

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 № 7 від 3 березня 2021 р.)*

**Свідоцтво про державну реєстрацію
друкованого засобу масової інформації
серії KB 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**

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E-mail: info@forestsscience.com.ua
www: <https://forestsscience.com.ua/uk>

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. 7 of March 3, 2021)*

**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 30, 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

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UDC 630*5:528.7

DOI: 10.31548/forest2021.01.001

Precision of measuring the height of trees in various ways

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Abstract. This study investigated the precision of measuring the height of trees using different methods. The paper evaluates the possibilities of using the stereophotogrammetric method to determine tree height indicators using unmanned aerial vehicles (UAV) in the conditions of a mature pine stand. The study compares the results of measuring the height of Scots pine trees with altimeters and height indicators determined from remote sensing data obtained using UAVs. In total, the study investigated six diverse ways to measure the height of growing trees. Experimental data on the height of the model trees were collected by three different altimeters (hand-held ground instruments) and the Phantom 4 Pro UAV. The use of UAVs involved optical capture and data collection using on-board equipment. Methods for determining the height of trees based on the results of processing data collected by quadcopter attachments were used. Specifically, the authors of this paper used the method of measuring the height of trees from a point cloud based on one-way vertical survey of model trees and calculating a digital crown height model (CHM) based on aerial photography of horizontal spans over a tree stand. The results of mathematical analysis of the conducted studies demonstrate the highest precision of the method using CHM to determine the height of growing trees. The value of the average random error in measuring the height of model trees using CHM was under 2%. The next most precise method of determining tree height was the TruPulse 360B laser-optical device, which demonstrated the highest precision among height meters. The use of the TruPulse 360b for ground-based measurements and the CHM method (based on UAV optical imaging data) yielded better results that meet the height precision standards for industrial inventory. Methods for determining the height of trees based on optical survey data from UAVs can be used for survey, inventory, forest management, and other works related to forestry and monitoring changes in forest ecosystems

Keywords: unmanned aerial vehicle, aerial photography, stereophotogrammetry, canopy height model, altimeter

Introduction

One of the main forest inventory indicators for determining forest productivity is the average height of tree stands. Instrumental measurement of tree height during a full-scale survey of a forest area is mandatory and requires considerable time and effort,

especially in complex tree stands with dense understorey and undergrowth. These and other factors affect the precision of measurements, both in flat terrain and in mountainous areas. The error in measuring the height of trees and calculating the average

Suggested Citation:

Bilous, A., Diachuk, P., Zadorozhniuk, R., Matsala, M., & Burianchuk, M. (2021). Precision of measuring the height of trees in various ways. *Ukrainian Journal of Forest and Wood Science*, 12(1), 6-16. doi: 10.31548/forest2021.01.001

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height of the stand directly affects the determination of such indicators as site index class, height category, stock of the tree stand and its change.

Altimeters by measurement technology are divided into three groups: trigonometric and geometric principles of operation and optical. Altimeters of the trigonometric principle of operation are always basic, i.e., they require recording the distance from the point of measuring the height of the trunk to the tree on site. At the same time, the height is measured by viewing angles to the base of the tree and its top. The geometric principle of measuring the height of trees is based on the rules of similarity of triangles. Optical altimeters are constructed based on the laws of optics (Myroniuk et al., 2019). If there is no correction for the slope of the terrain, the inclination of the tree, the shape of the crown, this can lead to considerable errors in measuring the height of a growing tree (Bragg, 2008).

Recent decades have seen a widespread use of laser-optical devices that are designed to measure the height of a tree and are based on the use of built-in elements, specifically an inclinometer and a laser rangefinder. Apart from the height, other measurements can be made, which gives these devices advantages over others.

With the technological advance, new ways to determine the parameters of growing trees based on remote sensing data have emerged (Forsman et al., 2016; Guimarães et al., 2020; Magnussen et al., 2016; Maselli et al., 2014; Mulla, 2013), which do not require direct height measurement.

Unmanned aerial vehicles (UAVs) are widely used for optical imaging or laser scanning to collect data for local tasks in rural areas (Eskandari et al., 2020) and forestry (Guimarães et al., 2020). Improving photogrammetry methods and algorithms for image processing helps improve the precision of constructing a dense point cloud, which serves as the basis for digital models of relief and terrain, as well as 3D models of spatial objects. As a result, the precision of the results of decrypting environmental objects also increases.

Modern demands of society for the precision and relevance of information on forest resources require a review of the methods of forest inventory used in practice (Myroniuk et al., 2018), and the introduction of remote data collection into the practice of forest inventory is one of the principal modern trends in the development of forest inventory

methods (Myroniuk et al., 2019). That is why it is relevant to justify the effectiveness and precision of determining the height of trees in forest areas using the data of remote sensing of the Earth using UAVs compared to the use of altimeters.

The purpose of this study was to test various methods and devices for measuring the height of trees in natural conditions and establish the possibility of using stereophotogrammetry methods to determine the height of trees from optical data collected using UAVs.

Materials and Methods

The experimental plot of this study was the principal use felling area in the Irzhavets Forestry of the State Enterprise “Nizhyn Forestry” (block 30, allotment 9) in the territory of Chernihiv region.

The study was conducted in an 80-year-old tree stand of site index class I^a with a composition of 7Ps3Qr and a relative density of 0.7, which grows in the conditions of a fresh hornbeam-oak-pine sudbrava ($C_{2 \text{ rII}} C$). The average diameter of the experimental stand was 44 cm.

The object of the study was the precision of measuring the height of trees using various methods and devices.

The study was conducted in three stages. The first stage involved selecting 30 model trees, assigning and applying unique identification numbers to their trunks. Height measurements of growing trees were made with *Suunto PM-5*, *Haglof EC II-D* and *TruPulse 360B* laser range finder-altimeter according to the instructions for use and measurement work (Laser Technology Inc., 2017).

During the second stage, a *Phantom 4 Pro* UAV was used to perform optical imaging. Remote sensing data was processed using Agisoft Metashape software (Agisoft Metashape, 2019).

To directly determine the height of trees, a method for measuring the height of trees and shrubs using UAVs was used (Bidolakh et al., 2018; Bidolakh et al., 2019). The UAV was installed at the level of the collar of a growing tree, which was subject to measurement. Subsequently, the UAV was manually raised to the top of the tree, the centre of the sight of its camera, calibrated parallel to the horizon, and aimed at the highest point of the tree. Under this condition, the attributive data of the photo of the top of the tree contained spatial information about coordinates and height, which was automatically

calculated by the GPS module (labelling method – *AM*) (Bidolakh et al., 2019).

To use photogrammetry methods to create spatial 3D models based on photographs, vertical equidistant photographic evidence of the entire axis of the trunk of the model tree was taken, with filming at equal intervals of UAV altitude gain. A total of 1,671 photos were taken for this method and 17 vertical lifts were performed for 30 model trees. This was conditioned upon the group spatial arrangement of some model trees.

As a result of photo processing, a point cloud of a model tree or tree group was created (Fig. 1) (Agisoft Metashape, 2019). Each of the points in

such a cloud had corresponding spatial coordinates in each system. The calculated point cloud contained enough spatial information to display a growing tree in a 3D editor to determine its height. The metric coordinate system WGS 84/UTM zone 36N (EPSG:32636) was used in the study. Measurements were performed by manually setting the beginning and end of a segment of interest using the linear measurement mode in Agisoft Metashape software. In manual mode, the highest point of the crown of the corresponding model tree was selected, from which the distance to the level of the collar was determined (method marking – *PC*).



Figure 1. Height measurement from a point cloud (PC method)

Additionally, tree height was determined using the crown height model (*CHM* method), which involved obtaining height based on a set of aerial photo processing operations to obtain rasters of the digital elevation model (DEM) and surface (DSM), as well

as calculating the output raster of the crown height model $CHM=DSM-DEM$. To create digital models, two horizontal spans were made over the tree stands at an altitude of 70 and 90 meters. As a result, 251 aerial photos were obtained, based on which a dense cloud of

points was calculated using Agisoft Metashape software, and they were classified by pertinence to land or trees. The calculated *CHM* raster was analysed using the Spatial Analyst tool package of the ArcGIS software, using the “Focal statistics” filter to determine height (Holiaka et al., 2018). The coordinates of the model trees were superimposed on the raster, which were determined from aerial photography materials by visual identification of the individual number of the model tree printed on the trunk. According to the given coordinates, the height values were read on the *CHM* raster image. Considering the displacement of the treetop from the perpendicular growth axis, the

search radius for maximum values was set to 0.75 m.

The third stage of the study consisted in control measurements of the trunk length of 30 felled model trees and the height of the stumps using the *South PD-520N* laser range finder (Table 1). Diameters were measured at breast height (1.3 m) using a *Haglof* “Mantax blue calipers” measuring fork. The sum of the length of the trunk of the felled tree and the height of the stump was an indicator of the true height value of each model tree separately. The distribution of the measured values of the height of model trees by thickness degrees (Table 1) is characterized by a representation of model trees on the experimental plot.

Table 1. Distribution of model trees by height and diameter at breast height

Degree of thickness, cm	Height, m							
	29	30	31	32	33	34	35	36
32			1					
36			1	1				
40	1	4	1	1			1	1
44		1			1	2		1
48					1	1	1	1
52			1	1			1	
56					1	1		
60				1		1	1	

Distribution of model trees by height and diameter at breast height. In general, during the study, height indicators were determined using six different methods for each of the 30 model pine trees in the growing state and 30 true height values of each model after felling (Table 2).

Results and Discussion

Table 2 presents the height data obtained by different methods for each of the 30 model trees and their true values.

The results of statistical data processing (Table 3) allow evaluating the advantages and disadvantages of using different methods of measuring growing trees that were used in this study. The highest measurement error was found for the *AM* method – 1.84, the lowest was 0.41 for *Haglof EC II-D*. The systematic measurement error was the largest for *Suunto PM-5* – 133.67 m, and the smallest – 11.96 m for *CHM*. The average random error, respectively, was the highest for *Suunto PM-5* – 2.01 and the lowest – 0.64 for *CHM*.

Table 2. Results of measurements of model trees using different methods

Model tree No.	Diameter, cm	Growing tree height measuring method, m						True tree height value, m
		<i>Haglof EC II-D</i>	<i>Suunto PM-5</i>	<i>TruPulse 360B</i>	<i>AM</i>	<i>PC</i>	<i>CHM</i>	
1	48.4	33.00	31.00	30.20	33.50	34.27	32.46	33.06
2	40.4	31.40	32.50	31.30	33.70	33.43	32.56	32.43
3	41.1	26.10	27.00	26.80	31.80	32.83	29.72	29.59
4	48.9	34.40	35.00	33.00	34.60	34.79	33.18	34.09
5	58.3	33.30	36.60	32.60	35.60	35.93	34.33	34.35
6	53.0	34.20	32.60	33.50	36.80	36.46	34.58	33.47
7	44.2	31.30	30.40	32.50	36.30	35.85	32.52	33.22
8	38.0	27.90	26.50	28.50	32.10	31.69	29.79	30.73
9	34.7	30.70	26.50	30.70	33.20	33.07	31.13	32.37
10	46.0	31.70	32.00	32.60	34.80	34.64	31.53	33.81
11	56.2	36.20	35.50	33.70	38.00	37.13	34.71	35.22
12	52.9	32.80	32.00	33.50	36.80	36.04	33.94	34.45
13	38.4	31.30	29.50	28.20	28.90	31.79	29.96	30.48
14	51.1	29.60	28.60	29.20	30.70	31.11	29.53	30.50
15	59.2	32.20	32.50	31.40	34.10	34.30	31.76	32.33
16	42.4	29.20	29.50	28.80	33.30	31.12	29.89	29.67
17	38.2	30.40	31.50	28.40	27.60	28.05	27.97	28.71
18	39.8	29.50	27.80	29.30	31.60	30.06	29.61	29.73
19	39.1	33.40	33.00	31.00	32.30	29.39	30.00	30.45
20	51.9	32.10	31.50	34.30	35.50	35.13	34.03	34.88
21	44.8	33.80	33.50	34.80	37.80	34.85	34.51	35.60
22	32.9	30.40	30.50	30.40	35.70	30.20	30.79	31.32

Table 2, Continued

Model tree No.	Diameter, cm	Growing tree height measuring method, m						True tree height value, m
		<i>Haglof EC II-D</i>	<i>Suunto PM-5</i>	<i>TruPulse 360B</i>	<i>AM</i>	<i>PC</i>	<i>CHM</i>	
23	48.9	37.50	37.50	35.40	38.40	35.65	35.15	36.33
24	49.8	35.10	35.50	34.60	37.30	34.27	34.43	34.70
25	39.5	35.00	34.50	34.50	39.30	37.38	34.99	35.90
26	57.8	38.10	38.50	36.90	40.20	38.85	36.31	35.48
27	45.7	34.90	35.50	32.00	35.70	33.17	33.52	33.70
28	41.5	34.30	34.30	32.80	38.00	34.46	34.56	35.30
29	40.0	29.90	29.20	28.70	31.70	31.30	30.13	30.23
30	53.9	32.20	33.50	30.90	33.90	33.79	31.34	31.98

Table 3. Results of statistical processing of the obtained tree height values

Statistical indicators	Tree height measuring method					
	<i>Haglof EC II-D</i>	<i>Suunto PM-5</i>	<i>TruPulse 360B</i>	<i>AM</i>	<i>PC</i>	<i>CHM</i>
Arithmetic mean	32.40	32.13	31.68	34.64	33.70	32.30
Mean square deviation	2.73	3.21	2.51	3.02	2.56	2.22
Standard error	0.50	0.59	0.46	0.55	0.47	0.40
Volatility ratio, %	8.42	9.98	7.91	8.73	7.59	6.86
Measurement error	-0.41	-0.67	-1.12	1.84	0.90	-0.51
Systematic error, m	69.60	133.67	25.28	58.04	47.16	11.96
Average random measurement error	1.45	2.01	0.88	1.41	1.28	0.64

The results obtained in this study, as well as research data from (Bidolakh et al., 2018; Bidolakh et al., 2019), further confirmed the study results in (Williams et al., 1994) regarding the highest precision of hand-held laser measuring devices.

The measurement error of laser devices is associated with the interference of side branches in aiming the laser at the top of the model tree, which is especially observed in conditions of growth and

development of a sparse stand. Trees in such stands of mature and over-mature age have a wide tent-shaped crown, where the highest point of the top of the tree is not always located in the centre of the crown and causes an underestimation of height (Fig. 1).

The *TruPulse 360B*'s issue of underestimating height readings with laser altimeters is illustrated in Figure 2, where the height indicators of the main number of model trees have underestimated values.

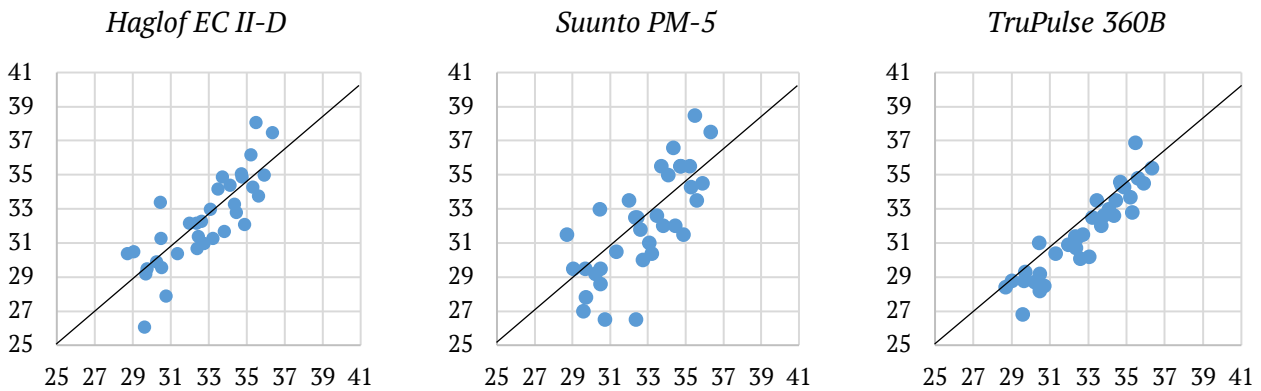


Figure 2. Comparison of the results of tree height measurement using altimeters

The use of the *Suunto PM-5* optical altimeter involves the use of two basic distances (15 and 20 m) and is characterized by the impreciseness of the height indicators of model trees. The specificity of using the *Haglof EC II-D* trigonometric altimeter compared to the *Suunto PM-5* has the advantage of the ability to arbitrarily change the base distance, which increases the precision of measurements. An increase in the base distance for the *Haglof EC II-D* may lead to a deterioration of the visibility of the top of the model trees and an increase in the time required to find a satisfactory sighting location. Most often, problems with viewing the top of a tree

arise in conditions of a dense tree stand and rolling terrain. When discussing the precision of methods for tree height measurement involving UAVs and the advantages of using *CHM* for tree stands, it should be noted that there are a significant number of methodological approaches to determining and specifying the parameters of growing trees, which are presented in (Guimarães et al., 2020) and (Sadeghi & Sohrabi, 2019).

When comparing the precision of height determination methods using UAVs (Fig. 3), one should note that creating a *CHM* requires the least amount of time to collect data in the field.

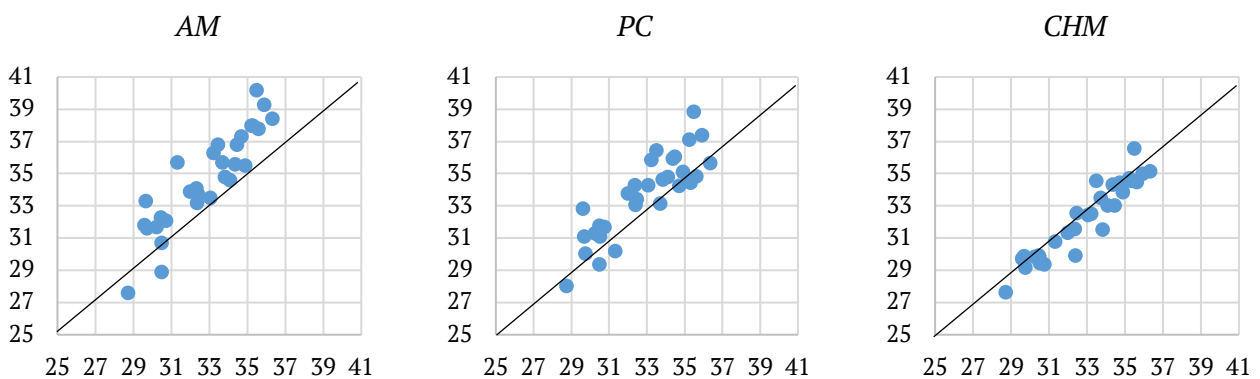


Figure 3. Comparison of height measurement using UAVs

An added advantage of *CHM* is that there is no need for a highly skilled UAV operator to pilot under the tree canopy, in contrast to the *AM* method (Bidolakh et al., 2018) and the creation of a growing

tree point cloud by the *PC* method. In addition, the weak point of remote methods using UAVs in pine stands is their dependence on the correctness of determining geographical and spatial coordinates

by the GPS module, due to the obstruction of signal passage through the forest canopy. Due to an unstable signal, the time spent on clarifying coordinates and constantly correcting them increases, which is recorded in the photo metadata. The specificity of the pine stand could lead to an increase in errors and deviations compared to the data for the beech stand (Bidolakh et al., 2019). Specifically, the average random error in the study of measurement precision was 0.72, and the systematic error was 15.03 m for European beech trees (*Fagus sylvatica* L.) in a deciduous stand with a composition of 10 Fs and a density of 0.4 (Bidolakh et al., 2019), and for Scots pine (*Pinus sylvestris* L.) trees in the stand under study, the average random measurement error was 1.41, while the systematic error was 58.04 m (Table 1).

Figure 4 shows the numbers and spatial location of model trees on the experimental plot according to the established coordinates. Additionally, Fig. 4 shows a coordinate grid, a legend (scale) of height values with gradation by colour. The results of height determination from the *CHM* raster image after using the “Focal statistics” filter (Fig. 4) were compared with other methods of height measurement based on aerial photography materials (Fig. 3). The obtained values are characterized by a considerable overestimation of the height indicators for the *AM* and *PC* methods. The height indicators found by the *CHM* method have the smallest deviations and are placed grouped regarding the true values of the height of the model trees.

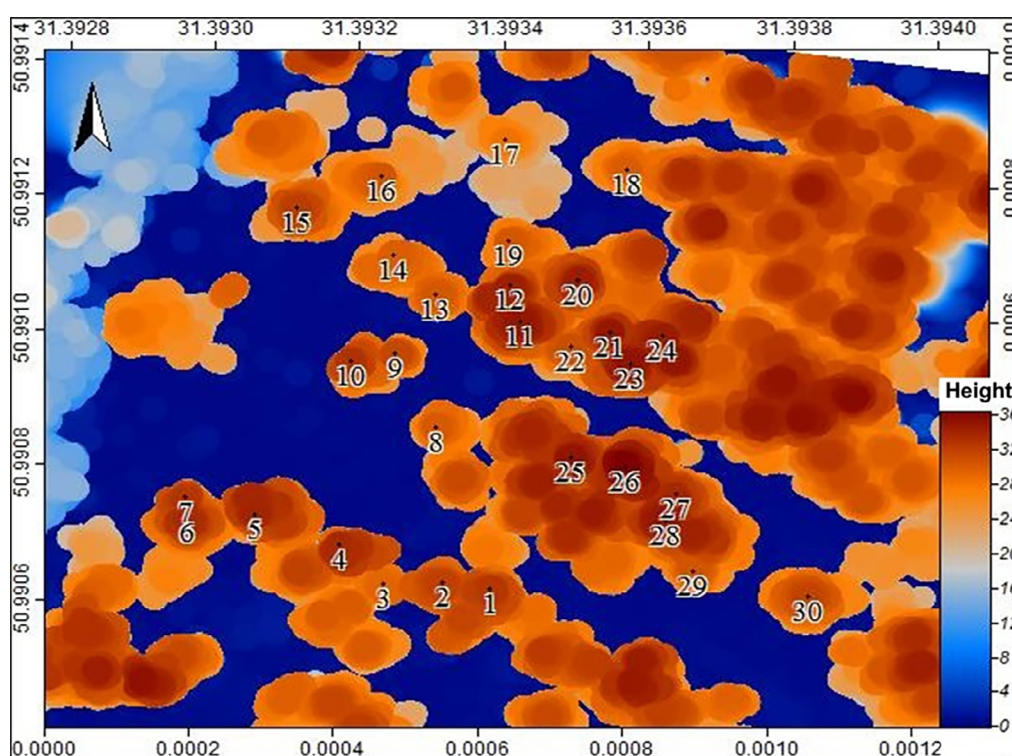


Figure 4. CHM after using the “Focal statistics” tools

CHM was the most precise of all the methods of measuring growing trees considered in this study. The *TruPulse 360B* laser-optical instrument was the most precise of the handheld ground altimeters. The mean random error of measurement for *TruPulse 360B* was 0.88 and for *CHM* was 0.64. First of all, this is explained by the independence of the *CHM* from

the actions of the operator, i.e., the human factor in the measurement is minimized.

The advantage of ground-based manual altimeters is the ability to quickly obtain the height value of the measured tree on site. The use of optical imaging using a UAV requires time to process and analyse the raw data using specialized software. On the

other hand, if it is necessary to establish the height of a considerable number of trees in the stand, the use of stereophotogrammetry methods has substantial advantages, which include less time spent on field work, the availability of information about the height of all identified trees, diverse possibilities in working with the obtained results; restriction of the area of interest (polygon, allotment), where inventory indicators are automatically set and simulated. In addition, when processing materials, aerial photos acquire a digital terrain model, which can later be used to create a scheme for developing a cutting area. Furthermore, the use of UAVs to determine the height of trees leaves an archive of records of the measurement process, which can be an additional tool for quality control of forest inventory operations.

Conclusions

Comparison of different methods allowed evaluating the precision of measurements and establish the advantages and disadvantages of height measuring devices that are actively used on the territory of Ukraine. The capabilities of UAVs for height measurement show the advantages and prospects of using optical surveying using UAVs to obtain data

during inventory, forest management, and survey work in forest areas.

The analysis of the results of using the *CHM* method showed the least impact of the human factor on the results, since the height of trees is measured with minimal operator involvement, which is essential for quality control of the implementation of economic measures and their design.

The value of the average random error for *CHM* was less than 2%, which allows determining the height of trees in pine stands with high precision and meets the requirements for production inventory according to the “Instructions for the regulation of the forest fund of Ukraine” (2014).

Further study is required to estimate the impact of the quality of signals from satellite positioning systems, under the forest canopy, on the precision of determining the height of trees using on-board UAV equipment in coniferous stands compared to deciduous ones.

The accumulation of ultra-high-resolution raster data obtained using UAVs allows increasing the ability to monitor forest stands and detect changes in their structure at the local level (forest area, block, stratum).

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Точність вимірювання висоти дерев різними способами

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Анотація. Дослідження присвячено перевірці точності вимірювання висоти дерев різними способами. В роботі оцінено можливості використання стереофотограмметричного методу для визначення показників висоти дерев за допомогою знімання з безпілотних літальних апаратів (БПЛА) в умовах стиглого соснового деревостану. Проведено порівняння результатів вимірювання висоти дерев сосни звичайної висотомірами та показників висоти, визначених за даними дистанційного зондування, отриманих за допомогою БПЛА. Загалом у дослідженні було розглянуто шість різних способів вимірювання висоти ростучих дерев. Дослідні дані про висоту модельних дерев збирали трьома різними висотомірами (ручними наземними приладами) та БПЛА Phantom 4 Pro. Застосування БПЛА полягало в оптичному зніманні та збиранні даних за допомогою бортового обладнання. Використано способи визначення висоти дерев, які спираються на результати оброблення даних, зібраних навісним обладнанням квадрокоптера. Зокрема, застосовано вимірювання висоти дерев із хмари точок, побудованої на основі одностороннього вертикального знімання модельних дерев, та розрахунок цифрової моделі висоти крон (СНМ) за даними аерофотознімання горизонтальних прольотів над деревостаном. Результати математичного аналізу проведених досліджень демонструють найвищу точність способу з використанням СНМ для визначення висоти ростучих дерев. Значення середньої випадкової помилки вимірювання висоти модельних дерев для СНМ становило менше ніж 2 %. Наступним за точністю визначення висоти дерев був спосіб вимірювання за допомогою лазерно-оптичного приладу TruPulse 360В, застосування якого продемонструвало найвищу точність з-поміж висотомірів. Використання TruPulse 360В для наземних вимірювань та способу СНМ (за даними оптичної зйомки з БПЛА) показало кращі результати, які відповідають нормативам точності визначення висоти для виробничої таксації. Способи визначення висоти дерев за даними оптичної зйомки з БПЛА можуть використовуватися для проведення обстежувальних, інвентаризаційних, лісовпорядних та інших робіт, які пов'язані із веденням лісового господарства та моніторингом змін у лісових екосистемах

Ключові слова: безпілотний літальний апарат, аерофотознімання, стереофотограмметрія, модель висоти крон, висотомір

UDC 630*182.59

DOI: 10.31548/forest2021.01.002

Regularities of the distribution of trees by diameter and the dynamics of the commodity structure of alder stands of the Slobozhanskyi forest typological district

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Abstract. This study reviewed the literature sources on the distribution of trees by diameter and an estimation of the commodity structure of alder stands in the Slobozhanskyi forest typological district and Ukraine as a whole, and the relevance of this paper was established. Forest typological and forestry zoning were compared to identify the region under study more clearly as a prerequisite for creating regional standards for forestry management. The distribution of black alder in the forest fund of the region under study was analysed, and forest inventory indicators were investigated in areas near alder stands. The distribution of black alder stands in the region by origin, forest types, density, and productivity was established. The authors considered the inventory and commodity structure of black alder stands in the conditions of the region under study. Models of the variability of the diameter of the modal tree stand, the ratio of the variability of the commercial part to the total variability of the tree stand diameter, considering the minimum and maximum diameters in the modal stand, were calculated. The dependence between the proportion of commercial trunks and the age of modal alder stands of vegetative origin was established. Tables of the dynamics of the commercial structure of modal alder stands were constructed, considering the distribution of commercial trunk volumes by thickness classes and subclasses, consistent with European approaches to round timber inventory. Upon drafting the standards, previously developed standards for the growth rate of modal alder trees of vegetative origin of the Slobozhanskyi forest typological district were applied. A comparative analysis of the dynamics of commercial wood yield in modal alder stands according to various standards was performed. According to the results of comparing the standards developed for Slobozhanskyi forest typological district with those developed for the whole of Ukraine, it was found that the latter have a substantially higher yield of commercial timber, which is primarily connected with the forest-growing conditions of the region and the vegetative origin of tree stands

Keywords: modal stands, black alder (sticky), marketability, thickness classes

Suggested Citation:

Buhaiov, S, Girs, O., & Pasternak, V. (2021). Regularities of the distribution of trees by diameter and the dynamics of the commodity structure of alder stands of the Slobozhanskyi forest typological district. *Ukrainian Journal of Forest and Wood Science*, 12(1), 17-24. doi: 10.31548/forest2021.01.002

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Introduction

Forestry is important for the national economy. Moreover, forests play an essential role for human health, maintaining natural balance. Therefore, the problem of forestry development is gradually becoming a priority in Ukraine. Presently, it is relevant to develop appropriate normative and informational materials for assessing and predicting the growth of the main forest-forming species, considering zonal features.

