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Modelling the Qualitative Structure of Scots Pine Trunks Using a Random Process

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Abstract. The study highlights a method for predicting the volume of qualitative categories of trunk wood for timber trunks of Scots pine, using a model of distribution of various qualitative zones along the trunk. The study is based on empirical material collected in the main-use cutting area, where the length of various qualitative wood zones from the butt to the top was determined for 245 model trees. The paper uses a semi-Markov probabilistic model to generalise the order of appearance and length of zones of timber wood, firewood, and waste, which was determined by three parameters: 1) input probabilities of the appearance of the corresponding qualitative zone in the butt part of the trunk (initial state); 2) matrix of distribution of zone lengths; 3) matrix of probabilities of changes in qualitative zones at different heights of the trunk. According to research data, it is generally accepted that pine trunks begin with timber wood. The beta distribution function is used to model the length of qualitative trunk zones, the parameters of which are selected depending on the relative height of the beginning of the corresponding trunk zone. The probabilities of changes in qualitative zones are calculated based on empirical data. The study identified that the distribution of timber and firewood lengths depends on the absolute height of the trunk location and the height of the trunk. For a mathematical generalisation of this process, the paper defines four zones within which the distribution of the length of the timber part of the trunk can be described by a single function. The probabilities of changes in qualitative zones are modelled depending on the relative height of trunks. On this basis, the method of simulation modelling of initial data sets has been developed, which can be used to develop tables of dimensional and qualitative wood structure for trunks of different diameters, heights, and categories of technical suitability. The study applies only to timber pine trunks, so other patterns are probable for trunks of other tree species, semi-timber, and firewood trunks. The developed methodology is appropriate to use when updating the tables of trunk volume distribution by variable-quality categories, which now need to be updated by introducing new requirements for the classification of timber wood in Ukraine

Keywords: timber tree, distribution function, semi-Markov probability model, tables of dimensional and qualitative structure

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Introduction

The transition of the Ukrainian forest industry to European standards for the classification of round timber by size and quality has led to the need to update the regulatory framework used in production when accounting for the trunk stock of wood. During 2019-2020, the first stage of development of standards was conducted, which provided for modelling the yield of round timber by thickness classes for ten main tree species: pine, spruce, fir, oak, beech, ash, hornbeam, birch, alder, aspen (Bilous et al., 2020). Notably, the proposed standards allow performing a preliminary assessment of the maximum possible yield of timber wood and its dimensional structure. This is due to the use of research material available at the Department of Forest Mensuration and Forest Management of the National University of Life and Environmental Sciences of Ukraine (about 20 thousand model trees), which was collected over the past two decades according to already abolished interstate standards. Therefore, to improve these standards, it is necessary to attract new empirical data. Evidently, getting a sufficient number of model trees will require substantial financial costs, and most importantly – time.

Most of the standards in Ukraine are developed by equalising empirical data using regression analysis methods. It is necessary to have a substantial amount of research material – from 400 to 600 model trees for each tree species to obtain such models with a sufficient level of adequacy and accuracy (Nikitin & Shvidenko, 1972). Because of this, there is a need for a deeper study of the relationship of random variables that affect the formation of the dimensional-qualitative structure of the volume of a tree trunk. In particular, the application of random process theory and simulation modelling allows obtaining a sufficient number of implementations of the simulated process to ensure the established accuracy and level of confidence probability.

In Ukraine, to display the dimensional and qualitative structure of trunks, the random process was first used in 1983 when performing a study on optimising the structure of logging in the conditions of the Ukrainian Carpathians (Developing Scientific Background, 1983). The idea of application belongs to Ya.A. Yudytsky,

who published a methodological basis for the possibility of applying random functions in solving sorting problems in 1985 (Yudytsky, 1985). This method was further developed in the papers of A.V. Poliakov, in particular, in the scientific finding “Adaptive industrial sorting of the cutting fund” (Poliakov & Poliakov, 1999, 2008, 2009). This was used to compile some standards (Kashpor & Strochynskyi, 2013) and update them in 2020 according to new European standards (Bilous et al., 2020). These studies are based on a stochastic model of the distribution of qualitative zones along the trunk, developed based on the theory of Markov processes for the assumption that the length of zones (i.e., the time when the system is in a certain state) is distributed according to the exponential law (Koroliuk & Turbin, 1976). As a result, it is established that the quality class of the next trunk zone, as an analogue of the next state of the Markov system, depends only on the quality class of the current zone (the current state of the system) and does not depend on its earlier states.

Modelling the probabilistic distribution of the appearance of the corresponding qualitative zone along the trunk is a difficult task even from the standpoint of the possibility of using statistical methods. The distribution of response values, i.e. the volume of wood of the corresponding quality class in the trunk stock, is usually far from normal. Because of this, based on trunk matching models (Adamec et al., 2019) and timber wood volume models (Fonweban et al., 2012) it is possible to successfully predict its volume in a separate trunk, but this approach does not work at the level of forest stands.

The problem posed requires a more complex methodological solution that would allow considering the probability of the appearance of a particular quality zone on the trunk, and then – the distribution of volume by quality classes. According to this, Fortin et al. (2009), considering each qualitative zone of the trunk as a binary characteristic (the presence of which on the trunk can be characterised by a value of 1, and the absence – 0), at the first stage, linear logistic regression was used to model the probability of occurrence of these zones depending on the biometric indicators of the tree trunk. Only

then a model of wood volume distribution of the corresponding quality class for birch and maple tree trunks in the province of Quebec in Canada were considered. Notably, the models were developed separately for four quality categories (categories of technical suitability) of trunks.

A similar approach, based on binary logistic regression to predict the probability of the appearance of qualitative zones on the trunk, was later used by specialists of the US Forest Service (Banzhaf et al., 2016). According to the researchers, a sufficient level of accuracy of such models should be expected only for general indicators aggregated at the level of stands. In some cases, modelling of the qualitative structure of the trunk volume was considered from the standpoint of the theory of statistical classification of trunk zones by quality. For example, Schneider et al. (2008) combined polynomial logistic regression to predict the number of finite wood quality classes and binomial logistic models to determine the probability of occurrence of each of them for trunks.

In general, the scientific literature in the context of the presented study is quite limited. Despite the availability of separate publications on predicting the qualitative characteristics of stem wood, the possibility of simultaneous modelling of dimensional and qualitative indicators was almost not considered. Based on this, it is necessary to recognise the importance of scientific ideas proposed earlier by Ya.A. Yudytsky

and O.V. Poliakov (Poliakov & Poliakov, 1999, 2008, 2008; Yudytsky, 1985).

The purpose of the study is to substantiate based on research material a model of the random process of the length of trunk zones by quality, namely timber wood, firewood, and waste. Determine the possibility of the practical application of the obtained process model in the development of standards.

Materials and Methods

Research material.

The study used research material collected in the SE “Horodnyansky lishosp” of the Chernihiv region. On the laid test area, 245 timber model scots pine trees were cut down, for which the height of the stump was determined, the quality zones were evaluated on the trunks, and their length was measured. A total of 821 timber zones and 307 firewood zones were allocated for model trees. The minimum length of timber was assumed to be 1.0 m, while for firewood segments – 0.5 m. After that, the employees of the company bucked the trunks for timber according to the current specifications and accepted the harvested forest products. A total of 266.7 m³ logging products is taken from the coup, including 248.5 m³ timber wood and 18.2 m³ firewood.

The general characteristics of the research material are presented in Table 1, where the height of the trees is given including the height of the stump.

Table 1. Statistical characteristics of model trees

Statistics	Diameter at a height of 1.3 m, cm	Height, m	Length of timber wood	
			m	share of height, %
Average value	36.1	27.1	19.5	71.6
Minimum value	20	18.7	7.1	27.7
Maximum value	53	37.4	27.1	88.6
Standard deviation, (σ)	7.0	2.6	12.4	1.0
Coefficient of variation (v), %	19.4	9.6	63.6	1.4

When analysing statistics, it is necessary to pay attention to a fairly wide range of variability in mensuration indicators of empirical data. This is indicated by the coefficients of variation of the diameter (19.4%) and the length of timber wood in absolute terms (63.6%). Instead, the relative values of the length of a timber tree are quite tightly grouped around the average (71.6%), with a standard deviation of only 1%.

Modelling the distribution of qualitative trunk zones.

The random process model determines the order of appearance and length of trunk sections of a certain quality from the butt to the top. In general, a quality class can have seven discrete values: *A, B, C, D* – for timber wood; *E* – for firewood areas that are limited on both sides by timber areas; *F* – for firewood, the zone of which begins after the last timber zone; *G* – waste (top of the trunk with a diameter at the lower end <2 cm). Notably, firewood zones of the *E* class were identified in a small number of model trees (out of 307 firewood zones, only 64 are classified as *E*), they had an average length of 1.2 m. Assuming that the effect of such segments on the total volume distribution is insubstantial, they were not considered in the simulation.

In accordance with the purpose of the study, the task can be simplified so that only one class of timber wood quality is considered – $T \in \{A, B, C, D\}$ and firewood – *F*. Since there are no transitions from the latter to the timber one, it can be assumed that *F* – is the absorbing (irrevocable) state of the system. In addition, placing a transition point from the zone on trunk *F* to zone *G* is not probabilistic in nature and depends only on the coincidence of a particular trunk. Given this, the qualitative structure of the trunk can be described as a random process where the quality class of the zone (may matter *T* and *F*) is the state of the process, and the length of the zone is the time it stays in this state. That is, the process states change discretely, and the time continuously – from the minimum (for timber wood – 1.0 m, for firewood – 0.5 m) to a certain maximum value.

Depending on the law of distribution of time being in a certain state, processes with discrete states and continuous time can be considered as Markov or semi-Markov processes. Semi-Markov

processes are a direct generalisation of Markov chains and processes and can be structurally defined in several ways (Koroliuk & Turbin, 1976).

In this paper, a semi-Markov model was chosen, which is defined by: 1) the initial distribution of input probabilities; 2) the matrix of functions of the distribution of random residence time in the state *i* provided that the transition takes place in the state *j*; 3) the transition probability matrix of the Markov chain. This approach allows assuming that the distribution functions of random residence time in the state *i* do not depend on the following state *j*, which the system will shift to. In this case, the distribution functions are not related to the transition probability matrix and can only depend on time and/or other indicators of the system. In addition, it is also possible to consider changing states *ii* by taking them into account in the transition matrix. In other words, the length of a zone does not depend on the quality of the next zone, and transitions can be made to the same quality class (from *T* to *T*).

With this design of the process, its evolution can be described as follows: starting from a certain state *i*, which is defined by a vector *p* in the initial distribution, the system spends time in this state ζ_i with distribution function $G_i(x)$; after the ζ_i time has elapsed, the state changes to *j* with a probability of p_{ij} , which is defined by the transition matrix *P*; once in the state *j*, the system spends in this state ζ_j time, etc., until the process goes into an absorbing state.

Process modelling methodology:

1. The initial distribution of input probabilities was calculated based on empirical data. In general, it is a vector of relative frequencies of occurrence of a certain quality class at the beginning of the cut trunk (from the stump):

$$p = \{p_i, i \in (1, 2, \dots, n)\}.$$

If quality classes that can acquire 5 attribute values (*A, B, C, D, and E*), provide numeric values, then $n=5$, and a random variable $x_i \in (1, 2, \dots, 5)$. The distribution function of such a discrete series will have the form:

$$F(x) = \sum_{i: x_i < x} p_i, \quad (1)$$

where $F(x)$ – distribution function; x – function argument; x_i – value of a random variable; p_i – probability of occurrence i -th quality class; i – summation indexes for which the inequality is met $x_i < x$.

Accepting the simplification that a timber tree is one class (T), then $n=2$, and a random variable $x_i \in (1, 2)$.

When generating a random process, the stump height (h^{st}) can be adopted as a fixed or mathematical model based on biometric indicators of the trunk. Considering the height of the stump is necessary because the vast majority of mathematical models of the generatrix describe the coincidence of the trunk, starting from the zero mark (from the earth's surface).

2. The law of time distribution (i.e., the lengths of timber zones) between the points of state change was determined based on research material. The absolute heights of the start points of each zone are listed as relative, according to the maximum possible length of the timber tree for a specific trunk height and the minimum length of the timber zone using the formula:

$$\hat{h}_i = \frac{h_i - h^{st}}{\tilde{h}_{max}^{zone} - h^{st} - \tilde{l}_{min}^{zone}}, \quad (2)$$

where \hat{h}_i – relative height of the beginning of the zone; h_i – factual height of the beginning of the zone, m; \tilde{h}_{max}^{zone} – mathematical model of the maximum height of the end of a timber tree, m; h^{st} – factual stump height, m; \tilde{l}_{min}^{zone} – minimum length of the timber area, m.

The choice of such a reference is due to the fact that the beginnings of timber zones are located on the trunk in the height range $h_i \in [h^{st}; \tilde{h}_{max}^{zone} - \tilde{l}_{min}^{zone}]$, i.e. above the point $\tilde{h}_{max}^{zone} - \tilde{l}_{min}^{zone}$ the process with probability 1 will move to the zone F of the firewood and will remain there until the transition to the state G.

The maximum height of the end of the timber part of pine trunks was determined based on a linear empirical model:

$$\tilde{h}_{max}^{zone} = a_0 + a_1 \cdot h, \quad (3)$$

where \tilde{h}_{max}^{zone} – maximum height of the end of the timber part, m; h – trunk height, m; a_0, a_1 – equation parameters.

It is necessary to present the values of zone lengths also in relative units to obtain experimental data in a comparable form. They were recalculated using the formula;

$$\hat{l}^{zone} = \frac{l^{zone} - \tilde{l}_{min}^{zone}}{\tilde{l}_{max}^{zone} - \tilde{l}_{min}^{zone}}, \quad (4)$$

where \hat{l}^{zone} – relative length of the zone; l^{zone} – actual zone length, m; \tilde{l}_{min}^{zone} – minimum zone length, m; \tilde{l}_{max}^{zone} – maximum zone length, m.

The numerator of this formula shows the random component of the length, and the denominator shows the range of values, that is, the difference between the possible maximum and minimum length.

The maximum length of the zone is limited to the maximum possible height of the end of the timber wood, so it was calculated using the equation:

$$\tilde{l}_{max}^{zone} = \tilde{h}_{max}^{zone} - h_i, \quad (5)$$

where \tilde{l}_{max}^{zone} – maximum zone length, m; \tilde{h}_{max}^{zone} – mathematical model of the maximum end height of timber wood (3), m; h_i – factual height of the beginning of the zone, m.

Modelling of the length distribution of qualitative zones was performed according to the given relative indicators using the beta distribution function, which describes continuous random variables that have a domain of definition in the interval [0-1]:

$$f(x) = \frac{1}{B(\alpha, \beta)} x^{\alpha-1} (1-x)^{\beta-1}, \quad (6)$$

where $B(\alpha, \beta)$ – beta function; x – independent variable, m; α, β – parameters.

The parameters of the distribution function were identified using the "Solution search" package in MS Excel. The optimisation criterion is the minimum sum of the squares of the differences between the empirical data and the model response. Next parameters α and β were aligned with the relative height using an equation of the form:

$$y = a_0 \cdot \exp(a_1 \cdot \hat{h}_i) + a_2, \quad (7)$$

where y – corresponding parameter of equation (6); a_0, a_1, a_2 – parameters; \tilde{h}_i – relative height.

The length of the firewood area (F) can be identified for a specific implementation of a random process as the difference between the height of its end (i.e., the transition to the waste zone G) and the height of the end of the timber part:

$$\tilde{l}^{fw} = \tilde{h}^{fw} - \tilde{h}^{zone}, \quad (8)$$

where \tilde{l}^{fw} – length of the firewood zone, m; \tilde{h}^{fw} – height of the end of the firewood zone, m; \tilde{h}^{zone} – end height of timber wood, m.

Height \tilde{h}^{fw} is calculated by the generative equation, which is covered in [10], for the condition that $f(h^{tr})=2$ cm (minimum diameter of the firewood in the upper section). The height of the end of a timber tree can be identified by the formula:

$$\tilde{h}^{zone} = \tilde{h}^{st} + \sum_1^i \tilde{l}_i^{zone}; \quad (9)$$

where \tilde{h}^{zone} – end height of the timber part, m; \tilde{h}^{st} – stump height, m; i – number of generated timber segments, pcs.; \tilde{l}_i^{zone} – length of the i -th timber segment.

3. Transient probabilities. As mentioned earlier, the zone quality class can have two values: – T and F . Hence, the transition probability matrix will take the form:

$$P = \begin{Bmatrix} p_{TT} & p_{TF} \\ p_{FT} & p_{FF} \end{Bmatrix}, \quad (10)$$

where p_{ij} – probability of transition from the state i to the state j .

Accepting that p_{TF} – is the value of some function $F(x)$, then $p_{TT}=1-F(x)$, since events TT and TF are incompatible and make up a complete group. In addition, the function $F(x)$ is non-decreasing, because moving up the trunk, the probability of switching to firewood wood increases. If F – is an absorbing state, then $p_{FT}=0$, and $p_{FF}=1$, i.e. transitions FT do not happen in the system. Hence, to determine the elements of the first row of the matrix, it is necessary to find $F(x)$. The beta distribution function (6) was also used for this purpose.

Implementation of a random process.

It is assumed that trunk diameter ($d_{1,3}$) and its height (h) an uniform distribution within the degree of thickness (gradation of 4.0 cm) and the height category is accepted, respectively:

$$d_{1,3} \in [d^{st}-2,0; d^{st}+1,9]; \quad (11)$$

$$h \in [h_{min}^p; h_{max}^p], \quad (12)$$

where d^{st} – average diameter of the degree of thickness, cm; h_{min}^p, h_{max}^p – minimum and maximum heights, respectively.

The algorithm for generating a qualitative structure of pine trunks using a random process can be presented in Table 2. The algorithm is implemented by the simulation method using inverse random variable distribution functions, where for each step (except for the third and last two), a uniformly distributed random number is generated as an argument to these functions.

Table 2. Algorithm for generating a high-quality trunk structure

Nº	Indicator	Source	Link
1	$d_{1,3}$	thickness limits	(11)
2	h	height discharge limits	(12)
3	\tilde{h}^{st}	average value or mathematical model	–
4	zone quality class	input probabilities	(1)
5	timber area length	distribution function	(2–7)

Table 2, Continued

Nº	Indicator	Source	Link
6	zone quality class	transient probabilities	(2, 6, 10)
7	timber area length	distribution function	(2-7)
...
$n-1$	length of the firewood area	generating function	[10], (8, 9)
n	waste	remainder to the top	-

Results and Discussion

In the study, it is accepted that the trunk starts with timber wood, that is, the initial state of the process is a quality class T . Under such conditions, the function of the initial distribution of input probabilities (1) for the accepted quality classes of zones (E, T) will acquire values: $P_E=0; P_T=1$, because the appearance of an E zone on the trunk wasn't considered. The height of the stump in

the experimental material lies in a rather narrow range of 0.10-0.15 m, so for modelling a random process, its average value is taken ($\tilde{h}^{st}=0,133$ m).

Fig. 1 shows the dependence of the absolute heights of the endpoints of the timber part of model trees on the trunk height, and a graph of their maximum values according to the mathematical model (3) and the identified parameters: $a_0=-2,896; a_1=0,9851$.

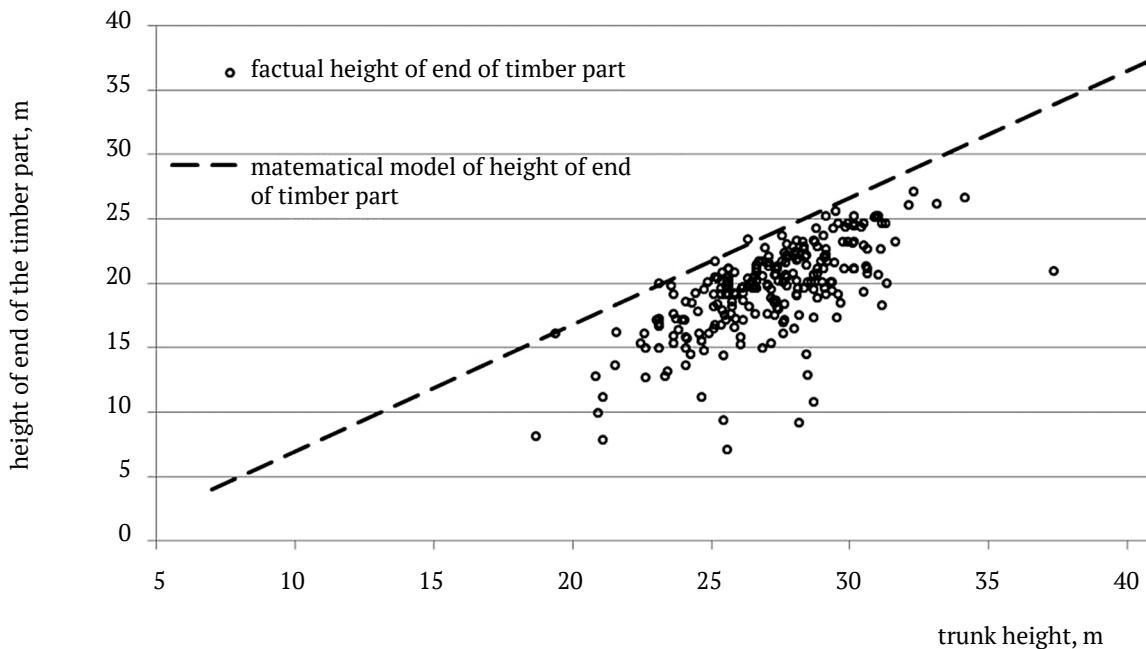


Figure 1. Dependence of the height of the end of the timber part of the trunk on its height

Applying equation (2-5) and considering that the minimum length of the timber zone does not depend on the mensuration indicators of the trunk

and is equal to $\tilde{l}_{min}^{zone}=1$, an array of experimental data on the dependence of the relative length of the zone on the relative height of its beginning is obtained

(Fig. 2). Analysing this graph, it can be assumed that the distribution of the relative length of the zone at an arbitrary relative height depends only on this height and does not depend on the height of the trunk.

