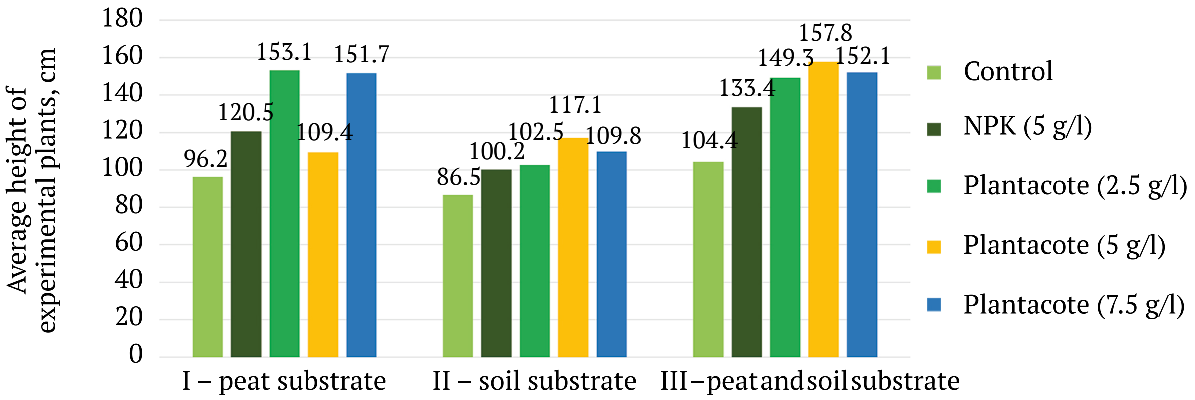


Figure 2. Height of cuttings of *Tamarix tetrandra* Pall. ex Bieb. depending on the modification of the substrate composition and the type and dose of starting fertiliser
Source: compiled by the authors

The studyby R. Madjar et al. on growing *Tamarix tetrandra* plants in a container culture with a decrease in the volume in the peat substrate showed a positive result. In addition to good plant growth on a substrate of leafy land, forest land, peat, and compost from crushed grapes in a ratio of 1:1:1:0.5, it was found that plants in the second year do not need top dressing. At the end of the growing season, in September, a decrease in the content of nutrients in the substrates was observed, which indicates that the use of the same substrates during the 3rd year of cultivation in container production of the studied plants requires top dressing [13].

The survival rate of rooted cuttings of *Forsythia ovate* Nakai and their preservation on the soil-based modification of the composition, on which spiraea and tamarix seedlings took root and remained worse than on other substrate options, was the highest. At the same time, the highest, respectively 95% and 90%, were in containers with soil mixture according to the option with the introduction of the slow-release starter fertiliser "Plantacote" at the rate of 5 g per litre of substrate.

Experimental seedlings of *Forsythia ovate* Nakai, which grew on the first (peat) modification of the substrate composition on the control (without fertiliser) and on the variant with the introduction of "Plantacote" fertiliser 7.5 g per litre of substrate (Fig. 3).

M.Z. Alam et al. developed a fertiliser application scheme and irrigation system in container plant culture of *Forsythia x intermedia* 'Spring Glory', which increased the morphometric parameters of the plants under study with minimal water use. Researchers investigated the application of slow-release fertilisers of various concentrations and irrigation schemes. It was established that the best growth of *Forsythia* was observed when applying fertilisers with a concentration of 4.7 kg·m^{-3}. Plant growth and development was weaker when the fertiliser concentration increased to 6.0 kg·m^{-3} [12].

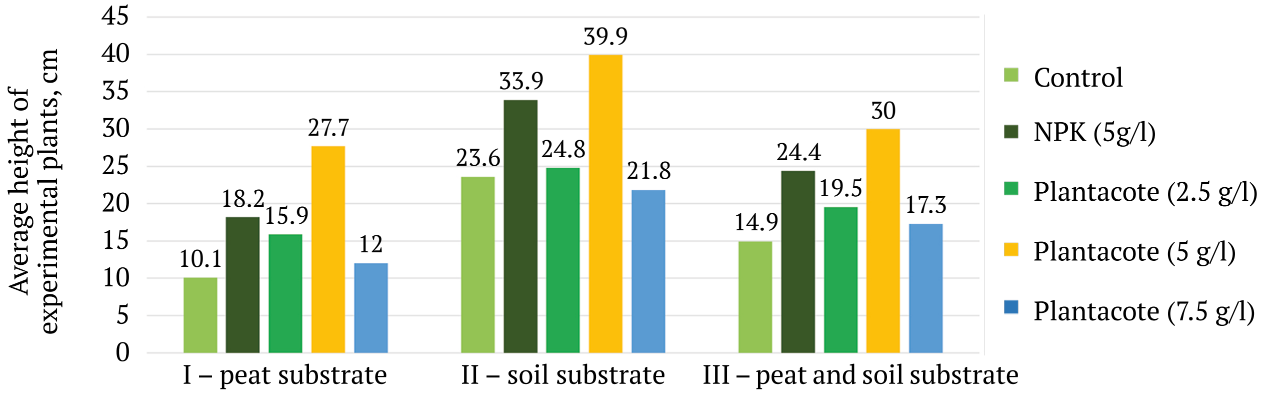


Figure 3. Height of cuttings of *Forsythia ovate* Nakai depending on the modification of the substrate composition and types and doses of starter fertiliser

Source: compiled by the authors

According to the latest assessment, the best condition of cuttings of *Spiraea japonica 'Goldflame'* was observed on the peat and soil modification of the substrate composition in the variant with a minimum (2.5 g·l^{-1}) dose of the "Plantacote" starter fertiliser. On the same modification of the substrate composition, the best condition was observed in *Tamarix tetrandra* Pall. ex Bieb. At the same time, the highest index of the condition of their seedlings was for options with the starting fertiliser "Plantacote" with the application doses recommended by the manufacturer (5 g·l^{-1}) and the maximum (7.5 g·l^{-1}). The revealed fact indicates that despite the low demand of tamarix for soil fertility, it reacts more actively than other plants to an increase in the content of nutrients in the substrate.

Unlike the previous two varieties, *Forsythia ovate* Nakai seedlings were in better condition on soil modification of the substrate composition according to the variant with the "Plantacote" starting fertiliser at the dose of (5 g·l^{-1}).

The condition of experimental plants, as studies have shown, correlates with the intensity of their growth in height. Thus, at the end of the experiment, the highest height of *Spiraea japonica 'Goldflame'* seedlings (48.5 cm) was in the variant with the best plant condition – with a minimum (2.5 g·l^{-1}) dose of "Plantacote" starter fertiliser on peat and soil modification of the substrate composition (Figure 1). At the same time, on modifications of the substrate composition with a peat component (options 1 and 3), the lowest height of spiraea seedlings was in the variant with the maximum dose of "Plantacote" starting fertiliser. An explanation of this fact requires additional research.

A close correlation between the average height of experimental plants and their condition was also characteristic of *Tamarix tetrandra* Pall. ex Bieb. and *Forsythia ovate* Nakai cuttings (Fig. 2). The highest average height of tamarix plants (157.8 cm) in container culture was, as well as the best condition of seedlings, on a peat and soil modification of the substrate composition with the "Plantacote" starting fertiliser according to the option with the manufacturer's recommended application dose (5 g·l^{-1}). Cuttings of *Forsythia ovate* Nakai are also more intensive in the growth of shoots (the average height of seedlings reached 39.9 cm, (Fig. 3) differed in the option with the best condition of experimental plants – in a container culture with an earthen modification of the substrate composition according to the variant with the starter slow-release fertiliser "Plantacote" in the dose recommended by the manufacturer (5 g·l^{-1}).

Similar studies on optimising the level of mineral nutrition in container culture when using various types of fertilisers with controlled release have shown their effect on the intensity of plant growth and development. When optimising the level of nutrition, it is possible to select a specific dose of fertilisers for each type or plant varieties, taking into account their needs [21; 22]. Substrate components have a similar effect on plant morphometric parameters and conditions. The researchers used five fertiliser application systems and seven types of substrate. The researchers also used slow-release fertilisers and various types of substrates. The substrate contains three different ratios – peat moss:vermiculite:perlite in the ratios 1:1:1, 1:2:3, and 3:1:2. Experiments have shown that peat-based substrates supplemented with alternative components or peat-free substrates can give better results than peat substrates [23]. These studies also confirm our results regarding the specific response of plants to changes in substrate components.

Conclusions

Considering the identified species-specific reactions of experimental plants, it can be recommended to use a substrate with a predominance of peat and soil components in its composition for growing cuttings of *Spiraea japonica 'Goldflame'* and *Tamarix tetrandra* Pall. ex Bieb. in container culture, and a soil modification of the mixture composition for the planting material of *Forsythia ovate* Nakai.

The study has established a number of advantages of using long-acting organo-mineral fertilisers in container culture as a starting point, in particular, "Plantacote". For growing cuttings of experimental plants, even the minimum (2.5 $g \cdot l^{-1}$) starting fertiliser dose of the slow-release fertiliser "Plantacote" is more effective than twice the dose (5 $g \cdot l^{-1}$) of traditional "Nitroamofoska". At the same time, for growing planting material *Tamarix tetrandra* Pall. ex Bieb., considering its specific reaction to increasing the dose of the starter fertiliser "Plantacote", it can be increased to 5 $g \cdot l^{-1}$.

The findings strongly indicate the presence of a species-specific reaction of experimental plants with different demands on soil conditions to the composition of the substrate and the types and doses of starting fertiliser used in container culture. They are the basis for the conclusion that a scientifically based improvement in the production of ornamental seedlings in container culture is possible by considering the species-specific reactions of cultivated plants to cultivation conditions. This suggests that the mass production of decorative planting material with a closed root system should be preceded by studies to establish species-specific reactions of cultivated plants to cultivation conditions, which are the basis for optimising the composition of the substrate, the level of mineral nutrition and improving the efficiency of container culture.

References

[1] Yezhov, V., & Lytovchenko, O. (2020). Marketing strategy of ornamental crops growing in Ukraine at the present stage. *Bulletin of Agricultural Science*, 11, 32-37. doi: 10.31073/agrovisnyk202011-04.

[2] Maurer, V.M., Pinchuk, A.P., Boboshko-Bardin, I.M., & Kosenko, Y.I. (2017). *Decorative nursery*. Kyiv: NULES of Ukraine.

[3] Maurer, V.M., Pinchuk, A.P., Boboshko-Bardin, I.M., & Kosenko, Y.I. (2018). *Modern technologies of forest seed production and tree nurseries*. Kyiv: NULES of Ukraine.

[4] Costa, J.M. (2003). The role of substrates in propagation. *Horticultural Production Chains Group, Wageningen University, by Netherlands, FlowerTECH*, 6(7), 22-27.

[5] Kelly, M. Stanton and Michael, V. Mickelbart. (2013). Growth and foliar nutrition of *Spiraea alba* Du Roi and *Spiraea tomentosa* L. in response to root zone pH. *Scientia Horticulturae*, 165, doi: 10.1016/j.scienta.10.027.

[6] Chong, C., & Lumis, G. (2000). Mixtures of paper mill sludge, wood chips, bark, and peat in substrates for pot-in-pot shade tree production. *Canadian Journal of Plant Science, 80, 669-675.*

[7] Liu, J., Xia, J., Fang, Y., Li, T., & Liu, J. (2014). Effects of salt-drought stress on growth and physiobiochemical characteristics of *Tamarix chinensis* seedlings. *The Scientific World Journal*, 2014, article number 765840. doi: 10.1155/2014/765840.

[8] Stanton, K., & Mickelbart, M. (2014). Maintenance of water uptake and reduced water loss contribute to water stress tolerance of *Spiraea alb*a Du Roi and *Spiraea tomentosa* L. *Horticulture Researc*h, 1, article number 14033. doi: 10.1038/hortres.2014.33.

[9] Kawaletz, H., Molder, I., Annighofer, P., Terwei, A., Zerbe, S., & Ammer, C. (2014). Pot experiments with woody species – A review. *Forestry*, 87(4), 482-491. doi: 10.1093/forestry/cpu017.

[10] Clark, M.J., & Zheng, Y. (2015). Species-specific fertilization can benefit container nursery crop production. *Canadian Journal of Plant Scienc*e, 95, 251-262.

[11] Clark, M.J., & Zheng, Y. (2017). Effect of topdressed controlled-release fertilizer rates on nursery crop quality and growth and growing substrate nutrient status in the Niagara Region, Ontario, Canada. *Hortscience*, 52(1), 167-173. doi: 10.21273/HORTSCI11309-16.

[12] Alam, M.Z., Chong, C., Llewellyn, J., & Lumis, G.P. (2009). Evaluating fertilization and water practices to minimize NO3-N leachate from container-grown Forsythia. *HortScience*, 44, 1833-1837. doi: 10.21273/HORTSCI.44.7.1833.

[13] Madjar, R., Mănescu, C., & Davidescu, V. (2010). The influence of fertilization and of culture substrate on the growth and development of some dendrological species. *Proceedings of the Romanian Academy Series B*, 3. 235-240.

[14] Borisenko, A.S. (2019). Features of vegetative propagation of *Forsythia ovat*e Nakai by separated parts from mother plants. In *Forest reproduction and forest melioration in Ukraine: origins, current state, current challenges and prospects in the Anthropocene: materials intern. scientific-practical Conference* (pp. 153-154). Kyiv: NULES of Ukraine.