According to the State Forest Register of Ukraine, as of January 1, 2011, black (sticky) alder (*Alnus glutinosa* (L.) Gaertn) is one of the most common softwood species in Ukraine: it occupies an area of almost 255 thousand hectares, or 4.2% of the forest fund of Ukraine, reserves of alder stands amount to about 27 million m³ (Forest Fund of Ukraine, 2011). Alder wood is valuable for the national economy, primarily due to the possibility of harvesting plywood boards. Therefore, it is important to determine the indicators of marketability dynamics in the study of alder stands.

Proceeding from this, the development of standards for alder stands of vegetative origin, considering regional features, is relevant for balanced forestry management in them.

Many researchers have investigated the productivity, forestry and commodity structure of black alder stands in different regions of Ukraine (Romashov, 1964; Davydov, 1978; Tkach, 1999; Storozhenko & Pasternak, 2009; Girs, 2011; Blyshchyk, 2015). Based on the results of a study by Belarusian scientists, it was found that the Gram–Charlier distribution provides a good approximation of experimental data (Baginsky, Katkov & Uss, 2017). Polish scientists have found that the percentile method very accurately predicted the distribution of diameters and exceeded the Weibull model, but its use should be limited to tree stands older than 20 years (Pogoda, Ochał & Orzeł, 2019).

M.V. Davydov compiled tables of the growth rate and marketability dynamics of complete overmature stands of black alder (Tables, 1958). The disadvantage of these tables is that they were designed for a large area and do not consider regional features of the formation of tree stands.

Our previous studies (Pasternak & Buhaiov, 2016; Buhaiov, 2017) established that in alder stands of I and I^a site index classes, the distribution of trunks by thickness degrees differs substantially. At the age of 30, alder stands that grow according to I site in-

dex class have a smaller average diameter, and about 80% of trees belong to the three smallest thickness degrees. In stands of I^a site index class, the number of stages of thickness is greater, and the distribution by stages is more uniform. With age, the distribution of trunks in tree stands of I site index class evens out, with most trunks concentrated in three medium degrees of thickness. Tree stands of I^a site index class are more differentiated, and trunks with a diameter significantly larger than the average appear in their structure earlier.

The purpose of this study was to establish the features of the inventory and commercial structure of black alder stands in the Slobozhanskyi district.

Materials and Methods

According to forestry zoning, the region under study (Slobozhanskyi district of the forest typological region of the fresh cluster (2 d) (Ostapenko & Tkach, 2002)) occupies part of the Livoberezhno-Dniprovskyi (northern and southern regions of the Poltava Plain) and Serednoruskyi forest-steppe districts of the Forest-Steppe region (Gensiruk, 2002).

For a detailed investigation of the inventory and commodity structure, 80 test areas were used in black alder stands of vegetative origin, and model trees were selected for 15 of them (Buhaiov & Pasternak, 2020). On the felled model trees, a complete analysis of the trunk was carried out and the output of dimensional and qualitative categories of wood was found. Out of the total number of experimental plots, it is necessary to allocate four permanent experimental plots, where measurements were carried out every five years (in 2005, 2010, 2015, and 2020).

The analysis of experimental plots by the main inventory indicators confirms that the tree stands selected for the study by origin, composition, site index class, relative density, and types of forest correspond to the most common conditions for the formation of alder stands in the Left-Bank Forest-Steppe of Ukraine.

The results of field and laboratory studies were processed using MS Excel, SPSS, and Statistica software.

To identify the patterns of distribution of inventory indicators of alder stands and determine the uniformity of experimental data, their statistical analysis was conducted. The main characteristics – arithmetic mean (\bar{X}), mean square deviation (σ), asymmetry (As), kurtosis (Es), minimum (min) and maximum (max) measures in natural values – for the experimental alder stands are presented in Table 1.

Table 1. Statistical characteristics of inventory indicators of tree stands on experimental plots

Inventory indicator	Statistics					
	\bar{X}	σ	Es	As	min	max
A , years	54.7	20.06	-0.25	0.59	24.0	105.0
D , cm	24.6	7.58	0.18	0.69	13.5	47.3
H , m	22.0	3.59	-0.48	-0.15	14.0	30.2
G , m ² ·ha ⁻¹	26.1	5.07	1.19	0.45	13.3	45.0
P	0.78	0.12	1.62	0.89	0.53	1.25

Analysis of statistical indicators shows that for age (A), average diameter (D), average height (H), sum of cross-sectional areas (G), indicators of asymmetry and kurtosis in natural values do not exceed permissible values ($As < 1.0$; $Es < 1.2$). Left-sided asymmetry was determined for height, while right-sided asymmetry was determined for the other indicators under study. The distribution of the values of age and average height is characterized by a sharp-peaked curve,

other indicators – by a blunt-peaked curve. The studied database of experimental plots describes black alder stands quite fully and is suitable for modelling the inventory and commodity structure.

To find the degree of tightness of the relationship between the inventory indicators of alder stands of the Left-Bank Forest-Steppe of Ukraine on experimental plots, a correlation matrix was constructed (Table 2).

Table 2. Correlation matrix of the main tax indicators of EPs

Indicator	A , years	H , m	D , cm	N , pcs.	P	G , m ² ·ha ⁻¹
A , years	1.00	0.84	0.91	-0.66	-0.43	0.48
H , m		1.00	0.86	-0.78	-0.42	0.67
D , cm			1.00	-0.71	-0.43	0.53
N , pcs.				1.00	0.47	-0.45
P					1.00	0.35
G , m ² ·ha ⁻¹						1.00

Analysis of the obtained correlation coefficients confirms the presence of a close relationship between such indicators as average age (A), average diameter (D), average height (H). The corresponding correlation coefficients range from 0.84 to 0.91. Relationships of the number of trees with average height (H), average age (A) and average diameter (D) are statistically significant. The sum of the cross-sectional areas (G) has a close correlation only with the average height (H) – 0.67, no significant correlation was found with other inventory indicators.

The theoretical series of diameter distribution was constructed according to the methodology

developed at the Department of Forest Inventory and Forest Management of the National University of Life and Environmental Sciences of Ukraine. After the list database was created, the parameters of their structure were obtained using the STRUK program.

Results and Discussion

According to the data of the “Forest Fund” database as of January 1, 2011, in the region under study, black alder forests cover an area of more than 26.6 thousand hectares with a wood stock of 4,789.0 thousand m³. By origin, 68% of black alder stands are of vegetative origin and 32% are of seed origin. In the region

under study, black alder stands are characterized as highly productive. Tree stands of site index class I occupy almost 35% of the total area of alder forests, class II – 29%, class I^a – 15%.

In the Slobozhanskyi district, medium density stands with a relative density of 0.7-0.8 (44.3%) are most common. In addition, considerable areas are occupied by tree stands with a density of 0.8-0.9 (24.1%). The share of low-density tree stands is insignificant. Predominant types of forest in the conditions of Slobozhan district are raw black alder sudbrava (C4-Vlch) and raw black alder dubrava (D4-Vlch) (Buhaiov & Pasternak, 2020).

Calculations of the inventory structure in the EXCEL environment using the STRUCTURE program have shown that the β -distribution is optimal for this experimental object.

The simulation results are represented by the following formulas:

$$V = -31,81 + 4,837 \cdot D - 0,1298 \cdot D^2 + 0,00107 \cdot D^3, \quad (1)$$

$$W = 1,03 - 7,47 \cdot 10^{-3} \cdot P_{dil} + 7,1 \cdot 10^{-5} \cdot P_{dil}^2, \quad (2)$$

$$R_1 = 0,51 - 1,47 \cdot 10^{-2} \cdot D + 3 \cdot 10^{-4} \cdot D^2, \quad (3)$$

$$R_2 = 2,16 - 1,4 \cdot 10^{-2} \cdot D, \quad (4)$$

where V is the variability of the diameter of the modal tree stand;

W is the ratio of the variability of the commercial part to the overall variability of the tree stand diameter;

R_1 and R_2 are the minimum and maximum diameters in the modal tree stand, respectively.

In addition, as a function of the average diameter (D), the relationship between the proportion of commercial trunks (P_{dil}) and the age (A) of modal alder stands of vegetative origin was established as follows:

$$P_{dil} = -22,5 + 5,727 \cdot D - 8,62 \cdot 10^{-2} \cdot D^2. \quad (5)$$

The Figure 1 shows a graph of the total number of trunks for 50-80-year-old modal alder stands based on the beta distribution parameters indicated above (Eqs.1-5).

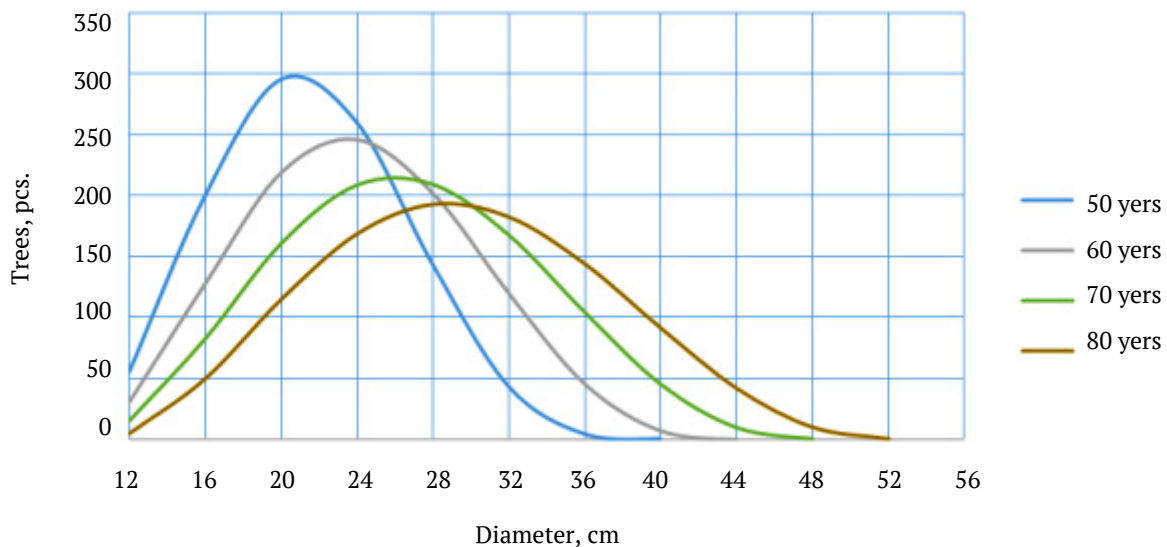


Figure 1. Distribution of trunks by diameter in modal alder stands of vegetative origin

On the graph, 1,000 trunks conditionally correspond to the total number of trees in the stand, i.e., 100% of all trees. Rows of commercial tree stands were also built.

Regularities of the inventory structure form the theoretical basis for constructing standards (tables of commodity structure and marketability dynamics). Regional growth tables (Buhayev &

Pasternak, 2020), tables of volume distribution of commercial alder trunks by thickness classes and subclasses (Forest inventory handbook, 2020) and the above parameters of the structure by diameter were used to model the dynamics of the commodity structure of alder stands of vegetative origin. Classes and subclasses of thickness of commercial timber were set according to the average diameter

of logs without bark: D1b – 14.5-19.4 cm, D2a – 19.5-25.4 cm, D2b – 25.5-29.4 cm, D3a – 29.5-34.4 cm, D3b – 34.5-39.4 cm, D4 – 39.5-49.4 cm. Norms were calculated according to the methodology developed at the Department of Forest

Inventory and Forest Management of the National University of Life and Environmental Sciences of Ukraine (Kashpor, 1999).

The dynamics of marketability of modal alder stands of the site index class I is presented in Table 3.

Table 3. Dynamics of commodity structure of modal alder stands of vegetative origin of Slobozhanskyi forest typological district

Age, years	Average		Stock, m ³ ·ha ⁻¹	Commercial timber by thickness classes							Firewood	Waste
	H, m	D, cm		D1b	D2a	D2b	D3a	D3b	D4	Total		
30	18.4	16.0	208	24	3					27	175	6
35	19.5	17.6	226	36	9	1				46	170	10
40	20.6	19.1	240	42	19	3				64	163	13
45	21.5	20.6	253	45	29	7				81	155	17
50	22.3	22.1	264	45	36	14	2			97	147	20
55	23.0	23.5	274	43	39	22	5			109	143	22
60	23.6	24.9	283	40	40	30	9	1		120	138	25
65	24.2	26.3	291	36	40	36	14	3		129	135	27
70	24.7	27.7	298	33	38	41	20	5	1	138	131	29
75	25.1	29.1	304	29	36	44	25	9	2	145	128	31
80	25.5	30.5	310	25	33	46	31	13	4	152	125	33

Notably, the norms of the dynamics of the commodity structure of modal alder stands are based on fundamentally new data on the distribution of the volume of commercial trunks of 16 cm and more by thickness classes and subclasses (Forest inventory handbook, 2020), consistent with European approaches to the inventory of round timber (DSTU

EN 1315-1: 2001, 2002). The volume of timber was set as the sum of the volume of wood trunks and wood from commercial trees. The authors also conducted a comparative analysis of the dynamics of commercial timber yield in modal alder stands according to various standards (inventory of business wood by upper and middle diameters) (Table 4).

Table 4. Comparative analysis of the dynamics estimation of the dimensional and qualitative structure of modal alder stands of vegetative origin according to current and European standards

Age, years	Commercial part of the modal stand, m ³ ·ha ⁻¹			Deviation in the commercial timber yield	
	stem stock	commercial timber stock		m ³ ·ha ⁻¹	%
		according to the old standards	according to European standards		
30	87	64	27	-37	-57.5
35	111	81	46	-35	-43.2
40	129	94	64	-30	-32.0
45	146	107	81	-26	-24.0

Table 4, Continued

Age, years	Commercial part of the modal stand, m ³ ·ha ⁻¹			Deviation in the commercial timber yield	
	stem stock	commercial timber stock		m ³ ·ha ⁻¹	%
		according to the old standards	according to European standards		
50	163	119	97	-22	-18.5
55	177	129	109	-20	-15.6
60	190	139	120	-19	-13.5
65	200	146	129	-17	-11.6
70	210	153	138	-15	-10.0
75	218	159	145	-14	-8.9
80	225	164	152	-12	-7.5

As Table 4 demonstrates, the commercial timber yield is significantly lower (by 7-57%) according to its estimates not by upper, but by middle diameters, with the greatest impact in the younger age of tree stands. The latter is explained by the fact that according to European standards, trees from the 8th to the 16th degree of thickness factually do not have commercial timber.

Comparing the standards developed for the Slobozhanskyi forest typological district with the standards developed for the whole of Ukraine (Girs, 2007), one can note that the commercial timber yield is substantially higher in the latter, which is explained by the specific features of the formation of tree stands in the region under study and vegetative origin. A decrease in the proportion of commercial timber in alder stands of vegetative origin after 60 years of age was also established in the studies of V.P. Tkach (Tkach, 1999).

Conclusions

The results of the analysis indicate that the alder stands of the region under study differ substantially from the tree stands of Polissia in Ukraine in terms of growth dynamics and marketability. Therefore, considering the European approaches to the inventory of round timber, the norms of the inventory structure and dynamics of the commodity structure of modal alder stands presented in this paper can substantially improve the quality of forestry management and the accuracy of determining the inventory indicators of alder stands of the Slobozhanskyi district.

The feasibility of using the developed standards should be established based on the results of the research and production audit. Further research is required to establish the patterns of timber distribution by quality class in black alder stands.

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Закономірності розподілу дерев за діаметром та динаміка товарної структури вільхових деревостанів Слобожанського лісотипологічного району

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Анотація. Проведено огляд літературних джерел щодо розподілу дерев за діаметром та оцінювання товарної структури вільхових деревостанів Слобожанського лісотипологічного району та України в цілому, встановлено актуальність такого дослідження. Наведено зіставлення лісотипологічного і лісгосподарського районування для чіткішого виокремлення регіону дослідження як передумови для створення регіональних нормативів для ведення лісового господарства. Здійснено аналіз поширення вільхи чорної (клейкої) у лісовому фонді регіону дослідження та вивчено лісівничо-таксаційні показники на ділянках під вільшаниками. Встановлено розподіл чорновільхових деревостанів регіону за походженням, типами лісу, повнотою та продуктивністю. Розглянуто таксаційну будову й товарну структуру чорновільхових деревостанів в умовах регіону дослідження. Розраховано моделі мінливості діаметра модального деревостану, відношення мінливості ділової частини до загальної мінливості діаметра деревостану, з урахуванням мінімального та максимального діаметрів у модальному деревостані. Встановлено залежність між часткою ділових стовбурів і віком модальних вільхових деревостанів вегетативного походження. Побудовано таблиці динаміки товарної структури модальних вільхових деревостанів з урахуванням розподілу об'ємів ділових стовбурів за класами і підкласами товщини, узгодженими з європейськими підходами щодо таксації круглих лісоматеріалів. При складанні нормативів застосовано попередньо розроблені нормативи ходу росту модальних вільшаників вегетативного походження Слобожанського лісотипологічного району. Проведено порівняльний аналіз динаміки виходу ділової деревини в модальних вільшаниках за різними стандартами. За результатами порівняння розроблених для Слобожанського лісотипологічного району нормативів із нормативами, розробленими для всієї України, встановлено, що у останніх вихід ділової деревини істотно вищий, що насамперед пов'язано з лісорослинними умовами регіону та вегетативним походженням деревостанів

Ключові слова: модальні деревостани, вільха чорна (клейка), товарність, класи товщини

UDC 630*5:620.9(477.42)

DOI: 10.31548/forest2021.01.003

Energy intensity of wood biomass of Zhytomyr Polissia forests

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Abstract. The development of renewable energy is one of the principal areas of decarbonization of the energy sector of Ukraine, including in forestry. Improving the efficiency of using wood biomass for energy purposes, along with providing an appropriate level of technological processes and technical equipment, requires reliable information tools for managerial decision-making. An essential component of this toolkit is regional assessments of the energy function of forest phytocenoses. The information base of this study included information from the database of Industrial Association “Ukrderzhlisproekt”, which contains a specific inventory characteristic of tree stands of the region under study, as well as a system of mathematical models for quantitative assessment of phytomass and mortmass of forests. As a result, quantitative values of the total energy intensity of phytomass and mortmass of the forests of Zhytomyr Polissia were established. The total amount of energy accumulated in the plant biomass of the region’s forests is 3,035.7 PJ, which is equivalent to 100.2 million tonnes of conventional fuel. At the same time, the share of the total energy intensity of mortmass is 11.1%. The structure of the energy intensity of plant biomass in the region is dominated by pine stands, which accumulate over 60% of the energy of the forests of Zhytomyr Oblast, namely 70.8% – in the phytomass of tree trunks. Over 40% of the energy is accumulated in the plant biomass of stands of the site index class I, which mainly grow in relatively poor forest conditions (subors). In the overall structure of the energy intensity of the mortmass (336.2 PJ), more than 60% belongs to the forest floor (212.8 PJ), but it is not considered as a source of renewable energy, dry matter – 12.3% (41.3 PJ), dry branches – 17.8% (almost 60 PJ). The results obtained in this study will serve as an information basis to devise a strategy for the development of forest bioenergy in the Zhytomyr region

Keywords: wood biomass, energy, mortmass, plantings, low-carbon development, inventory characteristics

Introduction

The development of renewable energy is one of the principal areas of decarbonization of the energy sector of Ukraine, which is reflected in the Low-Carbon Development Strategy adopted by the Cabinet of Ministers of Ukraine in 2018 (Strategy..., 2018). The document also makes provision for increasing carbon sequestration and reducing greenhouse gas

emissions in the forestry sector, specifically through the development of forest bioenergy.

Improving the efficiency of using wood biomass for energy purposes, along with providing an appropriate level of technological processes and technical equipment, requires reliable information tools for managerial decision-making. An essential

Suggested Citation:

Vasylyshyn, R, Yurchuk, Yu., Lakyda, I., & Bondarchuk, R. (2021). Energy intensity of wood biomass of Zhytomyr Polissia forests. *Ukrainian Journal of Forest and Wood Science*, 12(1), 25-33. doi: 10.31548/forest2021.01.003

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component of this toolkit is regional assessments of the energy function of forest phytocenoses, which also characterize the energy intensity of woody biomass and the energy productivity of modal tree stands (Vasylyshyn, 2018; Vasylyshyn, Lakyda & Sliusarchuk, 2019).

In the conditions of Zhytomyr Polissia, where forests are a key natural object that ensures the ecological balance of the environment and serves as a source of wood resources, assessing the energy intensity of wood biomass will provide a scientific basis to devise a regional forest bioenergy program.

Analysis of recent studies and publications

Currently, the problems of researching various aspects of energy production and consumption are reflected in technical (Dubrovin, Korchemnyi & Maslo, 2004), economic (Prokip, 2010), ecological (Vasylyshyn, 2016; Sytnyk, 2017) and biological (Kukhar, Kuzminskyi & Holub, 2005) scientific studies.

Fundamental bioenergetic studies of the innovative and technological direction of the use of plant biomass are currently conducted by scientists of the “Biomass” Scientific and Technical Centre and the Institute of Technical Thermophysics of the National Academy of Sciences of Ukraine under the leadership of H.H. Geletukha (Geletukha, 2021).

Scientific studies of researchers of the M.H. Kholodnyi Institute of Botany of the National Academy of Sciences of Ukraine also characterizes eco-oriented studies of the energy of natural ecosystems, using evidence from the study of the energy balance of the phytocenoses of Kyiv and its green zone (Didukh, 2007).

This scientific area is relevant for scientists from the European Union countries, since in the vast majority of cases the development of the economy here depends on imported natural gas. The specified topic

is presented in studies by representatives of the Swiss Federal Institute for Forest, Snow, and Landscape Research (Burg et al., 2018). They estimate that the annual theoretical potential of biomass in Switzerland is about 209 PJ, including 108 PJ due to wood biomass.

For the conditions of Spain, to estimate the amount of biomass in *Pinus sylvestris* L. stands, an international group of scientists used lidar scanning, which allowed establishing the amount of biomass for seven components of the stand: aboveground biomass, belowground biomass, trunk biomass, needle biomass, and biomass of large, medium, and small branches (Hernando et al., 2019).

Ecological consequences for the forest biogeocenosis from the use of wood biomass for energy purposes have become the object of research by scientists from Sweden (De Jong et al., 2017), who note that increasing the volume of wood biomass harvesting in Swedish forests may have adverse consequences for the state of the environment. An analogous study was also conducted by Polish scientists (Nurek, Gendek & Roman, 2019), who analysed the physical and chemical properties of crushed forest residues of *Pinus sylvestris* L. At the same time, for Uruguay, eucalyptus (*Eucalypts* Sp.) stands are a relevant energy resource of wood biomass, which are being studied to establish their productivity and energy intensity (Bentancor et al., 2019).

The purpose of this study was to estimate the energy content in the components of phytomass and mortmass of the forests of Zhytomyr Polissia.

Materials and Methods

The information basis of this study was information from the database of VO “Ukrderzhlisproekt”, which contains a specific inventory characteristic of tree stands (over 300 thousand forest plots) of the region under study (Table 1).

Table 1. Distribution of the number of forest plots in Zhytomyr Polissia by dominant forest-forming species

Type of woody plant	Quantitative indicator		Type of woody plant	Quantitative indicator	
	pcs.	%		pcs.	%
Silver birch	56,146	17.8	Common aspen	3,656	1.2
Common alder	31,128	9.9	Scots pine	178,794	56.8
Common hornbeam	1,445	0.5	European spruce	3,562	1.1
Common oak	35,421	11.2	Other tree species	4,890	1.6
Total				315,042	100.0

The method for estimating the energy intensity of wood biomass lies in an integrated combination

of the array of forest inventory data with a system of mathematical models for quantitative assessment

of the phytomass and mortmass of the forests of the region (Bilous, 2018; Schepaschenko et al., 2017; Shvidenko et al., 2014) and quantitative parameters of the specific energy intensity of the components of wood biomass (Shvidenko, Nilsson, Obersteiner, 2004; Vasylyshyn, 2018) of the main forest-forming plant species. For other wood species, the mentioned energy intensity indicators are set based on weighted average values of these species.

Results and Discussion

The processes associated with the supply, transformation, and use of energy are identified as key in the environment, since the effective functioning of any

natural ecosystems depends on their intensity. During the study, it was established that the estimate of the total amount of energy accumulated in the plant biomass of the forests of Zhytomyr Polissia (170.4 million tonnes of absolutely dry matter, namely 151.6 – phytomass, 18.8 – mortmass) is 3,035.7 PJ, including in phytomass – 2,699.5 PJ (Table 2).

According to its equivalent, this roughly corresponds to 100.2 million tonnes of conventional fuel (t c.f.); specifically, for coniferous stands – 1,866.4 PJ, or 61.6 million t c.f., for hard-wood stands – 500.4 PJ, or 16.5 million t c.f., soft-wood stands – 668.6 PJ, or 22.06 million t c.f. The energy share of other tree species is under 0.1%.

Table 2. Total energy content in plant biomass of Zhytomyr Polissia forests

Species group	Energy intensity of plant biomass, PJ	
	phytomass	mortmass
Coniferous	1673.0	193.4
Hard-wood	426.4	74.0
Soft-wood	599.7	68.9
Other tree species	0.3	0.1
Total	2,699.5	336.2

The share of the total energy intensity of mortmass in the total structure of energy accumulated in the plant biomass of the forests of Zhytomyr Polissia is 11.1%.