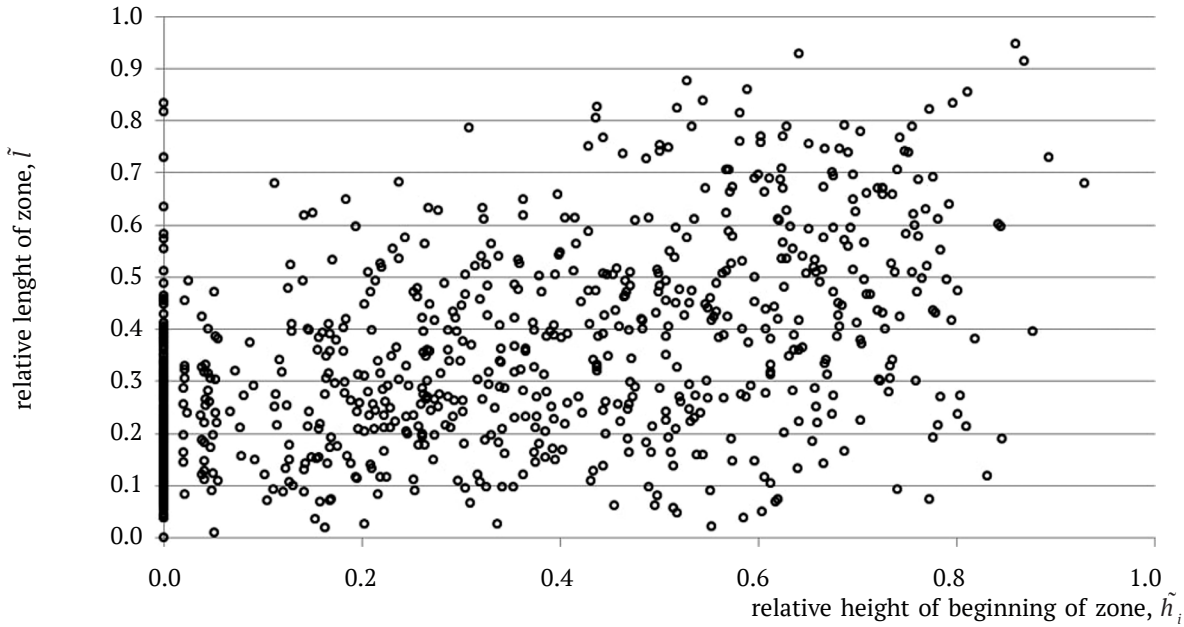


Figure 2. Dependence of the relative lengths of timber wood zones on the relative height of their beginning

Arrays of empirical data were analysed to confirm this assumption for different groups of trunk heights by *F*- Fischer's criterion and Student's *t*-test. This analysis confirmed the hypothesis that the groups belong to the same general population (at the level of substantiality $\alpha=0.05$).

In the future, the relative frequencies of occurrence of zone lengths for gaps in the relative height of the trunk are calculated: [0-0,1], [0,1-0,4], [0,4-0,7] and [0,7-1,0]. Graphs of empirical distribution functions for these intervals are shown in Fig. 3.

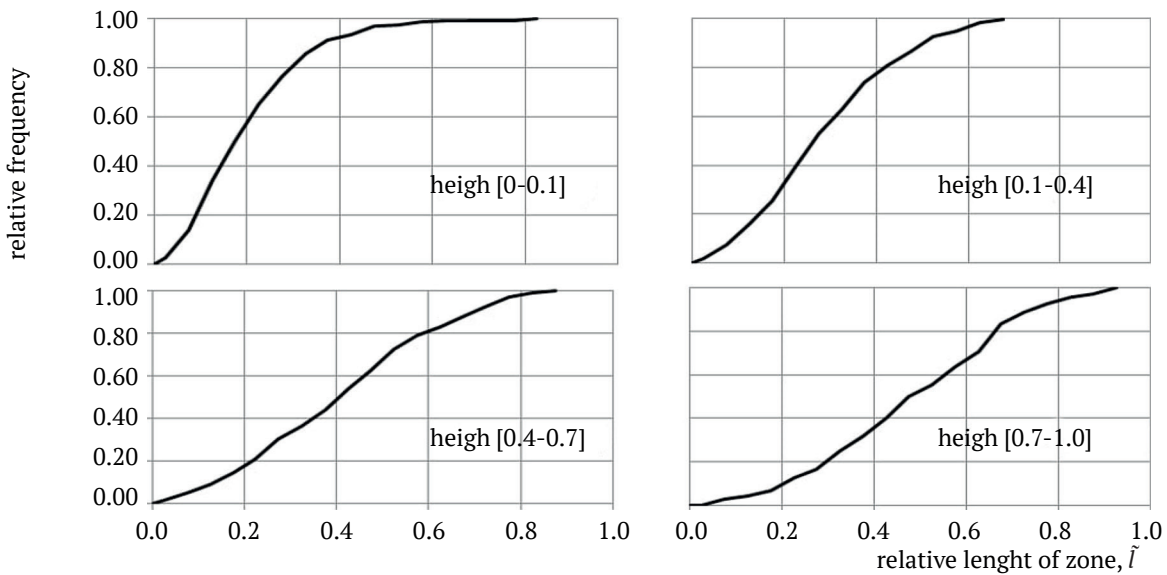


Figure 3. Empirical functions of distribution of relative lengths of timber wood zones at different relative heights of their beginning

From the above graphs, it can be seen that the distributions may differ from the exponential one, with an uncharacteristic form for the latter at the bottom and a bounded domain of definition.

Therefore, a random process can be classified as semi-Markov. Calculated parameters α and β of the equation (6) for those shown in Fig. 3 empirical distributions are shown in Table 3.

Table 3. Algorithm for generating a high-quality trunk structure

Parameter	Relative trunk height intervals			
	[0.0-0.]	[0.1-0.4]	[0.4-0.7]	[0.7-1.0]
α	1.946	2.156	1.997	2.467
β	7.979	5.388	2.874	2.636

The series of parameters that are shown in Table 3 were aligned using the equation (7). Graphs of their simulated values are shown in Figure 4, and the parameters of mathematical models are shown in Table 4.

Therefore, using mathematical models (2-7), at any point on the trunk, a distribution of the absolute length of the zone can be obtained, the parameters of which depend on the absolute height of this point and the height of the trunk (Fig. 5).

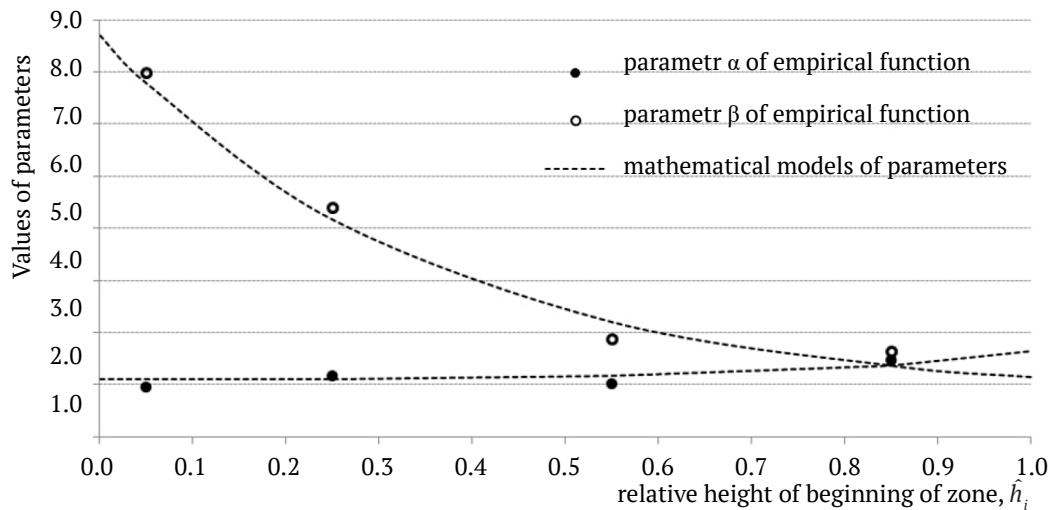


Figure 4. Mathematical models of parameters

Table 4. Parameter values of equation (7)

Parameter of equation (6)	Parameters of equation (7)		
	a_0	a_1	a_2
α	$7.113 \cdot 10^{-5}$	8.395	2.300
β	7.113	-2.846	1.387

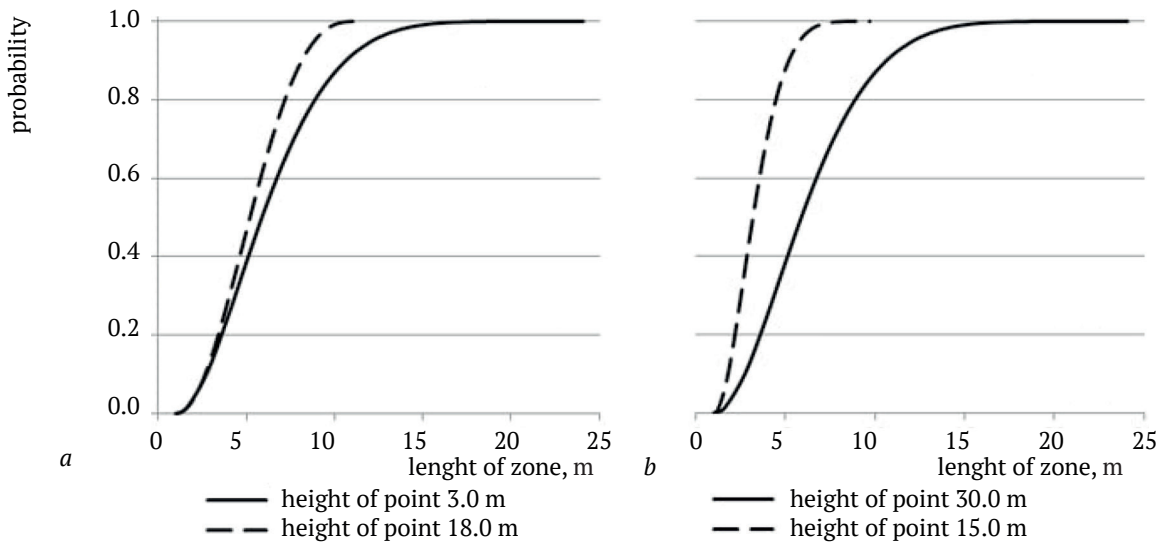


Figure 5. Graphs of simulated timber zone length distribution functions (*a* – for a trunk with a height of 30.0 m; *b* – for a point with a height of 3.0 m)

The end points of the timber wood that are shown in Fig. 1 are the points of transition of the system to the absorbing state. Calculating the

heights of these points in relative units using formula (2), it is possible to get a comparable array of experimental data (Fig. 6).

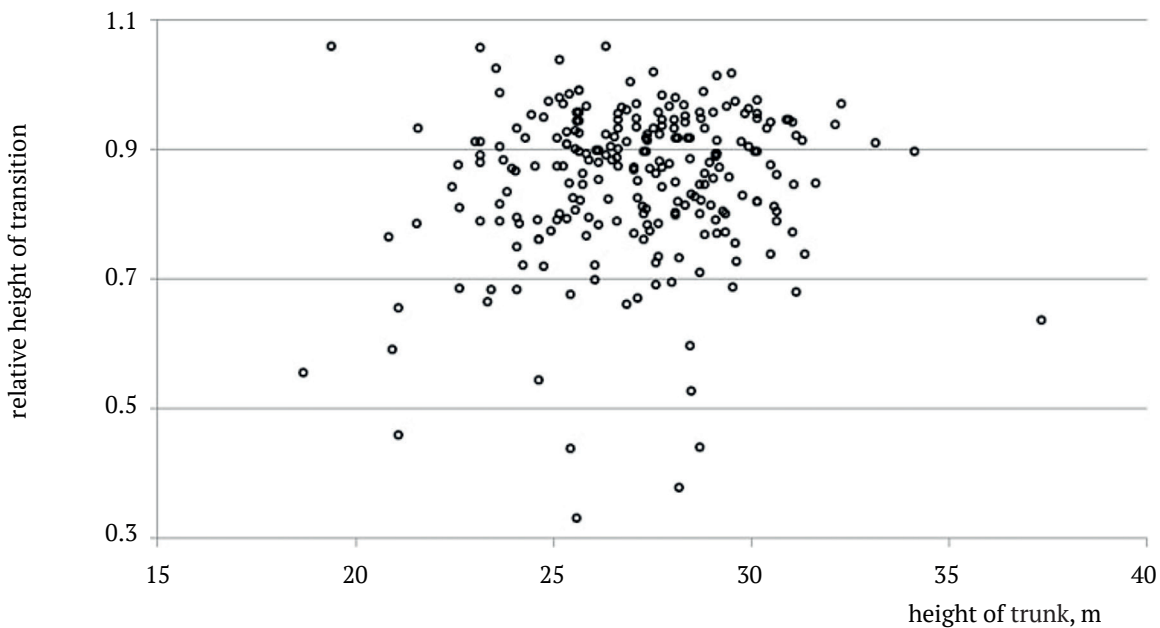


Figure 6. Dependence of the heights of the transition points to the absorbing state on the height of the trunk

As can be seen from Fig. 6, the distribution of transition points is weakly dependent on the height of the trunk. In addition, the analysed

arrays of empirical data for different groups of trunk heights by *F*- Fischer’s criterion and Student’s *t*-test confirmed that these groups belong

to the same general population (at the level of substantiality $\alpha=0,05$). In Figure 6 it can be seen that some values of relative heights are greater than one. These are the transition points located on the trunk in the interval $[\tilde{h}_{max}^{zone}-1; \tilde{h}_{max}^{zone}]$. When the next point hits this interval, the process will go into an absorbing state with probability 1, because the minimum length of the zone is T cannot be less than 1 m. Considering this, the transition probability distribution function can be represented as:

$$F(\tilde{h}_i) = \begin{cases} 0, & \tilde{h}_i < 0; \\ \int_0^{\tilde{h}_i} f(\tilde{h}_i) d\tilde{h}, & 0 \leq \tilde{h}_i \leq 1; \\ 1, & \tilde{h}_i > 1; \end{cases} \quad (13)$$

where $F(\hat{h}_i)$ – distribution function; $f(\hat{h}_i)$ – distribution density; \hat{h}_i – relative height.

The trunks of model trees were divided into intervals of 0.05 of the relative height (\hat{h}) to determine the distribution law and its parameters. In the future, the relative accumulated frequencies of occurrence of transition points to the state F are calculated, which fell into these gaps. Analysis of the empirical relative frequency distribution function showed that it is also approximated with sufficient accuracy by the beta distribution function (6) with the parameters: $\alpha=10,75$; $\beta=2,436$. Fig. 7 shows a graph of the distribution function (13) against the background of empirical data.

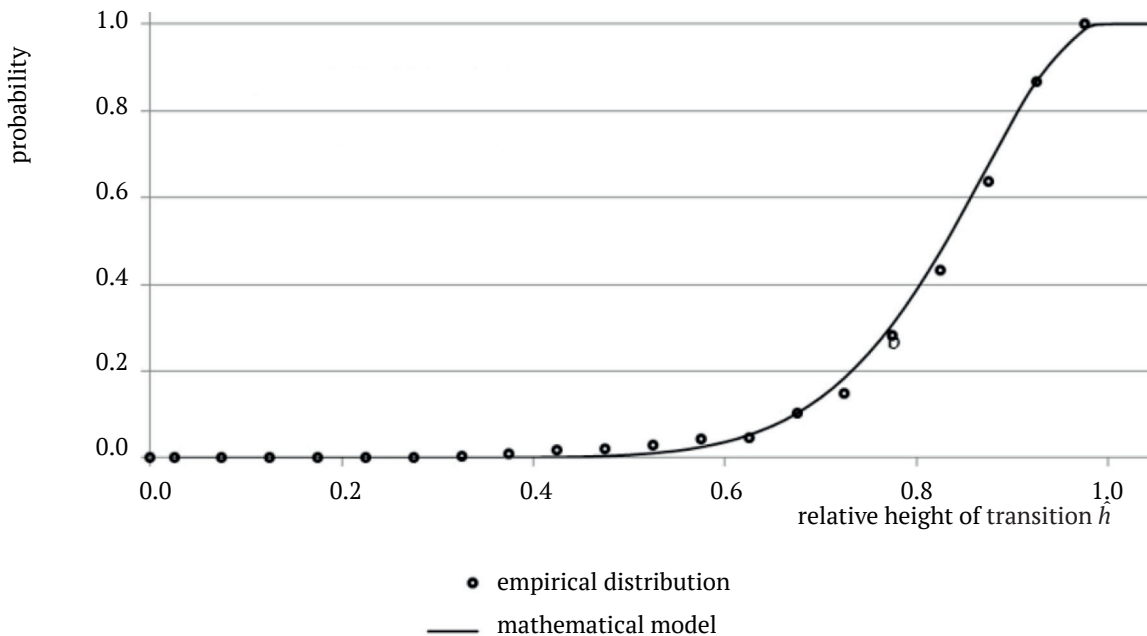


Figure 7. Distribution of relative heights of transition points to the absorbing state

Therefore, for the first row of the matrix (10) for a specific relative height, the transition probabilities can be determined using the equation (13).

The obtained mathematical models of the characteristics of a random process can be estimated using statistical methods. For the length of the zone, an interval estimate of the average is made, which is more reasonable and reliable than the point estimate. If the mathematical expectation of the zone length distribution model lies in the confidence interval of the average value for the

sample, then it is likely that the approximation error will not exceed the value of this interval.

Confidence intervals of the sample mean for probability 0.99 ($\alpha=0.01$) are calculated from the intervals of the relative height of the beginning of zones (Table 3) according to the formula:

$$\bar{x}_b \pm \frac{\sigma_b \cdot 2,58}{\sqrt{n}}, \quad (14)$$

where \bar{x}_b – sample average of the relative length of the zone; σ_b – sample standard deviation; n – number of zones.

The mathematical expectations of the beta distribution of relative zone lengths for each point in the empirical data are calculated by the formula:

$$\bar{x}_m = \frac{\alpha}{\alpha + \beta}, \quad (15)$$

where \bar{x}_m – mathematical expectation of the model; α, β – parameters of equation (6) of the Table 3. The obtained data are shown in Figure 8.

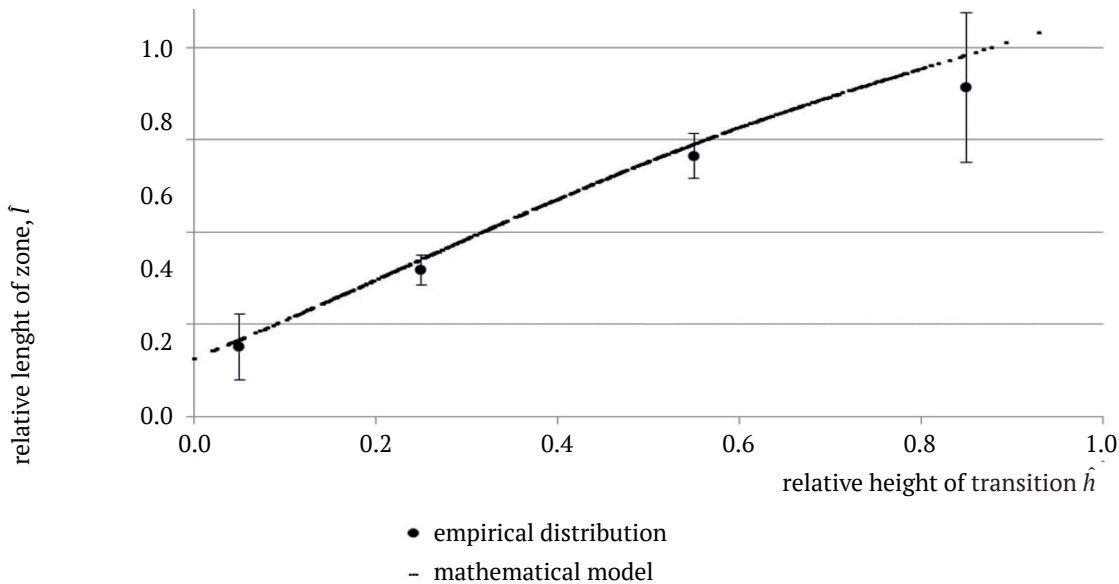


Figure 8. Confidence intervals of the average length of empirical data zones and their mathematical expectation based on the mathematical model

Analysis of the above graph shows that with a probability of 99%, the mathematical expectation of the simulated average length of the zone will be in the confidence interval, which indicates the acceptable accuracy of the mathematical model. In absolute terms, the mathematical expectation of the model is averaged over all points in the model trees (5.76 m) and approaches the empirical average (5.67 m), which also confirms this conclusion.