[15] Zhigalo, K.B. (2019). Features of propagation of *Spiraea japonica* 'Goldflamé' by woody and green cuttings. In *Forest reproduction and forest reclamation in Ukraine: origins, current state, current challenges and prospects in the Anthropocene: materials intern. scientific-practical Conference* (pp. 161-162). Kyiv: NULES of Ukraine.

[16] Soshenskaya, N.M. (2019). The use of growth substances to activate the rhizogenesis of cuttings *Tamarix tetrandra* Pall. In *Forest reproduction and forest reclamation in Ukraine: Origins, current state, current challenges and prospects in the Anthropocene: Materials intern. scientific-practical Conference* (pp. 183-184). Kyiv: NULES of Ukraine.

[17] Kalinin, M.I., Guz, M.M., & Debrinyuk, Yu.M. (1998). *Forest root science*. Lviv: IZMN.

[18] Kalinichenko, O.A. (2003). *Decorative dendrolog*y. Kyiv: Higher School.

[19] Vasilenko, M.G. (2017). Organomineral fertilizers and plant growth regulators in organic farming. *Bulletin of Agricultural Science*, 2, 11-18.

[20] Gotsky, Ya.G., & Stepanyuk, A.R. (2019). Advantages of application of granular organomineral fertilizers of prolonged action. *Bulletin of the National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorsky". Chemical Engineering, Ecology and Resource Conservation*, 1, 61-67.

[21] Agro, E.E., & Zheng, Y. (2014). Controlled-release fertilizer application rates for container nursery crop production in southwestern Ontario, Canada. *HortScience*, 49, 1414-1423. doi: 10.21273/HORTSCI.49.11.1414.

[22] Chen, Y., Bracy, R.P., Owings, A.D., & Quebedeaux, J.P. (2011). Controlled-release fertilizer type and rate affect landscape establishment of seven herbaceous perennials. *HortTechnolog*y, 21(3), 336-342. doi: 10.21273/HORTTECH.21.3.336.

[23] Šrámek, F., & Dubský, M. (2002). Influence of fertilization application and growing substrate on container-grown woody ornamentals. *Plant, Soil and Environment*, 48, 448-457. doi: 10.17221/4394-PSE.

Оптимізація складу субстрату та рівня мінерального живлення як основа удосконалення виробництва декоративних саджанців у контейнерній культурі

Віктор Мельхіорович Маурер, Андрій Петрович Пінчук

Навчально-науковий інститут лісового і садово-паркового господарства
Національний університет біоресурсів і природокористування України
03041, вул. Горіхуватський шлях, 19, м. Київ, Україна

Анотація. Сучасне суттєве збільшення обсягів вирощування декоративних саджанців у контейнерній культурі в деревних розсадниках зумовлено низкою вагомих переваг садивного матеріалу з нетравмованою кореневою системою. Водночас, агротехнологія виробництва таких саджанців у контейнерній культурі значно складніша, порівняно з традиційною. Передусім, це пов'язано з вирощуванням їх в обмеженому розмірами ємностей просторі та використанням штучно приготованого субстрату. Метою роботи було проведення біотестування трьох модифікацій складу субстрату для контейнерної культури *Spiraea japonica* 'Goldflame', *Tamarix tetrandra* Pall. ex Bieb., *Forsythia ovate* Nakai та різних доз стартових добрив «Нітроамофоска» та «Plantacote». У роботі використані як загальнонаукові методи аналізу, синтезу, активного експерименту, так і прикладні методики досліджень такі як біометричні, фенологічні, ґрунтові та агрохімічні. Дослідженнями встановлено наявність видоспецифічних реакцій дослідних рослин, з різною вибагливістю до ґрунтових умов, на склад субстрату та види і дози стартового добрива, що використовуються у контейнерній культурі. Зроблено висновок щодо підвищення рентабельності їх вирощування внаслідок використання більш дешевих місцевих компонентів для приготування субстрату. Проведені дослідження показали низку переваг використання в контейнерній культурі у якості стартового органо-мінеральні добрива пролонгованої дії, зокрема «Plantacote» дозою 2,5-5,0 $г·л^{-1}$. І також дали змогу стверджувати, що масовому продукуванню декоративного садивного матеріалу із закритою кореневою системою повинні передувати дослідження з встановлення видоспецифічних реакцій вирощуваних рослин на умови культивування, які є основою для оптимізації складу субстрату та рівня мінерального живлення вирощуваних рослин з метою підвищення ефективності виробництва декоративних саджанців у контейнерній культурі. Отримані результати будуть корисними для виробників садивного матеріалу та наукової спільноти, які працюють у напрямі розвитку контейнерної культури декоративних рослин

Ключові слова: укоріненні живці, живцеві саджанці, декоративний садивний матеріал із закритою кореневою системою, компоненти субстрату, стартове добриво

Received: 30/08/2022; Revised: 01/10/2022; Accepted: 28/11/2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4), 74-83

UDC 6630*5:630*12"46"
DOI: 10.31548/forest.13(4).2022.74-83

Height-Diameter Relationships and Stem Volume Equations in Young and Middle-Aged Forest Stands of Ukraine

Viktor Myroniuk*, Viktor Svynchuk, Andrii Bilous, Serhii Kashpor, Oleksandr Lesnik

National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

Abstract. Height-diameter (*h-d*) relationships in forest stands are commonly used in various scientific and practical forestry applications. Accurate *h-d* models combined with tree stem volume equations are recognised to be effective in growing stock volume estimation. *The purpose of the study* was threefold: 1) development of a set of mathematical models of the *h-d* relationship in young and middle-aged forest stands for ten forest-forming species in Ukraine; 2) modelling stem volume in above mentioned forest stands; 3) comparison of established mathematical models with corresponding ones for premature, mature, and overmature forest stands. The study was based on permanent and temporal sample plots data (about 600) established in forest stands during 1950s-2020s within the most forested regions of Ukraine (Polissia, Forest-Steppe, Carpathians). In total, about 10,000 sample trees were measured on the sample plots to accurately estimate their stem volume outside bark. The *h-d* models demonstrated very similar relationships between stem heights and diameters for most of our species except for spruce and fir in mountain Carpathian forests where the steeper *h-d* curves were obtained. The study revealed that birch and hornbeam tree stems had the lowest volumes among surveyed species. The results also indicated that tree species tend to have higher volumes (up to 7% for coniferous, and up 10% for aspen and birch forests) in young and middle-aged forest sands than in older ones. For the other species, a statistically significant difference between stem volumes of trees of different ages was not observed. The developed mathematical models can complement the corresponding models for older groups of forest stands since they revealed an important aspect of relationships between the key tree stem parameters. These models are also applicable for a more precise stem volume estimation during thinning operations in the young and middle-aged forests in Ukraine

Keywords: height curve, volume tables, height class, form factor, forecasting

Introduction

Relationships between tree heights and diameters (*h-d*) are widely used to determine tree stem volume in forest stands. Since most volume equations require measuring both diameter and height of trees [1], *h-d* models can be utilized to predict stem heights based on their diameters. From a practical perspective, *h-d* relationships are used to determine average heights by stem diameter classes which simplifies estimations of growing stock volume. In addition, the *h-d* relationships are applied in various stand growth models [2], in particular, to determine stand heights based on the corresponding average diameter.

The *h-d* relationships depend on tree species, growth conditions of forest stands [3; 4], and do not remain constant throughout time even in the same stand [5]. Differences in *h-d* relationships in even-aged and uneven-aged forest stands have been also investigated in the literature [6]. The shape of curves

Suggested Citation:
Myroniuk, V., Svynchuk, V., Bilous, A., Kashpor, S., & Lesnik, O. (2022). Height-diameter relationships and stem volume equations in young and middle-aged forest stands of Ukraine. *Ukrainian Journal of Forest and Wood Science*, 13(4), 74-83.

*Corresponding author

characterizing these relationships may change with age, i.e., have different steepness at different stages of the stand development. Sharma (2016) has revealed differences in *h-d* relationships for a number of coniferous tree species in natural forest stands and planted forests in Ontario, Canada [7].

Various mathematical models of *h-d* relationships have been tested in the literature. Most of them were developed to predict heights of individual trees based on their diameters. To characterize these relationships, various growth functions [8; 9] and some other nonlinear equations [10] were used. M. Liu et al. [11] tested 53 mathematical models and concluded that nonlinear functions have substantial advantages over linear ones. Such functions were found to be more flexible in describing various forms of relationship between tree heights and diameters. Additionally, D. Leduc & J. Goelz, [12] evaluated more than 40 mathematical equations and demonstrated that the highest accuracy of modelling could be achieved regardless of the form of the equations using relative heights and diameters instead of absolute values.

Generally, relationships of biometric parameters become more complex in uneven-aged and multi-layered stands which require more advanced approaches to characterize *h-d* relationships. For example, machine learning used in multi-layered tropical forest stands showed higher efficiency than parametric modelling methods [13]. Recent studies have also used mixed-effect models to fit *h-d* relationships [14]. Such models, in addition to the diameter of trees, which exhibits a fixed effect on the height of trees (i.e., thicker trees are systematically taller), incorporate random-effect factors (forest stand parameters). Random-effect parameters are believed to be effective in explaining a random *h-d* variation depending on the parameters of a particular stand. Many recent publications investigated the influence of density, productivity, and age of stands on the *h-d* relationships using mixed effect models [4; 15; 16].

Stem volumes are estimated using mathematical relationships between volume and other biometric parameters of stems which can be easily measured in a field [17]. Since diameters of growing trees can be measured more easily and with higher accuracy than height, models of *h-d* relationships are of great practical importance. Using such models for certain ecoregions, so-called local volume tables can be developed, which utilize only diameter of tree stems as an independent variable [18]. However, models of total stem volumes based on diameter and height of trees are considered to be more flexible [10].

The type of mathematical relationships between the diameter, height, and volume of stems can be quite diverse. Commonly, it is characterized using nonlinear equations [1; 19]. Models of stem taper are important for determining total and commercial wood volumes [20; 21]. In volume estimation, taper models can be used to predict diameters at specified heights and then determine the stem volume using well known formulae (Huber, Smalian, Newton, etc.) [17]. Additionally, some of taper models may have compatible volume equations, i.e. obtained via integration of taper equations [22-24]. As an alternative to these methods, a stem volume can be considered as a product of the volume of a solid (cylinder) and form factors. The form factor is the ratio of the stem volume to the cylinder volume which significantly simplifies estimation of the total stem volume [17]. This approach of volume modelling relies merely on adequately selected equations to characterize the variability of form factors depending on the diameter and height of trees [25].

The aim of the study is to develop mathematical models of tree stems *h-d* relationships in young and middle-aged forest stands of the main forest-forming species of Ukraine. Comparison of the results obtained with similar data for premature, mature, and over-mature stands would reveal main differences between these age groups of forest stands which represents the originality of this study.

Materials and Methods

The study is based on research materials collected in forest stands of Ukraine during 1950s-2020s. To develop mathematical models, the measurements of more than 10 thousand trees sampled on about 600 temporary and permanent plots were used. In general, the study covers 10 main forest-forming tree species in Ukraine: pine (*Pinus sylvestris* L.), spruce (*Picea abies* L.), fir (*Abies alba* L.), oak (*Querqus robur* L.), beech (*Fagus sylvatica* L.), ash (*Fraxinus excelsior* L.), hornbeam (*Carpinus betulus* L.), aspen (*Populus tremula* L.), birch (*Betula pendula* Roth.), and alder (*Alnus glutinosa* (L.) Gaerth). The sample plots were distributed among the most forested regions of Ukraine, i.e., Polissia, Forest-Steppe, and the Carpathians [26]. Considering the small size of trees in young and middle-aged stands, diameters of all trees on sample plots were measured using 2-cm diameter classes. To construct height curves, heights of 10-25 trees of dominant species selected from different diameter classes were measured. Average tree heights of the 2-cm diameter classes were used as a reference for sampling trees on the plot. According to the distribution of diameters and shape of height curve, 10-25 sample trees were selected and cut down on each plot. Their number was distributed proportionally to the total number of trees within 2-cm diameter classes. Diameters and bark thickness of felled trees were measured at mid-point of 2-m sections, then their volumes outside bark were estimated using the Newton's sectional formula.

Modelling h-d relationships

Relative values of tree heights and diameters were used to model the *h-d* relationships. Such approach allowed the development of a single mathematical model for forest stands of different ages, growth conditions, productivity levels, etc. The earlier studies [12] demonstrated that modelling *h-d* relationships using relative values can provide more accurate results. Thus, relative heights for all diameter classes at sample plots were calculated using the equation (1):

$$h_i^e = h_i / h_{ref}, \tag{1}$$

where h_i^e – relative height for the *i*-th diameter class; h_i – absolute height for the *i*-th diameter class, m; h_{ref} – height for the reference diameter class, m.

The diameter class of 16 cm was used as a reference based on its prevalence as average diameter on sampled forest stands. The authors believe that using the height that corresponds to the average diameter provides a more accurate calculation of relative heights as h_{ref} values in equation (1) are obtained with higher precision. The obtained data were summarised for each tree species and the average values of relative heights were calculated for all diameter classes observed in the study material. Equations (2-4) were used as mathematical models to characterize the *h-d* relationships. In particular, for pine, spruce, oak, beech, and ash, the following equation was used:

$$h_i^e = a_0 + a_1 d^{a_2}, \tag{2}$$

where a_0, a_1, a_2 – equation parameters; d – tree stem diameter, cm.