In the overall structure of the energy intensity of plant biomass of the region under study, the dominant positions are occupied by pine stands, which accumulate over 60% (1,844.8 PJ) of the energy volumes of Zhytomyr region forests. The next positions belong to oak and birch stands with 15.1% and 14.4%, respectively. The share of alder stands is about 7%, while the share of hornbeam, aspen, and spruce stands does not exceed 1%. It was established that spruce and pine stands are characterized by the

highest density of accumulated energy per unit area (Table 3). Quantitative values of phytomass energy density index for these tree stands reach 318.53 and 302.01 MJ·(m²)⁻¹, respectively. In general, the mentioned indicator within the tree stands of dominant forest-forming species varies from 197.95 MJ·(m²)⁻¹ for aspen stands to 318.53 MJ·(m²)⁻¹ for spruce stands. The average value of the phytomass energy density indicator within the stands of the region under study is at the level of 273.05 MJ·(m²)⁻¹. For mortmass, the mentioned indicator is an order of magnitude lower and is about 35 MJ·(m²)⁻¹, while the dominant positions in terms of energy density accumulated in mortmass belong to oak and spruce stands.

Table 3. Species differentiation of qualitative indicators of energy intensity of biomass of Zhytomyr Polissia forests

Dominant tree species in the stand	Qualitative indicator of energy intensity	
	phytomass energy density, MJ·(m ²) ⁻¹	energy density of mortmass, MJ·(m ²) ⁻¹
Silver birch	217.81	19.57
Black alder	210.18	32.25
Common oak	263.48	48.76

Table 3, Continued

Dominant tree species in the stand	Qualitative indicator of energy intensity	
	phytomass energy density, MJ·(m ²) ⁻¹	energy density of mortmass, MJ·(m ²) ⁻¹
Common aspen	197.95	43.75
Scots pine	302.01	36.17
European spruce	318.53	46.45
Average within the region	273.05	34.73

Analysing the indicators of the average increase in energy in the phytomass of tree trunks, it should be noted that its highest values are typical for spruce and birch stands – 65.12 and 59.13 GJ·ha⁻¹·year⁻¹, respectively. In general, in the conditions of Zhytomyr Polissia, an average of 51.81 GJ·ha⁻¹·year⁻¹ of energy is added (Fig. 1). In the region under study, over 40%

of energy is accumulated in the plant biomass of stands of site index class I [4]. About a third more are located in stands of site index class II, which is quite natural, given the regional distribution of the area and the site index structure of stands within the forest areas of Zhytomyr Polissia covered with forest vegetation (Table 4).

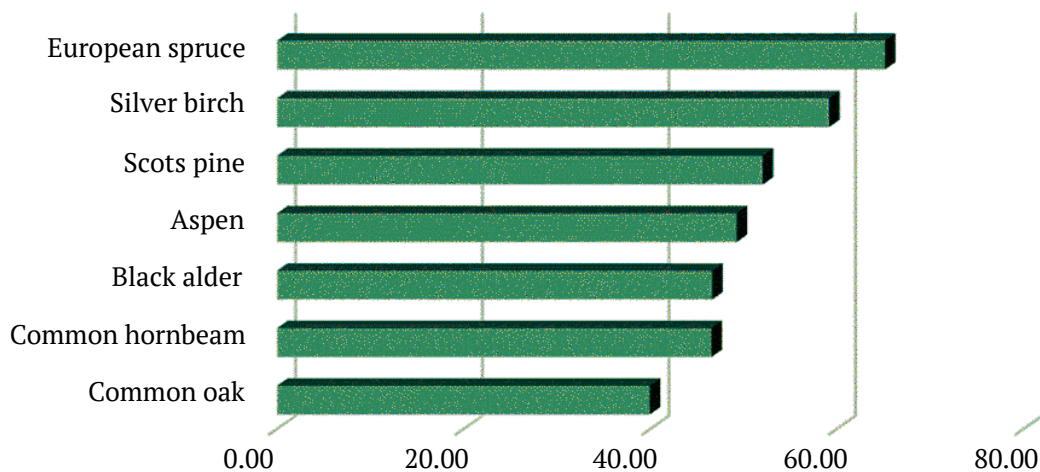


Figure 1. Energy gain in phytomass of tree trunks, GJ·ha⁻¹·year⁻¹

Table 4. Distribution of energy reserves in plant biomass of Zhytomyr Polissia forests within site index classes

Site index class	Energy intensity of plant biomass, PJ	
	phytomass	mortmass
I ^a and above	480.96	58.71
I	1146.27	136.78
II	858.06	111.19
III	166.52	24.16
IV	29.49	3.94
V and below	18.15	1.46
Total	2699.5	336.2

At the same time, analysing the qualitative indicators of energy intensity presented in Figure 2, it is worth paying attention to the difference in the trends of their change for phytomass and mortmass of forests in the region. Phytomass is characterized by a direct dependence of energy density on the productivity of stands, which is characterized specifically by the site index class. Quantitative values of the mentioned

indicator vary from $350.69 \text{ MJ}\cdot(\text{m}^2)^{-1}$ for tree stands of site index classes I^a and above to $139.30 \text{ MJ}\cdot(\text{m}^2)^{-1}$ for stands of classes V and below. Comparable trends are inherent in the change in the energy gain index in the phytomass of tree trunks, specifically in stands of site index class I^d, a value of $115.9 \text{ GJ}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ is observed, which gradually decreases to $16.1 \text{ GJ}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ in tree stands of site index class V^b.

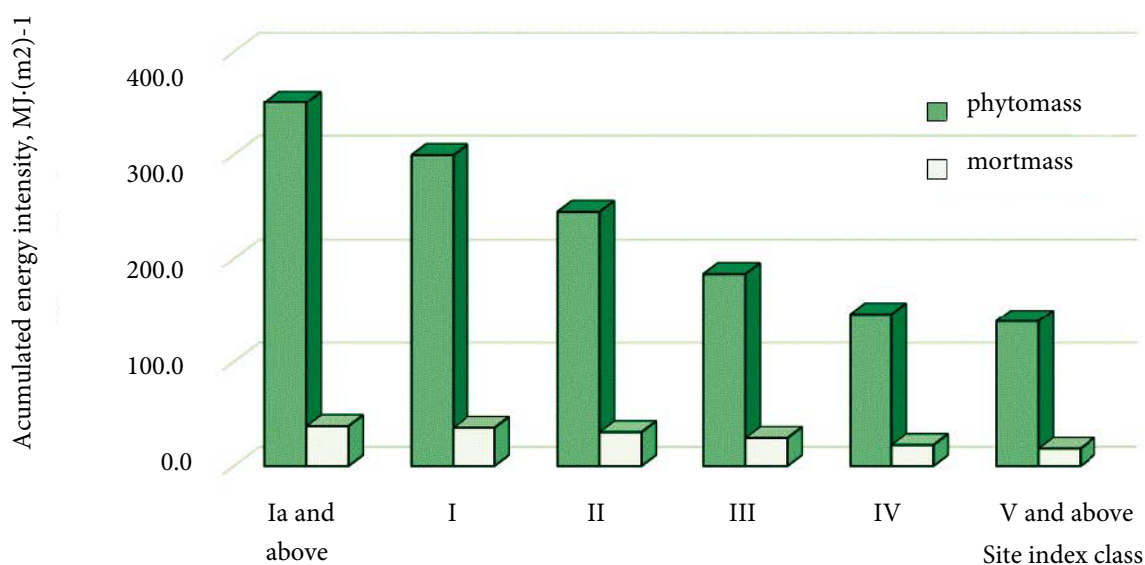


Figure 2. Quantitative values of qualitative indicators of energy intensity of biomass of Zhytomyr Polissia forests within site index classes

The intensity of energy production considerably depends on the types of forest conditions in which stands grow. During the study, it was established that the highest values of the energy gain index in the phytomass of tree trunks are inherent in tree stands in fresh subors (B_2) and fresh sudubravas (C_2), where its values are about $60 \text{ GJ}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$. At the same time,

the minimum values of this indicator are inherent in very dry and wet bors – 33.1 and $25.1 \text{ GJ}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$, respectively. In total, about 10% of plant biomass energy is accumulated in the forests of Zhytomyr Polissia (Table 5). Therewith, over 50% of the energy is concentrated in the biomass of tree stands in subors, where Scots pine stands dominate.

Table 5. Distribution of energy reserves in plant biomass of Zhytomyr Polissia forests within trophotopes

Trophotope	Energy intensity of plant biomass, PJ	
	phytomass	mortmass
Bors(A)	277.68	29.86
Subors (B)	1411.39	159.93
Sudubravas (C)	888.32	128.72
Dubravas(D)	122.08	17.73
Total	2699.5	336.2

As for the density of accumulated energy, here the highest values are inherent in stands in fresh subors (B_2), sudubravas (C_2) and dubravas (D_2) – over $320 \text{ MJ} \cdot (\text{m}^2)^{-1}$.

The component structure of the total energy intensity of phytomass of Zhytomyr Polissia forests is dominated by tree trunks, the share of which exceeds 70% (Table 6).

Table 6. Distribution of energy reserves in the phytomass of Zhytomyr Polissia forests by components

Species group, tree type	Energy intensity of phytomass by components, PJ						
	wood and trunk bark	wood and branch bark	needles (leaves)	roots	undergrowth, understory	living superficial cover	total
Coniferous	1228.79	107.81	23.14	271.93	11.33	29.99	1672.99
<i>of which Scots pine</i>	1214.53	106.60	22.86	269.30	11.21	29.72	1654.22
Hard-wood	289.09	54.70	4.87	62.17	6.74	8.88	426.44
<i>of which common oak</i>	266.12	50.25	4.38	56.10	6.27	8.16	391.29
Soft-wood	394.27	63.49	16.13	104.98	7.21	13.64	599.72
<i>of which silver birch</i>	260.82	49.22	13.51	64.18	4.56	8.72	401.02
<i>Common aspen</i>	10.46	1.28	0.26	4.53	0.24	0.43	17.19
Other tree species	0.22	0.03	0.01	0.05	0.005	0.01	0.32
Total	1912.37	226.04	44.14	439.12	25.29	52.51	2699.47

This component of wood biomass is currently the most important in terms of energy use of forest wood resources.

8.4% of the accumulated energy is concentrated in the phytomass of branches. It is also a significant source of renewable energy, which presently has considerable reserves to increase its share in the structure of the regional renewable energy sector. At the same time, the mentioned energy resource should be used in compliance with the principles of sustainable forest management, aimed at ensuring a sufficient level of formation of the biological cycle of food elements in the “forest – soil” system.

A fairly promising component of the energy potential of wood biomass is such components of the mortmass of the region’s forests as dry matter, coarse woody debris, and dry branches.

In total, over 330 PJ of energy has been accumulated in the mortmass of forests of Zhytomyr Polissia (Table 7).

During the study, it was found that about 60% of the total energy intensity structure of mortmass belongs to forest litter, but it is not considered as a source of renewable energy. At the same time, the energy intensity of dry matter is 41.3 PJ, or 12.3%, and dry branches – almost 60 PJ, or 17.8%.

Table 7. Distribution of energy reserves in mortmass of forests of Zhytomyr Polissia by components

Species group, tree type	Energy intensity of mortmass by components, PJ				
	dead wood	coarse woody debris	dry branches	forest litter	total
Coniferous	19.34	5.80	42.54	125.69	193.37
<i>of which Scots pine</i>	19.06	5.72	41.93	123.89	190.60
Hard-wood	6.35	3.06	11.07	53.49	73.97
<i>of which common oak</i>	5.78	2.76	10.15	49.00	67.70
Soft-wood	15.65	13.28	6.30	33.62	68.85
<i>of which silver birch</i>	7.93	7.05	2.58	19.29	36.85
<i>Common aspen</i>	1.97	0.55	0.31	1.22	4.04
Other tree species	0.01	0.005	0.01	0.03	0.05
Total	41.35	22.15	59.91	212.83	336.24

The energy intensity of the mortmass of coniferous tree stands accounts for 57.5%, while the share of the components of the mortmass of the tree stands under study, which can potentially be used for obtaining thermal energy (dead wood, coarse woody debris, and dry branches), is about 20%. For hard-wood stands, this ratio is 22.0% and 6.1%, respectively, and for soft-wood stands – 20.5% and 10.5%.

Conclusions

According to the results of the conducted studies, it was established that the total energy intensity of plant biomass in the forests of Zhytomyr Polissia is 3,035.7 PJ, which in its equivalent corresponds to

100.2 million tonnes of conventional fuel. The share of the total energy intensity of the mortmass of the forests of Zhytomyr Polissia is 11.1%. The structure of the energy intensity of plant biomass in the region is dominated by pine stands, which accumulate over 60% of the energy of the forests of Zhytomyr Oblast, namely 70.8% – in the phytomass of tree trunks.

Over 60% of the total energy density structure of mortmass (336.2 PJ) belongs to forest litter. At the same time, the energy intensity of dead wood is 41.3 PJ, and dry branches – almost 60 PJ.

The results obtained in this study will serve as an information basis to devise a strategy for the development of forest bioenergy in the Zhytomyr region.

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Енергоємність деревної біомаси лісів Житомирського Полісся

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Анотація. Розвиток відновлювальної енергетики є одним із базових напрямів декарбонізації енергетичного сектору України, зокрема й у лісовому господарстві. Підвищення ефективності використання деревної біомаси для енергетичних цілей, поряд із забезпеченням відповідного рівня технологічних процесів і технічного оснащення, потребує водночас надійного інформаційного інструментарію для прийняття управлінських рішень. Важливою складовою цього інструментарію є регіональні оцінки енергетичної функції лісових фітоценозів. Інформаційною базою дослідження слугувала інформація з бази даних ВО «Укрдержліспроєкт», що містить повидільну таксаційну характеристику деревостанів досліджуваного регіону, а також система математичних моделей для кількісного оцінювання фітомаси й мортмаси лісів. У результаті встановлено кількісні значення загальної енергоємності фітомаси та мортмаси лісів Житомирського Полісся. Загальний обсяг енергії, акумульованої у рослинній біомасі лісів регіону, становить 3035,7 ПДж, що за своїм еквівалентом відповідає 100,2 млн тонн умовного палива. Водночас, частка загальної енергоємності мортмаси складає 11,1 %. У структурі енергоємності рослинної біомаси регіону домінують соснові деревостани, в яких акумульовано понад 60 % обсягів енергії лісів Житомирщини, зокрема 70,8 % – у фітомасі стовбурів дерев. Понад 40 % енергії акумульовано у рослинній біомасі деревостанів I класу бонітету, які переважно ростуть у порівняно бідних лісорослинних умовах (суборах). У загальній структурі енергоємності мортмаси (336,2 ПДж) понад 60 % належить лісовій підстилці (212,8 ПДж), однак її не розглядають як джерело відновлювальної енергії, сухоостою – 12,3 % (41,3 ПДж), сухим гілкам – 17,8 % (майже 60 ПДж). Одержані у процесі дослідження результати слугуватимуть інформаційною основою для формування стратегії розвитку лісової біоенергетики в Житомирській області

Ключові слова: деревна біомаса, енергія, мортмаса, насадження, низьковуглецевий розвиток, таксаційні характеристики

UDC 630-221(7)

DOI: 10.31548/forest2021.01.004

Features of application of timber harvest methods in the forests of Ukraine

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Abstract. In this paper, we present the basic features of final felling in Ukraine. Prevailing timber harvest methods and their areas were considered. For analyzing the volumes of modern forest exploitation were data from permits for final felling on actual cuttings in of all forestry enterprises of Ukraine. Studies were conducted for the period 2019-2020. It was installed that clearcutting is the main timber harvest method (95 % in Kyiv region, 45 % in Lviv region). Among other methods, the leading place is shelterwood. During the study period, only two (uniform and strip) and three (group) reception of shelterwood were recorded. The areas of stands designed for shelterwood final felling are significantly lower than those defined by the rules. The use of the single tree selection method is more related to deciduous plantations, which indirectly indicates the predominance of deciduous stands of uneven-aged stands in Ukraine. Shelterwood and single tree selection removes methods are applied in Chernihiv, Chernivtsi, Ivano-Frankivsk, Kyiv, Lviv, Zakarpattia, Zhytomyr regions. A characteristic feature is the predominance of coniferous areas stands during clearcutting. Area of deciduous stands are larger compared to coniferous during shelterwood. Combined method is the less popular in Ukraine. It has been carried out at 9,4 hectares for two years. Average logging areas range from 1-2 hectares for clearcutting, 1-5 hectares for shelterwood and 2-8 hectares for combined method. Designed logging areas are significantly lower than those introduced by Ukrainian legislation. The implementation of the principles of close-to-nature forestry can be provided by reduction in the volume of clearcutting. Increasing of shelterwood and single tree selection methods, which are close-to-nature, will ensure the cultivation of mixed uneven-aged forest stands of high vigor, productivity and biological stability. Studies reflect regional and species features and benefits of timber harvest methods in the forests of Ukraine

Keywords: clearcutting, single tree selection removes, shelterwood and combined methods, even-aged and uneven-aged stand

Introduction

Forests are complex ecosystems that must be treated carefully and skillfully. The present is demanding a higher level of resource stewardship to conserve and protect a wide array of forest-related values. The total area of forest lands in Ukraine is 10.4 million hectares, forests covered area is 9.6 million ha or 15.9 per cent of the Ukraine's territory. Approximately

half of forest land areas are production forest, with the remainder in reserves and non-production forest areas. More than 16,1% of the total area of forest in Ukraine is held in reserves for conservation. The majority of the area available for wood production is artificial forest. By reserves of industrial stem wood, Ukraine ranks the sixth in Europe. In Ukraine, forest

Suggested Citation:

Tokarieva, O. (2021). Features of application of timber harvest methods in the forests of Ukraine. *Ukrainian Journal of Forest and Wood Science*, 12(1), 34-40. doi: 10.31548/forest2021.01.004

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stands dominated by finewood occupy 88,6% of wood covered area. Of them, pine accounts for 33,6% (*Pinus silvestris* L. leading the way), oak – 24,4% (*Quercus robur* L. dominates), and beech (*Fagus silvatika* L.) – 7,4% (Timber industry, 2007).

For each forest enterprise the allowable cut is calculated annually, based on forest inventory data and distinguished by tree species groups. The real size of harvest felling usually equals 84-90% of the allowable volume of cutting. Special use of forest resources at the allocated forest plot shall be carried out on the basis of a special permit (The Forest Code, 2006). Annually in Ukraine there harvested about 20 million m³ of wood. About 45% of wood is harvested in main cuttings, 70% of this wood is round.

Recent government measures include a pilot project of an electronic register of logging tickets for timber harvesting (State Forest, 2020).

Ecologically oriented forestry advocates for mixed (multiple-species) and structurally complex forests. This forestry is directed toward a diverse array of objectives (ecosystem function, biodiversity conservation, wildlife habitats, visual quality, nutrient recycling, water retention, soil productivity, carbon sequestration, and amenity values), in addition to the provision of classic economic forestry commodities (Yavorovskiy et al., 2019). Close-to-nature forestry is the system of forest management that promote a continuous renewal and formation of stands which most similar in structure and genesis to natural ones (Krynytskyi, 2017). Research of cutting methods and volumes of timber harvesting were carry out in mountain forests in Ukrainian Carpathians (Parpan et al., 2017). The effect of technological processes and systems of machines used in mountain forests on the forest environment were estimated by Byblyuk et al., 2010. The logging methods in Eastern European Countries, including Ukraine were studied by Moskalik et al., 2017.

Analyze of timber harvest methods on the entire territory of Ukraine were not conducted.

The aim of this study was to reveal the current volumes of forest use in Ukraine; to establish the prevailing methods of timber harvesting; to determine the average areas, in particular limited (by area) cutting; to identify the dependence of the use of non-clearcutting in coniferous and deciduous stands.

Materials and Methods

Materials for analyzing the volumes of modern forest exploitation were data from the open register of permits for timber harvesting in of all forestry enterprises

of Ukraine (Forest tickets). Studies were conducted for the period 2019-2020. In order to achieve the intended aim, we analyzed a large amount of data, among others, the characteristics of forest resources, methods of timber harvesting, their area, differentiation in terms of species. Particular attention was paid to the use of discontinuous felling methods within the regions of Ukraine.

Results and Discussion

In Ukraine forest growing relies on three parts of a silvicultural system: regeneration, stand tending and harvesting.

Regeneration method is a cutting procedure by which a new age class is created. The major regeneration methods are clearcutting, shelterwood, single tree selection and combined. Choosing of regeneration methods is carried out depending on the natural and economic conditions, location, the functioning role and species composition of the forests, type of regeneration (natural, artificial, coppice). To better understanding what regeneration methods is necessary to apply, we should to analyze the following parameters: the main function of forest, species composition, origin and structure of the stand.

Forests with ecological (protective) and social functions can be make a project at non-clearcutting methods. Carrying out of clearcutting in reserves is prohibited.

For growth even-aged (two-aged) forest it can be applied clearcutting and shelterwood methods.

Clearcutting (in Ukraine includes seed tree cutting) is a regeneration or harvest method that removes essentially all trees in a stand (Matthews, 1992).

Clearcutting method includes four stages of even-aged regeneration formation: mature stand → clearcut → establishment → tending → mature stand. It can be highly profitable. However, its application in ecological or social functions forests often involves unacceptable risks and impairs landscape values.

This method can be employed during coppice versus clearcutting.

Seed tree cutting is the removing of all trees except for a small number of trees retained for seed production and to produce a new age class in a fully exposed microenvironment. Seed tree method includes five stages of even-aged regeneration formation: mature stand → seed tree cut → establishment → removal cut → tending → mature stand.

The maximum area of clearcutting (seed tree cutting) in production forests can be up to 5 hectares

(only for deciduous trees), and in forests that are not used for timber production – 3 hectares (for deciduous and coniferous trees).

There are only clearcutting is used in Cherkasy, Dnipropetrovsk, Donetsk, Kharkiv, Kherson, Khmelnytsky, Kirovohrad, Luhansk, Mykolaiv, Odesa, Poltava, Rivne, Sumy, Volyn, Zaporizhzhia region.

Shelterwood is the cutting of most trees, leaving those needed to produce sufficient shade to produce a new age class in a moderated microenvironment. Shelterwood method includes five stages of even-aged regeneration formation.

Shelterwood has the next stages: mature stand → establishment cut → establishment → no removal cut → tending → mature stand.

Shelterwood method includes the various ways of successive regeneration felling together with the selection system. Old crop is felled over the area in uniform, group or strip. The number of receptions of uniform and strip shelterwood can be 2 or 3. The duration of this method is up to 20 years.

The maximum area of shelterwood in production forests can be up to 10 hectares, and in forests that are not used for timber production – 5 hectares.

Another type of harvesting is group shelterwood. It is logging cuts too small to be considered clearcut. The number of receptions of group shelterwood can be 3 or 4.

The maximum area of group shelterwood can be up to 300 m². The number of raincoats for felling is 4-8 pieces. The duration of these felling is 30-40 years. This cutting contributes to light demanding species growing faster.

Uniform, group, strip shelterwood method are intensively applied Chernihiv, Chernivtsi, Ivano-Frankivsk, Kyiv, Lviv, Ternopil, Vinnytsia, Zakarpattia, Zhytomyr region. For the last 2 years uniform and strip shelterwood were carried out in two receptions, and group shelterwood – in three.

The last reception of shelterwood is carried out in the presence of viable natural regeneration from seed in quantity: not less than 8 thousand pieces in pine forests; not less than 15 thousand pieces in beech and fir forests; not less than 12 thousand pieces in spruce forests; not less than 10 thousand pieces in oak, maple, ash and other forests. Figure 5 shows the area allocated for the first reception of uniform felling in a deciduous stand.

Single tree selection removes individual trees of all size classes more or less uniformly throughout the stand to maintain an uneven-aged stand and achieve other stand structural objectives. Single tree selection method is an uneven-aged method where indi-

vidual trees are removed uniformly throughout the stand, to increase growth of remaining trees and to provide space for regeneration. The basic tenets for successful single tree selection are to provide sufficient gaps for regeneration and to maintain vigor throughout the stand.

This method can be strong (removal cut 25-35%), medium (11-24%) and low (up to 10%) intensity. If is carried out strong cutting intensity, the frequency should be more than 20 years; medium intensity – 11-20 years and low intensity – up to 10 years.

In the last 2 years, the single tree selection method was used in Chernihiv (4,5 hectares), Chernivtsi (62 hectares), Ivano-Frankivsk (358 hectares), Kyiv (86 hectares), Lviv (272 hectares), Zakarpattia (164 hectares), Zhytomyr (22 hectares) region (Fig. 1). The largest areas of single tree selection method are carried out in Broshniv, Deliatyn, Sambir, Drohobych, Skole, Ivano-Frankivsk, Teteriv, Kolomyia, Rava-Ruska State Forestry Enterprise; Berehomet, Brustury State Forestry-Hunting Enterprise; Oster, Uzhhorod State Military Forestry Enterprise.

While single tree selection is been carried out, timber harvest is time consuming, but is the best way for continuous cover forestry.

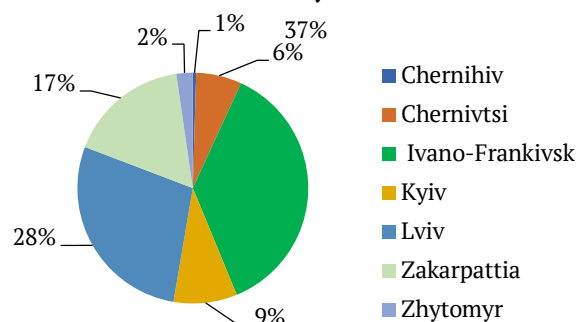


Figure 1. Distribution of the stand area intended for single tree selection method by regions of Ukraine

The distribution of areas of stands assigned to the single tree selection method by tree species allows assessing forestry benefits separately for coniferous and deciduous stands (Fig. 2).

As for the single tree selection method, it is most often used in deciduous stands (64%). Usually in Ukraine deciduous stands are uneven-aged and complex in structure. In coniferous stands, this method is used to transform even-aged in uneven-aged stands. Having selected the regions of Ukraine in which non-continuous methods are introduced to the greatest (Lviv) and least (Kyiv) extent, we obtained the following results (Fig. 3 and Fig. 4).

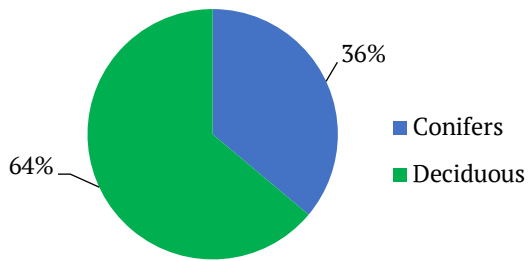


Figure 2. Distribution of the stand areas intended for single tree selection method by tree species

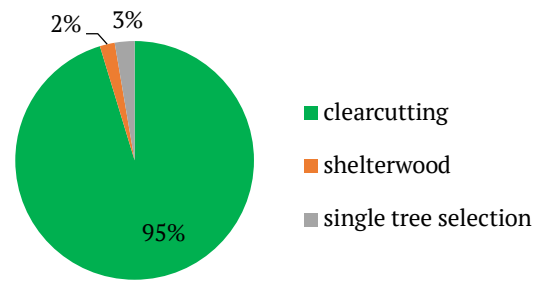


Figure 3. Distribution of used harvesting methods in Kyiv region

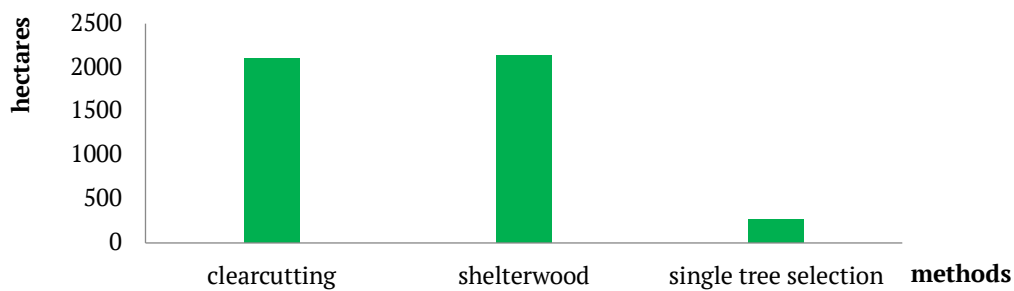


Figure 4. Area of harvesting methods in Lviv region

There are only 5% of area, where was carried out non-clearcutting methods in Kyiv region. In 95% of area was conducted not close-to-nature cutting. Kyiv region has a lot of recreational forest, in which better to provide ecologically oriented forestry, in particular single tree selection removes. There are the same area with clearcutting and shelterwood in Lviv region – more than 2000 hectares each. Single tree selection removes amount 270 hectares. So much more than half of the area is restored by close-to-nature forestry. In Ukraine there is a combined timber

harvest method. This method is a hybrid with the single tree selection and shelterwood methods. The maximum area of combined method is up to 5 hectares. Combined method was carried out only in Novoaidar State Forestry-Hunting Enterprise (4,4 hectares), Teteriv State Forestry Enterprise (5,0 hectares). The last one was carried out in coniferous stands located in the recreational area (Fig. 5, Fig. 6).