The accuracy of the mathematical model of the transition probability distribution (13) was acceptable both for the standard error of the simulation ($s_m=0.0184$) and the coefficient of determination ($R^2=0.996$).

Analysing the structure of the described random process, two main factors that substantially affect the final result of generating a qualitative trunk structure are distinguished.

First, it is the maximum length of timber wood. This indicator determines the scope of distribution of timber zone lengths and their possi-

ble maximum length, and the distribution of the height of the transition of timber zones to firewood ones. In practice, the height of the end of the timber part of the trunk is the basis for dividing trees into categories of technical suitability. Therefore, after modelling this indicator for semi-timber and firewood trunks, other characteristics of the random process can be easily identified.

The second factor is the form (or law) of the distribution of timber zone lengths. It is possible that for other tree species, approximating distributions will require applying different random functions than for pine, which indicates the need for further research.

The positive side of a random process is the property of creating implementations based on it that are not present in the sample but can exist with a certain probability in the general population. Evidently, if there are two identical trunks in the empirical material, in which a zone with a length of 3.0 m

and 4.0 m, respectively, begins at a certain height, then it can be argued that there are trunks in nature with a zone length of 3.1, 3.2 ... 3.9 m. Therefore, the formation of a simulation sample based on a random process considers such options, and therefore more fully reflects the object of research.

The methodology developed in this paper allows obtaining a pilot sample for further calculation of standards for the size-quality or commodity structure of plantings based on it. Admittedly, the question arises of the size of such a sample. According to previous studies (Poliakov & Poliakov, 1999, 2008, 2009), it was identified that for each "diameter-height" variant, stabilisation of the trunk volume distribution indicators occurs after 150 process generations.

Another issue is finding indicators of the trunk volume distribution based on the resulting process implementations. The most advanced methods for estimating the volume of the trunk are related to its creator, which allows for predicting the diameters from the butt to the top and calculating the median diameter and volume of any segment, knowing the height of its beginning and end. Therefore, obtaining data on the volume distribution of the array of generated trunks requires an adequate mathematical matching model and a conditional bucking algorithm in accordance with production specifications.

In recent studies, the mathematical model of the generatrix in the bark (A. Kozak, 2004), and the model of the ratio of diameters without bark and in the bark, are substantiated for ten main tree species of Ukraine. The parameters of these models were determined and tested in the framework of scientific-technical work (Developing Reference Data, 2020). The conditional bucking algorithm uses these models to determine the diameters of the generated trunk without bark at the transition points of quality zones and "bucking" the trunk so as to obtain the maximum

yield of timber of the highest quality classes. The algorithm allows using real specifications of round timber in the middle diameter without bark and length, therefore bringing the simulation result as close as possible to modern production conditions.

Conclusions

The study describes the methodological prerequisites for using a random process to model the distribution of the length of the timber part of tree trunks as the main characteristic that affects the dimensional and qualitative structure of wood reserves. The proposed approach allows predicting various combinations of biometric indicators of trees and increasing the level of reliability of mathematical models as the basis of volume tables. The results of the study show that the length of segments of the timber and firewood parts of the trunk depends primarily on the relative height of the trunk area where they are observed. For a mathematical generalisation of this process, the paper defines four zones within which the distribution of the length of the timber part of the trunk can be described by a single function. Thus, the developed algorithm allows for examining the regularities of the order of appearance of various qualitative zones of the trunk and using them during simulation modelling of the qualitative structure of tree trunks.

Despite the fact that the completed study concerns exclusively timber trunks, other patterns are possible in the distribution of quality characteristics for the trunks of semi-timber and firewood trees. In general, the results of the study indicate ways to improve the methodology for developing standards for the dimensional and qualitative structure of wood due to the lack of sufficient accumulated empirical data, which becomes especially relevant in the context of the introduction of new standards for wood classification in Ukraine.

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Моделювання якісної структури стовбурів сосни звичайної за допомогою випадкового процесу

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Анотація. У дослідженні висвітлено методика прогнозування об'єму якісних категорій стовбурової деревини для ділових стовбурів сосни звичайної, з використанням моделі розподілу різних якісних зон вздовж по стовбуру. Дослідження базується на емпіричному матеріалі, зібраному на лісосіці рубки головного користування, на якій для 245 модельних дерев визначено протяжність різних якісних зон деревини від окоренка до верхівки. Для узагальнення черговості появи та протяжності зон ділової деревини, дров і відходів у роботі використано напівмарковську ймовірнісну модель, яку визначали три параметри: 1) вхідні ймовірності появи відповідної якісної зони в окоренковій частині стовбура (початковий стан); 2) матриця розподілу довжин зони; 3) матриця ймовірностей зміни якісних зон на різних висотах стовбура. Згідно з дослідними даними, прийнято, що стовбури сосни починаються з ділової деревини. Для моделювання протяжності якісних зон стовбура застосовано функцію бета-розподілу, параметри якої підібрано залежно від відносної висоти початку відповідної зони стовбура. Ймовірності зміни якісних зон обчислено на основі емпіричних даних. У дослідженні виявлено, що розподіл довжин ділової та дров'яної деревини залежить від абсолютної висоти розташування на стовбурі та висоти стовбура. Для математичного узагальнення цього процесу в роботі визначено чотири зони, в межах яких розподіл протяжності ділової частини стовбура може описуватися єдиною функцією. Ймовірності зміни якісних зон змодельовано залежно від відносної висоти стовбурів. На цій основі опрацьовано методика імітаційного моделювання вихідних масивів даних, які можуть використовуватися з метою розроблення таблиць розмірно-якісної структури деревини для стовбурів різних діаметрів, висоти та категорій технічної придатності. Виконане дослідження стосується лише ділових стовбурів сосни, тож потрібно очікувати інші закономірності для стовбурів інших деревних видів, а також напівділових і дров'яних стовбурів. Розроблену методика доречно використовувати під час оновлення таблиць розподілу об'єму стовбурів за розмірно-якісними категоріями, які нині треба оновити шляхом запровадження нових вимог щодо класифікації ділової деревини в Україні

Ключові слова: ділова деревина, функція розподілу, напівмарковська ймовірнісна модель, таблиці розмірно-якісної структури

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Consequences of Catastrophic Landscape Fires in Ukraine for Forest Ecosystems and Population

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Abstract. According to the latest research and publications of international organisations, since the end of the 20th century, the number and frequency of catastrophic forest fires in the world have been increasing, which lead to large economic and environmental losses and human casualties. According to forecasts, negative changes in weather conditions should be expected on the territory of Ukraine, from the standpoint of fire danger: an increase in air temperature, a shift in seasons, an increase in the duration of vegetation and fire-hazardous periods, an increase in the frequency and intensity of heat waves and natural hydrometeorological phenomena, changes in water resources of local runoff. In 2020, several catastrophic fires occurred on the territory of Ukraine in the natural landscapes of different regions. Among the largest and most catastrophic fires that led to human casualties, and substantial economic, environmental, and social consequences are fires in Zhytomyr, Luhansk, Kharkiv, and Kyiv regions. The main prerequisite for such large fires was weather conditions, namely a long period without precipitation, high air temperature and wind gusts of 15-25 m/s. In Ukraine, there are two main critical periods in terms of the frequency and danger of forest fires: the first is in spring after the snow cover descends and before the formation of new greenery; the second is in late summer – in the first half of autumn when dry combustible materials appear on agricultural land, and people burn plant remains in the fields. The events of 2020 showed that the current system is not ready to effectively resist large forest fires and the need for its continuous improvement in accordance with new challenges. In the study based on available official information, data obtained through remote sensing and from the Geoportal “Landscape fires of Ukraine” (wildfires.org.ua) information is provided on the most catastrophic fires that occurred in the natural landscapes of Ukraine in 2020. The components of the system of protection of natural landscapes from fires are considered, the main shortcomings are identified and key recommendations for its improvement are formulated

Keywords: forest fires, emergencies, weather conditions, climate change, damage, human casualties

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Introduction

In 2020, several catastrophic fires occurred on the territory of Ukraine in the natural landscapes of different regions of the country. Among the largest and most catastrophic fires that led to human casualties, and substantial economic, environmental, and social consequences are fires in Zhytomyr, Luhansk, Kharkiv, and Kyiv regions. The main prerequisite for such large fires was weather conditions, namely a long period without precipitation, high air temperature and wind gusts of 15-25 m/s.

The issue of fires in natural landscapes at the international level began to be considered more than 30 years ago, which indicates the global nature of this problem (Goldammer, 2021). During this period, hundreds of international conferences dedicated to landscape fires were held, among which the most substantial are: the 1st International Wildland Fire Conference (IWFC) (1989, Boston, USA) (U.S. Forest Service, 1990); “Fires in the environment: ecological, atmospheric, and climatic importance of landscape fires” (1992, Berlin, Germany) (Crutzen & Goldammer, 1993); “Biomass combustion and global changes” (1995, Williamsburg, Virginia, USA) (Levine, 1996); 2nd IWFC (1997, Vancouver, Canada) (Goldammer, 2021); 3rd IWFC (2003, Sydney, Australia) (GFMC, 2003a); 4th IWFC (2007, Seville, Spain) (GFMC, 2007); 5th IWFC (2011, Sun City, South Africa); 6th IWFC (2015, PyeongChang, Gangwon Province, Korea) (Goldammer, 2021); 7th (2019, Campo Grande, Brazil) (Steil, 2020).

Ukraine joined the international community and global dialogue to promote international cooperation and develop new approaches to fire management in 2007 (4th IWFC). In 2013, a regional Eastern European Fire Monitoring Centre was opened in Ukraine based on the National University of Life and Environmental Sciences of Ukraine (<https://nubip.edu.ua/node/9083/1>), which is part of a global network with a central authority – the Global Fire Monitoring Centre (GFMC, <https://gfmc.online>). Now in Ukraine, the issue of fires in natural landscapes has become very important and is being discussed by production workers, managers and researchers at all levels – local, regional, and national: The First National Coordination Meeting on improving the prevention and extinguishing of forest fires in the exclusion zone (2016, Kyiv, <https://nubip.edu.ua/node/30993>); National Round Table “Fires in natural and cultural landscapes of Ukraine: development of National Fire Management Policy” (2017, Kyiv, <https://nubip.edu.ua/node/38179>); The Fifth National Coordination Meeting on improving the prevention and safe extinguishing of forest fires in the exclusion zone (2019, Kyiv, <https://nubip.edu.ua/node/42818>); Belarusian-Ukrainian staff exercises on joint extinguishing of large cross-border fires (2018, Gomel, Belarus, <https://nubip.edu.ua/node/48594>); The Second National Round Table “Fires in natural and cultural landscapes of Ukraine: development of an integral system of protection against fires in forests, agricultural lands, and other natural ecosystems” (2019, Kyiv, <https://nubip.edu.ua/node/59286>), etc.

Experts predict that from the standpoint of fire danger on the territory of Ukraine, negative changes should be expected, such as a change in seasons, an increase in air temperature, the duration of the fire danger period, frequency and intensity of heat waves and natural hydrometeorological phenomena, changes in water resources of local runoff (Balabukh et al., 2016; Shevchenko et al., 2014).

According to recent studies (Williams et al., 2011; Dowdy et al., 2019) and papers by international organisations (FAO, 2005, 2006, 2015; Goldammer, 2021; Tedim, 2015; Zibtsev & Goldammer, 2019; San-Miguel-Ayanz et al., 2020, 2021), since the end of the 20th century, the number and frequency of catastrophic forest fires in the world has been increasing, which lead to large economic and environmental losses, human casualties (San-Miguel-Ayanz et al., 2013, 2020). These large forest fires are unusually large-scale and have catastrophic consequences. According to Williams (2013), 0.1% of forest fires account for about 95% of the total area covered by the fire and 85% of the total cost of extinguishing them. In particular, the fire in China in 1987, which destroyed approximately 1.2 million hectares of forests and which killed more than 200 people was such (Salisbury, 1989). In the Republic of Botswana in 2008, fires covered a total area of 3.6 million hectares (Williams et al., 2010). During “Black Saturday” in February 2009, fires occurred in an area of about 2 million hectares, which destroyed entire cities and killed 173 people (Nolan et al., 2020). In the Russian Federation in 2010, fires burned about 2.3 million hectares,

killed 62 people, and destroyed hundreds of homes (Williams et al., 2011). In 2018, in the United States, California, during a fire that covered 92.9 thousand hectares, eight people were killed (Wikipedia, 2020). In 2019, fires in Australia covered about 10.7 million hectares, killing 33 people and destroying more than a thousand homes (Morris, 2020).

The dynamics of forest fires in Ukraine are characterised by a certain frequency, in particular, during 1990-2020, on average, 3-4 catastrophic fires occur in each decade (Soshenskyi et al., 2021; Zibtsev et al., 2019). Based on remote sensing methods, it was established that in 2001-2019, in Ukraine, fires covered 38.4 million hectares of natural territories (2.0 million hectares annually). The total number of fires during this period is 223 thousand cases (an average of 11.7 thousand a year) (Zibtsev et al., 2020). According to official data, during 1990-2019, an average of 3 thousand forest fires occurred in Ukraine on an area of about 4 thousand hectares annually (Zibtsev et al., 2019; Soshenskyi et al., 2021). The new era of climate change has increased average statistics. Considering the extreme year 2020, for the period of 1990-2020, the average annual fire area increased to 7 thousand hectares (Soshenskyi et al., 2021). The catastrophic scale of forest fires in Ukraine that occurred in 2020 will be covered in this study.

Materials and Methods

The data from official reports of organisations and enterprises, local authorities, and the state emergency service of Ukraine were used to reflect the fires of 2020 and their consequences. The information about the main climate indicators obtained from local weather stations was used to analyse the climate indicators that preceded catastrophic fires. The information from the Geoportal “Landscape fires of Ukraine” (wildfires.org.ua) was used to analyse spatial information about fires, which was developed within the framework of the implementation by the National University of Life and Environmental Sciences of Ukraine of the study No. 110/9-PR-2018 “Scientific-methodological support for the creation of a geoportal for risk assessment, forecasting, and prevention of wildfires in Polesia of Ukraine”. The geoportal uses the data of MODIS system (earthdata.nasa.gov), which are available in bitmap format in the repositories of the cloud platform *Google Earth*

Engine (GEE), and *MOD14 / MYD14* and *MCD64A1* products (NUBIP of Ukraine, 2020).

Results and Discussion

In 2020, several catastrophic fires occurred on the territory of Ukraine in the natural landscapes of different regions. Among the largest and most catastrophic fires that led to human casualties, and substantial economic, environmental, and social consequences are fires in Zhytomyr, Luhansk, Kharkiv, and Kyiv regions.

In the Zhytomyr region in April 2020, two regional emergencies occurred due to forest fires in the Narodytsky and Ovrutsky districts. The first large-scale fire occurred on April 3 near the village of Zvizdal of the Narodytsky district on the territory of the Narodytsky and Klishchivsky forest districts of the state enterprise “Narodytsky Spetslishosp” with the subsequent spread of fire through the territory of the Narodytsky, Davidkivsky, Klishchivsky forest districts of the Narodytsky district of the Zhytomyr region and to the territory of the Exclusion Zone and Unconditional (Mandatory) Resettlement (EZ and ZU(M)R). The fire developed for 9 days and reached an area of 7 thousand hectares, it was liquidated on April 14. On the night of April 16-17, 2020, a second emergency situation occurred in the Berezhetsky forestry of the state enterprise “Ovrutsky Lishosp” of the Zhytomyr region due to forest fires, which were caused by difficult weather conditions (strong winds of 20-25 m*s⁻¹) spread to the territory of eight forestry enterprises of the region (SE “Belokorovitsky Lishosp”, SE “Luhynsky Lishosp”, SE “Narodytsky Spetslishosp”, SE “Olevsky Lishosp”, SE “Ovrutsky Lishosp”, SE “Ovrutsky Spetslishosp”, SE “Slovechansky Lishosp”, and SE “Slovechansky Lishosp agro-industrial complex”).

The fire developed from seven blazes:

- 1 – the eastern outskirts of the village of Rudnia (ignition from a damaged power line);
- 2 – in the area of the villages of Verkhnia Rudnia, Srednia Rudnia, Nizhnia Rudnia (a blaze along the roadway);
- 3 – a forest area between the villages of Ostrov, Kosuli, Matsky (a source of fire near smouldering peat bogs);
- 4 – a forest area of the Povchansky forestry;
- 5 – the south-eastern outskirts of the village of Pershotravneve;

6 – a forest area between the settlements of Pischanytsia, mochulnya;

7 – Slobidske forestry between the settlements of Voznychi and Lchanky (smouldering peat bogs).

The total area of fires of the “second wave” reached 35 thousand hectares. More than 1 thousand people and 150 pieces of equipment, including three aircraft of the State Emergency Service, were involved in extinguishing fires every day. According to the Zhytomyr regional state administration, fires (during the second emergency) caused damage in the amount of more than

700 million hryvnias (SES of Ukraine, 2021b). The fire was extinguished on May 4. As a result of the fires, seven settlements were damaged – Lychmany village, Mahdyn village, Vystupovychi village, Berkivske village, Srednia Rudnia village, Nizhnia Rudnia village, Ostrovy village, where 82 households were destroyed and damaged, including 42 residential buildings, one church, and one sawmill. The contours and spatial location of fires obtained based on remote sensing data and using the tools of the geoportal “Landscape fires of Ukraine” are shown in Figure 1.

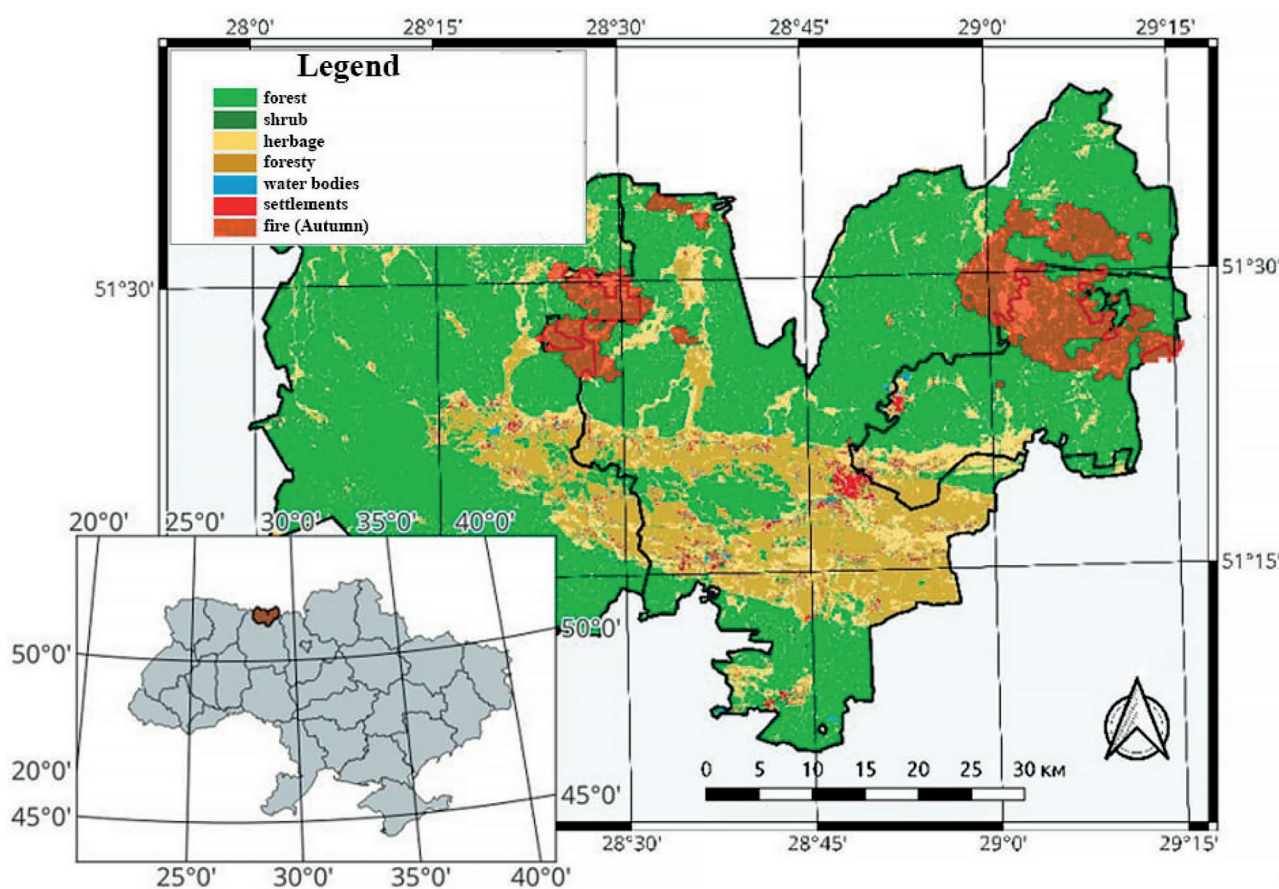


Figure 1. Forest fires in the territory of Ovrutsky and Narodytsky districts of Zhytomyr region, which occurred on April 3 and 16-17, 2020

The main reason for the development of fires to such catastrophic proportions was weather conditions, in particular, lack of precipitation for a long time (about one month without precipitation), wind gusts of 20-25 m*s⁻¹ during the

development of a fire, and high air temperature. The dynamics of average air temperature and precipitation during the period of fire hazard formation in the weather and during the development of fires are illustrated in Figure 2.