For fir, aspen, birch, and alder, the relative height model had the form:

$$h_i^e = a_0 + \frac{a_1}{d + a_2}. \tag{3}$$

The following mathematical model was used for hornbeam:

$$h_i^e = a_0 \cdot d^{a_1} \cdot \exp(a_2 \cdot d). \tag{4}$$

Predicted relative height values were used to calculate the absolute heights for each diameter classes using the reference height h_{ref}:

$$h_i = h_i^e \cdot h_{ref} \tag{5}$$

Obtained mathematical models of relative heights allow predicting the height of trees of different levels of productivity and growth conditions. This paper did not aim at developing the *h-d* relationships for stands of different site indices or density, but used standard stand height classes of the existing volume tables for the corresponding species [27]. Thus, 23.0 m was taken as the reference height of the I^a height class. The reference heights corresponding to the reference diameter class of 16 cm for other height classes were calculated using the equation (6):

$$h_{ref} = h_{16} = 23.0 - 2 \cdot I_R. \tag{6}$$

Height classes indices (I_R) of stands in accordance with the officially accepted numbering in forest industry of Ukraine [27] are provided in Table. 1.

Table 1. Indices and numbering of stand height classes in Ukraine

R	I^c	I^b	I^a	I	II	III	IV	V	V^a	V^b
I_R	-2	-1	0	1	2	3	4	5	6	7

Estimating stem volume

Stem volume was estimated using the equation (7):

$$V = g \cdot h \cdot f. \tag{7}$$

where g – cross-sectional area of stems at a height of 1.3 m above ground level (basal area), m²; f – cylindrical form factor; h – stem height, m.

Based on equation (7), the key methodological issue in stem volume estimation is modelling relationships between form factors and other tree stem parameters (e.g., diameter, height). In this study, a mathematical model of form factors as a function of stem diameters and heights $f=\psi(d, h, \dots)$ was used for such tree species as pine, spruce, oak, beech, and alder. Form factors for the rest of species were predicted based just on stem diameters, i.e. $f=\psi(d,\dots)$.

The parameters of mathematical models were calculated based on the nonlinear least squares (NLS) regression. In the modelling, several alternative equations were considered for each species. The final model was selected based on a combination of its simplicity and accuracy. The adequacy of models was evaluated using the Fisher's *F*-statistics and determination coefficient R^2 [28]. If several models had a statistically insignificant difference in accuracy, the preference was given to equations with fewer parameters.

Results and Discussion

The parameters of mathematical models (2-4) of relative heights for young and middle-aged stands of the main forest-forming tree species of Ukraine were established in this study (Table 2).

Table 2. Parameters of mathematical models of relative heights depending on stem diameters

No.	Tree species	Parameters of equations (2-4)		
		a_0	a_1	a_2
1.	Pine	3.812	-3.692	-0.0982
2.	Spruce	-0.635	0.6781	0.3174
3.	Fir	2.301	-51.76	23.79
4.	Oak	5.252	-5.178	-0.0710
5.	Beech	9.514	-9.418	-0.0364
6.	Ash	2.021	-2.260	-0.2866
7.	Hornbeam	0.288	0.5225	-0.0128
8.	Aspen	1.426	-8.982	5.109
9.	Birch	1.435	-9.549	5.930
10.	Alder	1.587	-14.75	9.137

Figure 1 shows an example of relative height curves for individual tree species. Among species, the *h-d* relationships are distinguished only for spruce and fir growing in the mountain forests of the Carpathians. For the rest of the main forest-forming tree species in Ukraine, the shapes of relative height curves were quite similar. The developed models of the tree *h-d* relationships in tabular form had been published in the new Forest inventory handbook (Table 2.1-2.10) [27].

Models of tree stem volumes outside bark for young and middle-aged stands of the main forest-forming tree species of Ukraine are given in Table 3.

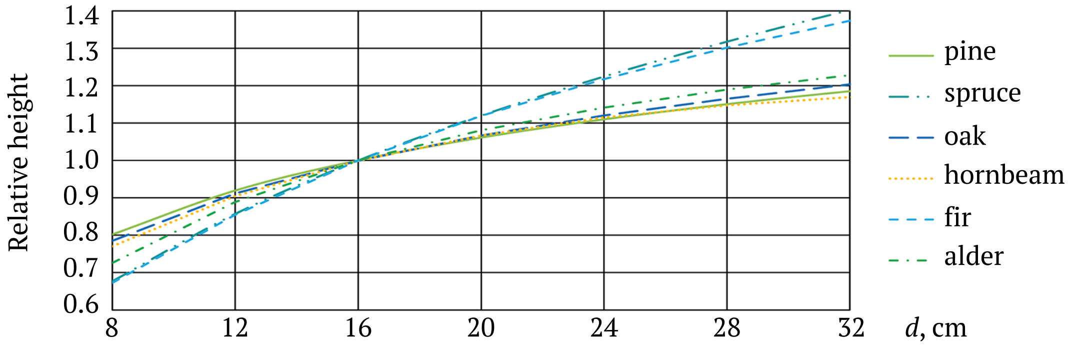


Figure 1. The relationships between tree heights and diameters in forest stands of different tree species

Table 3. Mathematical models of tree stem volumes outside bark

No.	Tree species	Mathematical model of stem volume outside bark
1.	Pine	$V_{ob}=(576.5+9059 \cdot h^{-2,207}-19.47 \cdot d^{0.5451}) \cdot d^2 \cdot h \cdot 7.854 \cdot 10^{-8}$
2.	Spruce	$V_{ob} = \left(521.0 + 4.300 \cdot h + \frac{301.8}{h-2.93} - 10.39 \cdot d^{0.811}\right) \cdot d^2 \cdot h \cdot 7.854 \cdot 10^{-8}$
3.	Fir	$V_{ob} = \left(588.4 - 2.864 \cdot d + \frac{62.75}{d-3.663}\right) \cdot d^2 \cdot h \cdot 7.854 \cdot 10^{-8}$
4.	Oak	$V_{ob} = \left(h^{0.0957} \cdot \exp\left(5.830 + \frac{0.9721}{d} + \frac{1.804}{h} - 0.00230 \cdot d\right)\right) \cdot d^2 \cdot h \cdot 7.854 \cdot 10^{-8}$
5.	Beech	$V_{ob} = \left(0.541 + \frac{1.570}{d^2} + \frac{6.963}{h^2} - \frac{3.915}{d \cdot h} - 0.07841 \cdot \frac{d}{h}\right) \cdot d^2 \cdot h \cdot 7.854 \cdot 10^{-5}$
6.	Ash	$V_{ob}=(435.2+685.2 \cdot d^{-0.9495}) \cdot d^2 \cdot h \cdot 7.854 \cdot 10^{-8}$
7.	Hornbeam	$V_{ob}=(371.3+1947/(d+4.585)) \cdot d^2 \cdot h \cdot 7.854 \cdot 10^{-8}$

Table 3, Continued

No.	Tree species	Mathematical model of stem volume outside bark
8.	Aspen	$V_{ob}=(-104.7+700.9\cdot d^{-0.0581})\cdot d^2\cdot h\cdot 7.854\cdot 10^{-8}$
9.	Birch	$V_{ob}=(654.4-40.02\cdot d^{0.538})\cdot d^2\cdot h\cdot 7.854\cdot 10^{-8}$
10.	Alder	$d<16$ cm $V_{ob}=(1677\cdot d^{-0.0991}\cdot h^{-0.5583}\cdot \exp\cdot(0.03624\cdot h))\cdot d^2\cdot h\cdot 7.854\cdot 10^{-8}$ $d\geq 16$ cm $V_{ob}=(398.1+314.3\cdot d^{-0.4555})\cdot d^2\cdot h\cdot 7.854\cdot 10^{-8}$

Note: V_{ob} – tree stem volume outside bark, m^3

The developed models of relative heights (2-4) and the mathematical models of tree stem volumes (Table 3) were used to construct volume tables by height classes for young and middle-aged stands [27; Table 2.42-2.51]. These tables are used for wood volume estimation extracted during thinning or salvage logging in young and middle-aged forests in Ukraine. In addition, the developed set of models significantly simplifies methods of growing stock volume estimation during sample-based forest inventory, since there is no need to measure heights of all tally trees on sample plots. Accordingly, the value of the variable h in the stem volume models (Table 3) can be estimated using equations (2-6).

As it was noted in earlier publications, the height curves that characterize the relationship between the heights and diameters of stems in forest stands of a certain tree species can be variable and depend primarily on age. Accordingly, the shape of the relative height curves obtained in this study was compared with the corresponding curves obtained for older stands [29]. To properly compare the shape of the curves, relative heights for both groups of stands were calculated using the common reference height obtained for diameter class of 24 cm. The relative height curves in both young and middle-aged, and premature, mature, and over-mature stands had similar shape for spruce, fir, and beech which predominate in the forests of the Ukrainian Carpathians. The relative height curves among these two age groups differ most for pine, oak, ash, birch, and aspen. Notably, significant differences in tree height growth of different age groups were noted by many other studies [7; 30]. As an example, Figure 2 shows relative height curves for individual tree species in stands of different ages.

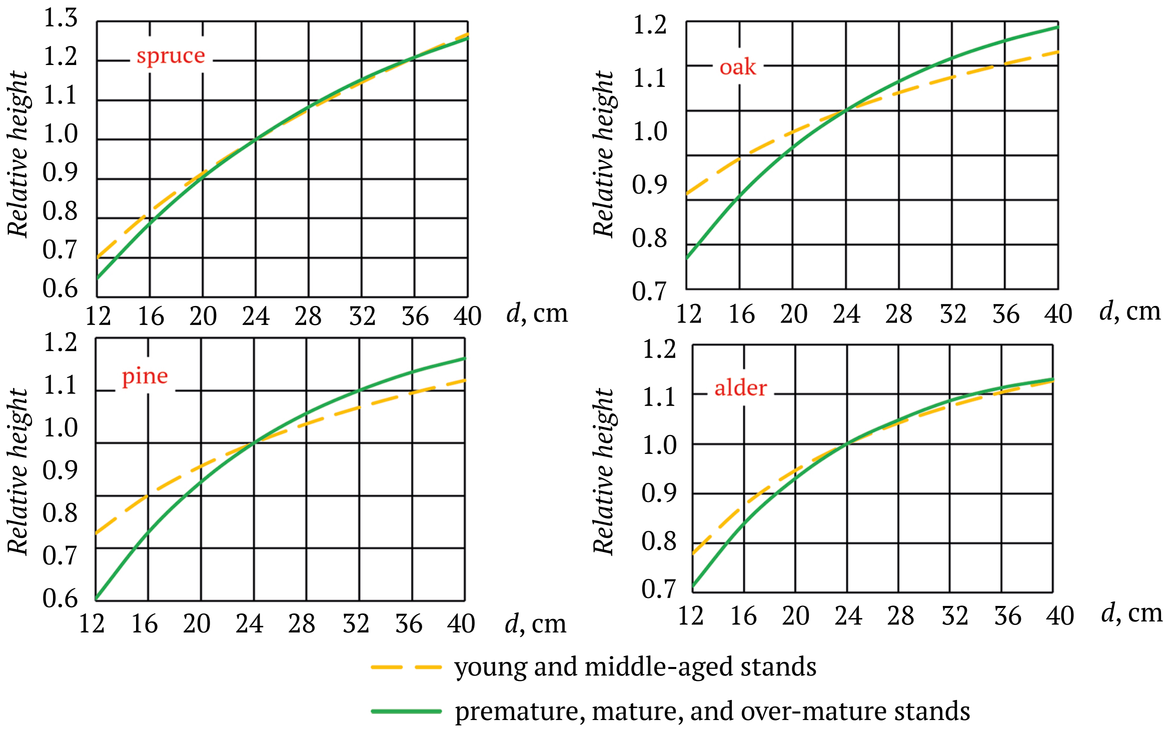


Figure 2. Relationships between tree heights and diameters in forest stands of different age groups

It is well known in forest mensuration that tree stem volumes of the same size, i.e., diameter and height, can vary due to differences in their shapes. Accordingly, there are distinguished tree species in the forests of Ukraine that have smaller stem taper, thus larger volumes. Based on the developed models (Table 3), stems of fir, oak, and aspen in young and middle-aged stands reach the largest volumes for fixed values of diameter and height. Hornbeam and birch are characterized by the smallest volume of tree stems. Regarding the volume of stems of the same size in stands of different age groups (young and middle-aged versus premature, mature, and over-mature), systematically higher (5-7%) volumes are observed in young and middle-aged stands for coniferous tree species. In some cases, this difference can surpass even 10%. Similar trends were also observed for some deciduous tree species of Ukrainian forests, in particular, stem volumes in young and middle-aged aspen and birch stands are 3-7% higher than in premature, mature, and over-mature forests. For other deciduous tree species, there is no systematic difference in tree stem volumes of the same size in different age groups. As an example, Figure 3 compares for selected tree species the volume of tree stems of typical sizes in forest stands of two age groups.