As can be seen from Table 1, the areas of stands designed for final felling are significantly lower than those defined by the rules (Rules, 2009).

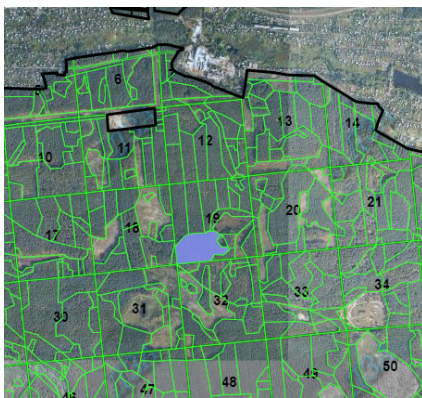


Figure 5. Shelterwood method area in Ivano-Frankivsk Forestry Enterprise

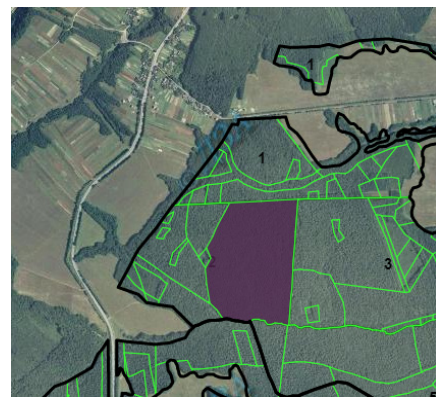


Figure 6. Combined method area in Teteriv Forestry Enterprise

Table 1. Average logging area, hectares

Regions	Clearcutting		Shelterwood		Single tree selection	
	Conifers	Deciduous	Conifers	Deciduous	Conifers	Deciduous
Chernihiv	2.12	1.85	5.25	4.08	4.50	-
Chernivtsi	1.49	1.32	1.80	2.07	7.75	-
Ivano-Frankivsk	1.84	1.34	1.04	1.10	3.00	3.58
Kyiv	1.79	1.77	3.76	-	3.15	2.53
Lviv	0.98	0.87	0.84	1.00	1.90	2.58
Zakarpattia	1.19	0.9	-	1.00	4.17	4.59
Zhytomyr	1.80	1.76	2.46	-	2.7	3.25

A characteristic feature of clearcutting is the predominance of areas in coniferous stands compared to deciduous. For example, in Ivano-Frankivsk region average logging area of clearcutting are 1,84 hectares of conifers and 1,34 hectares of deciduous stands. Shelterwood has the opposite feature. In all regions, except Chernihiv, the average area allocated for this timber harvest method in deciduous stands are larger compared to coniferous.

Single tree selection method has no restrictions on the area. Therefore, the maximum area of this method was up to 10 hectares.

The main method of cleaning loggers consists in collecting felling residues in heaps for decay. Less often it uses the fire method of cleaning areas from felling residues or combined (fire and non-fire methods).

Conclusions

Forest in Ukraine usually composed of one or very few tree species. To achieve an irregular structure, these stands must be transformed through by measures. These measures must consider current and future stand stability, the development of uneven-aged structure, promotion of natural regeneration and

sustained timber production. As we have seen, clearcutting remains the main method in Ukraine. The most foresters choose clearcutting because it's an efficient way to harvest timber and create an ideal site for growing the next generation trees. Shelterwood and single tree selection methods were used in Chernihiv, Chernivtsi, Ivano-Frankivsk, Kyiv, Lviv, Zakarpattia, Zhytomyr region.

The rich natural conditions of Ukraine allow the use of non-clearcutting methods on a much larger scale. The experience of such felling is insignificant in the eastern and southern regions of Ukraine. Usually shelterwood and single tree selection methods are time consuming, but they are the best way for continuous cover forestry.

Recently, methods of timber harvesting are moving away from clearcutting to selective cutting. The implementation of the principles of close-to-nature forestry can be provided by reduction in the volume of clearcutting. Increasing of shelterwood and single tree selection methods, which are close-to-nature, will ensure the cultivation of mixed uneven-aged forest stands of high vigor, productivity and biological stability.

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Особливості застосування систем рубок головного користування в лісах України

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Анотація. У роботі проаналізовано особливості проведення рубок головного користування в Україні. Розглянуто переважні системи рубок головного користування та їх площі. Для аналізу обсягів сучасного лісокористування було використано реєстр лісорубних квитків для всіх лісогосподарських підприємств України. Дослідження проведено за період 2019-2020 рр. Було встановлено, що суцільно лісосічна рубка є основною системою під час проведення рубок головного користування та становить 95 % у Київській області, 45 % у Львівській області. Серед несучільних способів рубок перше місце посідає рівномірно-поступова рубка. Протягом досліджуваного періоду було зафіксовано проведення лише двоприймних (рівномірно-поступових та смугово-поступових) і триприймних (групово-поступових) рубки. Причому суцільно-лісосічні рубки найчастіше проводять у хвойних деревостанах, а поступові – у листяних. Використання вибіркової системи рубок здебільшого стосується листяних насаджень, що опосередковано свідчить про переважання різновікових листяних деревостанів в Україні. Добровільно-вибіркові рубки проводили у Чернігівській, Чернівецькій, Івано-Франківській, Київській, Львівській, Закарпатській, Житомирській областях. Комбіновану систему рідко застосовують в Україні. Протягом останніх двох років її провели на площі 9,4 га. Середні площі рубок головного користування коливаються від 1-2 гектарів під час суцільних рубок, 1-5 гектарів під час поступових рубок та 2-8 гектарів при застосуванні комбінованої системи. Запроектовані площі рубок головного користування значно нижчі від тих, що запроваджені українським законодавством. Реалізацію принципів наближеного до природи лісівництва може бути забезпечено шляхом зменшення обсягів суцільних рубок. Збільшення площ поступової, вибіркової та комбінованої системи, які є більш наближеними до природи, забезпечать вирощування мішаних різновікових деревостанів із високою життєздатністю, продуктивністю та біологічною стійкістю. Дослідження відображають регіональні та видові особливості й переваги методів рубок головного користування

Ключові слова: суцільна, поступова, вибіркова та комбінована системи, одновіковий і різновіковий деревостани

UDC 674.049

DOI: 10.31548/forest2021.01.005

Use of a polymer shell of thermally modified wood to establish moisture diffusion patterns

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Abstract. This study analyses the process of thermal modification of wood, obtained by a controlled heating process. The unique technological properties (durability, low hygroscopicity, and dimensional stability) of thermally modified wood allow using it in various fields. Due to the effect of temperature, some chemical changes occur in the structures of the cell wall components (lignin, cellulose, and hemicellulose) of wood. This leads to an increase in density, hardness, hydrophobicity (water repulsion), thereby reducing the ability of wood to absorb moisture and swell. Products absorb moisture gradually, are less prone to swelling and drying out, but still need elastic coatings. It was proved that heat-treated wood eventually turns grey when exposed to sunlight, and therefore added surface treatment with a coating is necessary. Added application of protective substances on the surface of products made of thermally modified wood contributes to dimensional stability and protects against rapid weathering of the surface in open air conditions. Clear coatings and oils do not protect surfaces from discolouration during weathering. They are recommended for products made of thermally modified wood, which are used away from direct sunlight and rain. The parameters of moisture penetration into wood are mathematically modelled based on the quasi-stationary equation of moisture diffusion through a polymer film on the surface of a flat sample. The dynamics of changes in the moisture content in thermally modified wood were experimentally investigated under different regime parameters. Mathematical relations obtained from experimental studies allow calculating the moisture diffusion coefficient in thermally modified wood in the presence of a polymer shell. It was established that the application of a wax coating on the surface of the product reduces the moisture diffusion by more than 10 times for surfaces already treated at 160°C for one hour, which allows using it on objects with increased humidity

Keywords: wood, thermal modification efficiency, moisture absorption, water diffusion, decomposition, wood stability

Introduction

The unique technological properties (durability, low hygroscopicity, and dimensional stability) of thermally modified wood allow using it in various fields.

Designers often used this material for interior decoration due to the colour it acquires under high temperature. Due to the stability of geometric

dimensions and resistance to the external environment, thermally modified is used in the production of furniture, window frames, doors, parquet boards. Jirouš-Rajković & Miklečić (2021) claim that this material can be used as an external facade cladding, in the form of decking and garden paths. The material

Suggested Citation:

Tsapko, Yu., & Horbachova, O. (2021). Use of a polymer shell of thermally modified wood to establish moisture diffusion patterns. *Ukrainian Journal of Forest and Wood Science*, 12(1), 41-47. doi: 10.31548/forest2021.01.005

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is well suited for covering saunas and baths. Specific features of inhibiting the moisture advancement in thermally modified wood are that water-resistant components are formed, as well as capillary-porous elements, due to which a waterproof layer forms on the wood surface (Tsapko et al., 2021).

The resistance of thermally modified wood to weather conditions (UV rays, wetting) is slightly better compared to untreated wood, but added surface treatment with coatings is required. The market offers many substances for external treatment of wood. For horizontal surfaces (decks, decking, garden paths), Miklečić (2010) recommends penetrating treatment with oils. There are many oils on the market that retain the “natural” appearance of wood and resist weathering.

It is known that thermally modified wood turns grey over time. As reported by Schaller & Rogez (2007), clear coatings and oils do not protect surfaces from discolouration during weathering. Such surface treatment is recommended for products made of thermally modified wood, which are used away from direct sunlight and rain. Recently, increasingly more attention has been paid to the effect of sunlight on the surface of thermally modified wood. A novel approach has been developed to stabilize the dark colour of thermally modified wood by combining visible light screens with organic UV light absorbers (Slabčević et al., 2019).

Processing of thermally modified wood is similar to processing of dried wood, but it is necessary to consider the change in some of its properties. Akyildiz & Kesik (2014) found that thermally modified wood becomes more hydrophobic; absorbs moisture gradually; is less prone to swelling and drying, but still needs elastic coatings; has a darker colour that can fade due to light exposure.

Vernois (2001) noted that cracking of thermally modified wood occurs considerably less compared to natural wood due to improved dimensional stability. Cracking spruce and pine wood after thermal modification when exposed to external conditions without a protective coating was equivalent to cracking untreated wood with unpigmented coatings. Jëamsëa et al. (2000) found that oil application did not prevent cracking of thermally modified wood after natural exposure. However, Miklečić (2010) managed to reduce cracking of samples of thermally modified wood with oil treatment. The results of the study indicate that during accelerated weathering, samples without a protective surface coating had fewer surface cracks than thermally modified samples without a coating.

Pavlič et al. (2021) investigated the compatibili-

ty of nine different coatings with thermally modified Scots pine wood. Coatings applied to thermally modified wood showed better performance than coatings on unmodified wood. The authors attributed this phenomenon to altered characteristics of thermally modified wood, such as lower equilibrium moisture content, lower water permeability, increased dimensional stability, better resistance to UV radiation, and resistance to blue spot fungi compared to unmodified wood. Better penetration of the coating into modified wood and better wetting with protective substances were also demonstrated. Furthermore, solvent-based paint and varnish materials showed better results after one year of external weathering compared to water-based coatings.

Drying oils provide the best protection for wood products, but their use is limited to long-term polymerization. Armingier et al. (2020) investigated the drying behaviour of linseed oil, tung oil, and their 1:1 mixture. Repeated measurements of the water contact angle of coatings applied to beech and oak wood showed clear differences in wetting. Tung oil provided hydrophobicity to all wood samples shortly after application, even when used without a dryer. Linseed oil required a longer drying time and was more susceptible to the effects of the substrate, but eventually reached the highest contact angles after forced drying.

Thus, the literature sources indicated that thermal modification of wood improves the resistance to temperature and humidity factors. Added surface treatment with protective substances contributes to the stability of the product dimensions and protects against rapid weathering of the surface in open air conditions. New products are constantly appearing on the market, which are designed to protect the colour of wood in the interior and to prevent the product from dimensional changes in natural conditions. This indicates the relevance of this study to establish the effectiveness of protection of wood products with paint and varnish materials, which will contribute to the extension of the period of use of building structures in environmental conditions.

The purpose of this study was to estimate the effectiveness of surface treatment with oil-wax based on the determined diffusion coefficient on the resistance of products made of thermally modified wood to the temperature and humidity conditions of the environment.

Materials and Methods

To establish moisture absorption, the authors of this study used randomly selected 90 samples of horn-

beam wood of radial cross-section, previously dried. The samples had dimensions of 20×10×10 mm. Next, the samples underwent thermal modification at 160°C, 190°C, and 220°C, exposure in the chamber for 1, 10, 20 hours. According to the regime parameters of thermal modification, all samples were divided into nine groups and a group of control samples (unmodified wood) (Fig. 1).

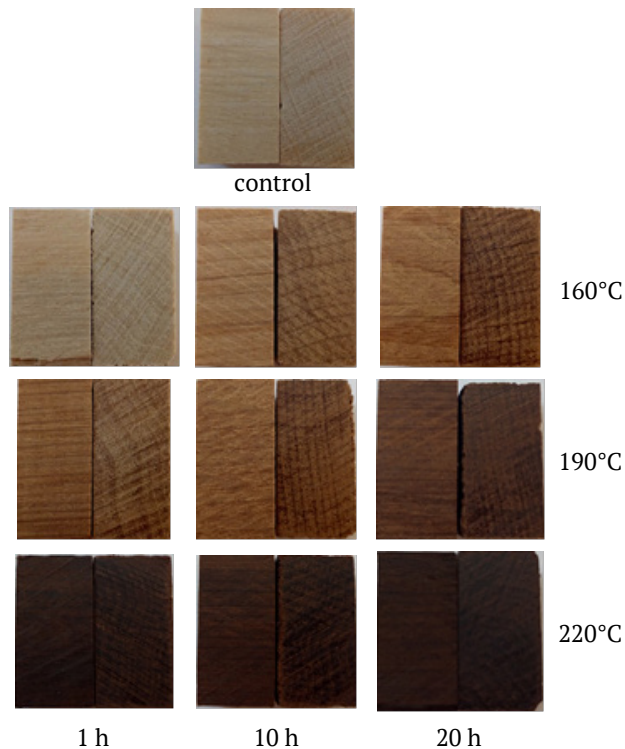


Figure 1. Prototypes of untreated (control) and thermally modified wood

Then the samples were treated with oil-wax by immersion with repeated treatment after the first layer dried in 24 hours. After drying, the samples were placed in a desiccator for 1 day. Subsequently, the dimensions and weight of each sample were recorded. The procedure was repeated on Days 2, 3, 6, 9, 13, 20, and 30.

Results and Discussion

The parameters of moisture diffusion into wood were modelled. The quasi-stationary equation of moisture diffusion through a polymer film on the surface of a flat wood sample is as follows:

$$\frac{d^2 C_w}{dx^2} = 0, \quad (1)$$

where C_w is the moisture concentration at a distance x from the middle of the wood sample (by thickness).

The double integral of Equation (1) is calculated according to the following formula:

$$C_w = Ax + B, \quad (2)$$

where A and B are constants found from the boundary conditions:

for $x=H$

$$C_w = C_0, \quad (3)$$

for $z=H+\delta$

$$C_w = C_1, \quad (4)$$

where H is half the thickness of the sample, δ is the thickness of the polymer shell, C_0 , C_1 is the moisture concentration inside the sample and in the external environment, respectively.

Through mathematical transformations, the solution (2) can be presented as follows:

$$C_x = \delta^{-1}(C_0(H+\delta) - C_1 H - (C_0 - C_1)x). \quad (5)$$

Since the diffusion flow of moisture through the wood surface covered with a shell is:

$$j = -S \cdot D \frac{dC_x}{dx}, \quad (6)$$

where S is the sample surface area, then, after substituting (5) into (6) and integrating, one obtains the expression for the diffusion flow of moisture:

$$j = \frac{S \cdot D(C_0 - C_1)}{\delta}. \quad (7)$$

Then the equation of the mass transfer process through the shell will have the following form:

$$\frac{S \cdot D(C_0 - C_1)}{\delta} = V_1 \frac{dC_1}{d\tau}, \quad (8)$$

where τ is the time; V_1 is the volume of the external environment.

Using the material balance equation, one finds the unknown values of equation (8) C_0 and C_1 :

$$V_0 C_0 + V_1 C_1 = m, \quad (9)$$

where V_0 is the volume of wood, m is the mass of moisture in the sample before the experiment.

From equation (9), one finds the value:

$$C_0 = C_0^* - \gamma C_1, \quad (10)$$

where $C_0^* = \frac{m}{V_0}$ is the initial moisture concentration

in the sample; $\gamma = \frac{V_1}{V_0}$ – the ratio of the volume of the external environment and the sample.

Substituting (10) into (8), one gets the equation for determining C_1 :

$$\frac{dC_1}{d\tau} = \frac{S \cdot D}{\delta \cdot V_1} (C_0^* - (1 + \gamma) C_1). \quad (11)$$

The integral of equation (11) under condition $C_1|_{\tau=0}=0$ gives the following expression:

$$\ln\left(\frac{C_0^* - (1 + \gamma) C_1}{C_0^*}\right) = -\frac{D \cdot (1 + \gamma)}{\delta^2 \cdot \gamma} \tau. \quad (12)$$

It follows from equation (12) that the moisture concentration in the sample changes, considering $\gamma \gg 1$ as a function of:

$$C_1 = \frac{C_0^*}{\gamma} \left(1 - e^{-\frac{D}{\delta^2} \tau}\right). \quad (13)$$

Having performed mathematical transformations, equation (12) can be presented as follows:

$$\ln\left(\frac{C_0^*}{C_0^* - \gamma C_1}\right) = \frac{D}{\delta^2} \tau. \quad (14)$$

The thickness of the polymer shell corresponded to a value of about 10 μm , the humidity in the desiccator was 100%, and the volume ratio of the external environment to the sample was 5. Table 1 presents the weight gain of samples when exposed to a humid environment.

Table 1. Results of experimental determination of sample mass gain

Thermal modification mode		Change in the mass of samples during exposure in a humid environment, g								
		Exposure time in desiccators, days								
T, °C	τ , h	0	1	2	3	6	9	10	20	30
control		1.82	1.86	1.88	1.91	1.94	1.99	2.00	2.03	2.03
	1	1.87	1.89	1.91	1.94	1.98	2.02	2.03	2.07	2.08
	10	1.87	1.88	1.90	1.92	1.97	2.00	2.01	2.03	2.05
	20	1.85	1.86	1.87	1.90	1.95	1.97	1.98	2.00	2.02
160	1	1.85	1.86	1.87	1.90	1.95	1.97	1.98	2.00	2.02
	10	1.85	1.86	1.87	1.90	1.95	1.97	1.98	2.00	2.02
	20	1.85	1.86	1.87	1.90	1.95	1.97	1.98	2.00	2.02
190	1	1.95	1.95	1.97	2.00	2.05	2.09	2.08	2.12	2.13
	10	1.86	1.86	1.87	1.90	1.93	1.95	1.96	1.99	2.00
	20	1.82	1.82	1.83	1.84	1.86	1.88	1.89	1.91	1.92
220	1	1.84	1.84	1.85	1.88	1.91	1.93	1.94	1.97	1.99
	10	1.77	1.77	1.77	1.78	1.79	1.81	1.80	1.83	1.84
	20	1.84	1.84	1.84	1.85	1.86	1.88	1.88	1.91	1.92

Figure 2 shows the dependence (14) on time τ for the control sample, Figure 3 – for processing mode 160/1, Figure 4 – for processing mode 190/1, Figure 5 – for processing mode 220/1. The tangent of the angle of inclination ($\text{tg}\alpha$) of this straight line gives the coefficient for τ , i.e.:

$$(\text{tg}\alpha) = \frac{D}{\delta^2}. \quad (15)$$

The moisture diffusion coefficients were calculated based on dependence (15), presented in Table 2.

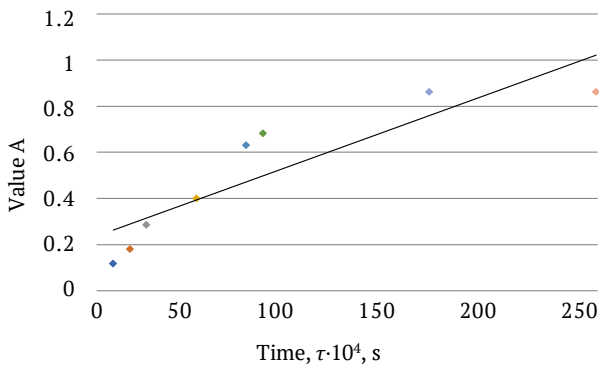


Figure 2. The dynamics of changes in the percentage of moisture in wood for the control sample

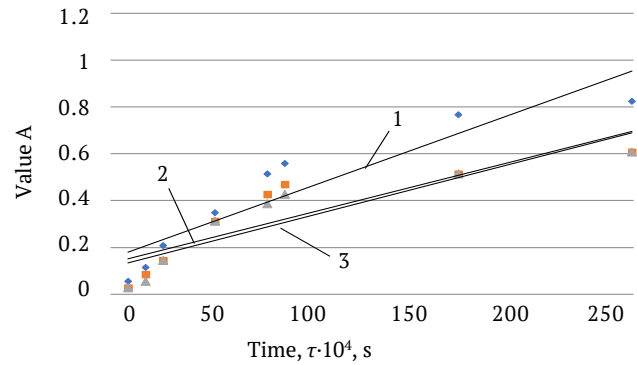


Figure 3. The dynamics of changes in the moisture content in wood thermally modified at 160°C for: 1 – 1 hour, 2 – 10 hours, 3 – 20 hours

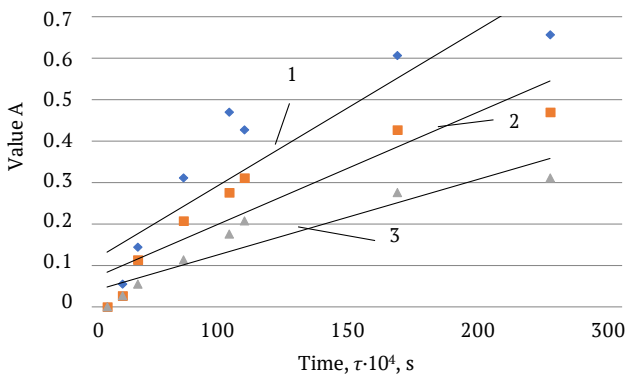


Figure 4. The dynamics of changes in the moisture content in wood thermally modified at 190°C for: 1 – 1 hour, 2 – 10 hours, 3 – 20 hours

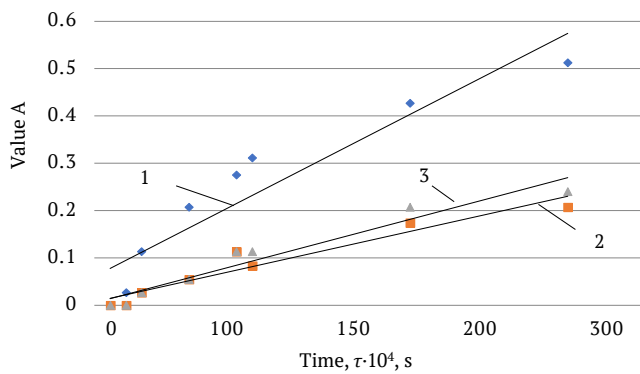


Figure 5. The dynamics of changes in the moisture content in wood thermally modified at 220°C for: 1 – 1 hour, 2 – 10 hours, 3 – 20 hours

Table 2. Diffusion coefficient value for moisture absorption of thermally modified wood, 10, 20 hours

Indicator	control sample	Modification mode parameters								
		Processing temperature, °C								
		160			190			220		
		Processing time, h								
		1	10	20	1	10	20	1	10	20
Moisture diffusion coefficient, $\cdot 10^{-8} \text{ m}^2/\text{s}$	0.753	0.077	0.0062	0.0047	0.0031	0.0028	0.0015	0.00127	0.000088	0.000177

Conclusions

Mathematical relations obtained from experimental studies allow calculating the moisture diffusion coefficient in thermally modified wood in the presence of a polymer shell. It was established that the application of a wax coating on the surface of the product reduces the moisture diffusion by more than 10 times for surfaces already treated at 160°C for one

hour. This coating considerably increases the service life of wood and allows it to be used on objects with increased humidity.

The research results will also help purposefully solve further tasks related to the creation of new means and methods of wood protection according to the conditions of wood operation at various facilities.