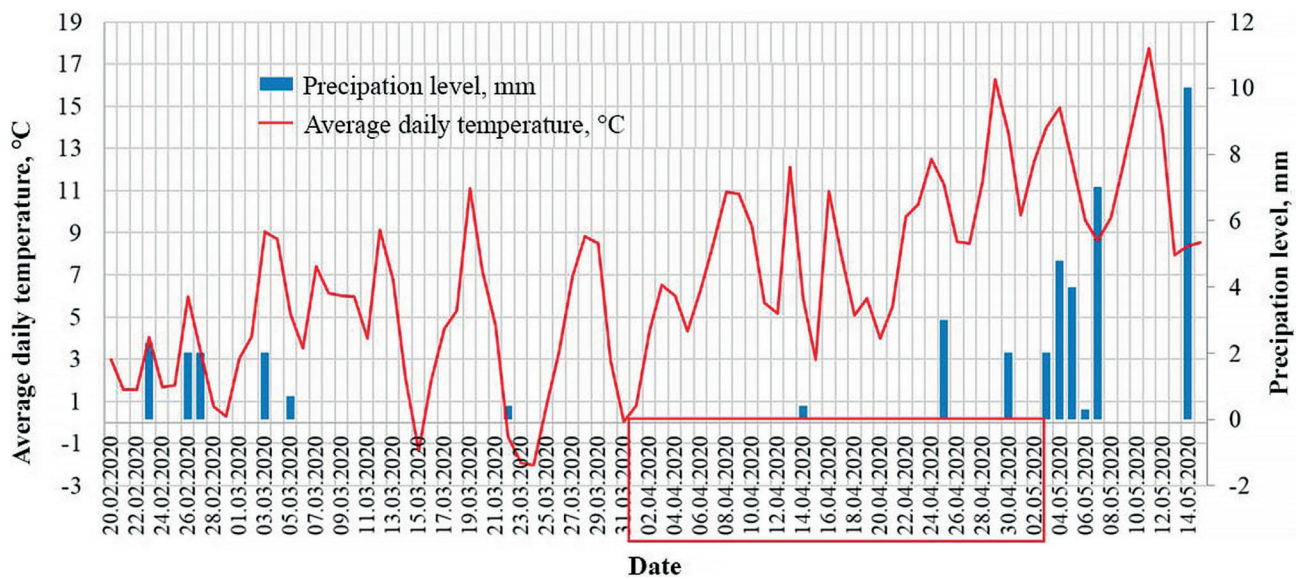


Figure 2. Dynamics of the average daily air temperature and precipitation for the analysed period (weather station of Ovruch, <https://rp5.ua>)

In the Kyiv region on the territory of the Chernobyl Radiation and Ecological Biosphere Reserve (hereinafter – Reserve) on April 3, a forest fire began, which spread from the south-west from the territory of the Drevliansky reserve, on April 7 reached the floodplain of the Uzh River, in the following days it spread in the northern and eastern directions. In another source of fire on April 8, a fire started in the central part of the Reserve, near the village of Chystogalivka, which approached the city of Chernobyl on April 10, and on April 13 approached the Chernobyl nuclear power plant (CHNPP), where it was stopped. On April 16, the fire broke out with renewed vigour due to the gusts of wind and spread to nearby villages in a south-easterly direction. The fire was contained on April 21. In another source of fire, in the southern part of the Reserve near the villages of Ivnytsia and Rozsokha, a fire started on April 13, which developed in the eastern and southern directions; it was localised on April 24. The fourth source of the fire was a fire that occurred on April 16 in the eastern part of the Reserve, near the village of Kryva Hora and developed in the eastern and south-eastern directions; it was localised on April 30 (Fig. 3).

According to official data, the total area covered by the fire for the period from April 3 to May 7 was 67.4 thousand hectares, in particular: on the territory of the Reserve – 51.8 thousand hectares; forest fund and ecosystem – 15.6 thousand hectares. As a

result of the fire on the territory of the reserve, the following areas were covered by fire: 32,413.1 ha – forests (23% of the total forest area); 10,721.8 ha – fallow forests; 3,530.5 ha – swamps; 5,200 ha – other territories (coastal strip of rivers, meadows, etc.). The damage caused by fire on the territory of the Reserve is approximately 8523.677 million UAH, among them – from damage to forests 8075.114 million UAH, damage to natural renewal – 441.874 million UAH, damage and destruction of swamps – UAH 4.975 million, destruction of bird nests – UAH 1.714 million (SAUEZM, 2021). Fires substantially damaged a number of rare biotopes that are listed in the Berne Convention, plant groups that are listed in the Green Book of Ukraine, pine-juniper *hylocomiosum* forests, and *seicheuchzeria-sphagnum* swamps (SAUEZM, 2020). More than 1,300 people and 300 pieces of equipment, including three planes and three helicopters of the State Emergency Service of Ukraine, were involved in extinguishing the fire every day. More than 1 thousand km of mineralised lanes and roads have been created in cluttered woodlands with heavy engineering equipment of the State Emergency Service of Ukraine, the Armed Forces, and the National Guard of Ukraine (SES of Ukraine, 2021b).

The contours and spatial location of fires obtained based on remote sensing data and using the tools of the geoportal “Landscape fires of Ukraine” are shown in Figure 4.



Figure 3. Remnants of Kriva Hora after a fire in April 2020 (shooting date – April 23, 2020, photo by Denys Vyshnevskiy)

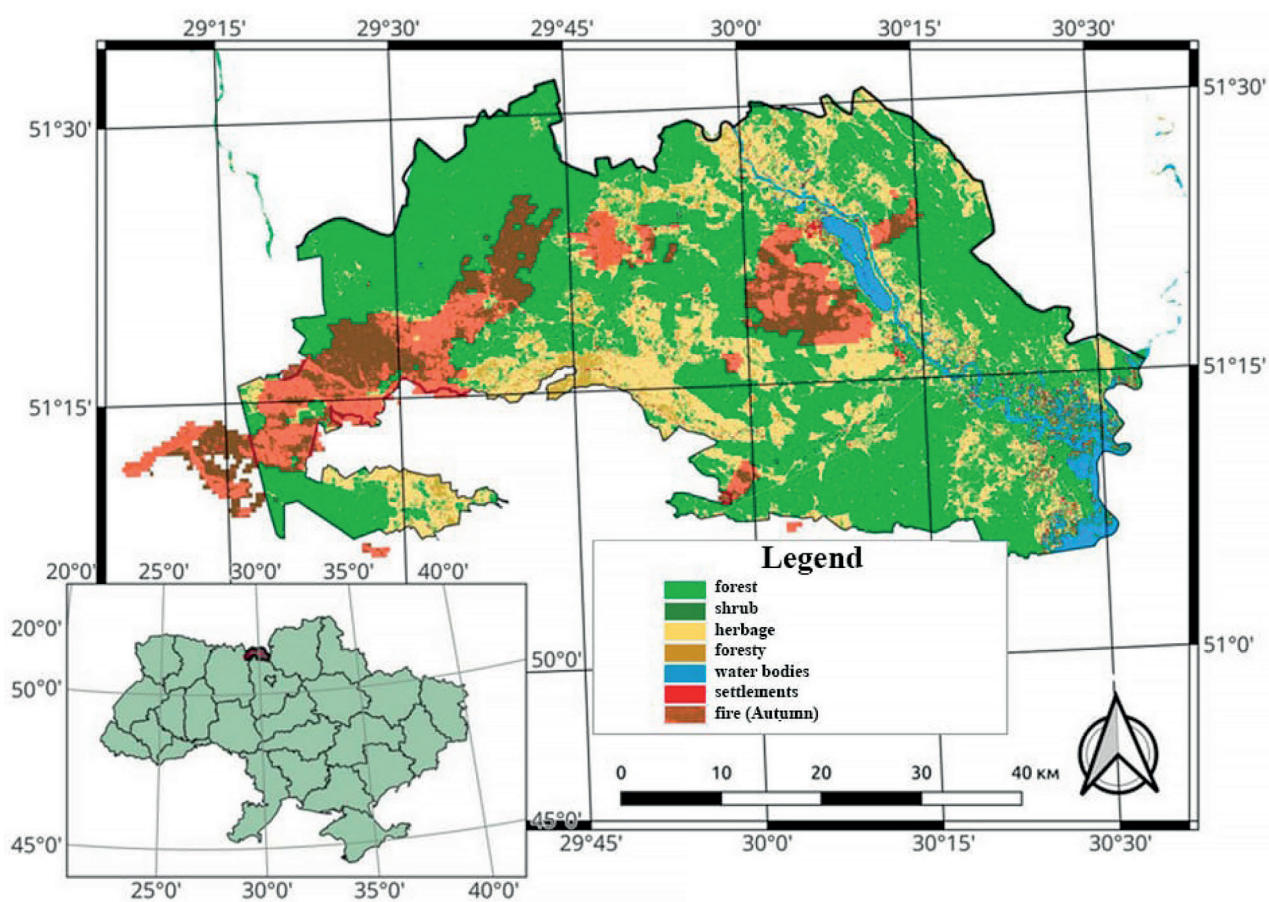


Figure 4. Fires in the territory of EZ and ZU(M)R, which occurred in April 2020

Analysing the climate indicators obtained from the Chernobyl weather station, a long rainless period was not observed – from March 12 to April 3, 2 mm of precipitation fell, which formed high risks

of fire occurrence and development (Fig. 5). In addition, on April 3-4, at the initial stage of the fire development, substantial wind gusts were observed – more than $10 \text{ m}^*\text{s}^{-1}$.

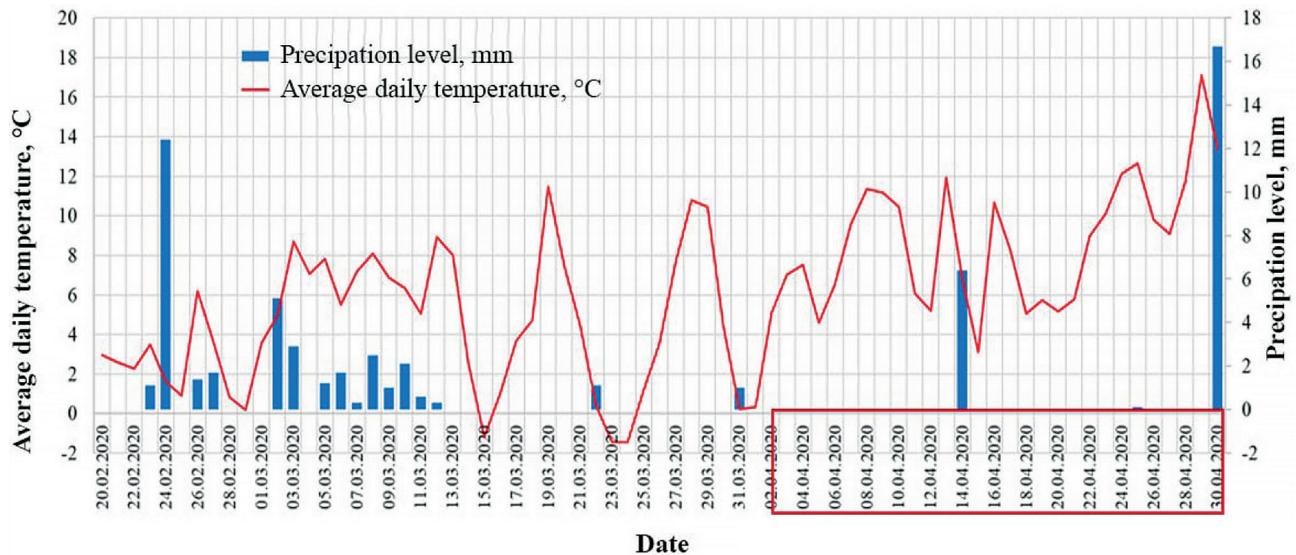


Figure 5. Dynamics of the average daily air temperature and precipitation for the analysed period (weather station of Chernobyl)

As shown in Figure 5, on April 14, 6.4 mm of precipitation fell, but this did not stop the fire, which developed until April 30, when 16.7 mm of precipitation fell.

In the Kharkiv region, on September 2, a forest fire broke out on the territory of the Dvorichansk forestry of the state enterprise “Kupiansk Lishosp” between the settlements of Horobivka and Hri-anukivka of the Dvorichansk district, which was caused by strong gusts of wind (up to $15 \text{ m}^*\text{s}^{-1}$) of variable directions and quickly spread to the territory of neighbouring localities – Horobivka and Hri-anukivka, which border the forest area. The weather conditions that formed during this period in the territory where the fire occurred contributed to the formation of high risks of fires and their development: almost a month without precipitation (with the exception of August 28 – 3 mm of precipitation) and an average daily air temperature of $15\text{-}25^\circ\text{C}$ (Fig. 6).

As a result of the fire, 22 private households were destroyed, the gas supply to four settlements

(the villages of Horobivka, Hri-anukivka, Kutkivka, Kasianivka) was cut off, 52 people were evacuated, and one person was injured. More than 479 people and 78 pieces of equipment were involved in extinguishing the fire, including two fire planes, one helicopter, and two fire trains from the “Kupiansk vuzlovyy” and “Osnova” railway stations. The amount of damage caused exceeds UAH 75 million (SES of Ukraine, 2021b, 2020). The fire was extinguished on September 5. The total area of the fire was 500 hectares, of which 100 hectares were covered by crown fire (Kharkiv OULMG, 2020).

In the Luhansk region, in the Novoaydar district on the territory of the Boriv and Akhtyr forest districts of the state enterprise “Sievierodonetsk LMH” on July 6, 2020, a forest fire broke out, which was caused by a strong gusty wind (up to $25 \text{ m}^*\text{s}^{-1}$) of variable directions and high air temperature ($+38^\circ\text{C}$) (Fig. 7), and spread to coniferous forests near the villages of Kapitanove and Voronove, and to the territory of the village of Smolianynove.

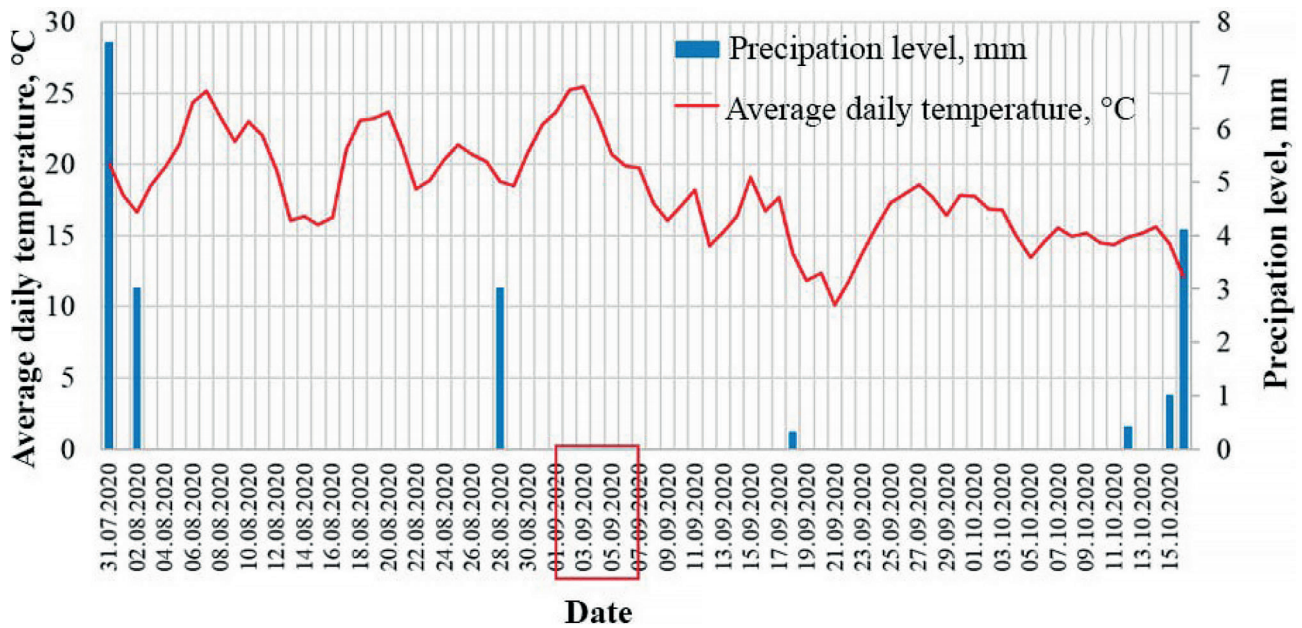


Figure 6. Dynamics of the average daily air temperature and precipitation for the analysed period (weather station of Velykyi Burluk, <https://rp5.ua>)

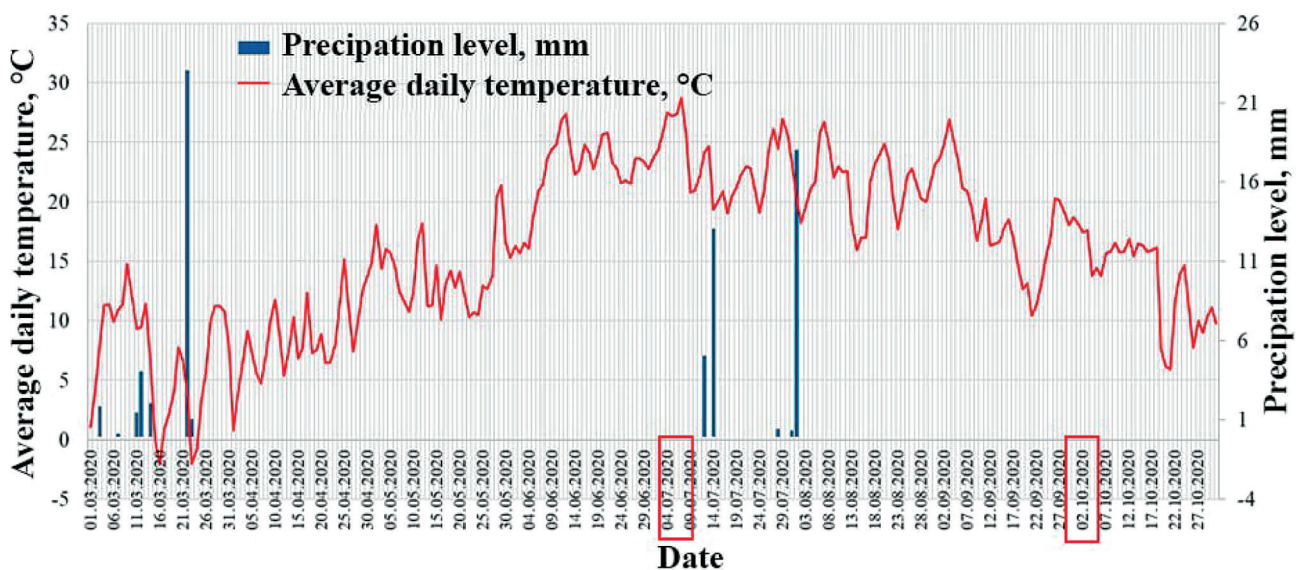


Figure 7. Dynamics of the average daily air temperature and precipitation for the analysed period (weather station of Bakhmut, <https://rp5.ua>)

According to official data, the total area of the fire was about 5 thousand hectares, as a result of the fire, 35 residential buildings were destroyed and 24 were damaged in the village of Smolianynove (Fig. 8), and 49 country houses in the horticultural society “Lake Vovche” of the Novoaidar district were completely destroyed (SES of Ukraine, 2021b). As a result of

the emergency, five people were killed and 471 people were injured. More than 1.4 thousand people and 250 pieces of equipment, including two AN-32P aircraft, were involved in extinguishing the fire (SES of Ukraine, 2021b). According to the Luhansk Regional State Administration, the forestry sector of the region suffered damage in the amount of about 5,304 mln UAH.



Figure 8. Destruction of residential buildings in Smolianynove village as a result of a forest fire (Photo by Oleksiy Kovaliov)

After the July catastrophic fires that occurred in the Luhansk region, the second series of large fires occurred in the fall: September 30 – October 1 on the territory of Stanychno-Lugansk, Sievierodonetsk, and Novoaydar forest hunting farms of the Luhansk region, there were 146 fires in ecosystems. Due to extremely difficult weather conditions (wind with hurricane gusts up to $25 \text{ m}^*\text{s}^{-1}$, long dry period), fires quickly spread to an area of more than 20 thousand hectares and became threatening to settlements. The most difficult situation was along the demarcation line in the territory of Stanichno-Lugansk, Novoaydar, and Sievierodonetsk districts, where 32 settlements were affected. According to the Luhansk regional state administration, as a result of the fire, 12 people were killed and 390 people were injured, 573 residential buildings were destroyed and 60 were damaged. 22 settlements were affected by the fire. The estimated amount of losses amounted to about UAH 12,228.375 million. More than 2.5 thousand people and more than 250 pieces of equipment, including three AN-32P fire planes and two helicopters, were involved in extinguishing the fire (SES of Ukraine, 2021a).

Based on the spatial-temporal information obtained from the geoportal “Forests of Ukraine” and remote sensing methods, the total area of forest fires was calculated, which amounted to 39.5 thousand hectares (Myroniuk et al., 2021). The spatial location of forest fires is shown in Fig. 9.

The number, size, and intensity of wildfires have increased substantially in many parts of the world in recent decades, and they are expected to continue to increase in the coming decades due to projected climate change (Moritz et al., 2012; Stephens et al., 2013). In the United States, only 1-2% of all fires are catastrophic, but they account for about 85% of the total cost of extinguishing fires and more than 95% of the total area of fires (Williams and Hyde, 2009).