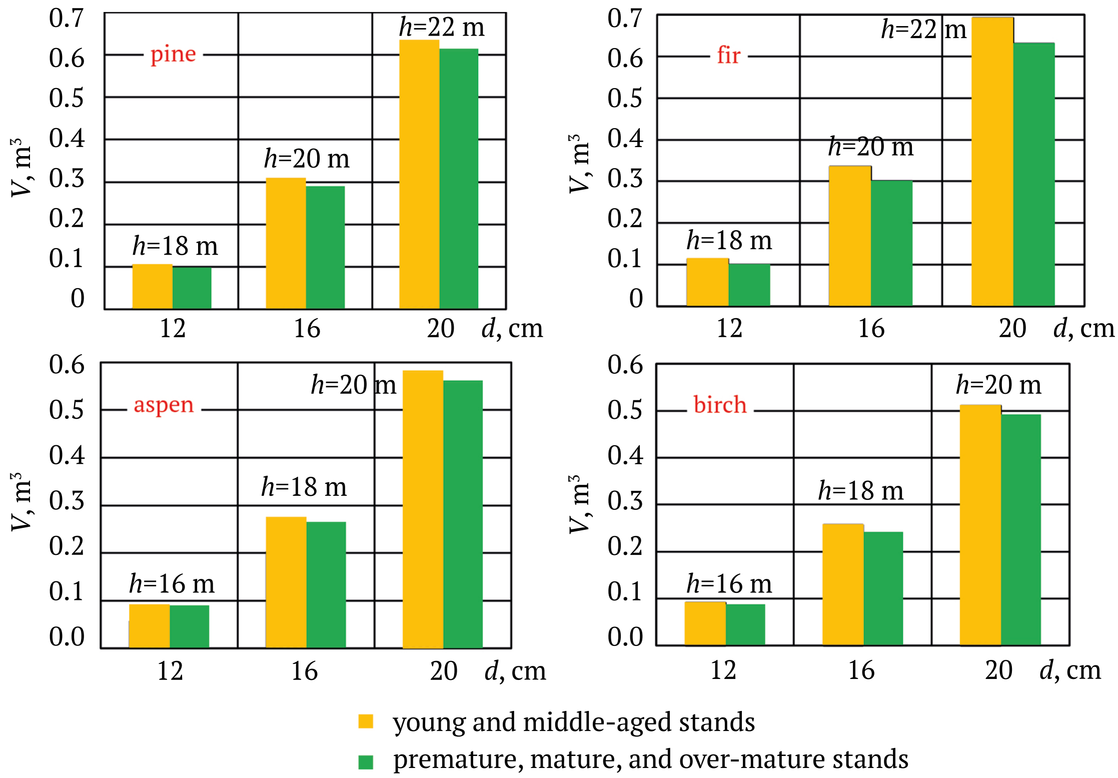


Figure 3. Comparison of stem volume in stands of different age groups

A comparison of the developed models of tree stem volumes in forest stands of Ukraine with data obtained in other European countries [29], showed distinct differences for some tree species. Mathematical models of the volume of tree stems in the forests of Germany, the Czech Republic, Poland, the Netherlands, Belgium, Great Britain, Finland, Norway, and Sweden were used. Stem volumes in these countries were modelled directly from the diameter and height of the stems using nonlinear regression equations, mainly with power or exponential functions. It was found that deviations in stem volumes for coniferous tree species generally do not exceed ±5% and only for the thinnest trees could reach 10% and higher. Among the tested models, the Swedish volume model for pine stems is characterized by the lowest differences (mainly up to ±2%) compared to the developed one in this study. The volume prediction for stems of spruce trees using various equations is characterized by nearly equal accuracy, with the exception of the volume model developed by Finnish scientists. Thus, the volume of spruce tree stems with heights of more than 15 m and diameters up to 20 cm in Finland is systematically lower (10-15%) than in Ukraine, Poland,

and Sweden. As an example, Figure 4 shows models of tree stem volumes as a function of diameter using two fixed values of height of 12 and 18 m for the predominant tree species in the forests of Ukraine. The choice of these values is explained by average tree heights in young and middle-aged forests of Ukraine.

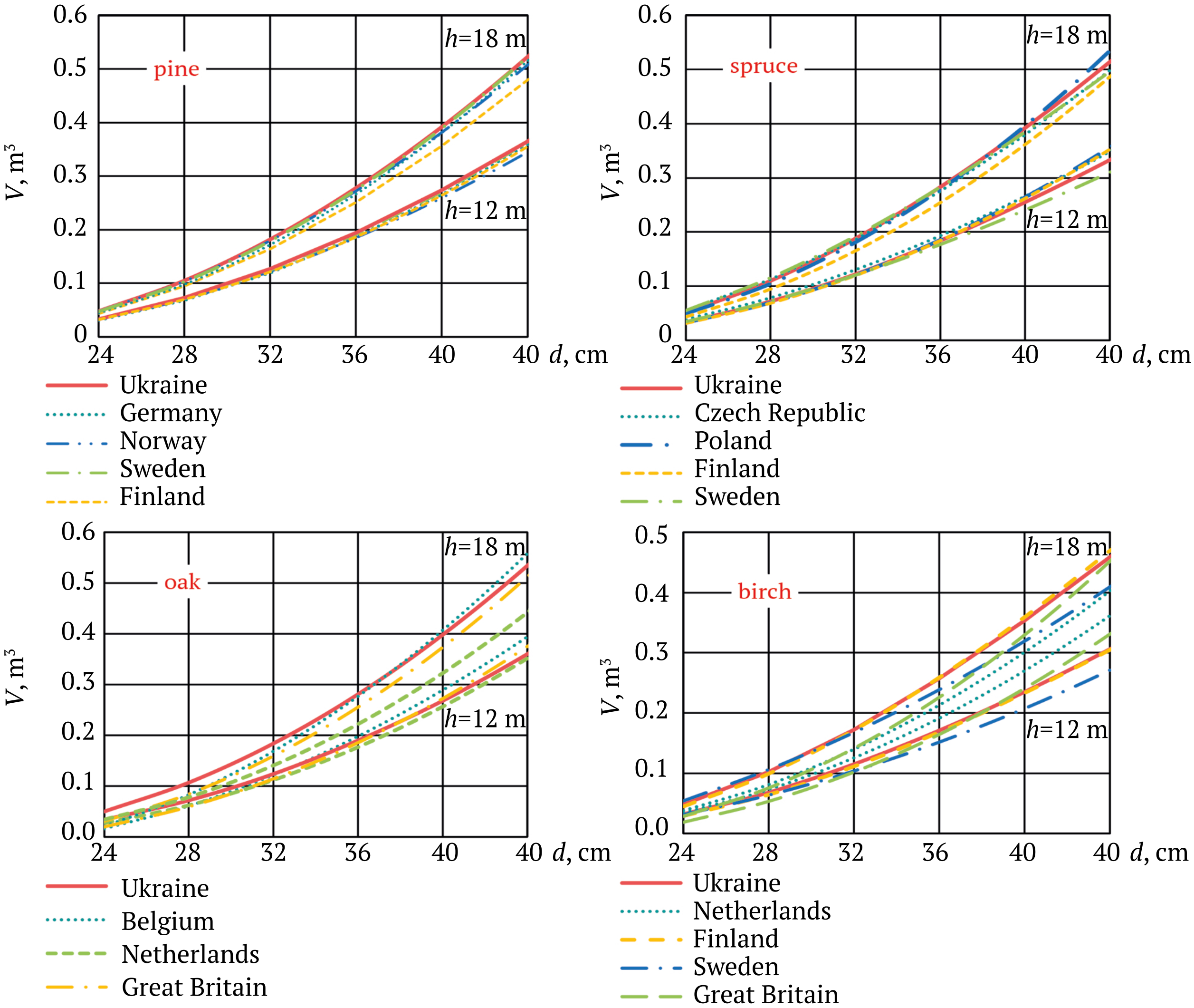


Figure 4. Comparison of the volume of tree stems as a function of diameter at a constant height

For deciduous tree species, volume curves are characterized by higher variability compared to conifers species (Fig. 4). Deviations in the stem volume for trees with diameters less than 16 cm often exceed 10%, and in some cases can reach more than 20%. However, the differences between developed in this study and published volume models [1] are not systematic. The stem volumes in Finland, Sweden, Great Britain, Belgium, and the Netherlands are systematically lower only for the thinnest trees (usually less than 20 cm in diameter) in comparison to the presented ones in this paper.

A detailed analysis of the developed mathematical models of tree stem volume and comparison of them with similar models for different European countries [1] indicates a high variability of volume estimates. Based on the identified differences in models for stands of different age groups (Fig. 2 and Fig. 3), the development of a set of national-scale mathematical models of stem volumes is reasonable. In Ukraine, two age categories of forest stands are proposed to consider for which systematic differences between stem volumes and *h-d* relationships were identified: 1) young and middle-aged stands, and 2) premature, mature, and over-mature stands.

Besides the practical aspect aimed at more accurate assessment of forest resources, the developed set of models has sufficient scientific importance. For example, mathematical models of *h-d* relationships in forest stands of different ages are widely used in forest ecology. This provides an understanding of tree competition in a stand, which can be used to justify effective treatment scenarios to increase forest productivity and sustainability. Stem volume models along with growth models are important for a reliable assessment of forest ecosystem functions (e.g., carbon sequestration) and forecasting forest vulnerability in response to climate change. The practical significance of the developed mathematical models is explained by their utility in wood volume estimation harvested in young and meddle-aged stands during thinning or salvage logging.

Conclusions

Accurate estimation of tree stem volumes is essential for addressing current and strategic forest management challenges. In particular, the differences in the growth of forest stands of different age categories should be explicitly explained by relevant mathematical models. This paper presents the modelling results of *h-d* relationships in young and middle-aged forest stands as well as the corresponding stem volume models. The study identified differences (up to 10%) between the volumes of trees of the same size in young and middle-aged forest stands compared to the older stands. Considering the differences in *h-d* relationships for individual tree species, the developed mathematical models allow refining the forecast of growing stock volume in young and middle-aged forest stands of Ukraine. Besides theoretical significance, the obtained results have practical applications in evaluation (including monetary valuation) of log-grade distribution of harvested wood during thinning operations. The use of mathematical models of *h-d* relationships could also significantly reduce labour costs of fieldwork operations during the national forest inventory of Ukraine, while the developed stem volume models could be used for accurate estimation of sample plot-level growing stock volumes.

References

[1] Zianis, D., Muukkonen, P., Mäkipää R., & Mencuccini, M. (2005). *Biomass and stem volume equations for tree species in Europe*. Tampere: Tammer-Paino Oy.

[2] Tian, X., Sun, S., Mola-Yudego, B., & Cao, T. (2020). Predicting individual tree growth using stand-level simulation, diameter distribution, and Bayesian calibration. *Annals of Forest Science*, 77(2), article number 57. doi: 10.1007/s13595-020-00970-0.

[3] Saunders, M.R., & Wagner, R.G. (2008). Height-diameter models with random coefficients and site variables for tree species of Central Maine. *Annals of Forest Science*, 65(2), 203-203. doi: 10.1051/forest:2007086.

[4] Zhang, X., Fu, L., Sharma, R.P., He, X., Zhang, H., Feng, L., & Zhou, Z. (2021). A nonlinear mixed-effects height-diameter model with interaction effects of stand density and site index for larix olgensis in Northeast China. *Forests*, 12(11), article number 1460. doi: 10.3390/f12111460.

[5] Mehtätalo, L. (2005). Height-diameter models for Scots pine and birch in Finland. *Silva Fennica*, 39(1), 55-66. doi: 10.14214/sf.395.

[6] de-Miguel, S., Pukkala, T., Assaf, N., & Bonet, J.A. (2012). Even-aged or uneven-aged modelling approach? A case for *Pinus brutia*. *Annals of Forest Science*, 69(4), 455-465. doi: 10.1007/s13595-011-0171-2.

[7] Sharma, M. (2016). Comparing height-diameter relationships of boreal tree species grown in plantations and natural stands. *Forest Science*, 62(1), 70-77. doi: 0.5849/forsci.14-232.

[8] Duan, G., Gao, Z., Wang, Q., & Fu, L. (2018). Comparison of different height–diameter modelling techniques for prediction of site productivity in natural uneven-aged pure stands. *Forests*, 9(2), article number 63. doi: 10.3390/f9020063.

[9] Temesgen, H., Hann, D.W., & Monleon, V.J. (2007). Regional height–diameter equations for major tree species of Southwest Oregon. *Western Journal of Applied Forestry*, 22(3), 213-219. doi: 10.1093 wjaf/22.3.213.

[10] Burkhart, H.E., & Tomé, M. (2012). *Modeling forest trees and stands*. Dordrecht: Springer. doi: 10.1007/978-90-481-3170-9.

[11] Liu, M., Feng, Z., Zhang, Z., Ma, C., Wang, M., Lian, B., Sun, R., & Zhang, L. (2017). Development and evaluation of height diameter at breast models for native Chinese Metasequoia. *PLOS ONE*, 12(8), article number e0182170. doi: 10.1371/journal.pone.0182170.

[12] Leduc, D., & Goelz, J. (2009). A height–diameter curve for longleaf pine plantations in the Gulf Coastal Plain. *Southern Journal of Applied Forestry*, 33(4), 164-170. doi: 10.1093/sjaf/33.4.164.