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**Встановлення закономірностей дифузії вологи
через полімерну оболонку термічно модифікованої деревини**

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Анотація. Проведено аналіз процесу термічного модифікування деревини, яку було отримано шляхом контрольованого процесу нагрівання. Унікальні технологічні властивості (довговічність, низька гігроскопічність і розмірна стабільність) термомодифікованої деревини роблять можливим її застосування у різних сферах. Унаслідок впливу температури виникають деякі хімічні зміни у структурах компонентів клітинної стінки (лігнін, целюлоза та геміцелюлоза) деревини. Це призводить до збільшення щільності, твердості, підвищується гідрофобність (відштовхування води), тим самим зменшується здатність деревини вбирати вологу і набрякати. Вироби поглинають вологу поступово, менш схильні до набрякання та всихання, але все-таки потребують еластичних покриттів. Доведено, що термооброблена деревина з часом набуває сірого кольору під впливом сонячних променів, а тому необхідне додаткове оброблення поверхні покриттям. Додаткове нанесення захисних речовин на поверхні виробів із термомодифікованої деревини сприяє стабільності розмірів і захищає від швидкого вивітрювання поверхні за умов відкритого повітря. Прозорі покриття та масла не захищають поверхні від знебарвлення під час вивітрювання. Їх рекомендують для виробів із термічно модифікованої деревини, які експлуатуються подалі від прямих сонячних променів та дощу. Математично змодельовано параметри проникнення вологи у деревину на основі квазістаціонарного рівняння дифузії вологи через полімерну плівку на поверхні плоского зразка. Експериментально досліджено динаміку зміни частки вологи в термічно модифікованій деревині за різних режимних параметрів. Отримані математичні співвідношення на основі результатів експериментальних досліджень дають можливість здійснювати розрахунки коефіцієнта дифузії вологи у термічно модифікованій деревині за наявності полімерної оболонки. Встановлено, що застосування воскового покриття на поверхні виробу зменшує процес дифузії вологи у понад 10 разів для поверхонь, оброблених уже за температури 160 °C упродовж однієї години, що дає змогу використовувати її на об'єктах із підвищеною вологою

Ключові слова: деревина, ефективність термічної модифікації, вологопоглинання, дифузія води, розклад, стійкість деревини

UDC 504.5:582.475

DOI: 10.31548/forest2021.01.006

Estimation of ^{90}Sr content in Scots pine timber based on measurement of beta particle flux density from the surface of the trunk bark

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Abstract. The measurement of the ^{90}Sr content in the components of forest ecosystems using radiochemical methods requires considerable time and effort to obtain output results. A less precise, albeit quick, assessment of this radionuclide at the stage of field work can considerably accelerate the decision-making on the possibility of involving a certain forest plot in experimental work or using it for economic purposes. Ukrainian and foreign scientific groups often devote publications to similar express methods for determining the content of biologically mobile radionuclides (^{137}Cs and ^{90}Sr): specific activity, pollution density, etc., since they allow considerably reducing the amount of field and laboratory work. Proceeding from collected field materials from 13 experimental plots of pure pine stands, close ($r=0.85-0.94$) statistically significant relationships at $p=0.05$ were found between the specific activity of ^{90}Sr in stem wood and the results of measuring the density of beta flow with a radiometer from the surface of the bark of Scots pine tree trunks at breast height (1.3 m) within a 10 km zone around the Chornobyl NPP. Direct, linear relationships were established between the average content of ^{90}Sr in the anatomical parts of tree trunks of pine stands (sap, core, and all wood) and the surface density of the flow of beta particles from the bark of trees, which were used to create regression equations suitable for preliminary assessment of the specific activity of the radioisotope under study in timber in the field conditions ($R^2=0.90-0.96$). A close correlation ($r=0.93$) was found between the average stand diameter and the concentration ratio of ^{90}Sr in sapwood to the specific activity of radionuclide in the core wood of trunks. The dependence of the ^{90}Sr content on the density of the flow of beta particles from the surface of the bark of tree trunks was established, and the ratio of the specific activity of this radionuclide between the sapwood and the core can be recommended as a method for rapid measurement of ^{90}Sr in Scots pine wood. However, given the small sample size and the importance of the issue under study, it is necessary to continue working in this area with an increase in the number of empirical data for pine stands, as well as attracting observations of other major forest-forming tree species in the exclusion zone

Keywords: forest ecosystem, radionuclide, specific activity, sapwood, core, trunk wood, Chornobyl Exclusion Zone

Suggested Citation:

Holiaka, D., Levchuk, S., Savytska, I., Lesnik, O., Gumeniuk, V., Morozova, V., & Prokopuk, Yu. (2021). Estimation of ^{90}Sr content in Scots pine timber based on measurement of beta particle flux density from the surface of the trunk bark. *Ukrainian Journal of Forest and Wood Science*, 12(1), 48-56. doi: 10.31548/forest2021.01.006

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Introduction

The heterogeneity of radioactive contamination lies not only in considerable spatial variability, but also in the heterogeneity of the radionuclide composition and various physical and chemical features of its redistribution in ecosystems (Khomutinin et al., 2020). At the same time, the root availability of biologically mobile radionuclides (^{137}Cs and ^{90}Sr) for the biomass of forest communities can vary by orders of magnitude, which is most often expressed as corresponding transition coefficients (Bilous et al., 2020). With this in mind, there is always a possibility of obtaining tree stand elements with considerably higher levels of radiological contamination in a “relatively clean” stand area, or vice versa. The results of such a phenomenon can be the exceeding of the levels of hygienic standards for the content of ^{137}Cs and ^{90}Sr for wood and wood products in the places of wood harvesting (Bilous et al., 2020). Another reason may be the need to considerably increase the sampling volume at the experimental plots for studying the migration of radionuclides, even within the 10-kilometre zone around the Chernobyl Nuclear Power Plant. This is because the small values of the specific activities of these radionuclides in the components of forest ecosystems often do not allow establishing indicators of their distribution with sufficient statistical significance (Khomutinin et al., 2020). Therefore, a preliminary clarifying field assessment of the radionuclide content, with the possibility of obtaining initial results within a few hours, will help start forestry or scientific work on forest areas affected by radiation pollution, without fear of obtaining contaminated forest products or unsatisfactory empirical research data.

Non-destructive methods for measuring the content of radionuclides in components of forest ecosystems are crucial for lifetime radiodosimetric studies of woody plants. With their help, the values of internal exposure of reference organisms are determined. This value usually reaches over 50% of the total exposure in the near zone around the Chernobyl NPP, mainly due to the decay of ^{90}Sr and its daughter radionuclide ^{90}Y (Beresford et al., 2020). Important criteria for the possibility of spreading such express methods are the cost of the equipment and the necessary qualification of the personnel to operate it. The development of these approaches and confirmation of their reliability are often covered in publications by Ukrainian and foreign scientists

(Aramrun et al., 2018; Keisuke et al., 2018; Yoschenko et al., 2011; Yoshihara et al., 2019). Improvement and testing of methods of radiation control of environmental components is an extremely urgent task for states that have a developed infrastructure of nuclear industry and nuclear power facilities or have experienced local radioactive contamination with technogenic radionuclides. In this aspect, special attention should be paid to forest ecosystems, since components of woody biomass can deposit up to 50% of the gross activity of ^{137}Cs and ^{90}Sr localized in forest areas (Holiaka et al., 2020a).

The relevance of this study is conditioned upon the possibility of using its results for an express estimation by indirect measurement of the content of ^{90}Sr in Scots pine wood, using one of the most common radiometers-dosimeters in Ukraine *STORA-TU RKS-01* (EKOTEST, Ukraine).

The purpose of the study is to characterize the dependence of the specific activity of ^{90}Sr of stem wood on the flow density of beta particles from the surface of the bark of Scots pine trees at breast height (1.3 m) in the exclusion zone.

To achieve the specified purpose, the main *research tasks* were set as follows: to identify and statistically evaluate the probable correlations and dependences of the specific activity of ^{90}Sr in the stem wood and its anatomical parts on the flow density of beta particles from the surface of the bark of Scots pine trees; to characterize the impact of forest inventory indicators on the ratio of ^{90}Sr content between the sapwood and the core of the trunks; propose an algorithm for rapid measurement of ^{90}Sr concentration in timber for forestry purposes and during radiological research.

This study was the first to confirm the statistical validity of using the surface density of the flow of beta particles for the separate assessment of the ^{90}Sr content in the anatomical parts of the trunk wood (sap, core) of Scots pine trees.

The practical significance of the results lies in the possibility of estimating the ^{90}Sr content in trunk wood in field conditions in forest plots of pine stands in a brief period of time (from 2 to 3 min). This will enable a more effective radiation monitoring of the forest ecosystems of the Chernobyl Exclusion Zone.

The development of methods for detecting and measuring radiation contamination levels is closely related to the technological advance of devices and

equipment used in this area. In fact, this is a separate area of research that is currently experiencing a “boom” thanks to modern advances in information technology and automation of most processes primarily for medical purposes, namely medical radiology and radiation medicine. However, improvements in this field are quickly finding practical application in other areas of radiology (Ewert, 2016; Volterrani et al., 2019). For instance, conventional personal dosimeters are used in coniferous forests in Japan affected by the Fukushima Nuclear Power Plant accident to assess the dynamics of ¹³⁷Cs content in forest floor throughout the year (Yoshihara et al., 2019). Approaches to mapping radionuclide pollution using robotic complexes and unmanned aerial vehicles are being developed and modified, where the content and composition of radioisotopes are estimated based on the measurement of their beta and gamma radiation (Briechle et al., 2018; Zabulonov et al., 2015). However, the mathematical apparatus used to implement the specified “ideas” was developed as early as the 1960s and 1970s (Khomutinin et al., 2018).

In radioecological monitoring of forest ecosystems, the rapid determination of radiation pollution of forest components without sampling allows solving two principal tasks simultaneously: the time spent by personnel in areas with increased levels of ionizing radiation is reduced; the barrier function of forests in contaminated areas is more fully ensured (samples are not transported to laboratories for measurements). With this in mind, Ukrainian and foreign scientists have developed several approaches for predicting the surface density of soil contamination by technogenic radionuclides and gamma emitters (IAEA, 2003), including aerial surveys (Pradeep Kumar et al., 2020), which later became the basis for creating pollution maps by radioisotopes characterized by alpha and beta decay (Kashparov et al., 2018; Kashparov et al., 2020). The establishment of restrictions on the removal of samples in case of exceeding the regulated levels of radiation pollution outside the Chernobyl Exclusion Zone contributed to the development of methods for assessing the content of radionuclides in the biomass of woody plant communities *in situ* and *in vivo* (Ministry of Health of Ukraine & State Emergency Service of Ukraine, 2008). This was successfully used to establish the lifetime internal exposure doses of pine and birch

trees within temporary radioactive waste containment sites (TRWCS) (Yoschenko et al., 2011). The constant redistribution of biologically mobile radionuclides in forest biogeocenoses requires validation and verification of the listed methods every time in case of their application, especially for ⁹⁰Sr, which migrates 7-10 times faster in soil and biomass elements compared to ¹³⁷Cs.

Materials and Methods

During 2017, at 13 experimental sites in the form of circular test plots, represented by pure pine stands, at a distance of 5-10 km from the Chernobyl NPP, the surface density of the flux of beta particles from the bark was measured, and wood samples were taken from 78 trees at breast height, according to the method of proportional-step representation. Average tax indicators of stands were in the following range: age – 27-97 years, diameter – 12-36 cm, height – 12-28 m, relative density – 0.62-1.19, stock of trunks – 129-409 m³·ha⁻¹. As of January 2020, soil pollution densities (in conversion) were in the following ranges: for ¹³⁷Cs – 170-1700 kBq·m⁻², for ⁹⁰Sr – 50-750 kBq·m⁻². The ⁹⁰Sr content in the stem wood was 0.9-23.1 kBq·kg⁻¹. Wood samples were taken using a *Haglof* increment borer (*d*=5.5 mm, *l*=500 mm) and mechanically divided into sapwood and heartwood anatomical parts.

The specific activity of ⁹⁰Sr in wood was measured using the radiochemical release of the radionuclide after drying the samples at 70°C, their mechanical homogenization, followed by ashing in muffle furnaces at temperatures up to 550°C (Central Research Institute of Agrochemical Service, 1985). The surface density of beta radiation particles of the trunk bark (φ_β) was determined using the *STORA-TU RKS-01* dosimeter radiometer in two stages: with the closed and open metal cover of the beta filter up to four Geiger–Müller counters, which corresponds to the values of estimates created only by gamma background (φ_γ) and gamma and beta pollution ($\varphi_{\beta+\gamma}$), respectively, after which the indicator was calculated as follows:

$$\varphi_\beta = \varphi_{\beta+\gamma} - \varphi_\gamma \quad (1)$$

The analysis of the obtained initial field and laboratory data was performed by *Microsoft Excel 365* and *RStudio 1.2* software products (*R 3.6* programming language).

Results and Discussion

Correlation analysis revealed close relationships between the arithmetic mean values of the flux density of beta particles from the surface of the bark and the specific activity of ⁹⁰Sr in the trunk wood ($r=0.94$) of Scots pine trees at the experimental sites (critical value $r=0.58$ for $p=0.05$), as well as its anatomical parts: sapwood ($r=0.85$) and core ($r=0.94$). A strong relationship was identified between the average diameter of the stand and the ratio of the content of ⁹⁰Sr in the sapwood to the specific activity of this radionuclide in the core ($r=0.93$). The concentration of ⁹⁰Sr in the stem wood and its parts was characterized by significantly lower values of the correlation coefficient ($r=0.02-0.49$) with other inventory indicators.

Graphical interpretation of the dependences of the specific activity of ⁹⁰Sr (A_{Sr-90}) and elements of the wood of the trunk on the flux density of beta particles from the surface of the tree bark (φ_β) indicates the possibility of its description by a simple linear function with only one angular coefficient

(Fig. 1). Predicted values of the angular coefficient of linear regressions were (\pm standard deviation) for sapwood – 23.1 ± 8.5 Bq·cm²·min·(kg·fr.)⁻¹, for heartwood – 42.3 ± 10.8 Bq·cm²·min·(kg·fr.)⁻¹, and the average value for the entire trunk wood (when combining anatomical parts) – 26.8 ± 6.8 Bq·cm²·min·(kg·fr.)⁻¹. The obtained results turned out to be comparable with the output data of a scientific study conducted 15 years ago in pine stands of 15-16 years of age within the boundaries of the TRWCS “Rudy lis” (Yoschenko et al., 2011), where the same coefficient for sapwood trunks was estimated at 26 ± 8 Bq·cm²·min·(kg·fr.)⁻¹. However, the mentioned studies were conducted at such an age of the trees, when the core part of the wood of the trunk was not yet formed, so the conditionally pointed indicator represents the entire wood of the trunk radially, which makes the compared results of the two experimental studies almost identical (Holiaka et al., 2020b). These studies, unlike the previous ones, allow using this method to estimate the content of the specific activity of ⁹⁰Sr in heartwood.

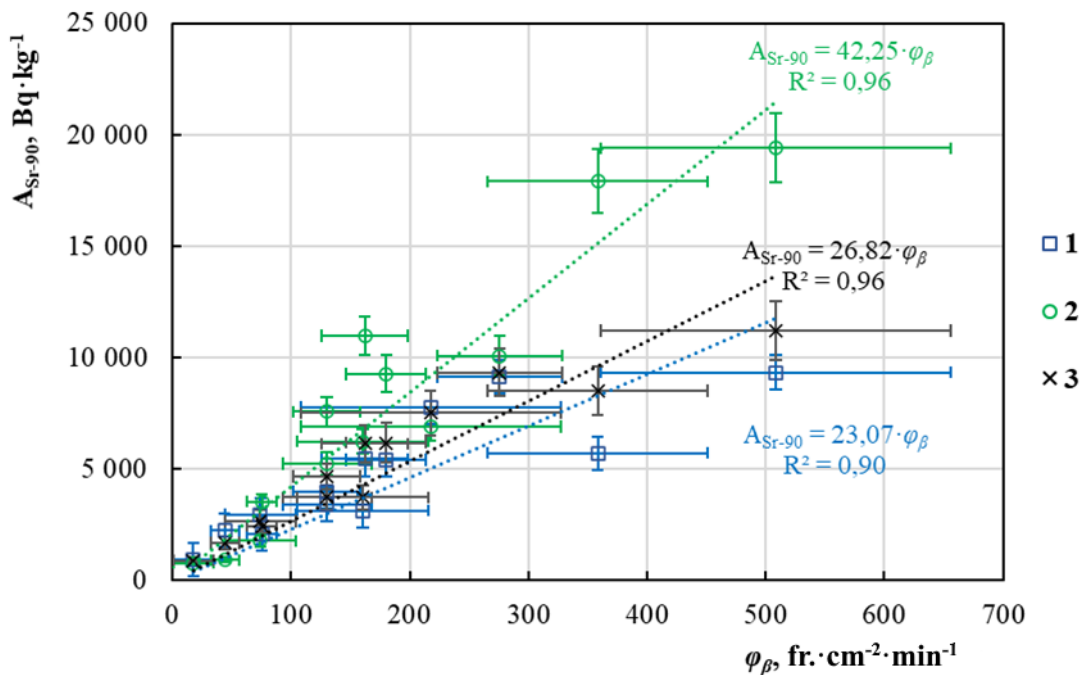


Figure 1. Dependence of the average specific activity of ⁹⁰Sr in the wood of the trunk (1 – sapwood, 2 – core, 3 – whole wood) on the surface density of the flux of beta particles at breast height

The increase in the ratio of the ^{90}Sr content in the sapwood to the specific activity of the radioisotope in the core ($A_{S/H}$) with an increase in the average diameter of the stand (D) in the pine plots (Fig. 2) is explained by the specific features of the deposition of this radionuclide in the stem wood. Presently, in the radial direction, ^{90}Sr accumulated most at the probable sapwood-core boundary of Scots pine trees in 1986-1992 (Holiaka et al., 2020b). From the indicated maximum of the specific activity of the radionuclide towards the bark of the trunk, the ^{90}Sr content in the wood gradually decreases several times. However, in trees older than 70 years (corresponding to an average stand diameter of more than 30 cm in this study), due to the low mobility of the radioisotope in heartwood after its formation, a site with a very low concentration of ^{90}Sr is formed in the centre of the trunk. This “dilutes” the average specific activity of the radionuclide in the core of the trunk, and accordingly, an increase in the values of the ratio of the ^{90}Sr content in sapwood to its specific activity in the core ($A_{S/H}$) is observed. This regularity contradicts the application of constructed linear regression equations (Fig. 1) and/or their predicted slope coefficients for esti-

imating the content of ^{90}Sr in stem wood elements depending on the flux density of beta particles from the surface of the bark, since they do not reproduce the relationship between ^{90}Sr concentrations in the anatomical parts of the tree trunk, considering the average diameter of the stand. Therefore, it is necessary to apply different algorithms to estimate the total specific activity of all wood and for individual anatomical components of the trunk wood. The most appropriate way to conservatively estimate the ^{90}Sr content in the trunk wood without isolating anatomical parts is to use the linear dependence of the specific activity of the radionuclide on the flow density of beta particles from the surface of the tree bark at breast height (Fig. 1). However, if it is necessary to estimate the radionuclide content in the sapwood and the core separately (which is usually necessary during radiological research of forests), it is better to first calculate the concentration of ^{90}Sr in the sapwood using the appropriate linear regression (Fig. 1) and then calculate the probable specific activity of the radionuclide for the core based on the change in the ratio of ^{90}Sr concentrations in the sapwood to its content in the core depending on the average diameter of the stand (Fig. 2).

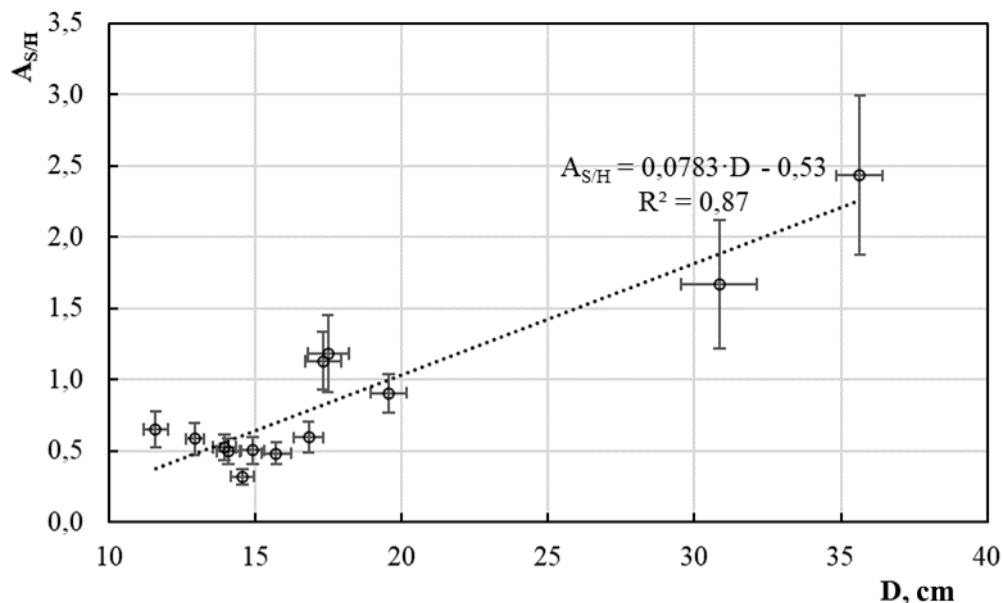


Figure 2. The dependence of the ratio of the specific activity of ^{90}Sr in the sapwood to the core on the average diameter of the stand

The obtained regularities for the express assessment of the ^{90}Sr content in the trunk wood of Scots pine stands by the developed method are not static. Since the release of the radionuclide into the environment in 1986, gradual transformation and redistribution of ^{90}Sr has been taking place in forest ecosystems, specifically in the trunks of woody plants. This requires periodic confirmation of the original quantitative indicators of this study in case of practical implementation of the method of indirect measurement of the specific activity of ^{90}Sr in stem wood based on the surface density of the flow of beta particles from the bark. It is also necessary to consider the “small” volume of observations obtained for reliable interpretation of the identified patterns to better understand the limiting factors for applying the presented approach.

Conclusions

According to the results of this study, the ability to use the beta-particle flux density indicator obtained

by measurements with the *STORA-TU RKS-01* radiometer-dosimeter from the surface of the bark of the tree trunk of Scots pine trees for the preliminary assessment of the ^{90}Sr content in the trunk wood in field conditions was confirmed. The relationship between the above-listed features is characterized by a direct linear dependence, which was used to construct regression equations and find their parameters. The express method of measuring the specific activity of a radionuclide described in this paper is suitable for use when the specific activity of the trunk wood exceeds $1 \text{ kBq}\cdot\text{kg}^{-1}$. Therefore, this method can be practically implemented within the 30-kilometre exclusion zone around the Chernobyl NPP. This ^{90}Sr estimation approach can be recommended for preliminary assessment of the radionuclide content during radioecological and lifetime radiodosimetry studies of pine phytocenoses. However, it is desirable to verify the method on the “own” array of observations, since the sample obtained in this and previous studies and their representativeness provide an insignificant amount of empirical data.

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Оцінювання вмісту ^{90}Sr у деревині сосни звичайної на основі вимірювання щільності потоку бета-частинок із поверхні кори стовбура

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Анотація. Процес вимірювання вмісту ^{90}Sr у компонентах лісових екосистем із застосуванням радіохімічних методів потребує значних затрат часу та праці для отримання вихідних результатів. Менш точна, однак швидке оцінювання цього радіонукліда на етапі польових робіт може значно пришвидшити процес прийняття рішення про можливість залучення певної лісової ділянки до експериментальних робіт чи використання її у господарських цілях. Вітчизняні й іноземні наукові колективи часто присвячують публікації схожим експрес-методам визначення вмісту біологічно мобільних радіонуклідів (^{137}Cs і ^{90}Sr): питомої активності, щільності забруднення і т. д., тому що вони дають змогу значно зменшити обсяги польових і лабораторних робіт. Спираючись на зібрані польові матеріали з 13 експериментальних майданчиків, чистих за складом соснових деревостанів, виявлено тісні ($r=0,85-0,94$), статистично значущі за $p=0,05$, зв'язки між питомою активністю ^{90}Sr у стовбурній деревині та результатами вимірювання щільності бета-потoku радіометром із поверхні кори деревних стовбурів сосни звичайної на висоті 1,3 м у межах 10 км зони навколо Чорнобильської АЕС. Встановлено прямі, лінійні залежності між усередненим вмістом ^{90}Sr у анатомічних частинах стовбурів дерев соснових деревостанів (заболоні, ядрі й усій деревині) та поверхневою щільністю потоку бета-частинок з кори дерев, що використані для створення регресійних рівнянь, які придатні для попереднього оцінювання питомої активності досліджуваного радіоізоотопу в деревині у польових умовах ($R^2=0,90-0,96$). Ідентифіковано тісну кореляцію ($r=0,93$) між середнім діаметром деревостану та відношенням концентрацій ^{90}Sr у заболоні до питомої активності радіонукліда в ядровій деревині стовбурів. Встановлено залежності вмісту ^{90}Sr від щільності потоку бета-частинок із поверхні кори стовбурів дерев та співвідношення питомої активності цього радіонукліда між заболонню і ядром цілком можна рекомендувати як спосіб для експрес-вимірювання ^{90}Sr у деревині сосни звичайної. Однак, враховуючи незначний обсяг вибірки та важливість розглянутого питання, необхідно продовжити роботи у вказаному напрямі зі збільшенням кількості емпіричних даних для соснових деревостанів, а також залученням спостережень за іншими основними лісотвірними деревними видами зони відчуження

Ключові слова: лісова екосистема, радіонуклід, питома активність, заболонь, ядро, стовбурна деревина, Чорнобильська зона відчуження

UDC 502/504:630*232:622.339(477.42)

DOI: 10.31548/forest2021.01.007

Environmental consequences of the adverse impact of unauthorized amber mining on forest areas of Zhytomyr region

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Abstract. Amber mining has already led to a regional environmental disaster. According to official data, over a thousand hectares of land, which are mainly located in the central Polissia region (Zhytomyr region), have suffered very severe damage and need to be restored. The environmental significance of such territories has been lost, and further use for forestry or agriculture is very risky. To develop the norms of anthropogenic loads on landscapes, it is mandatory to investigate anthropogenic transformation by identifying their current ecological state, establishing the dependence of changes on the intensity of anthropogenic loads individually for each natural region. The source materials for obtaining results are field research materials, tax descriptions of plantings, satellite and aerial photographs, as well as laying temporary test areas according to the generally accepted method in forestry. As a result of unauthorized amber mining in Zhytomyr region, the anthropogenic load on forestry landscapes is rapidly increasing, which causes irreparable damage, leads to an environmental and economic crisis of the region, an imbalance in the social situation of the region residents, significant losses in the field of forestry, and creates grounds for related environmental issues. There are considerable changes in the structure and mineral composition of the soil layer of forest lands, the herbaceous ground vegetation and understorey are completely or partially destroyed, the undergrowth undergoes a considerable transformation of growing conditions and anthropogenic pressure. Violation of the ecological balance of the forest at various stages of biological development can lead to irreversible consequences in the forestry sector. The results obtained are promising for further development of the method for ecological and economic estimation of the damage caused, which results in illegal amber mining

Keywords: dendro-reclamation, amber, forest areas, erosion, ecology

Introduction

Ukraine is distinguished by the richness of mineral resources, the development of which inevitably disrupts the existing ecosystems. In recent years, the problem of restoring considerable land areas damaged as a result of unauthorized amber mining in the Polissia amber-bearing district has become

acute. According to official data, over a thousand hectares of land have suffered very severe damage and need to be restored. The environmental significance of such territories has been lost, and further use for forestry or agriculture is very risky. The extraction of amber using motorized pumps destroys

Suggested Citation:

Kovalevskii, S., Marchuk, Yu., Maevskii, K., Kovalevskii, S., & Churilov, A. (2021). Environmental consequences of the adverse impact of unauthorized amber mining on forest areas of Zhytomyr region. *Ukrainian Journal of Forest and Wood Science*, 12(1), 57-67. doi: 10.31548/forest2021.01.007

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the soil structure and leads to abrupt deterioration of its water-physical properties. The difficulty of restoring such territories is related not only to financing, but also to the fact that there is no experience in dendro-reclamation of land with similar damage in the world practice. Therefore, a comprehensive assessment of the damage and its impact on all components of the ecosystem, specifically tree stands, is essential. Forest dendro-reclamation, as a relatively cheap and quite effective way of rehabilitating lands damaged by industry, has become widespread in the forest zone of Europe, Russia, and North America. During forest dendro-reclamation of disturbed lands, much attention is paid to the selection of an assortment of tree and bush species, the main element of the types of projected artificial forest stands.

Analysis of recent studies and publications Central (Zhytomyr) Polissia is one of the most wooded regions of Ukraine. The land fund of Zhytomyr region is 2,982.7 thousand hectares. In its composition, agricultural land has the highest specific weight – more than half (53.9%, or 1,608.5 thousand hectares) (Trembitskyi et al., 2011). More than a third of the land is made up of forests and forest areas covered with forest vegetation. Only 166.7 thousand hectares of land in the region are in their natural state: swamps, lakes, rivers, open lands.

Erosion processes are progressing on the territory of the region, the areas of eroded and erosion-dangerous lands are constantly growing. Erosion processes are widespread on 104.8 thousand hectares of agricultural land, which is 3.5% of the region's territory and 6.5% of the farmland area (Trembitskyi et al., 2011).

Forest vegetation in the past, a fairly humid and mild climate, a positive balance of moisture in the soil, a light mechanical composition and the lack of carbonation of the rocks led to the emergence of sod-podzolic (ungleyed and gleyed) soils, mainly of a light mechanical composition, in Polissia, namely in its central part (sandy, clayed-sandy, sandy-loam and sandy-light loamy) (Hooke et al., 1958). Sod-podzolic soils of Polissia are characterized by some negative features: acidic reaction, unsaturation of bases, scarcity of humus, the gross amount of nutrients (nitrogen, phosphate, potassium) and trace elements (Huck et al., 1958). The lack of any chemical elements in the soil causes their lack in plants.