A key factor contributing to the increase in the frequency and size of fires is climate, in particular, rising temperatures, uneven precipitation distribution, and longer fire-prone seasons. According to forecasts, negative changes in weather conditions in terms of fire danger should be expected in the territory of Ukraine (Balabukh et al., 2016; Shevchenko et al., 2014).

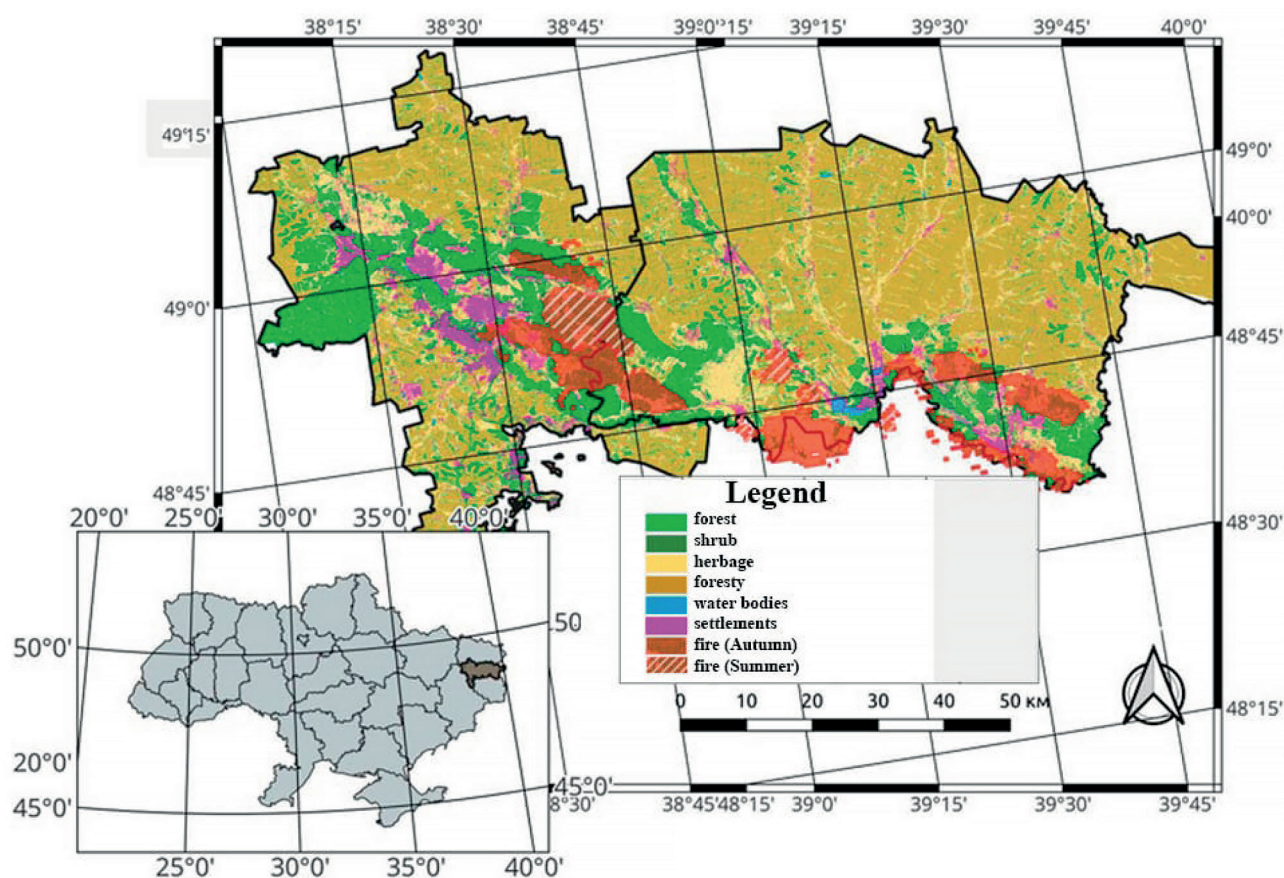


Figure 9. Fires that occurred in the Luhansk region, on the territory of the SE “Sievierodonetsk LMH”, the SE “Novoaydar LMH”, the SE “Stanichno-Lugansk DLMH”, and the SE “Kreminsk LMH”

Fires of 2020 in Ukraine have become a new type of fire. As a result of climate change, landscape changes, and economic causes, in particular, due to a lack of adequate forestry funding, fires occur that are difficult to control. The events of 2020 showed that the current system is not ready to effectively resist large forest fires. The State Emergency Service of Ukraine is best equipped with fire equipment, but the protection of forests from fires and extinguishing at an early stage is provided by foresters who directly depend on economic activities, that is, the material support and resource potential of each enterprise are different – less in low-forest areas and more in areas with a large share of forests, in particular, operational forests. Currently, forestry enterprises are experiencing a shortage of funding for the protection of forests from fires, so they are limited in implementing proactive measures and responding

with modern technologies. Only economically developed forestry enterprises are able to install video surveillance systems for detecting fires and forming mobile teams for early response to fires. The vast majority of forest fire stations today are equipped with vehicles from the 1980s and 1990s (mostly GAZ and ZIL brands). In modern conditions, one of the main stages of successful fire control is the use of fire modules that provide the fastest possible response and with which the fire at an early stage can be effectively resisted (Soshenskiy et al., 2021). In the system of forest protection from fires should use both light fire modules and large fire trucks (tank trucks). In conditions of high fire danger of the weather and high risks of fire development, it is necessary to launch an aggressive attack, when the maximum amount of equipment is used in the shortest possible time. It is important not only to

update the equipment but also to replace outdated hand tools with new modern ones, to use forestry methods to increase the fire resistance of forests and to learn how to use controlled fire technologies that can prevent large-scale fires in the future.

The number and area of fires in open landscapes are much larger than in forests, and they are often the cause of large forest fires. In fact, there is no system of fire protection of agricultural land, and land users are not interested in protecting land from fires. As a rule, in such areas, fires are extinguished by units of the state emergency service of Ukraine.

Conclusions

Analysis of the dynamics of forest fires over a long period of time indicates an increase in the frequency of large fires in the territory of Ukraine. Forest fires in 2020, which occurred in Zhytomyr, Kyiv, Kharkiv, and Luhansk regions and led to substan-

tial economic, environmental, and social consequences, destruction of residential buildings, infrastructure, and human casualties, indicate that the current system is not ready to withstand large fires. Given the new climatic conditions, changes in society and land use, it is necessary to develop a new National Fire Management System and take urgent legislative, organisational, scientific, and educational measures at the state level. One of the main elements of effective fire management is the management of combustible materials, in particular, the use of controlled firing to reduce the risk of fires. The forest fire management system needs to be substantially updated and improved, considering the current and future scenarios of fire danger. The very diverse and complex causes of fires indicate the need to consider not only natural fire and weather hazards but also the social and cultural aspects of the population.

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**Наслідки катастрофічних ландшафтних пожеж в Україні
для лісових екосистем та населення**

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Анотація. Згідно з останніми дослідженнями та публікаціями міжнародних організацій, з кінця ХХ ст. у світі збільшується кількість і частота катастрофічних лісових пожеж, які призводять до великих економічних та екологічних втрат, людських жертв. За прогнозами, на території України слід очікувати негативних змін погодних умов, з погляду пожежної небезпеки: підвищення температури повітря, зміщення сезонів, зростання тривалості вегетаційного і пожежонебезпечного періодів, зростання повторюваності та інтенсивності хвиль тепла та стихійних гідрометеорологічних явищ, зміну водних ресурсів місцевого стоку. В 2020 році на території України відбулося кілька катастрофічних пожеж у природних ландшафтах різних регіонів. Серед найбільших і найкатастрофічніших, які призвели до людських жертв, значних економічних, екологічних та соціальних наслідків, – пожежі в Житомирській, Луганській, Харківській і Київській областях. Основною передумовою таких великих пожеж були погодні умови, а саме тривалий період без опадів, висока температура повітря та пориви вітру 15–25 м/с. В Україні існує два основні критичні періоди, з погляду частоти та небезпеки виникнення лісових пожеж: перший – весняний, після сходження снігового покриву й до утворення нової зелені; другий – наприкінці літа – у першій половині осені, коли з'являються сухі горючі матеріали на сільськогосподарських угіддях, а люди спалюють рослинні рештки на полях. Події 2020 р. засвідчили неготовність чинної системи ефективно протистояти великим лісовим пожежам та потребу в її постійному удосконаленні відповідно до нових викликів. У статті на основі доступної офіційної інформації, даних, отриманих за допомогою ДЗЗ та з геопорталу «Ландшафтні пожежі України» (wildfires.org.ua) подано інформацію про найбільш катастрофічні пожежі, які трапилися в природних ландшафтах України у 2020 р. Розглянуто компоненти системи охорони природних ландшафтів від пожеж, виокремлено основні недоліки та сформульовано ключові рекомендації з її удосконалення

Ключові слова: лісові пожежі, надзвичайні ситуації, погодні умови, зміни клімату, збитки, людські жертви

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Assessment of the State of Green Spaces of the Park-Monument of Landscape Art of National Importance “Skala-Podilsky Park”

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Abstract. Green spaces of ancient parks are not only an important ecological component of the human environment, but also a cultural-historical factor of national identity. The history of landscape art in Ternopil region demonstrates the close ties of Ukrainian culture with Polish, Lithuanian, and Western European. Galicia is rich in architectural monuments of the past: fortresses, castles, defensive ramparts, courtyards, fortifications, fortified monasteries and temples, mansions and estates of the local gentry. Decorative parks, fruit orchards, and collections of medicinal plants were laid near such structures. Most of the old parks have undergone substantial negative changes due to the turbulent historical events in the 20th century, but some objects, even if in a neglected state, have been preserved and need restoration and maintenance.

Skala-Podilsky park-monument of landscape art of national importance was laid at the end of the 17th century. Since that, the park was repeatedly reconstructed. During this time, many ornamental and fruit-berry trees and shrubs, including exotic ones, were acclimatised. During the period of independence of Ukraine, the plantings were not properly cared for, which led to the destruction of the park’s infrastructure and a decrease in the number of valuable taxa.

A tax inventory of its dendroflora was conducted, and the vital and phytosanitary condition of trees and shrubs was determined on the Alekseev scale to organise the territory and reconstruct the park. 63 taxa of trees, shrubs, and lianas were identified. It is established that the overall indicator of the relative living condition of the park’s plantings is 57.7% and corresponds to the category “weakened”. Among the tree stands of the park, 800 trees with defetiveness (20% of all trees) were identified. According to the assessment of the phytosanitary condition of trees and shrubs, 41% belong to the category of “satisfactory”, 34% – “good”, 25% – “unsatisfactory”. Thus, a quarter of the registered trees require health-improving measures or removal from the plantings.

The obtained materials indicate the need for accounting and inventory of all ancient parks in Ukraine and the development of a system for their geoinformational monitoring to streamline revitalisation

Keywords: inventory of dendroflora, phytolandscape, sanitary condition of trees, rare trees

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Introduction

The main purpose of parks-monuments of landscape art is to preserve, maintain, and restore park landscape compositions, cultural legacy sites, and conduct excursions and mass recreation of the population. They are used for scientific studies, environmental education, youth education, etc. Such parks were created involving the best architects, whose creative skills forever left an important legacy in the history of Ukrainian park construction and substantially enriched it with compositional and planning techniques.

Ancient parks are an important part of our cultural legacy. The modern appearance of parks is substantially different from what they had during their heyday, both due to the turbulent historical events of the 20th century, and the natural aging of plantings, a substantial part of which has reached the age limit. Therefore, it is extremely important to preserve the old parks and revitalise them.

Skala-Podilsky Park is a monument of landscape art of national importance located on the territory of the village of Skala-Podilsky of the Borshchevsky district of the Ternopil region. In 1960, the park was classified as one of the most outstanding parks-monuments of landscape architecture.

The total area of the park according to the results of the approved land management project for organising and establishing the boundaries of the territories of the park-monument of landscape art of national importance "Skala-Podilsky Park" dated February 14, 2017, is 26 hectares. According to the regulations on the park-monument, the main part of the land plot of the park with an area of 25.6 hectares is in the use of the children's health complex "Zbruch" (now – children's health and recreation institution "Zbruch") – a branch of the Ternopil regional closed joint stock company for tourism and excursions "Ternopolturist", a plot of 0.40 hectares – Skala-Podilsk city municipal polyclinic of the Borshchevsky district (now – municipal non-profit enterprise "Skala-Podilsk territorial medical association" of Skala-Podilsk village council).

A special feature of this park is that it combines several functions while remaining in the

system of public green spaces. Such use requires the introduction of effective management, one of the tools of which is maintenance and reconstruction projects. Due to insufficient care, the green spaces of Skala-Podilsky Park lose their decorative and sanitary properties and no longer properly perform environmental and scientific-educational functions. It is necessary to conduct constant care of plantings to maintain the park in proper condition: conduct sanitary and reconstructive logging, measures to prevent wild self-seeding, and preserve plant compositions, so it is relevant to develop scientifically based design measures for the organisation of the territory and reconstruction of Skala-Podilsky Park.

The study of historical parks in different regions of Ukraine is covered in a number of scientific publications, namely: the phytocenotic structure of ancient parks and ways of its regulation was investigated by R.B. Dudin (Dudin, 2013); N.V. Hatalaska investigated the introducers of ancient parks-monuments of landscape art of the Central Dnieper upland region (Hatalaska, 2011); G.V. Denisova conducted a comprehensive assessment of the decorative effect of palace and park ensembles of the Western forest-steppe (Denisova, 2018); N.A. Oleksiychenko and S.M. Pidhovna conducted a retrospective and comprehensive analysis of parks-monuments of landscape art of the Ternopil region (Oleksiychenko & Pidhovna, 2019); parks-monuments of landscape art in Eastern Podillia were investigated by Yu.A. Klimenko (Klimenko, 1999, 2006), Yu.A. Elisavenko (Elisavenko et al., 2018).

The purpose of the study is to conduct a full-scale examination of the territory of Skala-Podilsky Park, an inventory of dendroflora, an analysis of its taxonomic, qualitative, and age structure, an assessment of life and phytosanitary conditions, an introduction of geoinformational monitoring of green spaces in the park.

Materials and Methods

The object of the study is green spaces on the territory of the park-monument of landscape art of na-

tional importance “Skala-Podilsky Park” in the village of Skala-Podilsky of the Borshchevsky district of the Ternopil region. An inventory of dendroflora was conducted in the summer of 2018 in accordance with the current “Instructions for the inventory of green spaces in localities of Ukraine” (Instruction, 2001). Considering the fact that the area of the Park is 26 hectares, the inventory of tree and shrub vegetation was conducted in two ways: in the central and North-Eastern parts of the park – by an individual tree inventory; in the rest of the territory – by a stand-level method. Biometric indicators were determined to analyse and describe the condition of plants: the diameter and height of trees, and the state of their vitality, established according to the technique of “Instructions for the inventory of green spaces in localities of Ukraine”.

Species of woody and shrubby plants are identified according to the determinant of N.M. Andronov (Andronov, 1974) and reference books of M.A. Kohno (Kohno, 2001, 2002). The taxonomic composition of dendrocenoses was determined by route surveys.

The phytosanitary condition of woody and bush plant species is assessed by external morphological features. The V.A. Alekseyev category scale (Alekseyev, 1989) was used to diagnose the vital state of plantings and tax indicators of trees: age, diameter, and height. A simplified assessment methodology was applied, dividing trees into three categories of condition, as required by the “inventory guide”...(Instruction, 2001): “good”, “satisfactory”, or “unsatisfactory”. Defective trees with the presence of visible or hidden trunk defects were determined separately: hollows, scuffs, cracks, splits, wood inflows, mechanical damage, rot, etc.

Both conventional instruments support – an optical altimeter, a Haglof measuring plug, a tape measure, and a modern global positioning device (GPS), Geographic information systems (GIS), and remote sensing devices were used (Kuziovich et al., 2021). The coordinates of each tree were obtained using Garmin eTrex 20 GPS with binding to reference points on the ground and its subsequent correction based on Landsat remote sensing materials

in the QGIS 3 GIS. In this way, a geoinformational database of the tree and bush vegetation was created, in which the coordinates of its location were combined with information on species, phytosanitary, and basic biometric indicators (Lakida, Bidolakh & Kusevich, 2020). This enabled the storage of it in digital format, automatically processing data, and displaying it on the map. Based on this approach, sustainable monitoring of the state of green spaces in the park was organised and 3D visualisation of the park territory was created in the specialised Realtime Landscaping Architect 16 programme.

Results and Discussion

As a result of the conducted research, the taxonomic composition of Park plantings was determined and analysed, its qualitative assessment was conducted and the phytosanitary condition was determined, and project proposals for the reconstruction of the park were developed in the form of an explanatory note, cartographic material, and a three-dimensional model of the territory.

As a result of the tax inventory of green spaces in Skala-Podilsky Park, 63 species and cultivars were identified (Table 1), of which 8 are pin plants, 16 are deciduous shrubs, and 2 are lianas. Among the main types of dendroflora are common ash, Norway maple, small-leaved linden, horse chestnut, robinia pseudoacacia, Scots elm, field maple, hornbeam, and bird cherry. During its heyday, hedges of European box and northern white-cedar were created in the park, which were regularly cared for. Their deformed fragments have been preserved to this day. The park is based on the remains of natural forest stands, as evidenced by centuries-old ash trees, lindens, poplars, and oaks. Among the pin species, artificially planted curtains of black and Scots pine, single trees of Weymouth pine, solitary and group plantings of European spruce and northern white-cedar were preserved in satisfactory condition. One silver fir tree has been identified, which is in a very good condition far beyond its range, which indicates the prospects for its wider use in landscaping of Podillia.

Table 1. Species composition of the dendroflora of Skala-Podilsky Park and its qualitative condition

No.	Wood species	Total trees	Quality condition		
			Good	Satisfactory	Unsatisfactory
1	2	3	4	5	6
1	Cherry plum (<i>Prunus cerasifera</i> or <i>Prunus divaricata</i> Ledeb.)	25	8	11	6
2	Silver birch (<i>Betula pendula</i> Roth.)	6	1	1	4
3	Dark birch (<i>Betula obscura</i> A. Kotula)	6	-	1	5
4	Common privet (<i>Ligustrum vulgare</i> L.)	1	-	1	-
5	Warty spindle (<i>Euonymus verrucosus</i> Scop.)	1	1	-	-
6	European birch bark (<i>Euonymus europaeus</i> L.)	2	1	1	-
7	Black elderberry (<i>Sambucus nigra</i> L.)	9	9	-	-
8	Black elderberry plumosa (<i>Sambucus nigra</i> 'Plumosa' L.)	1	1	-	-
9	Forest beech (<i>Fagus sylvatica</i> L.), purpurea form	1	-	1	-
10	Nicker dioecious (<i>Gymnocladus dioicus</i> (L.) K. Koch).	2	1	1	-
11	White willow (<i>Salix alba</i> L.)	8	3	3	2
12	Goat willow (<i>Salix caprea</i> L.)	5	-	-	5
13	Scots elm (<i>Ulmus glabra</i> Huds.)	127	66	37	24
14	Horse chestnut (<i>Aesculus hippocastanum</i> L.)	92	26	46	20
15	Red horse chestnut 'Brioti' (<i>Aesculus</i> × <i>carnea</i> Zeyh.)	2	-	2	-
16	Honey locust (<i>Gleditsia triacanthos</i> L.)	3	1	2	-
17	Northern European hawthorn (<i>Crataegus oxyacantha</i> L.)	3	3	-	-
18	Common hawthorn (<i>Crataegus monogyna</i> Jacq.)	7	2	4	1
19	Common walnut (<i>Juglans regia</i> L.)	41	23	11	7
20	Black walnut (<i>Juglans nigra</i> L.)	6	3	3	-
21	Mountain ash (<i>Sorbus aucuparia</i> L.)	5	3	2	
22	Common hornbeam (<i>Carpinus betulus</i> L.)	245	120	81	44
23	Forest pear (<i>Pyrus communis</i> L.)	14	3	7	4
24	Common oak (<i>Quercus robur</i> L.)	10	7	2	1
25	Northern oak (<i>Quercus rubra</i> L.)	2	1	1	-
26	Five-leaved ivy (<i>Parthenocissus quinquefolia</i> (L.) Planch)	17	17	-	-
27	Littleleaf mock-orange (<i>Philadelphus microphyllus</i> Gray.)	4	4	-	-
28	Wayfarer (<i>Viburnum lantana</i> L.)	1	1	-	-
29	Guelder-rose (<i>Viburnum opulus</i> L.)	5	5	-	-