[13] Ogana, F.N., & Ercanli, I. (2022). Modelling height-diameter relationships in complex tropical rain forest ecosystems using deep learning algorithm. *Journal of Forestry Research*, 33(3), 883-898. doi: 10.1007/s11676-021-01373-1.

[14] Zuur, A.F. (Ed.). (2009). *Mixed effects models and extensions in ecology with R*. Dordrecht: Springer.

[15] Bronisz, K., & Mehtätalo, L. (2020). Mixed-effects generalized height–diameter model for young silver birch stands on post-agricultural lands. *Forest Ecology and Management*, 460, article number 117901. doi: 10.1016/j.foreco.2020.117901.

[16] Temesgen, H., Zhang, C.H., & Zhao, X.H. (2014). Modelling tree height–diameter relationships in multi-species and multi-layered forests: A large observational study from Northeast China. *Forest Ecology and Management*, 316, 78-89. doi: 10.1016/j.foreco.2013.07.035.

[17] Kershaw, J.A., Ducey, M.J., Beers, T., & Hush, B. (2016). *Forest mensuration*. Hoboken: Wiley-Blackwell.

[18] Brooks, J.R., & Wiant, H.V. (2008). Ecoregion-based local volume equations for Appalachian hardwoods. *Northern Journal of Applied Forestry*, 25(2), 87-92. doi: 10.1093/njaf/25.2.87.

[19] Muukkonen, P. (2007). Generalized allometric volume and biomass equations for some tree species in Europe. *European Journal of Forest Research*, 126(2), 157-166. doi: 10.1007/s10342-007-0168-4.

[20] McTague, J.P., & Weiskittel, A. (2021). Evolution, history, and use of stem taper equations: A review of their development, application, and implementation. *Canadian Journal of Forest Research*, 51(2), 210-235. doi: 10.1139/cjfr-2020-0326.

[21] Salekin, S., Catalán, C.H., Boczniewicz, D., Phiri, D., Morgenroth, J., Meason, D.F., & Mason, E.G. (2021). Global tree taper modelling: A review of applications, methods, functions, and their parameters. *Forests*, 12(7), article number 913. doi: 10.3390/f12070913.

[22] Fang, Z. (2000). Compatible volume-taper models for Loblolly and Slash Pine based on a system with segmented-stem form factors. *Forest Science*, 46(1), article number 12.

[23] McClure, J.P., & Czaplewski, R.L. (1986). Compatible taper equation for loblolly pine. *Canadian Journal of Forest Research*, 16(6), 1272-1277. doi: 10.1139/x86-225.

[24] Özçelik, R., & Brooks, J.R. (2012). Compatible volume and taper models for economically important tree species of Turkey. *Annals of Forest Science*, 69(1), 105-118. doi: 10.1007/s13595-011-0137-4.

[25] Tenzin, J., Wangchuk, T., & Hasenauer, H. (2016). Form factor functions for nine commercial tree species in Bhutan. *Forestry*, 90, 359-366. doi: 10.1093/forestry/cpw044.

[26] Gensiruk, S.A. (1992). *Forests of Ukraine*. Kyiv: Naukova dumka.

[27] Bilous, A., Kashpor, S, Myroniuk, V., Svynchyk, V., & Lesnik, O. (2021). *Forest inventory handbook*. Kyiv: Vinichenko.

[28] Draper, N.R., & Smith, H. (1998). *Applied regression analysis*. Hoboken: Wiley-Interscience.

[29] Bilous, A., Myroniuk, V., Svynchuk, V., Kashpor, S., & Lesnik, O. (2022). Tree stem volumes by height classes in premature, mature and overmature stands of main sorest species of Ukraine. *Ukrainian Journal of Forest and Wood Science,* 13(3), 7-12. doi: 10.31548/forest.13(3).2022.7-12.

[30] Soshenskiy, O.M. (2016). *Peculiarities of biometrics structure, wood sort and merchantability structure of linden tree stands in the Lisostep of Ukraine* (Doctoral thesis, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine).

Співвідношення між висотами і діаметрами та рівняння об'єму стовбурів дерев у молодняках і середньовікових лісових насадженнях України

Віктор Валентинович Миронюк, Віктор Адамович Свинчук, Андрій Михайлович Білоус, Сергій Миколайович Кашпор, Олександр Миколайович Леснік

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Анотація. Співвідношення висот і діаметрів дерев (*h-d*) у лісових насадженнях зазвичай використовується в різних наукових і практичних задачах лісового господарства. При цьому точні моделі *h-d* у поєднанні з рівняннями об'єму стовбурів дерев ефективні в оцінці об'єму запасів. *Мета роботи* полягає в 1) розробці системи математичних моделей співвідношення висот і діаметрів у молодняках і середньовікових деревостанах для десяти лісоутворювальних видів Україні; 2) моделюванні об'єму стовбурів у зазначених категоріях лісових насаджень; 3) порівнянні виявлених залежностей із аналогічними даними для пристигаючих, стиглих і перестійних деревостанів. Дослідження ґрунтувалося на даних постійних і тимчасових пробних площ (близько 600), закладених у лісових насадженнях протягом 1950–2020-х років у найбільш лісистих регіонах України (Полісся, Лісостеп, Карпати). З метою точної оцінки об'єму стовбурів у корі на пробних площах було обміряно близько 10 тис. модельних дерев. Моделі співвідношення *h-d* були підібрані з використанням відносних значень висоти дерев та абсолютних значень діаметра, які продемонстрували дуже схоже співвідношення між висотою та діаметром дерев для більшості деревних видів, за винятком ялини та ялиці в гірських лісах Карпат, де були отримані більш круті криві висот. Встановлено, що стовбури берези та граба мають найменший об'єм серед досліджуваних деревних видів. Результати досліджень також засвідчили, що стовбури дерев, як правило, мають більший об'єм (до 7 % для хвойних і до 10 % для осики та берези) у молодняках і середньовікових лісових насадженнях, ніж у деревостанах старшого віку. Для інших деревних видів автори не виявили статистично значущої різниці між об'ємами стовбурів дерев різного віку. Розроблені математичні моделі можуть доповнювати відповідні моделі для старших груп лісових насаджень, оскільки вони розкрили важливий аспект взаємозв'язків між ключовими таксаційними показниками стовбурів дерев. Вони також можуть застосовуватися для точнішої оцінки об'єму стовбурів дерев під час рубок догляду в молодняках та середньовікових насадженнях України з практичної точки зору

Ключові слова: крива висот, об'ємні таблиці, розряд висот, видове число, прогнозування

Received: 17/09/2022; Revised: 04/12/2022; Accepted: 18/12/2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(4), 84-95

UDC 502:630*68:006.44
DOI: 10.31548/forest.13(4).2022.84-95

Integration of Environmental Values into the Management System of Forestry Enterprises in Accordance with the Requirements of Forest Certification

Oksana Pavlishchuk*, Pavlo Kravets, Andrii Churilov

Education and Research Institute of Forestry and Landscape-Park Management
National University of Life and Environmental Sciences of Ukraine
03041, 19 Horikhuvatskyi Shliakh Str., Kyiv, Ukraine

Abstract. The relevance of the study is conditioned by the importance of proper application of forest certification as a tool for responsible forestry. The lack of integrated approaches and formalities in the implementation of forest certification requirements is unacceptable from the standpoint of the interests of society and the environment. The purpose of the study is to substantiate the theoretical and practical foundations of integrating environmental values as one of the requirements for forest certification under the Forest Stewardship Council, into the management system of forestry enterprises. General and special methods (analysis, synthesis, generalisation, and comparison), and the regulatory framework for forest certification and the quality management standard were used for the research. The paper describes the concept of environmental values in the context of its components. It is proved that system, process-based, adaptive, and risk-oriented approaches to management are the basis for integrating the concept of environmental values into the management system of forestry enterprises. It is determined that the development of processes that cover the requirements of forest certification for environmental values and their documentary support are elements of the mechanism for integrating environmental values into the management system. Such processes are related to: identification of environmental values; determination of the purpose and criteria for making decisions on them; assessment of the impact of economic activities on them; development and implementation of measures for their conservation, maintenance, and protection; monitoring of the state and measures. Procedures, monitoring methods, training programmes, standard accounting and reporting forms are components of documenting these processes. The study results will be useful for improving the management system of forestry enterprises in accordance with the requirements of forest certification in terms of planning, organisation, monitoring, and control. The implementation of the tools and practical steps outlined for this purpose will contribute to the growth of efficiency of enterprises and their competitiveness in markets, access to which is determined by the requirements for the sustainability of the origin of forest products

Keywords: environment elements, FSC standard, compliance assessment, system approach to management, process approach to management, adaptive forestry

Suggested Citation:
Pavlishchuk, O., Kravets, P., & Churilov, A. (2022). Integration of environmental values into the management system of forestry enterprises in accordance with the requirements of forest certification. *Ukrainian Journal of Forest and Wood Science*, 13(4), 84-95.

**Corresponding author*

Introduction

Ensuring responsible forest management in the face of modern challenges as one of the tasks in the context of the Global Sustainable Development Goals requires effective tools [1]. Forest certification is a market-based tool aimed at ensuring environmentally balanced, cost-effective, and socially oriented forest management. Protection, maintenance, conservation of environmental values, avoiding the negative impact of economic activity on them is one of the components of the FSC (Forest Stewardship Council) principles, criteria, and indicators on which the FSC national standards are based [2; 3]. In Ukraine, this is the FSC National Forest Stewardship Standard of Ukraine (hereinafter – FSC national standard for Ukraine) [4]. As of October 2022, 95 Ukrainian forestry enterprises holding FSC certificates are implementing it in practice [5].

Formality in the practical implementation of the requirements of the FSC national standard, conjuncture of management and production decisions, in contrast to the systematic implementation of requirements, orientation to safety and risk-oriented approaches, are unacceptable from the standpoint of achieving the goals of responsible forestry. In terms of environmental values, the formality of management approaches can have both short-and long-term consequences that will lead to losses in environmental quality, deterioration of biodiversity, and a decrease in the potential of ecosystem services. That is why proper integration of forest certification standards, in particular, the FSC national standard for Ukraine, into the management system of forestry enterprises, systematic implementation of its requirements, focus on preventing any negative potential consequences – all this is evidence of maintaining the values of forest certification and environmental and social responsibility of forest owners and forest users.

The purpose of the study was to substantiate the theoretical and practical foundations of integrating the requirements of FSC certification in terms of environmental values into the management system of forestry enterprises.

The objectives of the study were:

– to define the concept of environmental values in FSC certification requirements;

– to systematise management approaches at forestry enterprises as a basis for responsible forestry management;

– to substantiate the mechanism for integrating environmental values as requirements of the FSC certification standard into the management system of forestry enterprises based on the development of appropriate management and production processes and procedural documentation.

The originality of the study consists in improving approaches to the management of forestry enterprises based on a well-founded mechanism for integrating forest certification requirements in terms of environmental values into the management system. Such a mechanism defines the requirements of forest certification not as additional to conventional forestry practices, but as the basis of management at the enterprise in accordance with the system, process, adaptive and risk-based approaches on which the FSC principles, criteria, and indicators of the forest management system are based.

Literature Review

A number of studies are devoted to the practical implementation of forest certification standards. They primarily reflect certain aspects of the impact of forest certification on the environment and society. For example, the authors of [6] evaluated the contribution of forest certification under the FSC scheme to biodiversity conservation using the example of such countries as Finland, Sweden, Estonia, and Latvia. Researchers argue the positive impact of FSC requirements on biodiversity conservation and their greater directivity in comparison with the national legislation of countries [6].

Using the example of forests of individual countries of South-Eastern Europe (Bosnia and Herzegovina, Croatia, Serbia, Slovenia), the authors of [7] investigated the impact of forest certification under the FSC scheme on ensuring sustainable management of state forests. Based on an analysis of the inconsistencies noted in publicly available certification assessment reports and a survey of those responsible for forest certification in forestry enterprises, the researchers concluded that forest certification has a positive impact on forest management practices and sustainable forest management, especially in terms of environmental and social aspects.

An assessment of the economic consequences of forest certification under the PEFC (Programme for the Endorsement of Forest Certification) scheme on the example of Spain is carried out in [8]. Although the researchers have not confirmed the impact of forest certification on improving financial performance, it is noteworthy to quantify the impact of forest certification on the profitability and turnover of companies.

The participation of communities in the management of FSC-certified and non-certified forest plantations on the example of Mozambique is considered in [9]. In general, the results show the importance of forest certification as a market tool for ensuring responsible forestry management.

P.G. Lemes, J.C. Zanuncio, L.A.G. Jacovine, C.F. Wilcken, S.A. Lawson assessed the impact of a number of certification schemes, including FSC, on the practice of integrated pest protection using the example of Australia [10]. In particular, they focused on the requirements for chemical pesticides prohibited by FSC. The researchers noted the positive impact of FSC certification on the integrated plant protection system against pests and emphasised the costs that accompany compliance with certification requirements.

The authors of [11] concluded that forest certification under the FSC scheme has a positive impact on fauna biodiversity based on a study conducted in Peru. The researchers made a conclusion based on a comparison of such effects in reference FSC-certified sites and those that did not have this status.

The impact of FSC certification on the Italian forest industry was investigated in [12]. The researchers considered such a tool in the context of responsible forest management and traceability of product origin. For a number of reasons for the introduction of FSC certification by Italian forest industry enterprises, the researchers noted the possibilities of expanding business relations between enterprises with an increase in product sales volumes in the future. This allows partially compensating for the operating costs of enterprises necessary to ensure compliance with FSC requirements.