The forest cover of the territory of Central Polissia increases from the southern regions to the northern ones from 5% to 50% and averages 33.3% (Pylpyenko et al., 2010). Among all types of forests in the territory of Central Polissia, suboral type forests are most common, which are mainly confined to sod-weak-podzolic and sod-medium-podzolic clayed-sandy and sandy soils of varying degrees of moisture (Lavrinenko, 1954). In fresh subors, pine is in optimal conditions for its development and produces the best quality timber (Kucheriavyi et al., 2006).

Amber manifestations within the forest part of the Zhytomyr region, discovered by scientists and locals, belong to the borders of the Zhytomyr Polissia. In its geological structure, the main place is occupied by Precambrian rocks covered by anthropogenic deposits (Vyshnivskyi & Kushnir, 2007). Considering the relatively small distance between the Klesivske deposit and the discovered areas of amber deposits, where it is currently being illegally mined in Olevskyi and Korostenykyi districts, as well as the similarity of the geomorphological and soil conditions of the territories, these areas should be considered a continuation of the Klesivske deposit. The lower layer of quartz sands of the intermountain formation of the Kharkiv series of the Oligocene is considered the most amber-bearing. It is represented by fine- and medium-grained sands of mainly greenish-grey colour with Glauconite, the content of which reaches 5%. The thickness of the layer of water-saturated sand is from one to five meters. The average amber content in sands of this type is 57 km³ (Shcherbak & Hoshovskyi, 2006).

Recently, the greatest activity of unauthorized amber mining on forest lands was observed within Olevskyi and Ovrutskyi districts of Zhytomyr region, Rokytnivskyi, Dubrovytskyi, Volodymyrets'kyi, Zarichnenskyi and Sarneskyi districts of Rivne region and Ratnivskyi and Liubeshivskyi districts of Volyn region. In addition, considering the geography of deposits, several other areas of the listed regions, as well as the territory of the Kyiv region, fall into a kind of risk zone. In fact, unauthorized amber mining covers almost the entire north-western part of Ukraine with an area over 14,600 km² (Kovalevsky & Legky, 2018; Nadtochii, 2007; Vyshnivskyi & Kushnir, 2007).

Amber mining is carried out by manual and hydro-mechanical methods (pump method, pumping). The latter currently prevails and has more catastrophic consequences for the environment. The

hydro-mechanical method of extraction consists in washing away the soil with a jet of water under high pressure up to 6-10 meters deep (Kovalevsky & Legky, 2018; Nadtochii & Myslyva, 2007, 2015; Slobodian, 2009). Extraction in this way destroys the fertile soil layer in the place of the probable occurrence of minerals because during “erosion” the humus layer is mixed with the main mass of underlying sandy and sandy-loam rocks. It takes decades to restore the fertile layer. During extraction by the pump method, the root system of trees is destroyed, which leads to the destruction of tens and hundreds of hectares of forest. Considerable damage to woody vegetation by such amber mining is explained by the fact that unauthorized development is mainly carried out in closed and semi-closed areas: forests, shrubs, forest belts, remote from settlements, in off-road conditions, which does not allow ensuring proper protection of deposits and manifestations (Nadtochii & Myslyva, 2007; Nadtochii & Myslyva, 2015; Slobodian, 2009).

However, the issue of reclamation and den-dro-reclamation of forest lands affected by unauthorized amber mining in the territory of Ukrainian Polissia, specifically in Zhytomyr region, is new and understudied. The first scientific papers on this issue appeared only five years ago, their main topics are satellite monitoring of affected areas (Slobodian, 2009) and assessment of environmental consequences and economic damage (Dorenko, 1979; Vovk et al., 2008; Nadtochii & Myslyva, 2015) caused by amber mining. In the studies of scientists, the authors of this paper found no analogues of a comprehensive approach to the assessment and restoration of forest areas disturbed as a result of amber mining in the Ukrainian Polissia.

Quite interesting today are the scientific studies of M. Kazimir and T. Bedernichek “Reclamation of Lands Disturbed Due to Amber Mining in Polissia: Problems and Prospects” (Kazimir & Bedernichek, 2017) and P. Nadtochii “Ecological and economic assessment of the impact of activities related to illegal amber mining on the environment of Zhytomyr region” (Nadtochii, 2015).

The scientific papers of S. Kovalevskiy and V. Legky “Integral assessment of anthropogenic transformation of forest landscapes of the Dubrovytskyi district as a result of unauthorized amber mining” and “Typological evaluation of forest areas of the Dubrovytskyi Forestry, disturbed as a result of

unauthorized amber mining” highlight the results of the study of forest stands of the Dubrovytskyi Forestry damaged as a result of illegal amber mining (Kovalevsky & Legky, 2017; Kovalevsky & Legky, 2018).

The purpose of this study lies in identifying the environmental consequences of the adverse impact of unauthorized amber mining on the land of the Forest Fund of the Zhytomyr region, which was covered with woody vegetation.

Materials and Methods

Research was conducted during 2018-2020 on the territory of the forest fund of the Zhytomyr Regional Department of Forestry and Hunting. According to the results of the reconnaissance of the damage on the territory of the mentioned enterprises, three state enterprises and seven forestry enterprises as part of them have been identified for further work: SE “Bilokorovytske Forestry” (Zamyslovytske, Ozerianske, Tepenytske, Poyaskiv forestries), SE “Olevske Forestry” (Yurivske and Kamianske forestries), SE “Slovechanske Forestry” (Syrnytsia and Mozhariv forestries). In the future, temporary experimental plots were laid out on the territory of blocks 20 and 21 of the Poiaskivske forestry, block 27 of the Mozharivske Forestry and block 29 of the Syrnytske forestry. Temporary experimental plots were laid in places of the most intense damage to sites due to amber mining, and in adjacent areas that were not adversely affected.

The source materials for this paper included field research materials, inventory descriptions of tree stands, satellite and aerial photographs, data from specialized literature, and orders of state authorities of Ukraine (Yanchuk et al., 2017). The study was conducted per generally accepted guidelines in forestry (Gordienko et al., 2000). The technology of the created forest cultivars, the conduct of economic activities in them was restored based on archival data and forest management materials and clarified during the survey in nature.

Experimental plots were laid in places characteristic of the sites. The experimental area was linked to the quarterly network. In nature, experimental plots were limited by visors, and pits (30×30×30 cm) were dug at the corners, and earth was left at a distance of 30-35 cm. The age of individual woody plants was determined according to the data of inventory descriptions, and if there were no such – visually, according to the general condition of plants, inventory

indicators, conditions of local growth. Measurements of the principal inventory indicators of trees were conducted according to the generally accepted method (Anuchin, 1982). The type of forest vegetation conditions was determined according to the forest typological classification of Alekseev-Pogrebniak (Pogrebniak, 1968) considering the indicators of forest types, soil, and relief. The volumetric mass was determined according to the pycnometric method in twofold repetition, the *pH* of the salt extract was determined by the potentiometric method, the hydrolytic acidity was determined according to Kappen, the amount of absorbed bases was determined by Kappen-Gilkovits, and the humus content was determined according to Turin. Soil analyses were performed in threefold repetition, with a permissible deviation from the arithmetic mean of no more than $\pm 5\%$ (Arinushkina, 1970).

Results and Discussion

Mass amber mining in the Zhytomyr region began somewhat later than in the neighbouring Volyn and Rivne regions. This was one of the prerequisites for the fact that the total area of damaged territories and forestry land is less than in neighbouring regions.

Areas of forest stands that require dendro-reclamation were identified on the territory of three enterprises. The most disturbed areas (336.60 ha) are on the territory of the "Bilokorovytske Forestry", "Olevske Forestry" (30.70 ha) and "Slovechanske Forestry" (2.15 ha). According to the results of the damage analysis, seven forestries have been identified for further research on the territory of the mentioned enterprises: SE "Bilokorovytske Forestry" (Zamyslovytske, Ozerianske, Tepenytske, Poyaskivske forestries), SE "Olevske Forestry" (Yurivske and Kamianske forestries), SE "Slovechanske Forestry" (Syrnytske and Mozharivske forestries). In the future, temporary experimental plots were laid out on the territory of blocks 20 and 21 of the Poiaskivske forestry, block 27 of the Mozharivske Forestry and block 29 of the Syrnytske forestry.

On the territory of the SE "Belokorovytske Forestry", the largest area of damaged land falls on blocks 20, 21, 22, and 25 of the Poiaskivske forestry, blocks 60 and 64 of the Yurivske forestry of the SE "Olevske Forestry", block 29 of the Syrnytske forestry of the SE "Slovechanske Forestry". Forest management data and visual inspection of disturbed areas indicate that, as a result of amber mining,

mainly medieval stands of *Pinus sylvestris* L., sometimes with an admixture of *Quercus robur* L., as well as young *Betula pendula* Roth, and maturing stands of *Alnus glutinosa* (L.) Gaertn were destroyed. In the vast majority of cases, forest stands were completely cut down, and in some cases burned together with the under-canopy cover. Part of the tree stands, specifically young *Betula pendula* Roth., died after flooding the top layer of soil with pulp from sandy horizons due to hydraulic washing from motor pumps. In many areas, washing operations led to a violation of the groundwater level.

As a result of the survey of sites, several types of soil cover violations were found. These are channels for water supply to hydraulic pumps, several types of craters, pits from primary and secondary manual digging, and so-called mining pits with reinforced walls.

Temporary experimental plots were laid in places of the most intense damage to sites due to amber mining, and in adjacent areas that were not adversely affected. Only on the territory of the Mozharivske forestry, experimental plots for comparison were laid out in relatively slightly disturbed areas.

Given the fact that, according to geologists, only about 20-30% of amber is extracted from the sub-surface by pumping, there is an elevated risk of repeated violations of the territory.

In the practice of local foresters, there have already been cases when areas prepared or already planted with forest cultivars were repeatedly disturbed. In addition, considering the already explored density of amber deposits, there is a significant probability of expansion of disturbed areas in the future.

Agrochemical indicators of soils, namely their chemical composition and physical and mechanical properties, often play a decisive role in the choice of tree species and the technology of creating tree stands. Since considerable areas of the surface of the territory under study within the boundaries of the lands of SE "Bilokorovytske Forestry" during illegal extraction of amber by the hydromechanical method are covered with a layer of overburden, the thickness of which reaches 0.9 m, there is a need to investigate the indicated potential substrate. In general, the overburden rocks that comprise the washed layer – quartz, quartz-glaucomite, Lower Cretaceous and Tertiary quartz sands, as well as Quaternary sandy-clayed deposits, are characterized by the corresponding indicators (Table 1).

Table 1. Composition and agrochemical properties of overburden on the territory of SE “Bilokorovytske Forestry” (2019 research)

Indicators	Overburden rocks		
	quartz-glaucinite sand	quartz sand	sandy loam soil
Mineralogical composition	quartz, glauconite, feldspars, phosphate, calcium, gypsum, pyrite, montmorillonite, hydromica, kaolinite	quartz, feldspars, micas, hydromica, montmorillonite	quartz, feldspars, micas, hydromica, chlorite, kaolinite, montmorillonite
Dry residue, %	0.1–0.4	0.04–0.05	0.002–0.04
pH of water	5.4–6.8	4.1–5.7	6.3–6.5
Sum of absorbed bases mg-eq·(100 g) ⁻¹	7–11	0–0.3	2.0–6.2
fraction < 0.01 mm, %	10	7.5–9.3	10.5
Humus, %	0.3–0.7	0.2–0.5	1.5–3.9
Mobile phosphorus, mg-eq·(100 g) ⁻¹	14	2.5	7.5
Mobile potassium, mg-eq·(100 g) ⁻¹	10	2.5	5.0

The complex total interaction of abiotic and anthropogenic factors, which are differently balanced in the territories under study, leads to the formation of different properties of disturbed land plots. As a rule, highly disturbed lands are covered with a layer of quartz sand. Areas formed by quartz-glaucinite sands are more favourable for plant growth. According to the results of the tests, it was found that they contain a considerable amount of nutrients, specifically calcium, potassium, phosphorus, manganese, sulphur, and trace elements. The pH index of sands containing glauconite is close to neutral, and this can explain the decrease in acidity in areas where

pumping of acidified water took place in horizons containing glauconite.

After illegal amber mining by hydro-mechanical method, disturbed forest lands are mainly represented by substrates composed of a mixture of fine-grained quartz sands. The main indicators of overburden that limit or sharply reduce the efficiency of biological development of land include acidity, nutrient content, and water content. The results of studies of the agrochemical properties of sandy substrates at the TEPs within the blocks 19, 20, 21, 22 of the Poiaskivske forestry of the SE “Bilokorovytske Forestry” are presented in Table 2.

Table 2. Agrochemical properties of substrates with an admixture of overburden on the TEPs, covered with self-seeding, within the boundaries of the Poiaskivske forestry of the SE “Bilokorovytske Forestry” (overburden layer 0-40 cm)

No.	Species	Age, years	Months	Agrochemical properties							
				pH (KCl)	humus, %	mobile nitrogen, mg·(100 g) ⁻¹	P ₂ O ₅ , mg-eq·(100 g) ⁻¹	K ₂ O, mg·(100 g) ⁻¹	S*	H*	V*
1	Ps, Bp	5	V	3.96	0.20	2.19	6.2	8.5	0.67	1.86	26.5
			VII	4.13	0.21	1.64	7.7	10.7	1.04	1.86	49.8
			IX	4.15	0.19	1.49	6.9	10.9	1.18	1.48	44.4
2	Ps, Bp, Pt	3–4	V	4.01	0.18	1.04	7.5	14.5	0.40	1.64	19.6
			VII	4.16	0.24	2.79	9.2	9.0	1.55	1.64	48.6
			IX	4.04	0.24	1.42	7.9	14.0	0.61	1.64	27.1

Table 2, Continued

No.	Species	Age, years	Months	Agrochemical properties							
				pH (KCl)	humus, %	mobile nitrogen, mg·(100 g) ⁻¹	P ₂ O ₅ , mg·eq·(100 g) ⁻¹	K ₂ O, mg·(100 g) ⁻¹	S*	H*	V*
4	Bp	3-4	V	3.82	0.18	1.68	6.6	8.5	0.45	1.64	20.4
			VII	3.76	0.18	1.47	7.0	13.5	0.99	3.45	22.3
			IX	3.84	0.22	1.82	7.4	12.0	0.55	1.97	21.8
5	Bp, Ag, Ps	2-4	V	4.49	0.22	2.78	9.0	12.0	2.67	1.15	69.3
			VII	4.39	0.22	1.77	9.0	14.5	1.73	1.15	60.1
			IX	4.25	0.20	2.01	6.3	10.5	1.37	1.31	51.0
6	Bp, Ps, Pt	2-3	V	4.20	0.14	1.14	5.2	13.5	1.37	1.31	51.0
			VII	4.24	0.22	2.66	5.6	15.5	0.98	1.15	46.0
			IX	4.21	0.22	1.26	5.0	14.5	1.17	1.15	50.4
7	Ps Bp	2-4	V	4.19	0.22	1.89	6.0	9.0	0.42	1.31	24.2
			VII	4.09	0.24	3.10	8.2	11.4	0.61	1.31	31.8
			IX	4.06	0.20	1.16	4.0	10.0	0.61	1.48	29.2

H* is the hydrolytic acidity, mg-EQ per 100 g substrate;

V* is the degree of saturation of the substrate with bases;

Ps is *Pinus sylvestris* L.;

Bp is *Betula pendula* Roth.;

Pt is *Populus tremula* L.;

Ag is *Alnus glutinosa* (L.) Gaerth.

According to the degree of acidity, the substrates under study are highly acidic. The pH response is within 2.76-4.49. Zonal soils are characterized by a low content of organic matter. According to the present study, the humus content in all the areas under study covered with a layer of overburden is extremely low and amounts to 0.14-0.24%. However, this fact indicates the presence of a humus-forming process and its connection with the functioning and development of biota. Overburden rocks in the study area contain a small amount of nitrogen, and therefore the content of its available form is estimated as very low. Almost all mobile nitrogen in the areas under study is in the ammonia form, since nitrate is prone to either rapid absorption by plant roots, or leaching into deeper layers, or transformation. The amount of available nitrogen (Table 2) indicates only the nature of its circulation in continuous cycles between vegetation and the substrate.

There are no substantial seasonal changes in the content of mobile nitrogen in anthropogenic washing substrates. In almost all the areas under study, there are two periods during the year, quite sharply

separated from each other: the period of predominant consumption, which coincides in time with the season of active vegetation, and the period of filling the labile fund, which covers the cold season. There-with, the formation of long-term reserves (humus reserves) almost does not occur. The content of mobile nitrogen in anthropogenic substrates may only be sufficient to meet the current needs of biota, but it may not be in reserve.

Agrochemical analysis of anthropogenic substrates allowed establishing that the content of available phosphorus (P₂O₅) during the entire growing season was 4.0-9.2 mg·(100 g)⁻¹, with some tendency to increase until the end of July. According to the degree of supply with available phosphorus (P₂O₅), the substrates under study also belong to the poor.

According to these indicators, they are inferior to zonal soils, where the P₂O₅ content ranges within 9.3-14.7 mg·(100 g)⁻¹ of soil. The amount of exchangeable potassium (K₂O) in the substrates of the experimental plots for the entire growing season was at 8.5-15.5 mg·(100 g)⁻¹ of the substrate, which

corresponds to the content of exchangeable potassium in zonal soils, where its amount ranges within 10.7-14.5 mg·(100 g)⁻¹ of soil. At plots No. 2 and 3, a decrease in the content of K₂O was observed in June, compared to the presence in May, and then it increases again until the end of September. In all other areas, the maximum content of metabolic potassium in substrates occurs in July. The highest K₂O content is observed during the growing season at plot No. 6, where its amount ranges within 13.5-15.5 mg·(100 g)⁻¹ of the substrate. Determining the degree of soil saturation with bases, along with determining the pH of the salt extract, hydrolytic acidity and the amount of exchangeable bases is one of the key methods of researching acidic soils for liming. On land plots No. 1, 2, 3, 4, 6, 7, the substrates under study belong to Group I according to the need for lime, since the degree of their saturation with

bases is 50% or less. Group II includes substrates at Plot No. 5, the degree of their saturation with bases is within 51.0-69.3%. These substrates require less lime. Thus, the data of the presented studies indicate the peculiarity of agrochemical properties of substrates. However, these substrates are non-toxic and because of their agrochemical properties, are quite suitable for the growth of both local and introduced woody plant species.

As a result of hydraulic washing, deep layers of soil are brought to the surface of the plots, and the upper layer of zonal soil is buried under a layer of up to 0.9 m. This affects the physical properties of overburden rocks, depending on the types of their substrate (Table 3). As a result of strong mixing, when using the hydro-mechanical method of amber extraction, all layers are mixed and, as a result, the humus layer is inferior in many respects to quartz sand.

Table 3. Physical properties of overburden on the territory of “Bilokorovytske Forestry”

Substrate type	Specific gravity, g·(cm ³) ⁻¹	Volumetric mass, g·(cm ³) ⁻¹	Hygroscopic humidity, %	Porosity coefficient	Filtration coefficient, m·(day) ⁻¹	Total porosity of the substrate, %
Humus layer of the soil	2.66	1.50	2.20	0.785	1.32	43.6
Quartz sand	2.65	1.55	0.80	0.724	1.61	41.5
Quartz sand with admixtures of glauconite and kaolin	2.65	1.40	4.60	0.893	1.37	47.1

Mineral nutrition is of significant importance for the physiology of the tree, since its normal growth requires a sufficient supply of certain mineral elements. At certain stages of growth and development, plants experience unique needs for elements of mineral nutrition, and therefore knowledge of the dynamics of consumption and redistribution of nutrients in the first years of plant life serves as the biological basis for agricultural technology of their cultivation.

The share of disturbed land is rather considerable and is growing every day. This indicator points to the considerable losses of wood raw materials, non-wood resources of the forest, understorey, undergrowth, and ground vegetation. At the same time, these losses increase the class of fire danger in damaged areas, which can lead to inevitable consequences. Disturbed forest areas are a source of forest pests and fungal diseases. The negative trend

that has developed in the forest massifs of individual forest farms renders forest certification impossible, which would otherwise allow the enterprise to move to a new level of management.

Conclusions

The massive spread of amber mining in recent years has socio-economic, legal, and geological prerequisites and entails environmental, social, and economic consequences. Mining is carried out by manual and hydro-mechanical methods, the latter currently prevails and is more catastrophic for the ecology of the region.

A catastrophic environmental situation is inherent in the centres of mass amber mining, which is the driving force for the imbalance of all ecological indicators of the area, the emergence of side environmental problems and can lead to irreversible consequences. The forest ecosystem is adversely affected at various stages of its development. Forest stands suffer from changes in the hydrological system of the region, which are associated with illegal extraction, which, in turn, can lead to an increase in the volume of lost timber. Having analysed the total

anthropogenic load on forest landscape systems, the authors of this paper found that most of the territory under study is characterized by substantial anthropogenic transformation. Within the area under study, powerful foci of unsatisfactory ecological state were formed due to unauthorized amber mining. Currently, there is a trend of rapid growth in the share of land converted as a result of illegal mining.

The main reasons for the negative changes in the region are the lack of a single ecologically balanced system of rational nature management and ignoring the parameters of permissible standards of load on landscape systems, the lack of relevant legislative acts on the regulation of illegal amber mining, the inaction of law enforcement agencies, the obstruction of the activities of forestry workers, the difficult socio-economic situation of the local population.

Further research is to establish the features and ways of stimulating natural vegetation renewal in areas degraded due to illegal amber mining, to investigate the influence of abiotic environmental factors on the processes of vegetation renewal, to develop a method for ecological and economic estimation of damage caused to forests as a result of unauthorized amber mining.

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Екологічні наслідки негативного впливу несанкціонованого видобутку бурштину на лісові ділянки Житомирщини

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Анотація. Видобуток бурштину вже призвів до екологічної катастрофи регіонального масштабу. За офіційними даними, понад тисяча гектарів земель, які переважно розташовані на території Центрального поліського регіону (Житомирська область), зазнали дуже сильних ушкоджень і потребують відновлення. Природоохоронне значення таких територій втрачено, а подальше використання для ведення лісового чи сільського господарства є дуже ризикованим. Для розроблення норм антропогенних навантажень на ландшафти обов'язковим є дослідження антропогенної трансформації шляхом виявлення їх сучасного екологічного стану, встановлення залежності змін від інтенсивності антропогенних навантажень індивідуально для кожного природного регіону. Вихідними матеріалами для отримання результатів є матеріали польових досліджень, таксаційні описи насаджень, супутникові та аерофотознімки, а також закладання тимчасових пробних площ за загальноприйнятою у лісовому господарстві методикою. Унаслідок несанкціонованого видобутку бурштину на території Житомирщини стрімко зростає антропогенне навантаження на лісгосподарські ландшафти, що завдає їм непоправимої шкоди, призводить до екологічної та економічної кризи району, дисбалансу соціального становища жителів району, значних збитків у сфері лісового господарства, створює підґрунтя для виникнення супутніх екологічних проблем. Відбуваються значні перетворення у структурі та мінеральному складі шару ґрунту лісових земель, повністю або частково знищується живий надґрунтовий покрив і підлісок, підріст зазнає значного перетворення умов місцезростання та антропогенного тиску. Порушення екологічної рівноваги лісу на різних етапах біологічного розвитку, може призвести до незворотних наслідків у лісгосподарській галузі. Отримані результати є перспективними для подальшого розроблення власної методики еколого-економічної оцінки заподіяної шкоди, наслідком яких є незаконний видобуток бурштину

Ключові слова: дендрорекультивація, бурштин, лісові ділянки, ерозія, екологія

UDC 57.061: 581.412: 581.6
DOI: 10.31548/forest2021.01.008

Nomenclature of woody plants in the state register of plant varieties of Ukraine

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Abstract. The efficiency of using plant resources depends on the correct use of plant names. In the scientific agricultural literature, Ukrainian names of plants belonging to the botanical and agrobiological classification are widely used, but neither of them are definitively ordered. The names of agricultural varieties were used in agricultural practice, namely during the systematization of zoned varieties of plants. When registering a variety, it is indicated to which taxon it belongs, and under this name it is entered in the State Register of Plant Varieties suitable for distribution in Ukraine. The list of plants accepted in the State Register is a mixture of correct and incorrect names, which arose as a result of the ill-conceived adaptation of the names of agrobiological nomenclature by comparing them to the names of botanical taxa. The State Register contains a list of registered varieties belonging to certain taxa, which are grouped by economic use. Varieties and taxa are sometimes placed in inappropriate groups. Varieties belonging to the same taxon are sometimes designated by different species names. For some taxa of woody plants, outdated Latin names are given or their spelling deviates from the accepted one. Some botanical taxa are designated by the names of varieties instead of the Ukrainian scientific name. There are russified names of crops instead of specific Ukrainian ones, and the rules of regulatory transliteration of varietal names are violated. The names of plants constructed in the State Register adversely affect professional literature. They destroy the system of agrobiological nomenclature and contradict the norms of the scientific style of the literary Ukrainian language. To correct the shortcomings, it is necessary to follow the recommendations of the International Code of Nomenclature for Algae, Fungi, and Plants and apply the “Rules of nomenclature, taxonomy, and cultonomy of plants”, developed to organize Ukrainian phytonymy

Keywords: taxa, species, trees, plant names

Introduction

Woody plant species comprise a considerable share of the cultural flora of Ukraine. Trees and shrubs are widely used in forestry, fruit growing and decorative gardening for wood, which has a variety of applications; edible fruits, which are an essential component of rational nutrition; aesthetic and

phytosanitary effect; the use of decorative, medicinal, and other properties. The effectiveness of using plant resources directly depends on the correct use of plant names, which may differ in scientific and folk nomenclature. Unlike the Latin nomenclature, where the names of taxa are regulated by the

Suggested Citation:

Mezhenkyj, V., & Mezhenka, L. (2021). Nomenclature of woody plants in the state register of plant varieties of Ukraine. *Ukrainian Journal of Forest and Wood Science*, 12(1), 68-75. doi: 10.31548/forest2021.01.008

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International Code of Nomenclature of Algae, Fungi, and Plants (Turland et al., 2018), Ukrainian scientific nomenclature stays rather disorganized. In the 21st century, several new dictionaries dedicated to plant names were published. The approach to their styling can be conventionally defined as “traditional”, based on names that were widely used in previous editions (Hrodzynskyi, 2001; Kohnno & Kuznetsov, 2001; Kusheriavyi, 2001; Kokhno, 2002; Kokho & Trofimenko, 2005). But other scholars, when selecting new names, suggest using a “national” approach based on popular names (Kobiv, 2005), or, conversely, guided by “international” views, harmonizing the Ukrainian nomenclature as much as possible with the Latin (Zyman et al., 2008). The authors of this paper believe that it is most appropriate to organize Ukrainian scientific names of tree species based on generally accepted international names (Mezhenskyj, 2010, 2017, 2018; Yakubenko et al., 2017).

The purpose of this study was to analyse the names of woody plant species accepted in the State Register of Plant Varieties Suitable for Distribution in Ukraine (State Register), which in numerous instances is used by the authors when determining which names to use to indicate the object of research.

Materials and Methods

The main dictionaries and reference books concerning the names of Latin and Ukrainian names of woody plants published in the 21st century, as well as the latest version of the State Register, were analysed. The latter was compared with the version of the State Register created five years ago (2016), which was analysed earlier (Mezhenskyj, 2017), as well as with the directory of zoned varieties (Raionovani, 1990), which preceded the State Register.