Table 1, Continued

1	2	3	4	5	6
30	Southern catalpa (<i>Catalpa bignonioides</i> Walt.)	2	-	2	-
31	Norway maple (<i>Acer platanoides</i> L.)	660	319	236	105
32	Field maple (<i>Acer campestre</i> L.)	440	128	196	116
33	Boxelder maple (<i>Acer negundo</i> L.)	5	2	3	-
34	Sycamore maple (<i>Acer pseudoplatanus</i> L.)	44	23	9	12
35	Purple-leaved Sycamore maple (<i>Acer pseudoplatanus</i> 'Atropurpureum' L.)	5	-	4	1
36	Sugar maple (silver) (<i>Acer saccharinum</i> L.)	4	2	2	-
37	Small-leaved linden (<i>Tilia cordata</i> Mill.)	235	61	135	39
38	Large-leaved linden (<i>Tilia platyphyllos</i> Scop.)	32	11	17	4
39	Common hazel (<i>Corylus avellana</i> L.)	7	4	3	-
40	Holly-leaved barberry (<i>Mahonia aquifolium</i> (Pursh) Nutt.)	1	1	-	-
41	European larch, (<i>Larix decidua</i> Miller ssp. Polonica (Raciborski & Wóycicki) Domin)	20	-	12	8
42	Maple-leaved sycamore (<i>Platanus orientalis</i> L.)	2	-	2	-
43	Common ivy (<i>Hedera helix</i> L.)	-	-	-	-
44	Robinia pseudoacacia (<i>Robinia pseudoacacia</i> L.)	544	58	214	272
45	European box (<i>Buxus sempervirens</i> L.)	171	30	139	2
46	Common snowberry (<i>Symphoricarpos albus</i> Blake)	15	10	5	-
47	Weymouth pine (<i>Pinus strobus</i> L.)	9	1	3	5
48	Black pine (<i>Pinus nigra</i> Arn.)	31	1	26	4
49	Scots pine (<i>Pinus sylvestris</i> L.)	12	4	3	5
50	Spirea willow or Meadowsweet willow (<i>Spiraea salicifolia</i> L.)	1	1	-	-
51	White poplar (<i>Pópulus álba</i> L.)	70	17	28	25
52	Canadian poplar (<i>Populus deltoids</i> W.Bartram ex Marshall)	7	-	-	7
53	Black poplar (<i>Populus nigra</i> L.)	6	-	2	4
54	Northern white-cedar <i>Thuja occidentalis</i> L.)	62	18	18	26
55	Northern white-cedar columnar (<i>Thuja occidentalis</i> L. "Columna")	4	4	-	-
56	Common bird cherry (<i>Padus racemosa</i> Gilib.)	4	1	2	1
57	Black cherry (<i>Prunus serotina</i> Ehrh.)	5	1	3	1
58	Sweet cherry (<i>Cerasus avium</i> (L.) Moench)	80	34	30	16
59	Dog rose (<i>Rosa canina</i> L.)	2	2	-	-
60	Apple tree (<i>Malus domestica</i> Borkh.)	60	3	27	30
61	European spruce (<i>Picea abies</i> (L.) Karst.)	39	1	16	22
62	Silver fir (<i>Abies alba</i> Mill.)	1	-	1	-
63	Common ash (<i>Fraxinus excelsior</i> L.)	722	309	250	163
Total		3953	1356	1606	991

A substantial amount of self-seeding undergrowth was identified in the park, namely: Norway maple, field and boxelder maples, sweet cherries, common bird cherry, cherry plum, common ash, black elderberry, common wayfarer, common viburnum, common hazel, etc. Acclimatised exotic taxa grow here, including: maple-leaved sycamore, sugar maple, late bird cherry, holly-leaved barberry, dioecious nicker tree, red horse chestnut, southern catalpa, honey locust, northern oak, black walnut, etc. Purple-leaved forms of sycamore maple and beech were identified, red book species – dark birch, black elderberry of dissected leaf form, mock-orange, willow spirea, etc.

The second storey of the Park stands is represented by mountain ash, hornbeam, Norway maple, field, and boxelder maples, cherry plum, Northern white-cedar, and other species. In general, the fullness and closeness of the park stand are high, which

determines the predominance of the forest type of landscape in Skala-Podilsky Park. Because of this, the grass cover is poorly developed, and there are also relatively few shrubs. Two lianas were identified: common ivy and five-leaved ivy.

Old trees grow in the park, more than a hundred years old, with a diameter of about 1 meter or even more at chest height. Such trees form a fund for identifying so-called patriarchal trees, or botanical monuments of nature with protected status. Century-old trees should also be protected as mother trees to produce valuable seeds. A unique specimen of the small-leaved linden, which is distinguished by its impressive size (229 cm in diameter) and multi-stemmed crown shape, deserves to be granted conservation status. The tree needs sanitary care and conservation.

The most interesting specimens of the park's century-old trees are presented in Table 2.

Table 2. Rare trees of Skala-Podilsky Park

No.	Tree type	Diameter (cm)	Height (m)	Age (years)	Necessary wellness measures
1	3	4	5	6	7
1	Forest beech (<i>Fagus sylvatica</i> L.)	122	32	160	crown cleaning
2	Forest beech (<i>Fagus sylvatica</i> L.), <i>F. purpurelistra</i>	98	29	110	crown cleaning
3	Silver willow (<i>Salix alba</i> L.)	86	20	80	crown cleaning
4	Scots elm (<i>Ulmus glabra</i> Huds.)	80	29	100	
5	Horse chestnut (<i>Aesculus hippocastanum</i> L.)	104	26	160	crown cleaning
6		120	24	160	crown cleaning
7		120	26	160	crown cleaning, conservation
8		122	27	160	crown cleaning, conservation
9	Honey locust (<i>Gleditsia triacanthos</i> L.)	72	28	80	pruning dry branches
10	Common hornbeam (<i>Carpinus betulus</i> L.)	88	25	140	crown cleaning, conservation
11	Common oak (<i>Quercus robur</i> L.)	140	34	180	crown cleaning
12	Northern oak (<i>Quercus rubra</i> L.)	110	32	100	
13	Norway maple (<i>Acer platanoides</i> L.)	84	30	90	pruning dry branches
14		86	30	90	pruning dry branches
15	Field maple (<i>Acer campestre</i> L.)	82	27	110	crown cleaning
16	Small-leaved linden (<i>Tilia cordata</i> Mill.)	156	31	180	conservation
17		229	22	240	treatment and conservation
18	European larch, (<i>Larix decidua</i> Miller ssp. <i>Polonica</i>)	84	31	120	crown cleaning
19		84	31	120	crown cleaning
20		84	31	120	crown cleaning
21		86	31	120	crown cleaning
22	Robinia pseudoacacia (<i>Robinia pseudoacacia</i> L.)	54/84	27	120	conservation

Table 2, Continued

1	3	4	5	6	7
23	Weymouth pine (<i>Pinus strobus</i> L.)	120	33	140	
24	Black pine (<i>Pinus nigra</i> Arn.)	105	28	120	
25	White poplar (<i>Pópulus álba</i> L.)	196	37	160	pruning dry branches
26		178	36	150	pruning dry branches
27	Common ash (<i>Fraxinus excelsior</i> L.)	152	34	160	conservation
28		122	32	140	crown cleaning
29		132	34	140	crown cleaning
30		126	32	140	crown cleaning

The share of viable trees in Skala-Podilsky Park is 75%, but this is an average result. Regarding individual species, different trees and shrubs feel different in similar conditions.

The overall indicator of the relative living condition of the park's plantings, calculated according to the Alekseyev method (Alekseyev, 1989), is 57.7% and corresponds to the category "weakened".

According to the criteria of phytosanitary condition of trees, it was identified that 41% of the total number of plants belongs to the category of "satisfactory", 34% to the category of "good", and 25% to "unsatisfactory".

Thus, a quarter of the registered trees require the use of health-improving measures or cutting down. The worst condition is characterised by the following species: Canadian poplar – all trees identified in the park are in an unviable state and are intended for extraction, black poplar – 66% of trees are in an unsatisfactory condition, and white poplar – 36%. In silver and dark birch trees, 66% and 80% of trees are dying off, respectively. There is a lot of drop-off in horse chestnut – 22% in an unsatisfactory condition, hornbeam – 19% in an unsatisfactory condition. Large indicators of the unsatisfactory condition of maples can be explained by the old age of these species and excessive thickening of Park plantings, which causes high intraspecific competition and, as a result, a high drop-off among young and ripening trees. The same can be said about the state of plantings of Robinia pseudoacacia, which are dying off en masse due to overripe age. Therewith, this breed is represented by a large number of viable young renewals and undergrowth.

The oaks identified in the park are in good condition, both local common and introduced

Northern (Red), walnuts – common and black. The predominant type of dendroflora of the park is common ash, whose century-old trees are in good living condition and often form an aesthetically attractive crown. Common ash trees, despite their old age and periodic droughts, firmly hold the dominant position (43% of the trees are in good condition, and 35% are in satisfactory living condition) and form a stable viable undergrowth throughout the park.

Examination have established that the condition of pin species is unsatisfactory: Scots pine, black pine, and Weymouth pine trees planted more than a hundred years ago are in a weakened state. The good condition was identified only in one black pine tree, 13% – in an unsatisfactory condition, the rest, although they look satisfactory, but do not show high viability. European spruce trees were also identified in the park, which are in good condition.

The best living condition in the is evidenced by such breeds as common ash, common and Northern oaks, small-leaved and broad-leaved linden trees, sugar maple, Norway, and field maples, Northern white-cedar, black and common walnuts, Robinia pseudoacacia, cherry. The poplars of all species are characterised by the lowest state of vitality which can be explained by their age and the completion of the life cycle, and fruit trees, competing with neighbouring wild trees.

Changes in the appearance of trees, in particular, their trunks, were also investigated for a comprehensive assessment of the Park's tree stands. Deviation from the normal shape of the trunk in forestry practice is considered a flaw (defectiveness). The presence of defect indicates a decrease in resistance, durability, or the presence of plant diseases, which negatively affects the condition of

plantings. Among the tree stands of the park, 800 trees with defectiveness (20% of all trees) were identified. Defectiveness is represented by the following types of changes: trunk curvature (8% of the total number of defective trees), multi-tip (two or more, 62%), hollows and trunk rot (21%), bark scraping

or burns (1%), and other deviations from the norm (8%). Some trees have several types of defects.

The main reason for the removal of trees to the felling in Skala-Podilsky Park is dead wood, in second place – trunk rot caused by the activity of pathogenic fungi (Table 3).

Table 3. Register of reasons for removing trees from plantings in Skala-Podilsky Park

No.	Reason for removing the tree	Number, pcs.	%
1	Dead wood	192	20
2	Trunk rot	181	19
3	Oppression	165	17
4	Thickening of the stand	99	10
5	Crown drying	84	9
6	Trunk tilt (risk of falling)	79	8
7	Dry top	80	8
8	Broken top	45	4
9	Trunk cancer	27	3
10	Bark damage	17	2
	Total	969	100

Almost 10% of the total number of trees have a dry top, which substantially affects the decrease in the viability and decorative effect of these specimens. The most common tree species with dry tops are poplars, elms, firs, ash trees, and maples.

Conclusions

The results of a study of green spaces in Skala-Podilsky Park showed the presence of 63 taxa of trees, shrubs, and lianas in it. Analysis of the living state of phytolandscapes of the research object allowed establishing that the overall indicator of the relative living state of plantings is 57.7% and corresponds to the category “weakened”. Among the woody plants of the park, 800 trees with defectiveness (20% of all trees) were identified. According to the assessment of the phytosanitary condition of trees and shrubs,

41% belong to the category of “satisfactory”, 34% – “good”, 25% – “unsatisfactory”. Consequently, a quarter of the registered trees require health-improving measures or removal from plantings and require urgent regulatory measures to improve their vitality and decorativeness.

It is advisable to conduct work on restoring its aesthetics, performing environmental and social functions, creating stable and artistically attractive landscape compositions, etc. to improve the overall condition of the park.

In general, the conducted research gives grounds to draw conclusions about the importance of systematic accounting, examination, and inventory of ancient parks in Ukraine, and the introduction of a system of their geoinformational monitoring to streamline and revitalise them.

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Оцінка стану зелених насаджень парку-пам'ятки садово-паркового мистецтва загальнодержавного значення «Скала-Подільський Парк»

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Анотація. Зелені насадження старовинних парків є не тільки важливим екологічним компонентом середовища проживання людей, а й культурно-історичним фактором національної ідентичності. Історія садово-паркового мистецтва Тернопілля демонструє тісні зв'язки української культури з польською, литовською та західноєвропейською. Галичина багата на архітектурні пам'ятки минулого: фортеці, замки, оборонні вали, двори, фортифікаційні споруди, укріплені монастирі і храми, маєтки і садиби місцевої шляхти. Біля таких споруд було заведено закладати декоративні парки, фруктові сади, колекції лікарських рослин. Більшість старовинних парків через буремні історичні події у XX столітті зазнали значних негативних змін, однак деякі об'єкти, нехай у занедбаному стані, збереглися і потребують відновлення та догляду. Скала-Подільський парк-пам'ятку садово-паркового мистецтва загальнодержавного значення було закладено наприкінці XVIII ст. В подальшому парк неодноразово реконструювали. За цей час тут було акліматизовано багато декоративних і плодово-ягідних дерев та чагарників, зокрема екзотичних. За період незалежності України не проводили належний догляд за насадженнями, що призвело до руйнування інфраструктури парку та зменшення кількості цінних таксонів. Із метою організації території та реконструкції парку-пам'ятки проведено таксаційну інвентаризацію його дендрофлори, визначено життєвий і фітосанітарний стан дерев і кущів за шкалою Алексеева. Виявлено 63 таксони дерев, кущів і ліан. Встановлено, що загальний показник відносного життєвого стану насаджень парку становить 57,7 % і відповідає категорії «ослаблений». Серед деревних насаджень парку виявлено 800 дерев із фаутністю (20 % усіх дерев). За оцінкою фітосанітарного стану дерев і кущів 41 % належить до категорії «задовільний», 34 % – «добрий», 25 % – «незадовільний». Отже, четверта частина облікованих дерев потребує проведення оздоровчих заходів або видалення з насадження. Отримані матеріали свідчать про необхідність проведення обліку і інвентаризації усіх старовинних парків України та розроблення системи їх геоінформаційного моніторингу з метою впорядкування ревіталізації

Ключові слова: інвентаризація дендрофлори, фітоландшафт, санітарний стан дерев, раритетні дерева

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Theatre and Amphitheatre as Structural Elements of Historical Parks, Gardens, Garden-Park Ensembles of 17th-20th Centuries

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Abstract. Theatre as a place for spectacles is a form of manifestation of public consciousness, a means of ideological and aesthetic education of the population. The theatre reflects the specific features of the development of society and is connected with its culture. In different periods, people sought to harmoniously combine nature and culture, so green theatres and other similar scenes always reflected the tastes and fashion of a certain era. The history of the development of garden theatres in European countries, in particular, in Ukraine, is examined. Types of theatres on the territory of historical gardens, parks, estates, palace and park complexes, garden-park ensembles of Europe and North America of the 17th-20th centuries are investigated. The study describes the history, evolution of development, and differences in the main types of such theatre structures. The prerequisites for the emergence and popularisation of theatres in open space are clarified. Based on the conducted research, a typological systematisation and definition of a garden theatre (amphitheatre) is proposed. Garden theatres are types of theatres (forest, landscape, green, air, water, summer, stone, mechanical, palace) and amphitheatres (stone, palace) located on the territory of gardens, parks, garden-park ensembles. They can be open (mostly summer, temporary) or closed (permanent), combined (have features of open and closed theatres). On the territory of gardens, parks, garden-park ensembles, several types of theatres can be located, a theatre and an amphitheatre; an amphitheatre can be part of a theatre. A comparative analysis of green, water, and other theatres is given. The characteristic features of the location of green, water, air, etc. theatres in the planning structure of the investigated objects, in particular, elements of topiary art and the assortment of plants, are identified

Keywords: water theatre, green theatre, garden theatre, outdoor theatre, summer theatre, air theatre

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Introduction

Landscape art reflects the cultural and social needs of society (Semenova-Prozorovskaia, 1998). From the end of the 18th – the beginning of the 19th century, the theatre becomes part of the sociocultural process in various forms and ways of mastering it by the audience, the theatrical repertoire reflects the ideological and ethical orientation, political, and spiritual content of the era. Theatrical art as a form of multi-level synthetic artistic communication rises to a high level of development, and the value of art increases (Kireeva, 2015). A mandatory component of a theatre structure that harmoniously combines the nature, architecture of buildings, and stage-and-spectator space of the created object is the environment, urbanised or historical landscape space (Proskuriakov & Humeniuk, 2018).

In the 17th-18th centuries, garden theatres appeared as theatre halls with a natural stage from an earthen mound and wings (Boboli Gardens in Italy, Versailles gardens in France, Lazienki island gardens in Poland, etc.), which were located in the side parts of the garden inside the bosques. The auditorium consisted of wide steps, mostly in the form of a semicircle. The interior of the stage and auditorium, backstage areas, steps and offices were arranged with molded hedges and trellises, with sculptures and fountains (Polish Encyclopedia, 2021). Garden theatres, bosquettes, garden halls, stalls, trellises, alleys, bulengreens, mazes, garden sculpture, swimming pools, and fountains were characteristic elements of baroque landscape compositions (Kucheriavyi, 2008).

Until the middle of the 17th century in Russia, the estate served for utilitarian purposes, church buildings were artistic accents that met aesthetic needs. The development of international relations and an active social life led to a change in the nature of the use of estates and their planning. Theatres as an entertainment element on the territory of parks began to be arranged in the 1660s (Semenova-Prozorovskaia, 1998).

Since the 16th century, the green theatre (teatro di verzura) has become a typical element of Italian gardens. Real open-air theatres were built (during the period of fashion for theatrical performances as entertainment at court), which were arranged from plants (wings and other theatrical elements were created from molded hedges made of

Buxus sempervirens L., scene – from the raised lawn and decorated with statues that may have referred to the themes of comedy and tragedy, in particular, commedia dell'arte (Theater of greenery, 2021)).

In Ukraine, in Volhynia, the first mention of the theatre occurs in the 16th century (Proskuriakov & Sinkevich, 2013). At the beginning of the 18th century there was an increase in the number of architects from Western European countries, mainly from France, who influenced the development of palace and park architecture at the Polish-Lithuanian Commonwealth. (Rychkov, 2019). In the 18th century, the Lubomirski Princes (owners of Rivne) laid a park in the city on the south side of the palace, on the territory of which there were alleys, stone statues, gazebos, imitations of the ruins of gothic buildings, an arena and a temporary theatre (the acting troupe consisted of gifted serfs) (Proskuriakov & Sinkevich, 2013). Rychkov (2019) notes that metal railings were installed on the roof of the “undefined building” (Vue de la Meterie), along the facade perimeter, so perhaps the princely family and their guests gathered at the top of theatrical performances and other open-air entertainment. The performances took place in a semicircular cour d'honneur.

In Latvia, the first open mass song theatre was built in the city of Riga in 1880. The spread of construction of large outdoor theatres of mass amateur performances began in the 1920-1930s in the parks of culture and recreation (PCR). It was a new socialist type of park, urban or district, cultural-educational institution in the open air among plantings; purpose – mass recreation, holding political and educational events, sharing experience, cultural entertainment. Some PCRs were created based on manor and other historical parks (Verhunov & Horokhov, 1987). Open theatres were successfully combined with the natural environment (relief, vegetation, water expanses were used to create architectural ensembles) (Bykov, 1954).

Summer, open, landscaped theatres have advantages over conventional closed-type theatre structures: they allow to combine spectacles with recreation in a natural environment (Proskuriakov & Humeniuk, 2013). According to Shyrochkova (2018), amphitheatres have gained popularity in the public spaces of Russian cities over the past 20 years.

In the 20th – early 21st centuries, interest in open theatres in parks, gardens, and other public places did not disappear, during this time a study of various types of theatres in European countries and North America was conducted. At the beginning of the 20th century Waugh (1917) researched the use and design of outdoor theatres in parks in North America and Europe. In the 1950s Bykov (1954) analysed the architecture of open theatres in parks, the composition of premises, the organisation of the stage, the arrangement of the amphitheatre, developed a classification of open theatres. In the 1990s Fagiolo, Giusti & Cazzato (1997) reviewed the features of water theatres in the baroque style, the development and distribution of green theatres. At the beginning of the 21st century Humeniuk (2019) investigated the development of the architectural typology of landscape theatres in modern Ukraine. It highlights the genesis of open theatres from ancient times to the present; examines and systematises the factors influencing the development of the architecture of theatres of this type. The architectural typology of landscape theatres is improved; modern principles and means of architecture of open theatres are defined. Grant (2007) investigated the oldest garden theatres in Italy using the example of gardens near the city of Lucca. Deguen & Thuillier (2015) conducted an inventory of green and water theatres, reviewed the genesis and evolution of green theatres, and identified the difference between a green theatre, an open-air theatre, and a garden theatre on the example of parks in France and in the world in general.

Proskuriakov & Humeniuk (2013) note that the creation of theatrical and entertainment structures (open theatres in the landscape) of a new architectural and social level is possible if the experience of the past and the problems of designing the present are considered. Amphitheatres appear in projects of new public spaces not only as a result of utilitarian needs, but also as a symbol of modern public space (Shyrochkov, 2018).

Thus, now there is a need to identify which types of theatres and amphitheatres are concentrated on the territory of gardens and parks of the 17th-20th centuries, to clarify the terminology for the purpose of their typological systematisation.

The purpose of the study is to analyse the types of theatres and amphitheatres on the territory of historical gardens, parks, manor, palace-and-park complexes, garden-park ensembles in Europe and North America of the 17th-20th centuries; to develop a typology of garden theatres.