A number of studies were devoted to FSC certification of ecosystem services [13-15]. In particular, the study [14] explored the capabilities of key stakeholders of the FSC certification system in terms of their ability to integrate forest ecosystem services: the capabilities of auditors for conformity assessment, national partners of FSC – for training activities, holders of FSC certificates – in terms of their experience in managing forest ecosystem services.

The paper [13] presents the results of a study of the demand for FSC certification of forest ecosystem services, considering the benefits and costs of certification of such services. The authors identified a number of factors that are important for stimulating the development of certification of ecosystem services (for example, price premium, expanding access to the global market, etc.), and outlined the challenges that are associated with this.

It is also worth noting the line of research that concerns the assessment of compliance with the requirements of forest certification standards. This area is important for continuous improvement of farming practices, considering the results of the assessment [16-18]. In particular, the authors of [16] determined factors affecting the characteristics of non-compliance with FSC requirements identified during the certification audit process. Such a study is important in terms of improving the effectiveness of FSC certification procedures and improving their quality.

The study [17] analyses non-compliance with FSC requirements identified by certification bodies in the audit process at the level of forestry management units in Indonesia. The researchers focus on finding the characteristics of forestry management units that affected the classes of corrective action requests and the time required to close them.

The study described in [18] concerns the field of activity of auditors who assess FSC compliance with the Brazilian standard. The researchers, among other things, draw attention to the significant number of minor non-conformances with the FSC standard for Brazil found in certified enterprises, especially in terms of social, legal, and environmental indicators. The conclusions of the study [18] relate to the areas of improving the quality of certification in terms of the process of assessment by certification bodies of compliance with the requirements of FSC standards, considering their regulatory framework.

Despite the best practices on forest certification, system approaches to the implementation of its standards based on the establishment of appropriate management and production processes and their proper support (documentary, organisational, etc.) require attention.

Materials and Methods

The study was based on general and special methods. In particular, methods of analysis, synthesis, generalisation, and comparison were applied to perform tasks in terms of defining the concept of environmental values in the requirements of FSC certification. The system analysis is used to outline approaches to management at forestry enterprises in accordance with the principles of responsible forestry. Based on the process approach, the management and production processes necessary for integrating environmental values into the management system of forestry enterprises are substantiated.

Obtaining scientific results required the following sequence of actions:

– generalisation and systematisation of requirements for environmental values as a component of the FSC national standard for Ukraine [4], which are reflected both in Principle 6 and in other principles of the standard in the context of avoiding negative impact on them, preventing and minimising risks;

– analysis of basic management approaches required for FSC-certified forestry enterprises (system, process, adaptive, risk-based) as a theoretical basis for making decisions on integrating environmental values into the management system;

– substantiation of the components of the mechanism for integrating environmental values into the management system of forestry enterprises at the managerial and production levels;

– identification of processes and their documentation on the example of environmental values as an element of integrating requirements into the management system of forestry enterprises.

The study was based on the requirements of the FSC National Forest Stewardship Standard of Ukraine [4]. The theoretical basis of the international standard ISO 9001:2015 "Quality Management Systems" is also used in terms of its process approach, the PDCA cycle ("Plan–Do–Check–Act") [19], and risk-based thinking, which is important for ensuring a results-based system.

Results

To substantiate the principles of integrating environmental values into the management system of forestry enterprises, first of all, it is necessary to outline the essence and content of the concept of such values. In particular, in the FSC national standard for Ukraine, environmental values are understood as elements of the biophysical and human environment, which include: ecosystem functions; biological diversity; water resources; soils; atmosphere; landscape values (in particular, cultural and spiritual values). The concept of environmental values implemented in this standard is aimed at protecting, maintaining, and conserving all components of such values.

According to the FSC national standard for Ukraine, the concept of environmental values consists in [4]:

– identifying and assessing environmental values;

– determining and evaluating the impact of economic activity on environmental values;

– preventing negative impacts of economic activity on environmental values, mitigating and correcting the impacts that have occurred.

The concept is implemented at the following stages: management planning; practical implementation of the plan in terms of reforestation, use of forests, their conservation and protection; monitoring. The concept covers the processes of analysis, evaluation, adjustment and adaptation of farming in accordance with the results obtained (the consequences of implemented decisions) and considering changing conditions (Fig. 1). The concept of environmental values is based on a risk-based approach and the precautionary principle in decision-making.

Achieving the goals for elements of environmental values requires appropriate economic measures both in forests that have operational (commercial) significance, and in relation to specific objects that have a protected status and are part of the conservation areas network of forestry enterprises. In the context of the concept of environmental values, such measures will contribute to the maintenance and conservation of values:

– ensuring sustainable forest use (both in terms of wood and non-wood forest resources);

– timely restoration of vegetation cover after harvesting and the use of ecologically well-adapted species to the conditions of the site, including native species;

– application of forestry practices that meet forest conditions and management goals (for example, leaving dead and decaying biomass in areas after harvesting and conserving forest structure).

The conservation areas network includes those areas for which conservation is the primary or sole purpose. Such a network is established from representative sample areas, conservation zones, protection areas, connectivity areas, and high conservation value areas. In addition to the territories that make up such a network, the FSC national standard for Ukraine defines approaches to their identification by enterprise, protection, conservation, management, and monitoring. At the same time, the standard provides for the active conservation and maintenance of the territories that make up the conservation areas network based on preventive measures within the framework of economic activities. If necessary, passive conservation is also applied (in particular, the prohibition of economic activity), if this is required either by the protected status of the territory or object defined by law, or by the selected regime for the components of the network in accordance with a certain purpose in relation to them.

Interaction with stakeholders (informing and engaging in decision-making) is an integral part of the concept of environmental values. For example, stakeholder consultations are seen as a source of the best available information to identify environmental values (e.g. rare and threatened species and their habitats; native ecosystems; high conservation values). Stakeholder engagement is provided for the process of developing strategies and measures to maintain and/or enhance high conservation values and monitor them [20-22]. At the same time, holders of FSC certificates in accordance with the requirements of the FSC national standard for Ukraine have obligations to interact with interested parties within the limits within which the activities of enterprises affect the rights of these parties. Thus, interested parties can express their interests in relation to the activities of an FSC-certified enterprise and demand compliance with their legal rights. However, they may not require the right to grant, modify, or suspend or revoke a business permit by a certified enterprise [22].

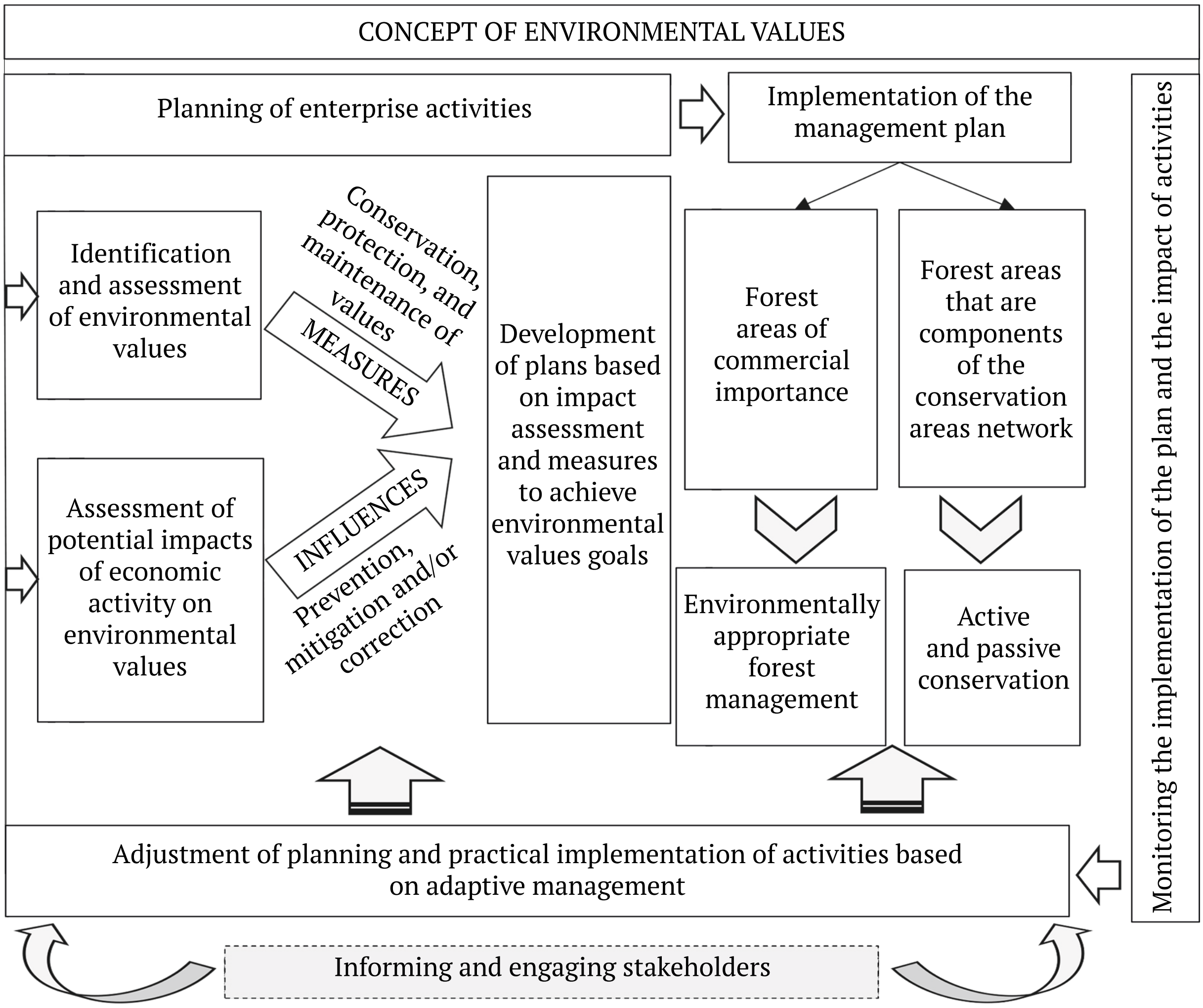


Figure 1. The concept of environmental values in the FSC National Forest Stewardship Standard of Ukraine
Source: developed by O.P. Pavlishchuk based on [4]

Thus, the above review of the concept of environmental values shows that its proper practical implementation requires both appropriate production practices and management approaches in forestry enterprises (Figure 2).

In terms of production activities, all its stages should be guided by the requirements of the FSC national standard for Ukraine, namely, in the process of reforestation, care of forest stands, harvesting, and protection of forests from pests and diseases. The requirements that need to be guided in production activities, among other things, relate to preventing negative impacts on environmental values, ensuring their conservation and protection. This is especially relevant for rare and threatened species and their habitats; representative sample areas; native species and genotypes (as opposed to alien species that may have invasive impacts); and natural watercourses and other water bodies. The standard attaches importance to the issues of minimising and/or avoiding the use of fertilisers, pesticides, and biological control agents. The development of infrastructure and the transportation process should also consider the need to protect and conserve environmental values. Thus, the practice of forestry should be consistent with the goals of forest management, be responsible and close to nature.

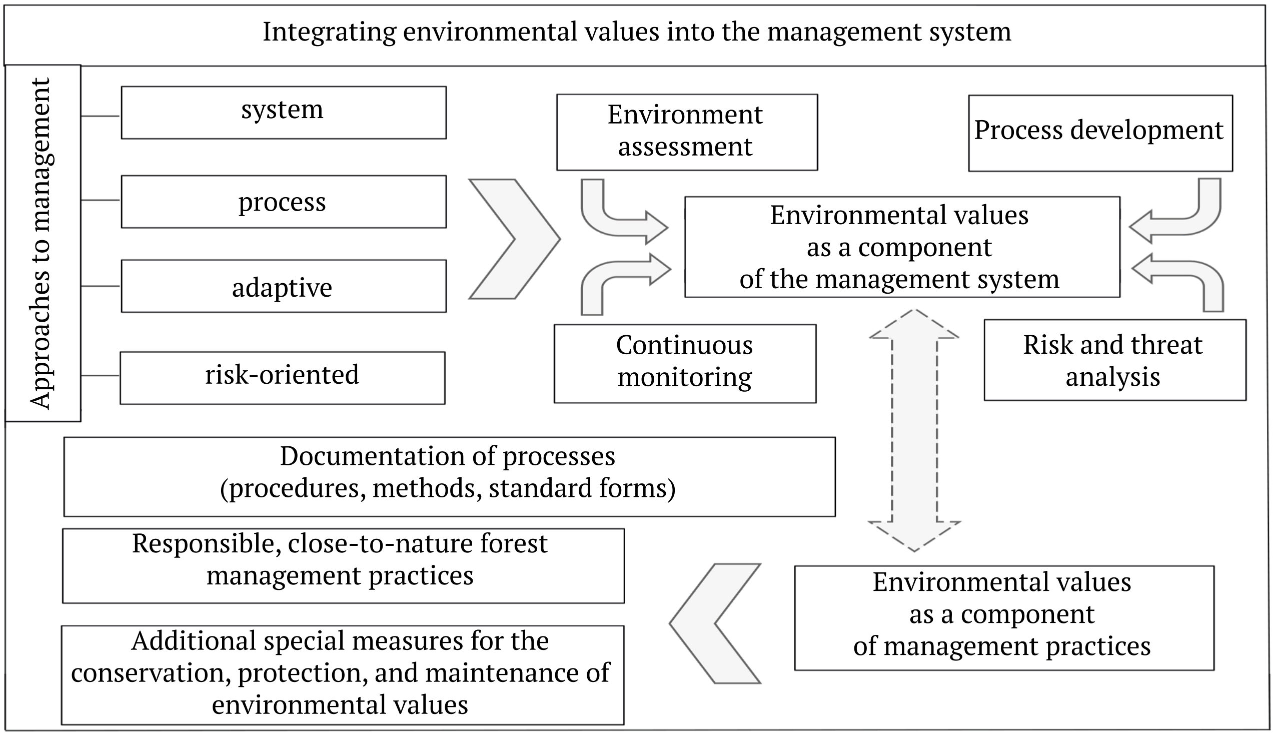


Figure 2. Components of the mechanism for integrating environmental values into the management system
Source: developed by O.P. Pavlishchuk based on [4]

As for the management component, first of all, the proper implementation in practice of the principles, criteria, and indicators of the FSC national standard for Ukraine requires enterprises to have an appropriate management system based on system, process, adaptive, and risk-oriented approaches. The use of the precautinary principle in decision-making is a tool to avoid negative impacts on environmental values during economic activity.