Results and Discussion

In 1961, the International Convention for the Protection of New Varieties of Plants (the UPOV Convention) was signed in Paris, which raised the nomenclature of agricultural plants to the level of international law. The UPOV Convention entered into force in 1968 and was then revised several times – in 1972, 1978, and 1991. Ukraine became a member of the International Union for the Protection of New Varieties of Plants (UPOV) in 1995, acceding to the 1978 Act, and in 2007 – to the 1991 Act. The UPOV Convention defines a variety as “a group of plants within the lowest known botanical

taxa” (International, 1991). Thus, varieties suitable for distribution in Ukraine are entered in the State Register, indicating the botanical taxon to which they belong.

Before the start of the State Register in Ukraine, the State Service for Varietal Testing of Agricultural Crops in the Ukrainian SSR annually issued lists of zoned varieties. In the last such reference book (Raionovani, 1990), woody plants are represented in the following cultivar groups:

- ✓ fruit crops (apple, pear, quince, etc.);
- ✓ berry crops (currants, raspberries, sea-buckthorn, etc.);
- ✓ nut-bearing fruits (hazelnuts, walnuts);
- ✓ mulberry;
- ✓ clonal rootstocks of apple trees;
- ✓ peach rootstocks;
- ✓ forest crops (poplar);
- ✓ flower and decorative crops (hybrid tea rose, garden jasmine, lilac, etc.).

The names of crops of zoned varieties of woody plants are usually one-word (apple, mulberry, poplar, etc.) and coincide, in most cases, with the Ukrainian names of botanical genera. If the composition of the same genus includes several different cultivars, they are also marked with one-word traditional names, e.g., “черешня” (sweet cherry) and “вишня” (cherry), “слива” (plum) and “алича” (myrobalan plum). Numerous decorative varieties of roses are distributed among cultons with a two-word name: “троянда чайногібридна” (hybrid tea rose), “троянда грандіфлора” (grandiflora rose), “троянда флорібунда” (floribunda rose), “троянда поліантова” (polyantha rose), “троянда напівплетиста” (semi-climbing rose), “троянда плетиста” (climbing rose). Several other cultures have two-word names: “волоський горіх” (walnut), “смородина чорна” (black currant), and “жасмин садовий” (garden jasmine). In the case of the last two varieties, the adjective is placed in an incorrect postposition to the noun, while in the names of these cultons it should be the other way around. The applied name “смородина чорна” (black currant) is a calque from the Russian language, where there is a need to distinguish the cultures “красная смородина” (red currant) and “чёрная смородина” (black currant). In the Ukrainian language, there is no such need, since the word “смородина” denotes only one native species – *Ribes nigrum*, and the fruit culture based on this taxon and its hybrids. At the

same time, Ukrainian language has a common generic name for the genus *Ribes* – “порічки”. Due to the similarity of this spelling of the variety to the species name, this name is perceived as a species, although in this case, as in all others, it is not the taxon name, but a culton name. A cultivar name that matches the generic name *Philadelphus* should be correctly reflected as “садовий жасмин”. In the names of groups of roses, the adjective must precede the noun. However, according to the system adopted in the edition, the names of similar cultures were ordered by the nesting method when the generic name was placed first. Because of this, such names are perceived as specific names, although they are not.

Thus, zoned varieties of agricultural plants were usually assigned to certain cultivars and cultivar groups. The names of these cultons had Ukrainian names that are part of the agrobiological terminological system. Traditional Ukrainian names of crops in most cases coincide with botanical generic names. Due to russification, the names of some cultivars have a distorted appearance, such as “грецький горіх” (instead of “волоський горіх” – walnut), “персик” (instead of “бросквина” – peach), “абрикос” (instead of “абрикоса” – apricot). The disadvantage of this list of zoned varieties is also the mistaken attribution of almonds to berry cultivars.

With Ukraine’s independence and accession to the UPOV, the system of registration of plant varieties has changed. Registered varieties, instead of the list of zoned varieties, began to be entered in the State Register because only registered varieties were allowed for industrial cultivation in Ukraine. Since the registration of a new variety is linked to the name of the taxon to which this variety belongs, varieties in the State Register began to be grouped not by cultivar names, but by taxon names. However, the lack of awareness of the transition from the agrobiological nomenclature adopted for zoned varieties to the botanical nomenclature adopted for registered varieties has led to an eclectic mixing of both systems.

In the latest version of the State Register, effective as of March 4, 2021 (Derzhavnyi, 2021), varieties of woody plants are distributed among the following economic groups:

- ✓ agricultural: cereals (*Vitex agnus-castus* L.);
- ✓ agricultural: fodder (*Vitex cannabifolia* L.);
- ✓ fruits and berries (*Malus domestica* Borkh.; *Pyrus communis* L.; *Cydonia oblonga* Mill. and others);

- ✓ grapes (*Vitis vinifera* L.);
- ✓ decorative and medicinal products (*Rhododendron simsii* Planch.; *Syringa vulgaris* L.; *Rosa* L. etc.);
- ✓ forest (*Pinus sylvestris* L.);
- ✓ others (*Salix fragilis* L.; *Salix viminalis* L.; *Paulownia* Sieb. et Zucc. etc.).

This classification is surprising because there is no reason to classify species of the genus *Vitex* as cereals or fodder cultivars. Compilers of the State Register unjustifiably placed the fruit varieties of “хеномелес каліфорнійський” (California chaenomeles) in the group of decorative cultivars, although the varieties of “хеномелес японський” (Japanese chaenomeles) are located among fruit cultivars. The name of the group itself, “fruits and berries”, unscientifically contrasts berries with fruits. Grapes are isolated from fruit plants. The authors of this paper can agree with this because the cultivation of grapes has long been transferred to a specific industry – viticulture, although it meets the definition of “fruit cultivar”.

Woody plants comprise the largest share of fruit cultivars, the vast majority of which are represented by trees, shrubs, and lianas. Varieties are distributed among taxa of different ranks. This is usually the species name: *Prunus avium* L., *Ribes rubrum* L., *Viburnum opulus* L., etc. Some of the taxa are given a generic name, such as *Actinidia* Lindl., or a section rank, such as *Rubus* subgenus *Eubatus* sect. *Moriferi* & *Ursini*. However, other pages contain varieties that belong to particular species of these genera, e.g. *Actinidia chinensis* Planch. or *Rubus idaeus* L. Individual varieties are marked not by publicized nothospecies names, but by hybrid formulas: *Cydonia oblonga* Mill. × *Malus domestica* Borkh. The disadvantage of all the names listed in the State Register is that the authors of taxa and taxon rank designations are italicized, while they should be displayed normally. There are cases of incorrect or outdated citation of authors: *Actinidia purpurea* Rehd. × *Actinidia arguta* Planch. instead of *Actinidia arguta* (Siebold & Zucc.) Planch. ex Miq. × *Actinidia arguta* var. *purpurea* (Rehder) C.F.Liang ex Q.Q.Chang, *Chaenomeles* × *californica* W.Clarke ex C.Weber instead *Chaenomeles* × *californica* W.B.Clarke ex C.Weber, *Chaenomeles japonica* (Thunb.) Lindl. instead of *Chaenomeles japonica* (Thunb.) Lindl. ex Spach, *Paulownia* Sieb. & Zucc. instead of *Paulownia* Siebold & Zucc., *Prunus avium* L. instead of *Prunus avium* (L.)L., *Vitex cannabifolia* L. instead of *Vitex cannabifolia* Siebold &

Zucc., and the last name is outdated. It is merely a synonym to *Vitex negundo* var. *cannabifolia* (Siebold & Zucc.) Hand.-Mazz. It is not necessary to include numerous synonyms along with the taxon name, such as *Cornus mas* L. (*Cornus maculata* L.; *Cornus erythrocarpa* St.-Lag.; *Cornus flava* Steud.; *Cornus homerica* Bub.; *Cornus nudiflora* Dumort.; *Cornus praecox* Stokes; *Cornus vernalis* Salisb.; *Macrocarpium mas* Nakai; *Cornus sativa* Poit. et Turp.; *Eucrania mascula* Raf.), or *Pistacia vera* L. (*Pistacia trifolia* L.; *Pistacia narbonensis* L.; *Pistacia nigricans* Crantz; *Pistacia terebinthus* Mill.; *Pistacia officinarum* Ait.; *Pistacia macrophylla* Pers.; *Pistacia reticulata* Willd.), which are unnecessary “information noise”. There is currently no sense in adding the label *sensu stricto* to the generic name *Cydonia* Mill.

A substantial disadvantage of the State Register is the use of outdated names that do not correspond to the current level of knowledge. For instance, hazelnut varieties are placed under the taxon name *Corylus maxima* Mill. This comes from the fact that, according to the method of examination of hazelnut varieties, they were classified as *Corylus maxima*. Since there is currently no reason to separate *Corylus maxima* from *Corylus avellana* L., new hazelnut varieties are entered in the State Register under the correct name, but the simultaneous indication of two names of the same taxon confuses agrarians. Some of them use outdated names in their scientific papers, referring to the State Register, which is unreasonably considered exemplary on nomenclature issues. The listing of varieties of the same crop under distinct species names leads to more misunderstandings: *Vaccinium myrtilloides* Michx. and *Vaccinium corymbosum* L., with the first taxon being named “чорниця канадська” (Canadian blueberry) and the second being “лохина високоросла” in one place and “чорниця” in another. Blackberry varieties are placed in various places under an outdated name *Rubus* subgenus *Eubatus* sect. *Moriferi* & *Ursini*. In fact, registered blackberry varieties are complex hybrids between representatives of different sections of the subgenera *Rubus* and *Idaeobatus*. Placing *Cydonia oblonga* ‘IC 2-3’ and ‘IC 4-6’ varieties under the name *Pyrus communis* is incorrect. In numerous instances, “mines” are laid already at the stage of examination of varieties because the applicant of a new variety is offered to choose a botanical name from the list of approved taxa names, which does not correspond to the current level of knowledge.

As for Ukrainian names, the State Register demonstrates blatant inconsistency. In some cases, the Ukrainian name of the taxon corresponding to the Latin original is given: *Cydonia oblonga* – “айва довгаста” (oblong quince), *Actinidia chinensis* – “актинідія китайська” (Chinese actinidia), in other cases it is replaced by a borrowed cultivar name. For instance, *Vaccinium corymbosum*, “лохина щиткова” (blueberry corymbosum), is named “лохина високоросла” (after the American cultivar name – Highbush Blueberry). *Hippophae rhamnoides* L., “щець жостероподібний”, is called “обліпиха крушиновидна” (after the Russian name, the species epithet of which does not correspond to the Latin original because “крушина” is *Frangula*, and *Rhamnus* is “жостір”; “обліпиха” is an acceptable name for a fruit cultivar, but there is no need to replace it with the specific Ukrainian generic name of a plant native to Ukraine). *Juglans regia* L., “горіх царський”, is called “горіх грецький” (a Russified name that is an Ukrainism in Russian), which is known in culture as “волоський горіх”. Some taxa in the Ukrainian language have one-word names (“черешня”, “смородин”), so the imitation of the Russian name for *Ribes nigrum* L. as a “смородина чорна” is superfluous. Some taxa that have a binary specific Latin name are translated by the one-word Ukrainian name *Ribes rubrum* L. – “порічки” (instead of “порічки червоні”). Recognition of the genus *Prunus* s.l. led to the replacement of the species names of stone cultivars. However, in the use of gardeners, it is worth leaving the traditional names of cultivars: “абрикоса” (apricot), “вишня” (cherry), “мигдаль” (almond), remembering the difference between the binary taxon name and the cultivar name. It is worth getting rid of the Russified names “абрикос” (in Ukrainian “абрикоса”), “персик” (in Ukrainian “бросквина”). Varieties of one of the stone crops included in the State Register are assigned to the taxon with the outdated name *Prunus divaricata* Ledeb. and called “алича” (plum spreading, cherryplum). In fact, these are interspecific hybrids of *Prunus cerasifera* Ehrh. × *Prunus salicina* Lindl., which in horticultural practice is called “гібридна/великопліда алича” (hybrid or large-fruited myrobalan plum). Similarly, varieties registered as “вишня звичайна” (common cherry) – *Prunus cerasus* L., are interspecific hybrids of *Prunus avium* (L.)L. × *Prunus cerasus* L. This also applies to other cultivars where varieties of interspecific

origin are assigned to one of the parent species, although they belong to recognized nothotaxa.

The names of Ukrainian varieties are duplicated in Latin transliteration, and the names of varieties in Latin have Ukrainian matches. However, the names are transliterated so that it is impossible to correctly establish the original name, e.g., the apple variety 'SQ 159' is translated as 'СКЮ 159'. Instead of the normative transliteration approved by

Resolution of the Cabinet of Ministers No. 55 of 27.01.2010, the State Register for some reason applies the rules of the GOST 7.79-2000 standard (ISO 9:1995), which Ukraine did not adopt. The names of varieties are accompanied by names in Russian, and Ukrainian varieties are either translated, or transliterated, yet or left in the original spelling. These and other inconsistencies are also inherent in previous versions of the State Register (Mezhenskyj, 2017).

Names of tree cultivars according to different classification systems

Botanical classification		Agrobiological classification	Inappropriate taxon names in the State Register
Latin species name	Ukrainian species name	cultivar name	
<i>Chaenomeles japonica</i> (Thunb.) Lindl. ex Spach	Японська айва звичайна, або хеномел(ес) японський	Японська айва	Хеномелес японська
<i>Corylus avellana</i> L.	Ліщина авельська	Фундук	Ліщина звичайна
<i>Cornus mas</i> L.	Дерен чоловічий	Дерен	Дерен справжній (кизил)
<i>Diospyros kaki</i> L.	Хурма какі	Хурма	Хурма східна
<i>Hippophae rhamnoides</i> L.	Щець жостероподібний	Обліпіха	Обліпіха крушиновидна
<i>Juglans regia</i> L.	Горіх царський	Волоський горіх	Горіх грецький
<i>Prunus armeniaca</i> L.	Слива вірменська, або абрикоса	Абрикоса	Абрикос звичайний
<i>Prunus cerasifera</i> Ehrh.	Слива вишненосна, або алича	Алича	Алича (слива розлога, вишнеслива)
<i>Prunus cerasus</i> L.	Слива вишнева	Вишня	Вишня звичайна
<i>Prunus dulcis</i> (Mill.) D.A.Webb	Слива солодка	Мигдаль	Мигдаль звичайний
<i>Prunus persica</i> (L.) Batsch	Слива перська	Бросквина (персик)	Персик звичайний

Botanical classification		Agrobiological classification	Inappropriate taxon names in the State Register
Latin species name	Ukrainian species name	cultivar name	
<i>Rhododendron simsii</i> Planch.	Рододендрон Сімса	Рододендрон	Азалія Сімса
<i>Rosa</i> L.	Шипшина	Шипшина; троянда	Троянда
<i>Rosa damascena</i> Mill.	Шипшина дамаська	Етероолійна троянда	Троянда ефіроолійна дамаська
<i>Ribes nigrum</i> L.	Порічки чорні, або смородина	Смородина	Смородина чорна
<i>Ribes rubrum</i> L.	Порічки червоні	Червоні порічки; порічки	Порічки
<i>Ribes uva-crispa</i> L.	Порічки виноградокучеряві, або агрус виноградокучерявий	Агрус	Агрус звичайний
<i>Salix viminalis</i> L.	Верба лозова (лозяна)	Верба (лозова верба, кошикарська верба)	Верба прутувидна
<i>Vaccinium corymbosum</i> L.	Лохина щиткова	Високоросла лохина	Лохина високоросла; чорниця

Under the influence of the State Register, in scientific works, namely in theses, in recent decades, incorrect constructions of names that do not correspond to the nomenclature code or the norms of the scientific style of the Ukrainian language have been increasingly used (Mezhenskyj, 2020).

Conclusions

In crop production, namely in forestry and horticulture, two systems of nomenclature are used in parallel: agrobiological, which operates on the names of cultivars, and botanical, which is based on the scientific names of taxa. The State Register of plant

varieties suitable for distribution in Ukraine contains inconsistencies in the names of taxa and cultivars and the distribution of varieties by use groups. There is an unconscious replacement of the cultivar names with names that follow species names in form. This destroys the system of agrobiological nomenclature and contradicts the norms of the scientific style of the literary Ukrainian language. It is possible to correct the situation by following the recommendations of the International Code of Nomenclature for Algae, Fungi, and Plants and consistent application of the “Rules of Nomenclature, Taxonomy, and Cultonomy of Plants”.

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Номенклатура деревних рослин у державному реєстрі сортів рослин України

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Анотація. Ефективність використання рослинних ресурсів залежить від правильного вживання назв рослин. У науковій сільськогосподарській літературі широко застосовують українські назви рослин, що належать до ботанічної та агробіологічної класифікації, проте обидві з них остаточно не упорядковано. Назви сільськогосподарських культур вживали в аграрній практиці, зокрема під час систематизації районованих сортів рослин. У процесі реєстрації сорту позначають, до якого таксона він належить, і під цією назвою вносять до Державного реєстру сортів рослин, придатних для поширення в Україні. Перелік рослин, що прийняті в Державному реєстрі, є сумішшю правильних і неправильних назв, що виникла внаслідок неосмисленого адаптування назв агробіологічної номенклатури шляхом уподібнювання їх назвам ботанічних таксонів. Державний реєстр містить перелік зареєстрованих сортів, що належать до певних таксонів, які згруповано за господарським використанням. Інколи сорти й таксони розміщено в невідповідних групах. Сорти, що належать до одного й того самого таксона, подекуди позначені різними видовими назвами. Для деяких таксонів деревних рослин наведено застарілі латинські назви або їхнє написання має відхилення від прийнятого. Частина ботанічних таксонів замість української наукової назви позначено назвами культур. Трапляються зросійщені назви культур замість питомо українських, порушуються правила нормативної транслітерації сортових назв. Сконструйовані у Державному реєстрі назви рослин негативно впливають на фахову літературу. Вони руйнують систему агробіологічної номенклатури і суперечать нормам наукового стилю літературної української мови. Для виправлення недоліків потрібно дотримуватися рекомендацій Міжнародного кодексу номенклатури для водоростей, грибів і рослин і застосовувати «Правила номенклатури, таксономії та культономії рослин», розроблені для упорядкування української фітонімії

Ключові слова: таксони, види, дерева, назви рослин

UDC 630*231:582.475(477.41)
DOI: 10.31548/forest2021.01.009

“Green Book”: Levels of functioning, syntaxonomy, structuring

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Abstract. In the light of modern scientific concepts of phytocenotic diversity, the study of its preservation is now a new and somewhat holistic outlook on this global problem for humanity. According to the pan-phytocenocentric concept, its solution should be implemented at the local, regional, national, and international levels. Protection of phytocenotic diversity in Ukraine has become an integral part of the concept of eco-balanced development, national programs for the conservation of biodiversity as a mandatory element of national environmental policy. Therefore, it is important to preserve phytocenotic diversity as a set of phytocenotic taxa that reflect all levels of organization of phytocenoses and which were formed during phytocenogenesis in various ecological conditions. The purpose of this paper is a comprehensive level analysis of the current composition of the rare phytocenotic pool of Ukraine, establishing a new list of rare syntaxa, working out the latest structure of the second official edition of the “Green Book of Ukraine” and outlining tasks for the future. In this context, a critical analysis of the syntaxonomic composition of the current rare phytocenotic pool of Ukraine was carried out, methodological violations of isolating syntaxa were found, and the structure of describing rare syntaxa was proposed. The authors identified 983 associations of 104 formations that will be used as the basis for the second official edition of the Green Book of Ukraine. An essential element of syntaxonomic protection of vegetation is also the creation of regional lists of rare associations, based on the principles of creating the “Green Book of Ukraine”. This study is the first to outline a modern rare phytocenotic pool for the main natural regions: Ukrainian Polissia, Ukrainian Carpathians, Podil part of the forest zone, Forest Steppe of Ukraine, Steppe of Ukraine, Mountain Crimea

Keywords: vegetation, rare association, rare phytocenotic pool, “Green Book of Ukraine”, regional green lists

Introduction

One of the priority areas of modern scientific thought is the development of principles and the formation of conceptual foundations of the latest environmental outlook. The latter increasingly becomes a philosophy of the survival of humanity in general

and the preservation of optimal conditions for the existence of heterogeneous living and non-living nature. In the real practice of the relationship between human society and nature, this task is transformed into an ideal of sustainable ecosocial de-

Suggested Citation:

Ustymenko, P., Popovych, S., & Dubyna, D. (2021). “Green Book”: Levels of functioning, syntaxonomy, structuring. *Ukrainian Journal of Forest and Wood Science*, 12(1), 76-87. doi: 10.31548/forest2021.01.009

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velopment. Such development involves preserving the authenticity of the relevant natural objects over time, as well as increasing their self-organizing potential in a co-evolutionary way. This is evidenced by the close attention of international environmental organizations to this problem and program developments carried out under the auspices of the United Nations, UNESCO, UNEP, IUCN, and others.

For Ukraine, the problem of the ecostate stability, and therefore the state of its biodiversity, is particularly relevant, as it is recognized as a priority at the state level. Firstly, the methodology of this approach is consolidated in the Constitution of Ukraine; secondly, it is the result of signing and ratifying the relevant convention of an international multilateral treaty; and thirdly, the conservation of biodiversity is included in the seven priorities of national environmental policy. Therefore, the protection of phytocenotic diversity in Ukraine has become an integral part of the concept of eco-balanced development and national biodiversity programs. This is also noted in the draft "National Strategy for Forest Management of Ukraine until 2035".

In this area, the main focus is on preserving vegetation cover as the initial link of all bioenergetic processes that occur in the biosphere. In this regard, the urgent task is to preserve and maintain the natural phytocenogenetic process in the vegetation cover. Phytocoenoses, as elementary phytocoenoses, collectively form a higher-order structure – vegetation. Preservation of phytocoenoses solves the ecoproblem at three principal levels of the organization of living things: phytocenotic pool, phytogene pool, and ecosystems of the planet (Shelyag-Sosonko, 1999; Stoyko, 2011).

The defining stage in recognizing the importance of syntaxonomic protection of rare vegetation at the ecosystem level is the creation of "Green books" ("green lists"), as a certain register of groups that require special conservation. Usually, such registers provide information about their group structure, phytocenotic features, distribution, phytosociological and botanical value, measures to optimize conservation regimes and balanced use, and the state of conservation (Popovych, 2002; Shelyag-Sosonko, 2003a; Stoiko & Shelyag-Sosonko, 2005; Ustymenko, Shelyag-Sosonko & Vakarenko, 2007).

For the entire short history of syntaxonomic protection in Ukraine as a science, theoretical foundations for the preservation of rare groupings

were developed and the principles of their isolation were formulated, a model of the structure was proposed and three editions of the "Green Book of Ukraine" were made: two scientific monographic works "Green Book of the Ukrainian SSR: rare, disappearing and typical plant communities in need of protection" (Shelyag-Sosopko, 1987), "Green Book of Ukraine. Forests" (Shelyag-Sosonko, Ustymenko, Popovuch & Vakarenko, 2002), the first official publication – "Green Book of Ukraine" (Didukh, 2009).

An essential event for the development of the science of rare plant communities was the publication of S.Y. Popovych's monograph "Synphytozoology of forests of Ukraine" (Popovych, 2002). The author conducted a theoretical and methodological generalization of scientific materials on the protection of forest vegetation of Ukraine, revealed the theoretical foundations of the strategy for the protection of phytocenodiversity at the basic levels of its ecosystem organization, presented a new approach to the allocation of phytocenodiversity according to regional and horological criteria, carried out a synphytozoological assessment of the forest cenotic pool.

The monograph "Management of protected forests of Ukraine" (Shelyag-Sosonko, 2003b) provides a list and brief scientific and environmental characteristics of rare forest associations of nature reserves of Ukraine.

Considerable factual material of research on the rare phytocenotic pool of Ukraine, which has been tested in numerous scientific papers and reports on scientific research, is critically summarized in the monograph "Rare phytocenotic pool of Ukraine" (Ustymenko, Shelyag-Sosonko & Vakarenko, 2007). The authors highlighted modern aspects of phytocenological and synphytozoological studies, analysed the state of conservation of phytocenodiversity of the nature reserve fund of Ukraine for categories of the highest geosociological rank. In this thorough study, a rare phytocenotic pool is also characterized and analysed in terms of phytocenotic, phytosociological, botanical, and geographical significance, representativeness, amplitude and density of distribution, the nature of changes in phytocenotic areas, position in the succession series, and the potential for recovery of phytocoenoses.

In the context of the development of the ecological network of Ukraine for the identified key territories of the international, national, and regional

levels of Forest-Steppe and Steppe, a list of rare phytocenoses is given, the rare phytocenotic pool is analysed, the degree of transformation of these groups is established and the main threats for them are clarified (Dubyna & Movchan, 2013; Ustymenko et al., 2018).

Thus, the idea of preserving a rare phytocenotic pool is especially relevant for Ukraine, whose vegetation cover has undergone substantial quantitative and qualitative transformations, which has led to the depletion of the phytocenotic pool and the deterioration of the phytocenogenesis. Over the past decades, a considerable series of other publications has covered this issue, continuing the discussion of methodological foundations and practical measures for the conservation of rare phytocenoses in Ukraine.

The purpose of the present paper was a comprehensive level analysis of the current composition of the rare phytocenotic pool of Ukraine, establishing a new list of rare syntaxa, as well as working out the latest structure of the second official publication of the “Green Book of Ukraine”.

Materials and Methods

The research materials were the rare phytocenotic pool of Ukraine, modern geobotanic literature, and field factual material of the authors collected in all natural regions of the country over the past half-century.

The methodology for determining rare phytocenotaxonomic diversity is based on a set of methods for syntaxa inventory and matrix synphytosozological assessment of the phytocenotic pool (Didukh, 2009), which are well tested in the Ukrainian phytocenological literature. Field studies were carried out using classical geobotanical methods (detailed route, cartographic, laying of temporary experimental plots, geobotanical description, etc.) (Yakubenko et al., 2018). During the desk stage of research, field data were systematized and synphytosozological analysis was performed. Rare syntaxa of forest vegetation were identified on the principles of dominant classification (Didukh, 2009). Synphytosozological assessment of the phytocenotic pool was carried out per the “Methodology of synphytosozological assessment of natural plant communities subject to protection and included in the Green Book of Ukraine”, approved by the Order of the Ministry of Environmental Protection and Natural Resources of Ukraine No. 257 dated 27.05.2009.

Results and Discussion

According to the panphytocenocentric concept, all rare plant groups at all levels of phytostroma organization are subject to continuous protection. Let us briefly consider synphytosozological problems at each of these principal levels.

International level.

Global warming of the biosphere climate has become one of the most urgent environmental problems of the present time, with a far-reaching impact of these processes on society, the environment, and the economy. Undoubtedly, the main effects of such an impact primarily affect the state of natural indigenous ecosystems. Therefore, it is not difficult to predict the consequences:

1) the growing areas of some species of biodiversity will be changed due to changes in the boundaries of natural zones, in some cases some species will completely disappear;

2) the modes, types, intensity, and frequency of exposure to vegetation of various natural environmental factors – floods, hurricanes, landslides, fires, insects, pathogens, etc. – will change;

3) there will be mostly negative changes in the stability of life, primarily in forest, steppe, and swamp ecosystems, and the productivity of autochthonous woody and herbaceous plants;

4) the efficiency of functioning of vulnerable ecosystems will change rapidly, specifically their impact on biogeochemical cycles, the state of biodiversity, and the reduction of carbon sequestration by forests (with the implementation of rapid growth of such scenarios, forests will turn from carbon storage facilities into sources of emissions);

5) the reproductive cycles of species of biodiversity of natural ecosystems, the course of their successions will change, and their ecotic and social functions will change;

6) there will be a decrease in the amount of natural population biodiversity, especially species with a narrow climatic range (stenotopic), as well as species on the border of their ranges, relicts and endemics.