Materials and Methods

Theoretical methods of research, analysis, synthesis, comparison, and generalisation of the obtained information based on professional literature and theoretical publications are applied. The theoretical material is summarised, varieties of theatres and amphitheatres for three centuries are identified and analysed, comparisons are made, and common and distinctive features of garden theatres and amphitheatres are established. The typology of garden theatres is developed and the corresponding terminology is systematised.

Results and Discussion

Theatre (translated from Greek – a place for entertainment) as a phenomenon is an integral part of national development (Proskuriakov & Sinkevich, 2013). It is a form of public consciousness, a means of ideological and aesthetic education of the masses. The theatre reflects the specific features of development, ideals, and contradictions of society, and is closely related to its culture (Ukrainian Soviet Encyclopedia, 1983).

Since the middle of the 17th century with the development of scenography and theatrical architecture, open-air scenes, green theatres, and amphitheatres, places for spectacles were created in the gardens (Deguen & Thuillier, 2015). Over a long historical period in European countries, ensembles were formed (a spatially and functionally connected set of architectural structures, topography, vegetation, reservoirs, and other elements of the landscape that make up an integral architectural and artistic composition), through gradual development and addition or in the process of one-time construction. The main principles of the ensemble are the presence of an ideological and artistic idea, coordination of proportions, rhythm, subcontracting main and secondary elements, the use of aesthetic qualities of the local landscape, and the possibility of audience perception of the overall

three-dimensional composition. Palace-and-park complexes are large, historically formed ensembles with a palace, park, economic, and religious buildings (Verhunov & Horokhov, 1987). Parks are large (usually more than 10-15 hectares) green areas, landscaped and artistically designed for outdoor recreation. In the 18th century, a natural grove or a section of forest with picturesque alleys, clearings, ponds of free outlines, gazebos, and sculpture were called a park. Verhunov & Horokhov (1987, 2007) note that parks are now considered as an important element of the citywide system of landscaping and recreation; they perform health, cultural-educational, aesthetic, and environmental functions.

There are ancient parks (parks-monuments) that have memorial-historical, architectural-artistic, scientific importance and are subject to protection and restoration by methods of conservation, restoration, or reconstruction, and manor parks that are historically formed at a city or country estate. The ensemble of the latter usually consists of the main house, residential outbuildings, ponds, orchards, etc.; they have a smaller size compared to the palace-and-park complex. The Historical Park as an example of the culture of park construction of the past (until the middle of the 20th century) is protected by the state even if it is partially preserved (Verhunov & Horokhov, 1987, 2007). The theatre and amphitheatre are components of an ensemble of park, entertainment, and spectacle structures harmoniously combined with the natural elements of the landscape (Kucheriavyi, 2008).

Garden is a plot with cultivated plants, a landscaping object with an area of at least 5-10 hectares, occupied by plantings of trees and shrubs, alleys, lawns, flower beds, and small architectural forms. It usually has a stage, playgrounds, childrens sector, reservoirs; it is a certain planning composition. The garden is designed for short-term recreation. The landscape of the garden is usually man-made, anthropogenic in nature. For historically formed gardens, straight alleys, parterres, terraces, and direct connection with the house (palace, manor) are typical (Verhunov & Horokhov, 1987, 2007).

For Italians, the garden was an extension of housing. For the French, the garden was turned into a "city" (for example, in Versailles) with streets and alleys, star-shaped alleys, galleries, theatres, bosques, halls, offices. Music concerts, theatre performances,

dances, and games were held in green halls (Kucheriavyi, 2008). In incomplete bosquets (moulded walls with a lawn inside), a green theatre, a maze, reservoirs, fountains, and flower beds were arranged (Verhunov & Horokhov, 1987; Kucheryavy, 2008).

In Russia, in the 18th century, the green theatre developed, forming around itself an energy field of spiritual communication, dialogue between the public and the stage, and an independent artistic communicative field. Theatre room types have also been formed (Kireyeva, 2015). In Ukraine, Volhynia in the 19th – early 20th centuries there was the largest number of private towns, where magnates staged performances in private summer gardens. For example, in the city of Zhytomyr (Zhytomyr Polesia), theatrical performances were held at the Khoroshansky summer theatre (Proskuriakov & Sinkevich, 2013). In the city of Tuchyn (Volyn Polesia), in Tuchynsky park (now a monument of landscape art) at the beginning of the 19th century, voivode M. Valievsky built a small theatre in the garden, where performances and concerts were held, mainly on the occasion of the birthdays of family members and other anniversaries (Andrzejowski, 1861; Aftanazy, 1994). At the end of the 19th century – in the first half of the 20th century, most county towns had one specialised theatre and several adapted premises, and summer theatre venues (located in parks and private estates) (Proskuriakov & Sinkevich, 2013). In particular, in the village of Kopylov (Kyiv Polesia) on the territory of the estate of Baron M. von Mecca (now a park – monument of landscape art "Kopylovsky") at the end of the 19th century a special theatre was arranged in the garden (Meck, 1973; Dzyba & Shchebuniaieva, 2017). In the city of Lutsk in 1916, a wooden summer theatre "Lubarts Castle" was built in the castle itself, where live pictures (a prototype of electric theatres) were shown (Proskuriakov & Sinkevich, 2013).

The desire to harmoniously combine nature and culture was inherent in all historical periods. Green theatres have always reflected the tastes and fashion of a particular era. These were cosy offices and huge amphitheatres, grandiose and minimal, simple scenery, refined venues for performances using the latest technologies (Deguen & Thuillier, 2015).

Thus, for 300 years, theatres were organised in gardens, parks, palace-and-park complexes and ensembles, which, depending on the period of creation,

had different functions and meanings. The garden theatre was originally a characteristic element of the baroque gardens of Italy (as the treatises state “Dezaillier dArgenville” the Encyclopedia “Diderot and dAlembert”) and over time, it spread in various forms in the gardens of France, Germany, England, and other countries (Grant, 2007).

According to Kucheriavyi (2008), Majdecki (2010), the baroque outdoor garden theatre was more like a palace theatre than an antique amphitheatre. The stage was slightly raised and looked like a wide semicircle separated from the audience by a ramp. Behind the stage, fenced off by high curtains were the actors offices. The walls were decorated with figured wallpaper, sculptures were installed in niches (Kucheriavyi, 2008).

The Renaissance and baroque garden mediates some elements of the theatrical typologies of antiquity with a special form of theatre, namely green theatre. Stage metaphor and topiary virtuosity are used to interpret plants as theatre architecture (The theaters of greenery, 2021).

The concept of green theatre appears in the 17th century (Deguen, 2013). Giovanni Battista Aleotti in 1606 first proposed such a version of the theatrical structure (Grant, 2007). The term “green theatre” in dictionaries and architectural manuals appeared only in the 19th century (The theatres of greenery, 2021). According to the definition given in the Methodological dictionary of the garden of Marie-Helene Benettiere, the green theatre is an architecture created entirely or partially from plants, with a parterre or stands in front of a stage in a park, garden, or forest; usually an open space that is used during the summer season. The dictionary of ancient and modern architecture of Aviler (1782-1832) states that the garden theatre is an elevated terrace, which is decorated with a perspective from alley plantings of trees or gazebos for pastoral play; an amphitheatre, which is located opposite the terrace and has a staircase made of lawn or stone; the lowest space between the theatre and the amphitheatre is occupied by the ground floor (Deguen, 2013).

The green theatre is a structure designed for outdoor performances, which is arranged in parks and gardens using natural terrain. As a wall, a fence made of hedges or climbing plants on special supports or frames is used (Verhunov & Horokhov, 1987; Yakovlieva-Nosar, 2009; Terms and concepts used in

landscape architecture, 2021). Hedges vary in size, but are mostly unchanged in shape: it is a raised area of lawn with flat wings, with straight curtains made of moulded hedges (Grant, 2007). Humennyk (2015) adds that a green (park) theatre is a complex of theatre buildings where green spaces or ornamental vegetation are used as structural and spatial planning components of the entire structure (cultural-entertainment complex). By another definition, a green theatre (Theatre de verdure) is a landscape that is artistically designed with plants, enabling open-air performances (comedy, dance, music, etc.) (National Center for Textual, 2012). The arrangement of green theatres in many European cities became widespread in the 1920s-1930s and 1950s (Deguen, 2013).

Green theatres in Italy were concentrated around theatre academies. Some of the first were theatres with hedges in the gardens around the city of Lucca, which were arranged as halls for performances by representatives of literary academies (Grant, 2007). In green theatres, the space and action of theatrical dialectics are reversed. The space is visualised ephemerally, it is created from living plants that change over time, while the theatrical action is immortalised in sculptures of mythical heroes located on the sides of the stage, placed in niches in the background (Villa Marlia, Garzoni) or in zropylaea-kiosks (Villa Bianchi Bandinelli, Geggiano). The show is not a necessary event. Such a theatre is primarily an object of Arts Topiary. Wings are an element that puts it in close relationship with theatrical illusionism, which, however, precisely because of the dynamism inherent in the substance of the living matter, does not respond to the real movements of stage art (The theaters of greenery, 2021).

In the Garzoni Garden in Koloda (Italy), a small green theatre on the edge is a kind of synthesis of the garden space in general. In the lower part of the garden, there is a mixed linear layout, which may be due to the evolution of theatre halls. There is a relationship between the lower part and the upper part, as between the stalls and the stage. The presence of two satyrs, which are depicted as pillars of an illusory arch with a water theatre in the centre, which is dominated by Glory, confirms the character of the scene as satirical in the Vitruvian style (The theaters of greenery, 2021).

Villa Reale Park is the most ancient ensemble with a single elliptical system of halls, bounded by a

green corridor (The theaters of greenery, 2021). The park is divided into three gardens of different eras: the baroque garden (second half of the 17th century, Giardino all'italiana style), the romantic park and the deco garden, built in the 1920s (Villa Reale di Marlia, 2021). At the end of the 17th century, a grotto, water, and green theatres were created in the park.

Green theatres are also typical in Russia. In particular, in 1830, a green theatre for 1,500 spectators was built in the Neskuchny garden. The stage was a clearing, behind the curtains – trees and shrubs (Pluzhnikov, 1995; Verhunov & Horokhov, 2007). The theatre lasted until 1835 (Semenova-Prozorovskaia, 1998).

One of the varieties of the Green theatre is, in our opinion, vertyugaden – a terraced park elevation with a semicircular staircase (like an amphitheatre) and a moulded green wall (Pluzhnikov, 1995; Tymofienko, 2002; Verhunov & Horokhov, 2007; Kurbatov, 2008). It was used to view park prospects, delineating, and accentuating the space (ground floor, pool), and as a green theatre for performances played against the background of a formed green wall; was decorated with sculptures and topiaries (Tymofienko, 2002, Verhunov & Horokhov, 2007, Kurbatov, 2008).

The green theatre in the gardens of Gerenhausen (Germany) was established in 1689-1692. It has a rectangular stage (size 62×58 m²), which gradually narrows and rises in the far part, creating a perspective effect. On both sides of the stage, live hedges are created of *Carpinus betulus* L. for the background and changing room, in front of which are placed gilded lead figures and moulded pyramids with *Taxus baccata* L. The auditorium (for 500 visitors) is formed in the shape of an amphitheatre (Fig. 1). The theatre serves as a place for theatrical and dance performances.

The green theatre in the Mirabel Gardens palace-and-park ensemble (Austria) is located along the western side of the small stalls. It was built between 1704 and 1718. The walls and wings are formed from *Carpinus betulus* L. Performances, concerts, and festivals are held here (Fig. 1).

The green theatre in Liashky Murovany in Ukraine was established in 1734 in the southern part of the park outside the castle (Fig. 1), but it has not been preserved to this day.

The green theatre of the Rundal palace-and-park ensemble in Latvia (architect F. Rastrelli) had the shape of an amphitheatre. After the renovation, 600 spectators are placed in raised rows in the form of stairs covered with lawns. The backstage area is formed from *Carpinus betulus* L., along the perimeter of the theatre grows a moulded hedge with *Carpinus betulus* L. and free-growing *Picea abies* (L.) H. Karst. creating good acoustics. Two pavilions were built on the territory of the theatre.

Green theatre in the garden of the Fightsgeheim Palace (Germany) was created as a decoration in 1767-1768. The proscenium is placed on a raised platform surrounded by six pairs of curtains formed from *Carpinus betulus* L. (Fig. 1). On the stage, in front of each backstage, there were colourful, bright figures of “actors” made of sandstone. It was an improvisation of the Italian “play-comedy” del arte. In the western part, the theatre is separated by the trellis of *Picea abies* (L.) H. Karst.

The green theatre in the gardens of Villa di Giagiano was established in 1768 for performances. It is located in the southern part of the garden at the end of Piazzone square, which is located parallel to the front of the building, where there is a parterre bordered by a curb with *Buxus sempervirens* L. and *Citrus limon* (L.) Osbeck. in containers. The theatre is slightly raised, and the curtains are formed from high moulded hedges of *Laurus nobilis* L. in the foreground and a moulded living wall of *Cupressus sempervirens* L. – on the far side. The proscenium consists of two late baroque prosceniums, which are represented by double arches topped with triumphal pediments with the coats of arms of the Bandinelli and Zondadari families. Statues of Tragedy and Comedy by the Maltese sculptor Bosio are installed in the niches of the arches. Parallel to the green theatre there is a long alley with *Cupressus sempervirens* L. and *Quercus ilex* L. which leads to the entrance gate (Villa di Geggiano, 2021).

The following types of theatres, located in historical gardens, parks, palace-and-park ensembles and complexes are not widely spread: mechanical, stone, water, palace, air, Sylvanian, landscape. Grant (2007) believes that the water (teatro dacqua), green (teatro di verzura) (formed from hedges), and palace (teatro avanti il palazzo) theatres are varieties of garden theatre, which the study also agrees with.

Name and period of creation of the theatre	Plan of a garden, park, or garden-park ensemble (Google Maps)	Plan or image of the theatre
Green theatre and amphitheatre stage, Gerenhausen gardens, Germany. Architect M. Westerman, 1689-1692., reconstruction of 1974		
Green theatre, Mirabel Gardens palace-and-park ensemble, Austria. Architect L. von Hildebrandt, reconstruction –architect P. de Nobile, 1704-1718		
Green theatre. Liashky Murovany castle park, Ukraine. Architect G. Klein, 1734		
Green theatre and lawn amphitheatre. Rundal palace-and-park ensemble, Latvia. Architect F. Rastrelli, gardeners K. and M. Weiland, 1736-1740 Reconstruction of 1985-2004 Reconstruction project – Giproteater institute, 1977		
Green theatre, garden of Feitsheheim Palace, Germany, 1767-1768		
Green theatre, Gardens of Villa di Giagiano, Italy, 1768		

Figure 1. Types of theatres on the territory of gardens, parks, garden-park ensembles of the 17th-19th centuries

In 1750-1753, a mechanical theatre was created in the park of the Hellbrunn residence (near Salzburg, Austria) on the instructions of Archbishop Andreas Jakob von Dietrich to entertain guests (Fig. 2). This is a stone scene, where 256 wooden figures move using a hydraulic drive, depicting ev-

eryday scenes of a medieval city to the sounds of a water organ. There are many quaint grottoes and turntable fountains around the theatre (Helbourne, 2021). This is the oldest open-air stage in Europe, which still hosts concerts and theatrical performances (The Stone Theater, 2021).

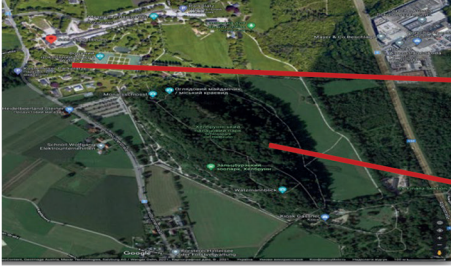
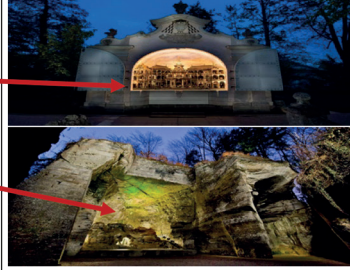

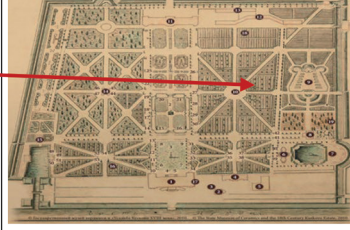

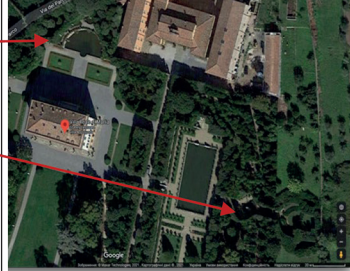


Name and period of construction of the theatre	Plan of a garden, park, or garden-and-park ensemble (by Google Maps)	Plan or image of the theatre
Mechanical theatre, Hellbrunn Palace Complex, Austria, 1752		
Air theatre, architectural-park ensemble, Kuskovo estate museum, Russia, 1760.		
Water and green theatres, Villa Marlia, Italy, 17th century.		
Chinese theatre in bosquet. Tsarske Selo State Museum-reserve, Alexandriysky park, 1778. Architects A. Rinaldi, I.V. Neielov		

Figure 2. Types of theatres in gardens, parks, garden-and-park ensembles of the 17th-19th centuries

The Stone opera Chinese theatre is located in the bosquet of Alexandria Park (Tsarske Selo State Museum-reserve). The project was developed in 1778 by architect A. Rinaldi, construction took place

under the direction of I.V. Neielov. The building had European features; the architectural forms and exterior decor of the theatre were quite simple. The interior was magnificent. The central ledge, stage

portal, and ceiling lamp were decorated with images of the Chinese people, dragons, shields with zodiac signs, and other elements of oriental decor. In the central imperial and two side grand ducal ledges, there were authentic works of Chinese art: decorative lacquer panels, porcelain, and furniture. In 1902, electric lighting was installed in the theatre. In 1908-1909, the building was completely renovated (architect S.A. Danini), the stage of the 18th century was reconstructed for staging major opera and ballet performances. The improved heating system allowed to use the summer theatre throughout the year. In 1941, the theatre partially burned down (Chinese Theater, 2021).

Water theatre is a hybrid form of green theatre (Deguen & Thuillier, 2015). It usually has fountains, statues, waterfalls, mosaics, and the final axis of the tufa exedra (National Centre, 2012), one or more water alleys decorated with sculptures, vases to form various decorated perspectives for performances, concerts, parties, balls.

One of the first water theatres was held at Villa Aldobrandini in Italy. It was the main compositional node of the garden. It has a semicircular wall with tufa grottoes and statues, above the wall, the living walls of *Cupressus sempervirens* L. grow. Behind the wall, the hill rises sharply up, and a cascade flows from above between two columns, which begins in the alley of *Cupressus sempervirens* L. and after two tufa dams, it falls to the theatre. That is, the upper part of the garden is connected by cascades, and the lower part is connected by alleys directed to the decorative facade of the palace (Kurbatov, 2008).

The exedra-shaped water theatre is part of the 17th-century architecture of Villa Reale di Marlia park (Italy). The main waterfall is located inside an artificial cave created from stones and limestone deposits. High on both sides, between the water jets, there are two zoomorphic sculptures: a lion and a panther. The entire composition is fenced with high hedges made of *Quercus ilex* L., *Laurus nobilis* L. Below, water flows through five stone masks and pours into small three-bladed bowls. Then it flows into a large semicircular pool, from where it spreads into fountains and canals, using the force of gravity to descend to the lake in the park (Villa Reale di Marlia, 2021).

The air theatre was established in 1760 in the eastern part of the park of the architectural-park ensemble "Museum-estate of Kuskovo" (Russia).

The theatre consisted of a turf amphitheatre (three semicircular benches with a passage in the centre) for 80-100 spectators and a stage platform made of lawn. The amphitheatre was located to the south of the stage, so the performance area had sufficient sunlight. The stage, located on a 1.5 m high embankment, was bordered by a bosquet of *Betula pendula* Roth. A living wall was formed around the bosquet of *Berberis vulgaris* L. Six paired wings served as a trellis with *Picea abies* (L.) H. Karst. which provided excellent acoustics. During the performances, the stage was covered with wooden flooring. The musicians were placed in the orchestra pit, which was hidden by a flowerbed on the side of the auditorium. The changing rooms for the actors were two round towers made of moulded living walls (Fig. 2) (Air theater, 2021).

The air theatre also operated in Pavlovsk park in the suburbs of St. Petersburg from 1811 (architect A.N. Voronikhin). The theatre was open, the stage a small rise from the lawn among the free-growing trees. The wings were created from moulded hedges of *Caragana arborescens* Lam. against the background of wooden trellises. The seats for the audience, located in the amphitheatre, are made of earthen steps covered with turf. As a perspective, the general upper outline of trees in a group or array (clearly defined, cut, blurry, etc.) was an overhead line (Verhunov & Horokhov, 1987; Pluzhnikov, 1995).

The Sylvanian (forest) theatre is an open type of theatre located in the forest, often decorated with classical columns and statues. Built-in benches can be covered with a lawn, there are complex compositions of shrubs and herbaceous plants (Waugh, 1917). Founded in 1910, the forest theatre in Carmel-by-the-Sea (California, USA) is the oldest outdoor theatre west of the Rocky mountains. The initiator of its creation was the writer G. Geron. The theatre was set up on a concave hillside facing out, surrounded by pine and oak stands. The stage and seating benches were made of wood. The theatre was created for performances where the actors were local residents of the community (Forest Theater, 2021). Also famous is the green theatre in Shakespeare's garden in the Bois de Boulogne (France), around which grow the species of plants mentioned in the works of the playwright (Deguen, 2013). Landscape theatre – a theatre structure that is harmoniously combined with the relief and landscape

features of the surrounding area (Humeniuk, 2015, 2019). It can be located “on land” or “on water”; a theatrical performance (large orchestral concerts, folk and music festivals, mass choral performances) can be watched by many spectators (Proskuriakov & Humeniuk, 2014).