Regarding the theoretical foundations of integrating environmental values into the management system, it is worth noting first of all the importance of a system approach in the management of forestry enterprises. According to this approach, forestry enterprises are considered in the unity of their components – factors of the internal environment (goals and objectives, structure, technologies, resources) and in relation to the external environment. Interdependence of elements of the enterprise environment (external and internal), understanding the contribution of each of them to the characteristic of the whole and orientation on achieving goals under changing conditions is the basis of a system approach. Transformation of resources obtained from the external environment on the basis of appropriate internal processes is carried out in order to obtain economic, social and other results of activity.

These theoretical foundations confirm the importance of constant analysis of factors of the external and internal environment of enterprises in their interrelation, assessment of the impact of changes, determination of potential consequences of strategic, tactical, and operational decisions to preserve the integrity of the system and ensure its efficiency and effectiveness.

Integration of environmental values into the management system requires the use of a process approach in enterprises, which consists in presenting them as an integral system through the prism of interrelated processes. To achieve the planned result, it is necessary to define and implement appropriate processes at the management and production levels and consider their interaction and resource support.

The process approach is the basis of the international standard ISO 9001 "Quality Management

Systems" [19]. PDCA cycle (*Plan–Do–Check–Act*) – according to this standard, is a tool for managing processes and the system in general. The implementation of the process approach requires defining the goals of the system, developing processes, determining the necessary resources for obtaining results, identifying, analysing, and assessing risks. A component of the process approach is monitoring, analysing and evaluating processes and performance from the standpoint of the company's policy and plans. Adjusting plans, identifying opportunities and ways to improve the future, considering the business environment of enterprises, is also a component of the process approach in management. At the same time, the quality result depends on the quality of each process: from collecting initial information to implementing the plan and evaluating its implementation with further adjustments.

A risk-based approach is essential to prevent undesirable consequences. It is necessary to better understand the business environment and identify factors that may have negative impacts on processes and the management system in general. This approach increases the effectiveness of the system by avoiding potential negative impacts on it.

Integration of a risk-based approach into the management system is carried out at the stage of planning and implementing processes to reduce the negative impact of uncertainty, increase the capabilities of enterprises, and increase the efficiency of their activities in a dynamic environment.

An adaptive management approach is important for the proper response to the dynamism of environmental conditions. A component of this approach is the analysis and assessment of the company's business environment, its strengths and weaknesses, threats and risks. According to the adaptive approach, the company's activities, results, and processes should be constantly monitored. Based on the analysis and assessment of the environment and monitoring, decisions are made on the appropriate modification of the management system, adjustment of decisions to achieve the goals set.

The stages of adaptive management are: planning, implementation of activities, monitoring, evaluation and, if necessary, appropriate adjustment of management plans and practices. The key to adaptive management is the openness and transparency of the decision-making process through the participation of stakeholders at all stages.

Adaptive management is especially important in the context of climate change, which requires appropriate adaptation both in terms of management and forest use practices. For example, these questions are the subject of study by many researchers, in particular, J. Hörl, K. Keller, R. Yousefpour (exploring adaptive forest management strategies in the context of climate change) [23], J. Thomas, M. Brunette, A. Leblois (focusing on the decision-making process of private forest owners regarding the adaptation of forestry to climate change) [24].

Thus, the success of the implementation of FSC principles, criteria and indicators of responsible forestry in general, depends on the orientation of the company's management to the approaches described above, aimed at establishing a sustainable and viable system. Successful integration of environmental values as a requirement of the FSC national standard for Ukraine into the management system will require its appropriate modification in terms of processes, procedures, responsibility, and documentation.

Thus, the components of the mechanism for integrating environmental values (the element of the FSC national standard for Ukraine) into the management system are:

– establishment of management of forestry enterprises based on system, process, adaptive, and risk-based approaches, which are the basis for making effective and efficient decisions aimed at the long-term development of enterprises;

– development of processes covering applicable requirements for environmental values at the management and production levels;

– documentation support, in particular, the development and implementation of procedures and methods that determine the sequence of actions, responsibility, and other components necessary for the protection, conservation, and maintenance of environmental values to be systematically implemented in the practice of the enterprise.

As for the first component of the mechanism, it is important to realise that the long-term development of forestry enterprises requires their orientation to ensure environmentally balanced, cost-effective, and socially useful forestry, considering a wide range of forest values and their importance in countering global environmental threats. This requires a transformation of conventional approaches and an informal approach to forest management in compliance with applicable legislation, where specific practical solutions consider economic, environmental, and social components.

According to the second component of the above-mentioned mechanism, the implementation of the concept of environmental values requires the introduction of appropriate processes at the management and production levels of forestry enterprises, which cover, in particular:

1. Identification of elements of environmental values.

2. Definition of a goal for elements of environmental values, considering the requirements of the standard for their conservation, protection, maintenance, and/or enhancement.

3. Determination of decision-making criteria for elements of environmental values that correspond to the set goal.

4. Assessment of elements of environmental values (for example, for their vulnerability, sensitivity to various types of impacts, rarity, etc.).

5. Assessment of the impact of economic activities on environmental values, identification of threats and risks to them from anthropogenic, abiotic, and biotic factors.

6. Development of strategic, tactical, and operational measures to achieve certain goals regarding the elements of environmental values with their reflection in the company's plans (implementation of measures in the planned activities of the enterprise).

7. Implementation of measures to achieve the goals of elements of environmental values at the strategic, tactical and operational levels at various stages of forestry activities (implementation of measures in forest management practices).

8. Monitoring the state of elements of environmental values, implementation of strategic, tactical, and operational measures and their effectiveness in achieving certain goals.

9. Reviewing, adapting, and adjusting strategic, tactical, and operational measures to conserve, protect, maintain, and/or enhance elements of environmental values in accordance with the monitoring results and considering changing conditions (both at the planning and business operations stages).

10. Informing and engaging stakeholders in activities related to identifying, evaluating, developing measures and monitoring environmental values (the process of interaction with stakeholders).

An integral part of the processes of developing and implementing measures at different levels regarding environmental values is to prevent negative impacts of economic activities on them, or to mitigate or correct those impacts that have already occurred. In addition, one of these measures should be to prevent illegal or unauthorised activities (for example, collecting rare and threatened species, poaching, etc.).

All the above-mentioned processes actually complement those that are more general in nature and are related to appropriate practices for the use of forests, their regeneration, protection, conservation. Notably, processes regarding environmental values relate to both forest and non-forest ecosystems (for example, the requirements for identifying native ecosystems, their representative areas and implementing appropriate measures for them are set out in Principle 6 of the FSC national standard for Ukraine [4]).

As for documenting the integration of environmental values into the management system, the current practice of forestry enterprises contains only some of its components. In particular, such components include: forest management plan and other forest management materials; files of forest mensuration; provisions and protection obligations for nature reserve fund objects of Ukraine (those located on the territory of a forestry enterprise); nature chronicles for nature conservation agencies, whose land border on the territory and / or located within the management unit without removal from the permanent user (this applies to national nature parks, biospheric, nature reserves, etc.). Moreover, documentary support covers materials of environmental impact assessment, which is carried out by forestry enterprises in accordance with the law of Ukraine "On Environmental Impact Assessment" [25]. However, this and other industry documentation of forestry enterprises do not provide proper documentary support for the integration of environmental values into the management system in accordance with the requirements of the FSC national standard for Ukraine. Thus, additional documentation is required, namely:

– the procedure for assessing environmental values (among other things, it should define the goals and objectives in this area, regulate the responsibility of employees, outline the methodology for identifying and evaluating environmental values with the necessary level of detail sufficient for further monitoring of the impact of activities);

– the procedure for assessing the impact on environmental values (among the general components, such as the goal, objectives, should contain the procedure for employees to assess the impact on values with the regulation of responsibility of each of them; appropriate lists of typical economic measures that may have a potential impact on environmental values, a description of typical impacts, and measures aimed at preventing and mitigating them);

– the standard forms necessary to reflect: the list of values, their characteristics, compiled based on desk and field study; the results of assessing the potential impact of economic activity on environmental values at a reasonable level (forest plot, compartment, etc.) indicating the degree of such impact, and a description of the necessary measures to avoid or mitigate it; the results of monitoring the state of environmental values, the effectiveness of implemented measures for them in accordance with the goals set; the results of interaction with stakeholders on issues related to environmental values.

Documenting the integration of environmental values into the management system also requires appropriate training programmes that promote the proper professional competence of employees. The procedure for the engagement of stakeholders in planning and monitoring the management activities of a forestry enterprise is important.

Proper integration of environmental values into the management system of forestry enterprises is a testament to their responsibility to society and the environment, and a guarantee of increasing their contribution to mitigating global threats. At the same time, the FSC national standard provides opportunities for forestry workers to reach their potential in terms of making decisions about environmental values, without imposing specific options for action, defining only the framework of permitted and necessary activities. The systematic practice of implementing requirements for environmental values makes them an integral part of responsible management and evidence of commitment to forest certification values.

Discussion

The study results should be considered in the context of existing developments of researchers in the field of forest certification. Most scientific research in this area concerns the impact of forest certification on certain elements of the forest management system of enterprises that hold certificates, and related to the general impact of forest certification on the environment and society. In particular, the practical implementation of FSC certification requirements is considered in the context of economic, environmental, and social aspects of forest management: biodiversity conservation [6; 11], ecosystem services [13-15], integrated plant protection against pests [10], ensuring traceability of the forest product supply chain [12], relationships with stakeholders as participants in the forest certification system [21; 22].

The positive impact of forest certification on the competitiveness of forest industry enterprises, which is demonstrated on the example of Italy [12], generally allows asserting the possibility of improving the image of certified enterprises as environmentally and socially responsible organisations, including the possibility of expanding their sales markets for forest products, for which the independent party has confirmed the constancy of origin. This is an economic advantage of forest certification. Positive are the opportunities for forest certification based on the relevant requirements of FSC principles, criteria and indicators [2; 3] to influence the increase of public awareness about forests and forestry management, strengthening the engagement of stakeholders in the planning and monitoring processes at forestry enterprises, as discussed in [21; 22]. This is considered by the researchers as a social component of the practical implementation of forest certification requirements for conflict prevention in relation to forests and forestry management.

Considering the requirements of the FSC principles, criteria, and indicators [2; 3], it is possible to generalise the environmental benefits of their implementation by enterprises, which include: maintenance and conservation of biodiversity, forest ecosystem services and other elements of the environment, ensuring the sustainability of forest use, avoiding or minimising the negative impact on the environmental values of economic activity. The social benefits of forest certification, in addition to those mentioned earlier, also include ensuring compliance with the legal rights of workers, occupational health and safety in forestry, and avoiding gender inequality and discrimination on various grounds. Strengthening engagement with stakeholders, particularly local communities, is an element of socially beneficial management as a goal of forest certification.

Attention in scientific research to the procedures for assessing compliance with the requirements of forest certification standards, as done in [16-18], is conditioned by the importance of this component in the context of ensuring the integrity, openness, and transparency of the certification system. The context of these publications emphasises that the assessment of compliance with FSC requirements in the framework of certification audits, in addition to the control function, plays an important role in identifying weaknesses in the forest management system and contributes to the development of specific areas and actions for improving responsible forestry practices.

Thus, all these areas of scientific research are important both in general for improving the forest certification system at the level of its various participants (certificate holders, stakeholders, certification bodies, national partners of FSC in countries), and for the proper practical implementation of the requirements of FSC principles, criteria, and indicators [2; 3]. However, most studies consider forest certification as a market tool for responsible forestry in the context of its external influences on the environmental, economic, and social components of the forestry management system. At the same time, existing studies focus to a lesser extent on the role of forest certification as a tool for improving the management system of forestry enterprises in terms of processes, procedures, and methods. They should be considered as components of the internal environment of forestry enterprises, which strengthen it and contribute to the production of positive internal and external effects.