To slow down the above-mentioned processes in Europe for the implementation of the “Convention on the Conservation of Wild Flora and Fauna and Natural Habitats in Europe” (Bern, 1979) and numerous relevant initiatives, resolutions, directives (especially Annex I of the Biotope Directive and Resolution 4) the concept of biotope protection has been

introduced, which provides only partial preservation of associational phytocenodiversity and a minimal share of rarity. According to this document, coastal, halophytic, non-marine aquatic, herbaceous, shrubby, forest, continental rocky, scree, psamphytic, and sparse forest communities are subject to conservation in Europe (Andrienko & Onyshchenko, 2008), which usually characterize higher taxonomic ranks. Biotopes are very rarely identified at the level of plant associations, as is customary for “green books”. In general, in the EU countries, the leading area of biodiversity protection is the preservation of local populations of rare plant and animal species, as well as unique or reference natural ecotopes, regardless of whether rare species of biodiversity occur there. Already after the adoption of the Bern Convention and the so-called housing directive, the Strategy for the Preservation of Plant Life or its analogues for different regions was agreed at the international level, the Convention on Biodiversity (Rio de Janeiro, 1992) was approved, as well as dozens of other documents that allow fulfilling the purpose of preserving living nature in its various manifestations. It is the Convention on Biodiversity that makes provision for the biocenotic level of wildlife conservation. The pan-European strategy for the preservation of biological and landscape diversity (Sofia, 1995) is a demonstrative example of the implementation of this convention, which comprehensively covers various aspects and approaches of environmental protection activities – from population to biocenotic and eco-network. Undoubtedly, such activities are organized in a more complex way at the planetary level. However, biotope protection and syntaxonomic protection are related concepts, but not identical.

In this context, the problem of preserving the types of living organization, which ensures the functioning of the biosphere and the maintenance of eco-balance at the phytostromal level, first of all, in the most sensitive component of phytocenodiversity – rarity, becomes relevant. In this regard, in 1996, Yu.R. Shelyag-Sosonko and T.L. Andrienko called for work to be started on the selection of plant groups rare for Europe and the creation of the “Green Book of Europe”. They also believed that the selected syntaxa should be cited not only according to the dominant classification, but also according to the Braun-Blanquet system (Shelyag-Sosonko & Andrienko, 1996). This proposal is considered in the

scheme for describing a rare phytocenosis for the new edition of the “Green Book of Ukraine”.

National level.

In Ukraine, the first official publication of the Green Book of Ukraine (2009) became a defining event for the history of syntaxonomic protection of rare vegetation at the ecosystem level. At this stage of the development of synphytosozology, this publication became a register of plant communities that needed special preservation. For each phytocenosis, information about its vertical and horizontal structure, features of functioning, distribution, phytosozological and scientific value, measures to optimize conservation regimes and balanced use, and representativeness of the nature reserve fund is provided.

The structure of the “Green Book of Ukraine” was developed per the requirements of the “Regulations on the Green Book of Ukraine”, which was approved by the Resolution of the Cabinet of Ministers of Ukraine in 2002. To identify rare groupings, a synphytosozological assessment of plant associations was carried out according to this method. Such assessment is based on the principles of the importance of dominant species involved in the formation of phytocenosis both as functional and specific-territorial biosystem. In addition, according to this method, eight diagnostic features of groups are distinguished (phytocenotic, phytosozological, botanical-geographical significance, regional representativeness, ecological-phytocenotic amplitude and density of distribution, nature of changes in the cenoareal, position in the successional series, potential for recovery), each of which has four gradations. Furthermore, the authors of this study prepared materials for the new edition of the “Regulations on the Green Book of Ukraine” in the context of the second edition of the “Green Book of Ukraine”. The content of its text has been corrected, to which changes and clarifications have been introduced, which will contribute to the quality improvement of the implementation of particular, effective measures to preserve and reproduce rare plant groups. Therefore, the “Green Book of Ukraine” is a legally established mechanism for the protection of rare phytocenoses and their habitats in Ukraine, which are necessary for joint preservation. This official document supports a consistent legal tradition in the field of biodiversity protection in Ukraine.

The current official edition of the “Green Book of Ukraine” (2009) also contains information on the condition, distribution, and features of rare and endangered species, as well as typical natural plant communities subject to protection. This edition comprises 160 articles that provide information about 800 associations of 111 vegetation formations in Ukraine. Among the types of vegetation in Ukraine, the richest is the rare phytocenotic pool of forest vegetation, which has 308 associations, 62% of which are confined to mountain ecosystems. The rare phytocenotic pool of Steppe vegetation has 222 associations, and the highest aquatic vegetation has 137 associations. In other types of vegetation, it is less numerous: shrubby and prostrate shrubby vegetation of the Carpathians and Crimea – 32 associations, grass and prostrate shrubby vegetation of xerotic type on outcrops and sands – 32, meadow vegetation – 20, swamp vegetation – 39, halophytic vegetation – 10 associations. This representation of rare associations generally correlates with the phytocenotic richness and diversity of vegetation types in Ukraine, the degrees of their conservation and disturbance, the diversity of ecotopes, botanical and geographical features, etc. (Ustymenko, Dubyna & Vakarenko, 2010). Thus, the “Green Book of Ukraine” has become a theoretical foundation for developing practical measures for the conservation, reproduction, and use of plant communities.

Currently, work has begun in Ukraine on the preparation of a new (second) official edition of the “Green Book of Ukraine”, in which the authors of this paper are directly involved. Since the publication of the first official edition, a lot of new synphytosozological and geobotanic information about the rare phytocenotic diversity has been accumulated, which, together with the materials of special studies of the rare phytocenotic pool, is a sufficient basis for preparing a new edition. This process requires the presentation of up to date geobotanic information for each of the rare syntaxa, detailed cartographic material, clarification of the main threats, and development of types of conservation modes.

The quantitative and qualitative state and composition of rare plant communities in Ukraine have changed substantially over the past few decades. The number of localities with rare phytocenoses, which, due to their ecobiotic characteristics and origin, are sensitive to anthropic influence, has considerably decreased. Their phytocenotic content has

also changed. Therefore, the obvious phytosozological task of today is a critical analysis of the available lists of rare vegetation syntaxa, conducting the most complete inventory of them based on the results of the latest phytocenological studies, synphytosozological assessment, and ensuring comprehensive preservation.

In recent years, the authors of this paper have thoroughly analysed the syntaxonomic composition of the current rare phytocenodiversity of Ukraine and critically evaluated the content of geobotanic descriptions in the phytosociological database. As a result, several problematic issues were identified that needed to be considered upon drafting a new list of rare groups for inclusion in the second official edition of the “Green Book of Ukraine”. The following aspects of the legitimacy of a considerable share of syntaxa turned out to be problematic: the inconsistency of association names with the content of geobotanical descriptions, based on which they were established; selection of associations by individual descriptions; violation of the principles of syntaxonomic protection; associations were established based on small fragments of the mosaic of plant communities; assignment of true association rank to syntaxons of lower rank, i.e., sub-associations or variants of associations were considered associations; inclusion of syntaxa that have disappeared from autochthonous indigenous ecotopes due to natural or anthropogenic factors in the list of rare phytocenotic pool; associations were described several decades ago and are currently not confirmed by modern research, etc. In total, the authors of this paper identified 134 illegitimate rare associations, including 83 forest associations, two shrub associations, 30 steppe associations, two meadow associations, seven swamp associations, and two water associations, as well as eight associations for outcrop and sand groups (Fig. 1).

A detailed analysis of the current rare phytocenotic pool, the latest results of modern synphytosozological research and the latest geobotanical information on rare phytocenotic diversity, as well as the materials of the authors’ own research, allowed establishing quantitative and qualitative indicators of the current state and composition of the rare phytocenotic pool of Ukraine, which will form the basis for the preparation of the second official edition of the “Green Book of Ukraine”.

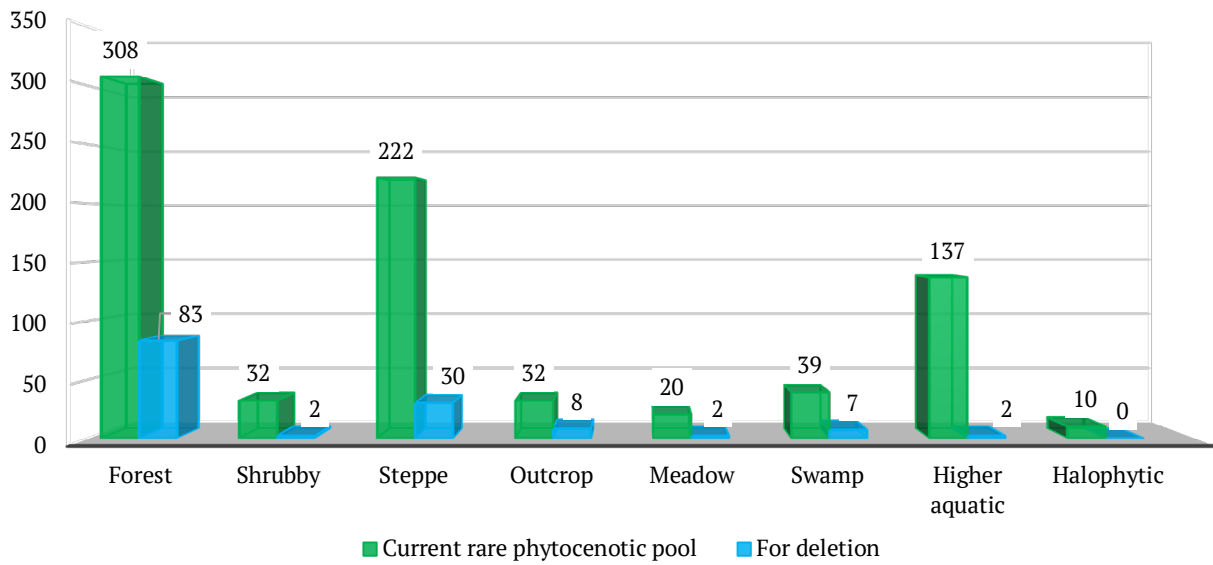


Figure 1. Quantitative ratios of legitimate and illegitimate rare associations of Ukraine

Thus, the modern rare phytocenotic pool of Ukraine has 983 associations, which are included in 104 formations. Forest vegetation is characterized by the most numerous rare phytocenotic pool, which has 363 associations of 22 formations. Shrubby vegetation is represented by 32 rare associations of eight formations; steppe – 300 associations of 24 formations; grass and prostrate shrub groups of xerotic type on outcrops and sands have 31 associations of seven formations; meadow vegetation is represented by 20 associations of five formations;

for swamp vegetation, 61 associations of 10 formations are established; halophytic vegetation is distinguished by the smallest rare phytocenotic pool, which has 12 associations of three formations; the highest water vegetation covers 163 associations of 25 formations (Fig. 2). As a result of the comparison of the quantitative compositions of the rare phytocenotic pool of the two official editions of the “Green Book of Ukraine” (current and new), it was established that the phytocenotic pool proposed for protection will be increased by 186 associations (Fig. 3).

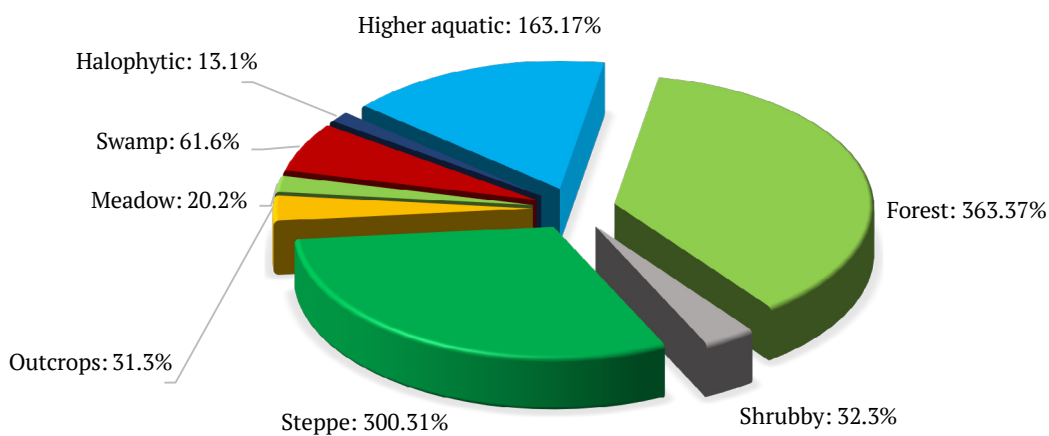


Figure 2. Rare phytocenotic pool of vegetation types in Ukraine: richness and ratio

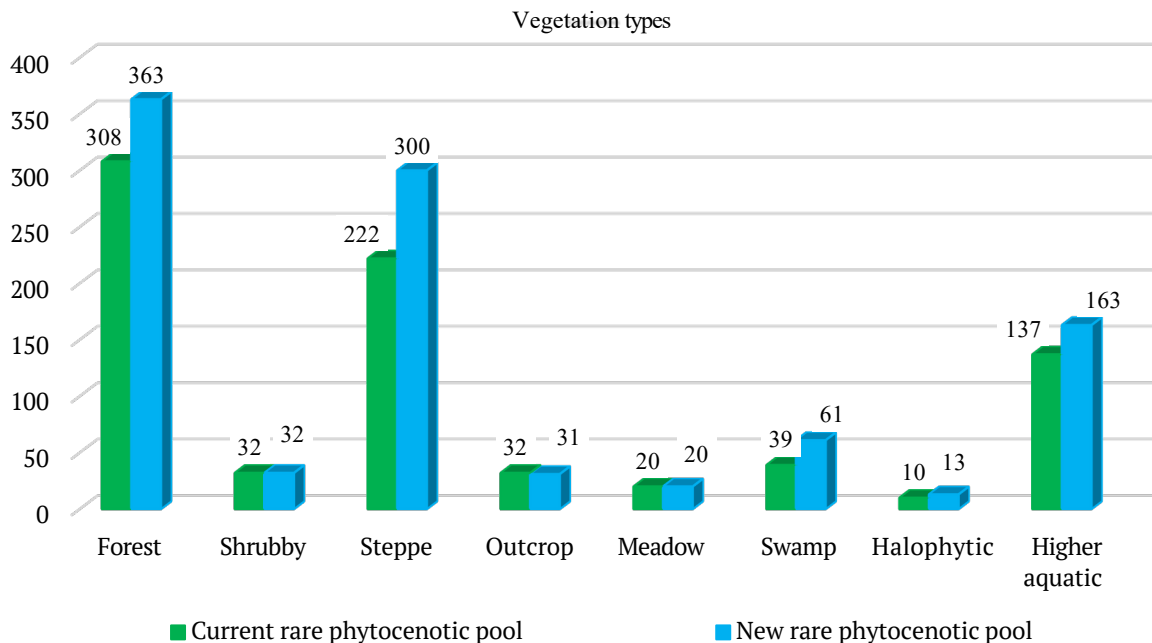


Figure 3. The ratio of the number of rare associations in the current (2009) and planned editions of the “Green Book of Ukraine”

In connection with the above, the authors of this paper believe that the scientific foundation of improving the description scheme of rare phytocenoses of the “Green Book of Ukraine” is one of the methodological foundations of the development of modern synphytosozology in Ukraine. From a practical standpoint, scientific foundations are also necessary to develop the organizational component of plant life conservation in Ukraine.

For more detailed information about the status of a rare syntaxon in relation to its scientific and phytosozological value, the new edition of the “Green Book of Ukraine” suggests describing it according to the following indicators:

- ✓ binominal scientific name of the dominant plant association;
- ✓ ecological and floristic classification syntaxa corresponding to the dominant association;
- ✓ synphytosozological category, index, and grouping status; phytocenotic range and state of distribution in Ukraine;
- ✓ eco-conditions;
- ✓ biotope;
- ✓ scientific botanical value;
- ✓ motives of protection;
- ✓ general phytocenotic characteristics; renewable potential;

- ✓ representation in the nature reserve fund, position in the eco-network system;
- ✓ factors of negative influence;
- ✓ biotechnical and sociotechnical recommendations;
- ✓ main sources of information;
- ✓ distribution map of the rare group.

In the future, it is worth moving on to evaluating indicators only for environmental content.

In the new “Green Book of Ukraine” all types of vegetation organization will be presented according to a single scheme based on the classification of vegetation according to the dominant principle. As noted above, the factual material obtained based on descriptions of rare phytocenoses revealed considerable heterogeneity of associations of different types of vegetation. Therefore, the structure of the new edition of the “Green Book of Ukraine” justifies the need to adopt a morphological and physiognomic principle, according to which the predominance of life forms and the resulting physiognomy of a rare phytocenosis are taken into account. This edition will also encourage further steps in the development of syntaxonomic vegetation protection, namely:

- 1) identification of new localities of rare plant communities;

2) creation of new nature reserves in places of newly discovered localities of rare phytocenoses;

3) organization of a system of phytocenological monitoring of the state of rare phytocenoses and conducting necessary scientific research: the current state of groupings, ecotope conditions, mapping with geographical coordinates, forecasting natural and anthropic transformation, etc.;

4) development of a system of practical measures to introduce differentiated regimes for the conservation, reproduction, and eco-balanced use of rare plant communities;

5) conducting appropriate environmental and educational work and informing the public, state authorities, and local self-government about the state of rare phytocenoses.

For the national level, it is worth noting another important aspect of the issue – the beginning of the so-called monographic typological “green lists” in Ukraine. In this context, in 2002, the first monograph “The Green Book of Ukraine. Forests” was released (Sheliah-Sosonko, Ustymenko, Popovych, Vakarenko, 2002). In this genre of publications, it is advisable to present security syntaxa in more detail at the level of individual vegetation types. Therefore, due to the intensive degradation of the steppe biome, first of all, it is necessary to prepare scientific editions “Green List of the Steppe of Ukraine”, and in the future for other types of vegetation as well, primarily hydrophilic ones.

Regional level.

An essential element of the syntaxonomic protection of vegetation is also the creation of regional (for natural and administrative regions) “green lists” of rare associations based on the principles of creating the “Green Book of Ukraine”, which should be the only legal document in the country. First of all, for certain natural regions of Western Ukraine, S.M. Stoyko and his colleagues (Stoyko, Milkina, Yaschenko et al., 1998) developed and published the “Regional Green Book” for the first time, which lists rare phytocenotic pool for the Ukrainian Carpathians, Western Polissia and the broad-leaved forest zone of Ukraine. For the administrative regions of Ukraine, this process is still at the initial stage of formation, since now, such lists are compiled only for some administrative regions (Zakarpattia, Kyiv, Kirovohrad, Odessa, Poltava, Kharkiv). Undoubtedly, these lists require critical analysis. It is also important that leading experts in this field are involved in their compilation.

Developing this area of research, the authors of this paper most fully determined the modern quantitative and qualitative composition of the rare phytocenotic pool for the Ukrainian Polissia, the Ukrainian Carpathians, the Podil part of the forest zone, the Forest Steppe, the Steppe, and the Mountain Crimea (Fig. 4).

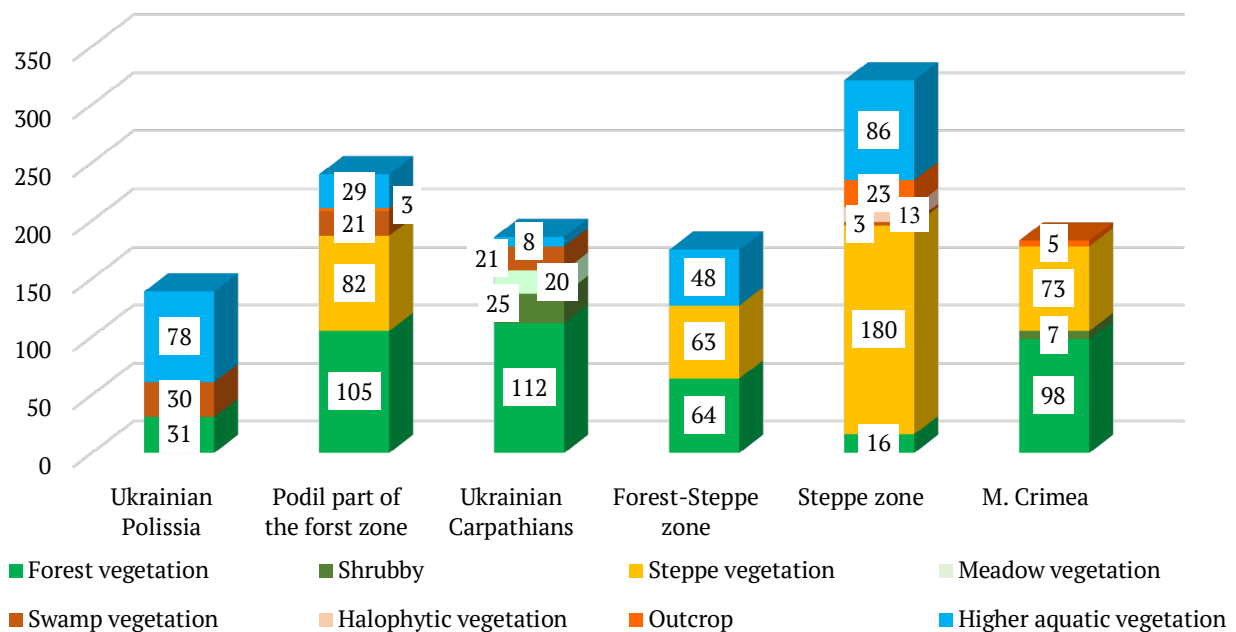


Figure 4. Number of rare associations in natural regions of Ukraine

Of these natural and geographical regions, the steppe zone (321 associations) is syntaxonomically the richest rare phytocenotic pool, and it is the least numerous in the Ukrainian Polissia (139 associations). For other regions, these indicators are approximately equal, they range from 175 (Forest-Steppe) to 240 associations in the Podil part of the forest zone. Rare phytocenotic pools of the Steppe zone, the Ukrainian Carpathians and the Podil part of the forest zone are more diverse. They cover rare associations of five types of vegetation, for the Mountain Crimea it is formed by associations of four types of vegetation, and for the Ukrainian Polissia and Forest-Steppe it is represented by associations of three types of vegetation. Such proportions of indicators generally correspond to the phytocenotic richness and diversity of vegetation in the regions, the degree of its preservation, and the volume of use of natural resources. Among the vegetation types, only rare forest associations are represented in all natural regions, the richness of which ranges from 16 associations in the steppe zone to 112 associations in the Ukrainian Carpathians. In four natural regions, there are rare associations of Steppe, swamp, and higher aquatic vegetation. Rare meadow vegetation is found only in the Ukrainian Carpathians.

In general, among the natural regions of Ukraine, the phytocenotic pool of mountain ecosystems – the mountainous Crimea and the Ukrainian Carpathians, as well as the Podil part of the forest zone – is characterized by the richness and diversity of rare associations. This fact is explained by the considerable diversity of ecotopes of these regions (areas of slopes of different steepness and exposure, different heights above sea level, different hydrothermal regimes), the significant breadth of ecological and phytocenotic amplitudes of edifiers, which

determines the syntaxonomical richness of phytocenoses formed by them, the participation in the creation of phytocenoses of a significant number of sozophytes and species of considerable botanical and geographical importance, the originality of the phytocenotic pool.

Local level.

It is also expedient for the development of science and nature conservation practice to draft “green lists” for certain important botanical areas, especially nature-reserve territories of higher ranks – biosphere and nature reserves, national natural and regional landscape parks, certified forestry enterprises, etc. For this level, it is also worth noting this aspect of the problem. In times of global eco-challenges, it is also important for a phytocenologist to record the beginning of the formation of evolutionary-anthropically new phytocenotic systems, especially aggregations of autochthonous and exotic plants with a high phytocenotypical involvement.

Conclusions

The principal area of protection of rare phytocenoses should be the prevention of negative anthropogenic influence and their protection from destructive natural phenomena. Ecological justification of sozotechnical measures for such groups to stabilize negative changes in the phytocenotic diversity of vegetation cover in wider landscapes should be based on the principles of applying a system of preventive and direct protection methods depending on homeostasis and their geosozological category, as well as a differentiated approach to the introduction of various types of conservation regimes for rare phytocenoses depending on their intended purpose. From an ecological standpoint,

an essential task is to justify conservation regimes in local areas, considering the severity and duration of reservation. The specifics of conservation of rare phytocenoses also depend on the number and area of their localities, the characteristics of edaphotopes, dynamic trends in groupings, and the degree of threat of their extinction.

Generally, the idea of preserving a rare phytocenotic pool is especially relevant for Ukraine, whose vegetation cover has undergone substantial quantitative and qualitative transformations, which

has led to the depletion of the phytocenotic pool and the deterioration of the phytocenogenesis. Therefore, a relevant and urgent environmental issue still is the study of the current state of the country's rare phytocenotic pool, an adequate action of which is the maintenance of the "Green Book of Ukraine" and other "green lists". Next is the development and legislative approval of fees for the illegal destruction or destruction of legitimate rare phytocenoses. Each rare plant group also needs a synphytosozological passport.

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«Зелена Книга»: рівні функціонування, синтаксономія, структуризація

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Анотація. Дослідження фітоценотичної різноманітності у світлі сучасних наукових концепцій її збереження нині є новим і певною мірою холістичним світоглядом щодо цієї глобальної для людства проблеми. Відповідно до панфітоценоцентричної концепції її вирішення має здійснюватися на локальному, регіональному, національному і міжнародному рівнях. Охорона фітоценотичної різноманітності в Україні стала невід’ємною частиною концепції екозбалансованого розвитку, національних програм збереження біорізноманітності як обов’язкового елементу державної природоохоронної політики. Тому актуальним є збереження фітоценотичної різноманітності як сукупності фітоценотичних таксонів, які відображають усі рівні організації фітоценосистем та які утворилися у процесі філоценогенезу в різноманітних екоумовах. Метою публікації є комплексний рівневий аналіз сучасного складу раритетного фітоценофонду України, встановлення нового переліку раритетних синтаксонів, опрацювання новітньої структури другого офіційного видання «Зеленої книги України» та окреслення завдань на майбутнє. У цьому контексті проведено критичний аналіз синтаксономічного складу нинішнього раритетного фітоценофонду України, виявлено методичні порушення їхнього виділення, запропоновано структуру опису раритетних синтаксонів. Автори визначили 983 асоціації 104 формацій, які будуть взяті за основу другого офіційного видання «Зеленої книги України». Важливим елементом синтаксономічної охорони рослинності є також створення регіональних (обласних) переліків раритетних асоціацій за принципами створення «Зеленої книги України». Уперше визначено сучасний раритетний фітоценофонд для основних природних регіонів: Українського Полісся, Українських Карпат, подільської частини лісової зони, Лісостепу України, Степу України, Гірського Криму

Ключові слова: рослинність, раритетна асоціація, раритетний фітоценофонд, «Зелена книга України», регіональні зелені списки

УКРАЇНСЬКИЙ ЖУРНАЛ ЛІСІВНИЦТВА ТА ДЕРЕВИНОЗНАВСТВА

Науковий журнал

Том 12, № 1. 2021

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 англomовних текстів:

С. Воровський, К. Касьянов

Комп'ютерна верстка:

О. Глінченко

Підписано до друку 23 листопада 2022 р. Формат 60*84/8

Умов. друк. арк. 10,4

Наклад 50 прим.

Адреса видавництва:

Національний університет біоресурсів і природокористування України

вул. Героїв Оборони, 10, м. Київ, Україна, 03041

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www: <https://forestsscience.com.ua/uk>

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Scientific journal

Volume 12, No. 1. 2021

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 10.4

Circulation 50 copies

Editors office address:

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03041, 15 Heroiv Oborony, Kyiv, Ukraine

E-mail: info@forestscience.com.ua

www: <https://forestscience.com.ua/en>