This paper, as well as the studies by the above-mentioned researchers, concerns the possibilities of the positive impact of forest certification under the FSC scheme on the conservation, protection, and maintenance of environmental values. However, in this study, unlike others, forest certification is considered as the basis of management of forestry enterprises, considering system, process, adaptive, risk-oriented approaches and other elements of the mechanism for integrating its requirements into the decision-making system. The precautionary principle in FSC principles, criteria, and indicators [2; 3] determines the appropriate process of making managerial and production decisions, taking into account the possible impacts of economic activity, and estimated potential risks for achieving goals. Appropriately developed, implemented, and documented processes for planning and organising the activities of forestry enterprises, monitoring, evaluation, and adaptation would contribute to the growth of the contribution of FSC certified forestry enterprises to ensure environmentally appropriate, economically viable and socially beneficial forest management for present and future generations.

Conclusions

The presented substantiation of the principles of integrating environmental values into the management system of forestry enterprises in accordance with the requirements of forest certification allows drawing the following conclusions:

– the concept of environmental values is an integral part of the FSC principles, criteria, indicators, and the FSC national standard for Ukraine developed on their basis; reflecting the environmental component of responsible forestry, this concept defines the necessary areas of activity for the conservation, protection, and maintenance of various elements of environmental values both within the framework of general forest management practices and within the framework of those special additional measures necessary to achieve their goals;

– the implementation of the concept of environmental values in the context of its components to identify such values, assess them, determine the potential impact of economic activity on them and, accordingly, the development and implementation of measures to prevent such impacts or mitigate them, conserve and maintain values, requires appropriate approaches to both the management system and practical activities;

– the mechanism for integrating environmental values into the management system is based on such basic approaches to management as system, process, adaptive, risk-oriented, which create the basis for making and implementing effective and effective decisions in management;

– the possibilities of modifying the management system and forest use practices in terms of integrating environmental values are determined by: systematic analysis of the external and internal environments of the enterprise in the relationship of their factors; flexibility of management and production processes developed in accordance with the set goals; systematic assessment of potential risks and threats to the implementation of these processes; constant monitoring of the company's activities;

– the development of processes in accordance with the applicable requirements of forest certification for environmental values at the management and production levels, and their documentary support in the form of procedures, methods, standard forms of accounting and reporting are integral components of the successful integration of requirements for environmental values into the management system and practice of the enterprise;

– the processes regarding environmental values, considering the applicable requirements in the FSC national standard for Ukraine, should reflect the identification of environmental values, assessment of the impact on them, development of measures in accordance with the goals set for their conservation, maintenance, protection, monitoring their condition and measures, and adjustment if necessary;

– proper interaction with stakeholders as one of the processes related to environmental values will contribute to the balance of environmental, economic, and social interests, avoiding social tension and possible conflict situations around issues related to environmental values.

The research prospects are further related to the assessment of the requirements of the concept of environmental values in accordance with the principles, criteria, and indicators of forest certification in the context of applicable country legislation. It is also necessary to substantiate the principles of better integration of the concept of environmental values into forestry practices at the level of specific measures for elements of such values.

References

[1] Sustainable development goals. (n.d). Retrieved from https://www.un.org/sustainabledevelopment/.

[2] FSC Principles and criteria for forest stewardship FSC-STD-01-001 V5-2. (2015). Retrieved from https://connect.fsc.org/document-centre/documents/resource/392.

[3] International generic indicators FSC-STD-60-004 V2-0. (2018). Retrieved from https://connect.fsc.org/document-centre/documents/resource/262.

[4] The FSC National Forest Stewardship Standard of Ukraine FSC-STD-UKR-01-2019 V 1-0. (2019). Retrieved from https://fsc.org/en/document-centre/documents/resource/428.

[5] FSC Facts & Figures in Ukraine. (2022). Retrieved from https://ua.fsc.org/ua-en/fsc-facts-figures-in-ukraine.

[6] Lehtonen, E., Gustafsson, L., Lohmus, A., & Stedingk, H.V. (2021). What does FSC forest certification contribute to biodiversity conservation in relation to national legislation? *Journal of Environmental Management,* 299, article number 113606. doi: 10.1016/j.jenvman.2021.113606.

[7] Malovrh, Š.P., Becirovic, D., Maric, B., Nedeljkovic, J., Posavec, S., Petrovic, N., & Avdibegovic M. (2019). Contribution of forest stewardship council certification to sustainable forest management of state forests in selected Southeast European Countries. *Forests*, 10(8), article number 648. doi: 10.3390/f10080648.

[8] Zubizarreta, M., Arana-Landín, G., Wolff, S., & Egiluz, Z. (2023). Assessing the economic impacts of forest certification in Spain: A longitudinal study. *Ecological Economics*, 204(A), article number 107630. doi: 10.1016/j.ecolecon.2022.107630.

[9] Degnet, M.B., Werf, E., Ingram, V., & Wesseler, J. (2022). Community perceptions: A comparative analysis of community participation in forest management: FSC-certified and non-certified plantations in Mozambique. *Forest Policy and Economics*, 143, article number 102815. doi: 10.1016/j.forpol.2022.102815.

[10] Lemes, P.G., Zanuncio, J.C., Jacovine, L.A.G., Wilcken, C.F., & Lawson, S.A. (2021). Forest Stewardship Council and Responsible Wood certification in the integrated pest management in Australian forest plantations. *Forest Policy and Economics*, 131, article number 102541. doi: 10.1016/j.forpol.2021.102541.

[11] Campos-Cerqueira, M., Mena, J.L., Tejeda-Gómez, V., Aguilar-Amuchastegui, N., Gutierrez, N., & Aide, T.M. (2020). How does FSC forest certification affect the acoustically active fauna in Madre de Dios, Peru? *Remote Sensing in Ecology and Conservation*, 6(3), 274-285. doi: 10.1002/rse2.120.

[12] Galati, A., Gianguzzi, G., Tinervia, S., Crescimanno, M., & Veca, D.S.L.M. (2017). Motivations, adoption and impact of voluntary environmental certification in the Italian Forest based industry: The case of the FSC standard. *Forest Policy and Economics*, 83, 169-176. doi: 10.1016/j.forpol.2017.08.002.

[13] Jaung, W., Putzel, L., Bull, G.Q., Guariguata, M.R., & Sumaila, U.R. (2016). Estimating demand for certification of forest ecosystem services: A choice experiment with Forest Stewardship Council certificate holders. *Ecosystem Services*, 22, part A, 193-201. doi: 10.1016/j.ecoser.2016.10.016.

[14] Jaung, W., Putzel, L., Bull, G.Q., Kozak, R., & Elliott, C. (2016). Forest Stewardship Council certification for forest ecosystem services: An analysis of stakeholder adaptability. *Forest Policy and Economics*, 70, 91-98. doi: 10.1016/j.forpol.2016.06.004.

[15] Savilaakso, S., & Guariguata, M.R. (2017). Challenges for developing Forest Stewardship Council certification for ecosystem services: How to enhance local adoption? *Ecosystem Services*, 28, part A, 55-66. doi: 10.1016/j.ecoser.2017.10.001.

[16] Hălălisan, A.-F., Popa, B., Heras-Saizarbitoria, I., Boiral, O., Arana-Landin, G., Nicorescu, A.-I., & Abrudan, I.V. (2021). Procedural factors influencing forest certification audits: An empirical study in Romania. *Forests*, 12(2), article number 172. doi: 10.3390/f12020172.

[17] Hermudananto, R.C., & Ruslandi, P.F.E. (2018). Analysis of corrective action requests from Forest Stewardship Council audits of natural forest management in Indonesia. *Forest Policy and Economics*, 96, 28-37. doi: 10.1016/j.forpol.2018.07.012.

[18] Piketty, M.-G., & Drigo, I.G. (2018). Shaping the implementation of the FSC standard: the case of auditors in Brazil. *Forest Policy and Economics*, 90, 160-166. doi: 10.1016/j.forpol.2018.02.009.

[19] ISO 9001:2015. Quality management systems – Requirements. (2015). Retrieved from https://www.iso.org/standard/62085.html.
[20] Kravets, P.V. (Ed.). (2021). *Manual on the practical implementation of the FSC national forest stewardship standard of Ukraine*. Kyiv: FSC Ukraine.
[21] Pavlishchuk, O.P., & Kravets, P.V. (2020). Interactions with interested stakeholders in accordance with the FSC national forest stewardship standard of Ukraine. *Ukrainian Journal of Forest and Wood Science*, 11(1), 55-65. doi: 10.31548/forest2020.01.055.
[22] Pavlishchuk, O.P., & Storchous, O.V. (2021). *Forest certification according to FSC national forest stewardship standard of Ukraine: opportunities for stakeholders*. Kyiv: FSC Ukraine.
[23] Hörl, J., Keller, K., & Yousefpour, R. (2020). Reviewing the performance of adaptive forest management strategies with robustness analysis. *Forest Policy and Economic*s, 119, article number 102289. doi: 10.1016/j.forpol.2020.102289.
[24] Thomas, J., Brunette, M., & Leblois, A. (2022). The determinants of adapting forest management practices to climate change: Lessons from a survey of French private forest owners. *Forest Policy and Economics*, 135, article number 102662. doi: 10.1016/j.forpol.2021.102662.
[25] Law of Ukraine № 2059-VIII "On Environmental Impact Assessment". (2017, May). Retrieved from: https://zakon.rada.gov.ua/laws/show/2059-19#Text.

Інтегрування цінностей довкілля в систему менеджменту підприємств лісового господарства згідно з вимогами лісової сертифікації

Оксана Петрівна Павліщук, Павло Васильович Кравець, Андрій Михайлович Чурілов

Навчально-науковий інститут лісового і садово-паркового господарства
Національний університет біоресурсів і природокористування України
03041, вул. Горіхуватський шлях, 19, м. Київ, Україна

Анотація. Актуальність дослідження зумовлена важливістю належного застосування лісової сертифікації як інструменту відповідального лісогосподарювання. Відсутність інтегрованих в систему менеджменту підприємств підходів та формальності у реалізації вимог лісової сертифікації є неприйнятними з погляду інтересів суспільства та довкілля. Метою дослідження є обґрунтування теоретичних та практичних засад інтегрування цінностей довкілля, як однієї з вимог лісової сертифікації за схемою Лісової опікунської ради (Forest Stewardship Council), в систему менеджменту підприємств лісового господарства. Для дослідження використані загальні та спеціальні методи (аналізу, синтезу, узагальнення та порівняння), а також нормативну базу лісової сертифікації та стандарту менеджменту якості. В статті охарактеризовано концепцію цінностей довкілля у розрізі її складових. Обґрунтовано, що системний, процесний, адаптивний та ризик орієнтований підходи до менеджменту є основою інтегрування концепції цінностей довкілля в систему менеджменту підприємств лісового господарства. Визначено, що формування процесів, які охоплюють вимоги лісової сертифікації щодо цінностей довкілля та їх документальне забезпечення, є елементами механізму інтегрування цінностей довкілля в систему менеджменту. Такі процеси пов'язані з: ідентифікацією цінностей довкілля; визначенням мети та критеріїв прийняття рішень щодо них; оцінюванням впливу на них господарської діяльності; розробленням та впровадженням заходів для їх збереження, підтримання, охорони; моніторингом стану та заходів. Процедури, методика моніторингу, навчальні програми, типові форми обліку та звітності є складовими документального забезпечення зазначених процесів. Результати дослідження будуть корисними для удосконалення системи менеджменту підприємств лісового господарства згідно з вимогами лісової сертифікації в частині планування, організації, моніторингу та контролю. Реалізація окреслених для цього інструментарію та практичних кроків сприятимуть зростанню ефективності підприємств та їхній конкурентоспроможності на ринках, доступ до яких визначають вимоги щодо сталості походження лісопродукції

Ключові слова: елементи середовища, FSC стандарт, оцінювання відповідності, системний підхід до менеджменту, процесний підхід до менеджменту, адаптивне лісове господарство

УКРАЇНСЬКИЙ ЖУРНАЛ ЛІСІВНИЦТВА ТА ДЕРЕВИНОЗНАВСТВА

Науковий журнал

Том 13, № 4. 2022

Заснований у 2010 р. Виходить чотири рази на рік

Оригінал-макет видання виготовлено у відділі науково-технічної інформації
Національного університету біоресурсів і природокористування України

Відповідальний редактор:
Г. Івченко

Редагування англомовних текстів:
С. Воровський, К. Касьянов

Комп'ютерна верстка:
О. Глінченко

Підписано до друку 23 листопада 2022 р. Формат 60*84/8
Умов. друк. арк. 11,2
Наклад 50 прим.

Адреса видавництва:
Національний університет біоресурсів і природокористування України
вул. Героїв Оборони, 10, м. Київ, Україна, 03041
E-mail: info@forestscience.com.ua
www: https://forestscience.com.ua/uk

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Scientific journal

Volume 13, No. 4. 2022

Founded in 2010. Published four times per year

The original layout of the publication is made in the Department of Scientific
and Technical Information of National University of Life
and Environmental Sciences of Ukraine

Managing Editor:
H. Ivchenko

Editing English-language texts:
S. Vorovsky, K. Kasianov

Desktop publishing:
O. Glinchenko

Signed for print of November 23, 2022. Format 60*84/8
Conventional printed pages 11.2
Circulation 50 copies

Editors office address:
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony, Kyiv, Ukraine
E-mail: info@forestscience.com.ua
www: https://forestscience.com.ua/en