A summer theatre is a seasonal theatre structure that operates only during the warm season (mainly in summer) (Proskuriakov & Humeniuk, 2013, Humeniuk, 2015). Such theatres are mainly intended for touring performances, and concerts specially staged in natural and architectural environments (Bykov, 1954; Humennyk, 2015). They can be placed in parks, gardens, or wooded areas. There are summer concert theatres (1000-1500 seats), natural theatres (2000-3000 seats), and historical-architectural theatres. It is also possible to combine the summer theatre with a year-round theatre (an open amphitheatre with a year-round theatre; an open amphitheatre on the roof of the city hall; an open amphitheatre with a closed dance hall; several amphitheatres). They place such theatres in the green zone. According to the degree of openness, summer theatres are divided into open, indoor, and closed (Losieva, 1990).

The palace theatre is a closed-type theatre that operates throughout the year on the territory of palace-and-park complexes and ensembles, mainly in their entrance part (puppet theatre of the Schönbrunn Palace, Austria). Schönbrunn Palace, 2021); theatre in the eastern part of Brussels park, established in 1782, etc.).

An amphitheatre in ancient roman architecture is a spectacular structure in the shape of an ellipse with stepped rows of seats. Italian Renaissance gardens are characterised by the arrangement of amphitheatres as the completion of the flat part of the garden with a semicircular wall of stone or moulded plants, which usually ended with a stepwise slope. The stone walls were decorated with niches with sculptures and a balustrade (Bohovaia & Fursova, 1988). In the 17th-18th centuries, amphitheatres began to be built in parks as decorative structures for entertainment events (Verhunov & Horokhov, 1987; Kurbatov, 2008; Terms and concepts, 2021). Levshyn (1805-1808) noted that the amphitheatre is a structure for a spectacle, located on the slopes of hills of small steepness, ledges are created in several rows in a semicircle, curving outside or inside, which are

reinforced with timber and covered with turf, decorated with moulded trees, green walls, vases; stairs are created from stone, wood, or lawn. At the end of the 18th century, trees were planted in the form of an amphitheatre (“Chinese grove” in the Sheremet-yevo estate in Moscow) (Verhunov & Horokhov, 1987; Pluzhnikov, 1995). In Baroque parks, an amphitheatre was the semicircular end of a square located opposite the palace (Kurbatov, 2008).

Regular amphitheatre garden in Boboli Gardens (Italy) in 1612-1631 was transformed into an open square for theatrical performances. In the centre of the amphitheatre in 1790, an Egyptian obelisk was installed, which in 1840 was combined with a monolithic bowl of grey granite (Bobolis Garden, n.d., Bobolis Garden, 2021). The amphitheatre looked like half a roman hippodrome, framed by masonry in the form of a staircase of six rows of seats and a balustrade with niches. The amphitheatre hosted Italys first opera performances. In the 19th century, the amphitheatre lost its theatrical function (Bobolis Garden, 2021).

The amphitheatre in the gardens of Versailles (France) was built by A. Lenotre in 1680 in the ballroom. On one side of the amphitheatre was a staircase made of lawn, on the other – a staircase made of limestone covered with shells. Water descended the stairs, forming a cascade. The amphitheatre was created for performances that took place in the arena, the musicians were placed above the cascade (Peruz de Monclo, 2006).

The amphitheatre in Claremont park (England) was designed by C. Bridgeman in 1716, built in 1720-1722 – carved on a hillside with concave and convex terraces. The upper terrace was bordered by an alley of trees in a semicircle, behind which the forest grew. A rounded pond was created at the bottom of the amphitheatre (Fig. 3). In 1738, W. Kent expanded the pond to create a large irregular lake. The lake became the centre of the Clermont garden, and the amphitheatre was more of a decoration and fashionable element of the time. After reconstruction at the end of the 20th century, the amphitheatre was closed to the public (Claremont Landscape Garden, 2018).

The open-air amphitheatre in the palace-and-park complex “Royal Łazienki” (Poland) was built in 1785, in 1790 it was rebuilt according to the project of J.K. Kamsetser (Fig. 3). It consists of two parts: an

auditorium for 950 spectators and a stage separated by a water channel. The amphitheatre was modelled after the Herculaneum theatre. The semi-circular auditorium is based on arcades. It has stone sculptures depicting Aeschylus, Euripides, Sophocles, Aristophanes, Seneca, Shakespeare, Calderon, Racine, Moliere, Lessing, etc. The stage, located on an artificial island, is surrounded by artificial ruins

modelled on the architecture of the Roman forum, as an example of the style of the late 18th century. To the left, behind the stage, there is a one-story pavilion with actors dressing rooms. There is a place for an orchestra between the stage and the canal. During the performances, a moat was also used (Amphitheater in the Royal Łazienki, 2021). It serves as a venue for performances to this day.

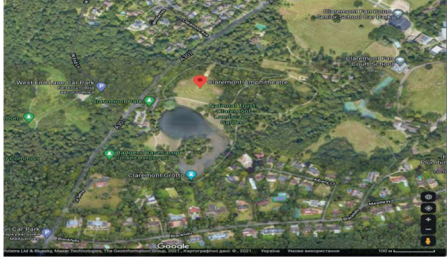
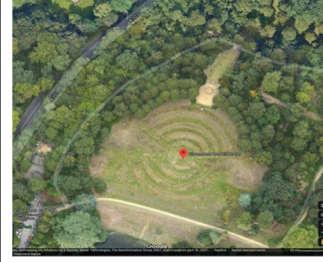
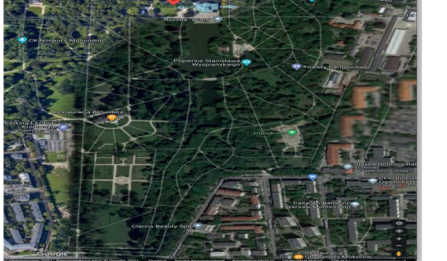

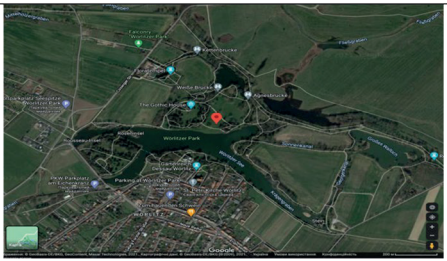
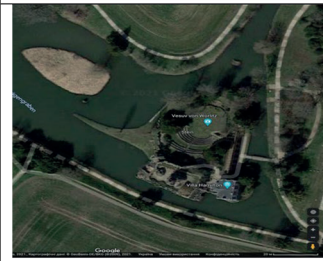
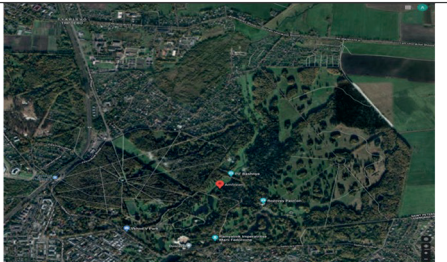
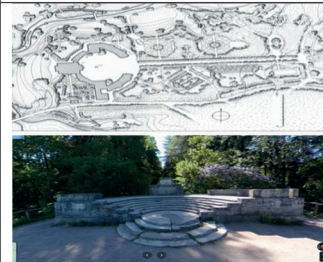
Name and period of construction of the amphitheatre	Plan (Google Maps)	Historical plan or image of the theatre
Lawn amphitheatre, Claremont Park, England (1720-1738). Architects C. Bridgeman, V. Kent		
Amphitheatre on the water. Royal Łazienki palace-and-park complex, Poland (1785-1790). Architect J.K. Kammsetzer		
Antique amphitheatre. Garden-park kingdom of Dessau-Verlitz, Germany (1792). Architect F. Erdsmandorf, gardener I. Eiserbek		
Amphitheatre. Pavlovsky Park, Russia (1793). Architect V. Brenne		

Figure 3. Types of theatres in gardens, parks, garden-and-park ensembles of the 17th-19th centuries

The ancient amphitheatre (ruins) was created as a decoration in a landscape park on the Stone island of the Verlitz Lake in the Garden-and-park kingdom of Dessau-Verlitz (Germany) in 1792 (Kucheriavyi, 2008).

During the second stage of development of Pavlovsk Park (Russia) (Pavlovsk State Museum-reserve) in 1793, the architect V.F. Brenna arranged two amphitheatres – stone (Greek model) on the right bank of the river Slavyanka and green (rows of terraces and stairs) on the left bank of the river, as a decoration. The stone amphitheatre was decorated with a white marble statue of the goddess Ceres, which occupied a prominent place in the entire panorama of the right bank (State Museum-reserve Pavlovsk, 2021).

The Longwood garden theatre (USA) (modelled after the design of the open-air theatre of Villa Gori near Siena, Italy) was created by Pierre S. du Pont in 1914 in the southwestern part of the estate in Longwood for concerts and performances. The theatre was an amphitheatre and an auditorium with 1,550 seats, located on a lawn. The stage is two-tiered and is located on a hill. There are walk-in closets under the stage. The curtains around the proscenium are formed in the shape of columns made of *Thuja occidentalis* L. After a renovation in 1927, seven round bowls and nozzles were installed under the removable front stage cover to form a ten-foot water curtain; on the upper level, there are two centre bowls and roof fountains on the wings. Fountains have multi-coloured lighting. The theatre is surrounded by plantings of *Gymnocladus dioica* (L.) K. Koch., *Magnolia × soulangeana* Soul.-Bod., *Taxodium distichum* (L.) Rich., *Tsuga canadensis* (L.) Carrière (Loongwood Gardens Theater, 2021).

Thus, an amphitheatre in historical gardens, parks, manor houses, palace-and-park complexes, garden-park ensembles is a spectacular structure in the form of an ellipse or semicircle, with stepwise rows of seats for spectators, evenly rising ledges

around the stage, arena, behind the stalls or on the side of it. The auditorium area can start immediately from the stage or orchestra pit, or balconies. In parks, amphitheatres often occupy covered natural or artificially formed hillsides decorated with sculptures, moulded trees, and stone walls (Pluzhnikov, 1995; Verhunov & Horokhov, 2007; SBS N. 2.2.-16: 2019; Humennyk, 2019). The functions of modern amphitheatres have expanded somewhat in the urban environment. City amphitheatre is a structure consisting of a large staircase (straight, broken, curved, mixed configuration), designed for spending time outdoors. For a comfortable seat, the height of the steps has to be 45-50 cm. An amphitheatre can also be part of a building or complex of buildings (Shyrchkov, 2018). Shyrchkov (2018) identifies three functions of an urban amphitheatre: a city grandstand (places for observing the landscape or street activity); a recreation area (in addition to the main objects of observation, such as mass events, a new object characteristic of modern developed cities-informal street life); a modern public space focused on substantial prototypes.

Based on the conducted analysis, it is suggested to consider all types and varieties of theatres (green (created from elements of topiary art), air (combining free-growing woody plants with elements of topiary art), water (combining water elements with elements of topiary art), summer, stone, mechanical, palace) and amphitheatres (stone, lawn), which are located on the territory of gardens, parks, garden-park ensembles *garden theatre (amphitheatre)*. They can be open (temporary) or closed (permanent), combined (a combination of open and closed theatres). Forest theatre (created in an array of forest stands) and landscape theatre (open air) are considered separately, and can be either part of garden theatres or separate theatres. The developed typology of garden theatres located on the territory of historical gardens, parks, manor houses, palace-and-park complexes, and garden-park ensembles is displayed in Figure 4.

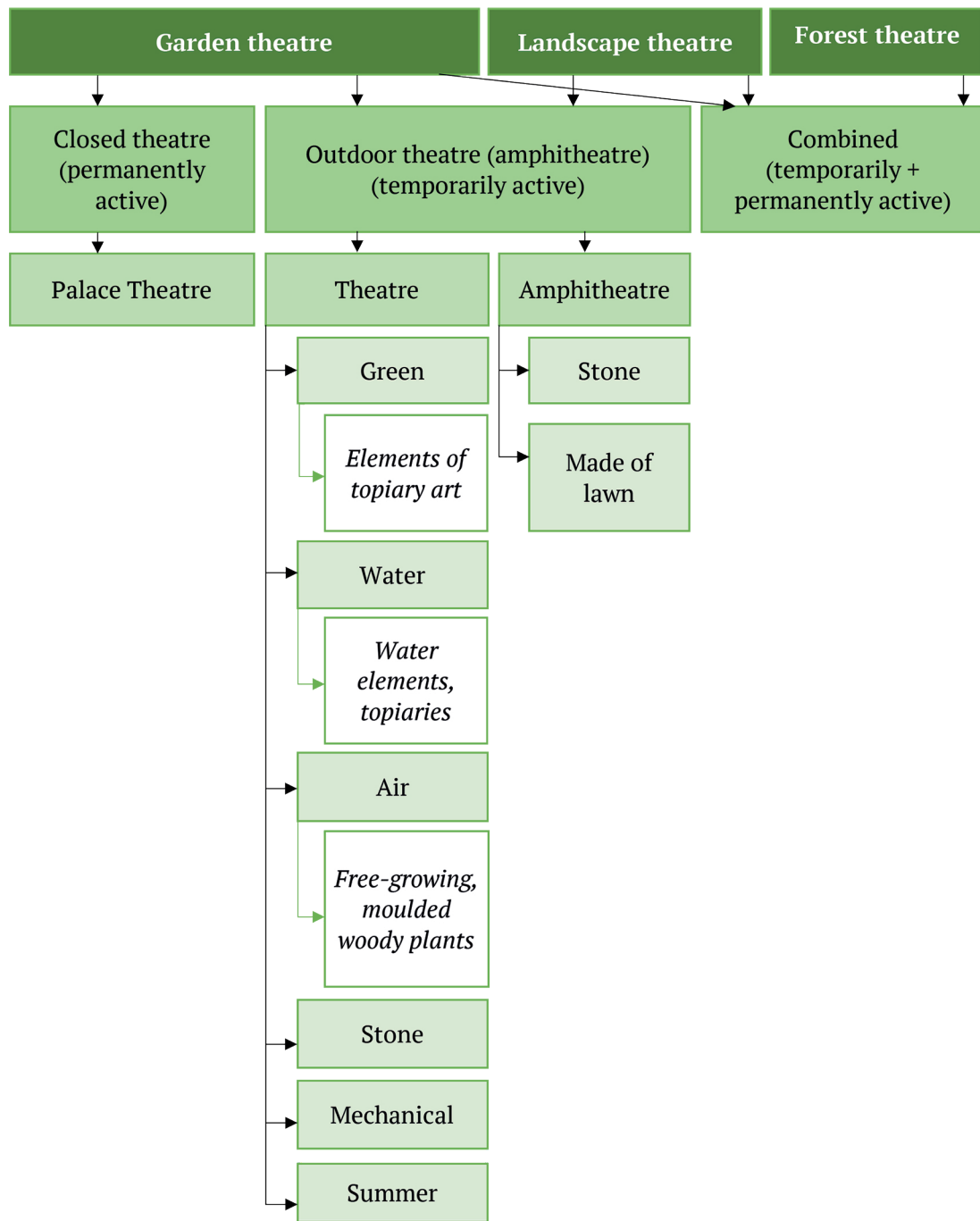


Figure 4. Typology of garden theatres

Conclusions

On the territory of gardens, parks, and garden-park ensembles, the following types of theatres are distinguished: garden, forest, and landscape. Varieties of garden theatre are green, air, water, summer, stone, mechanical, palace. Several types of theatres can be located on the same territory (Hellbrunn Palace Complex and Schonbrunn Palace park, Austria; Villa Marlia, Italy) or theatre and amphitheatre (Rundāle palace-and-park ensemble, Latvia), the amphitheatre can be part of the theatre (Gerenhausen gardens, Germany).

Theatres have different purposes: a place for performances, concerts, festivals, and decoration

(improvisation of performances). For the construction of green theatres, an integral part of water, air, and summer theatres, the following elements of topiary art are used: green walls, hedges, borders, moulded plants, trellises, bosquettes, halls.

Various types of woody plants are used to form elements of topiary art, depending on the climatic conditions of the country. The most common ones: *Picea abies* (L.) H.Karst., *Carpinus betulus* L., *Caragana arborescens* Lam., *Betula pendula* Roth., *Berberis vulgaris* L., *Taxus baccata* L., *Quercus ilex* L., *Laurus nobilis* L., *Cupressus sempervirens* L.

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Театр та амфітеатр як структурні елементи історичних парків, садів, садово-паркових ансамблів XVII-XX ст.

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Анотація. Театр як місце для видовищ є формою вияву суспільної свідомості, засобом ідейного і естетичного виховання населення. Театр відображає особливості розвитку суспільства та пов'язаний із його культурою. У різні періоди люди прагнули гармонійно поєднувати природу і культуру, тож зелені театри та інші подібні сцени завжди відображали смаки та моду певної епохи. Розглянуто історію розвитку садових театрів у європейських країнах, зокрема в Україні. Досліджено види театрів на території історичних садів, парків, садиб, палацово-паркових комплексів, садово-паркових ансамблів Європи та Північної Америки XVII-XX ст. Охарактеризовано історію, еволюцію розвитку та відмінності основних видів таких театральних споруд. З'ясовано передумови виникнення та популяризації театрів на відкритому просторі. На основі проведених досліджень запропоновано типологічну систематизацію та визначення садового театру (амфітеатру). Садові театри – це різновиди театрів (лісовий, ландшафтний, зелений, повітряний, водний, літній, кам'яний, механічний, палацовий) та амфітеатрів (кам'яний, газонний), що розміщені на території садів, парків, садово-паркових ансамблів. Вони можуть бути відкритими (здебільшого літніми, що діють тимчасово), закритими (які діють постійно), комбінованими (мають риси відкритих і закритих театрів). На території садів, парків, садово-паркових ансамблів можуть розміщуватись декілька різновидів театрів, театр та амфітеатр; амфітеатр може бути частиною театру. Наведено порівняльний аналіз зелених, водних та інших театрів. Виявлено характерні особливості розташування зелених, водних, повітряних тощо театрів у планувальній структурі досліджених об'єктів, зокрема елементів топіарного мистецтва та асортименту рослин

Ключові слова: водний театр, зелений театр, садовий театр, відкритий театр, літній театр, повітряний театр

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Organic Carbon in the Plant Biomass of Forests in Kyiv region

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Abstract. The carbon capacity of forest phytocenoses serves as one of the basic criteria for potential opportunities to ensure low-carbon development of the country and fulfil international obligations in the context of the Paris climate agreement. The information base of the study was information from the database of the Ukrainian State Forest Management Planning Association, which contains a specific tax characteristic of stands in the Kyiv region, and a system of mathematical models for quantitative assessment of phytomass and mortmass of forests.

As a result, quantitative values of organic carbon volumes in phytomass and mortmass of forests of the Kyiv region and Kyiv city are established. The total amount of carbon accumulated in the plant biomass of the region's forests is 61.8 million tonnes, of which 60% is accounted for by pine stands. The share of carbon accumulated in the mortar of forests of the Kyiv region is 10.5%. The highest density of deposited carbon per unit area is characterised by ash and oak stands with indicators of 10,08 and 9,921 kg*(m²)⁻¹ accordingly. More than 40% of organic carbon is accumulated in the plant biomass of bonitet class I stands, which mainly grow in relatively poor forest conditions (barrens). Recreational-protective forests of the region have the highest organic carbon densities per unit area – 10.53 and 10.49 kg*(m²)⁻¹ accordingly. Among the objects of the nature reserve fund, the dominant positions in terms of the volume of the indicator under study belong to nature reserves – 82.7% and about 8% is accounted for by national nature parks. In the total carbon structure of mortmass (6.5 million tonnes), more than 60% is forest litter. Therewith, the carbon content of mortmass plantings of coniferous tree species is 4.1 million tonnes or 62.9%.

The results obtained in the course of the study will serve as an information basis for forming a strategy for regional low-carbon development

Keywords: biomass, carbon, deposition, environmental monitoring, mortmass, plantings, phytomass

Suggested Citation:

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Introduction

One of the key criteria for ensuring National Low-Carbon Development (Strategy, 2018) and compliance with international obligations in the context of the Paris Agreement (The Paris agreement, 2016) is the carbon capacity of forest phytocenoses. Currently, forests are the most efficient reservoir for long-term accumulation and retention of atmospheric carbon during their growth, and in wooden building structures and wood products with a substantial service life (Ince, Tayancli & Derogar, 2021; Sun et al., 2021).

Therewith, the phytomass and mortmass of forest stands are the basis for the establishment of reserves of forest combustible materials, and, accordingly, the source of carbon emissions as a result of forest fires (Soshenskyi et al., 2021). That is why forest carbon capacity management, as a component of sustainable forest management, determines the effectiveness of forestry management in the context of global climate change (Shvidenko et al., 2014; Vasylyshyn, 2016).

The forests of this region are a key natural object that not only ensures the ecological balance of the environment in conditions of excessive man-made load but also serves as an important source of raw materials for the development of the regional economy. In this context, the quantification of carbon capacity in plant biomass components will be an important information factor in the establishment of regional environmental and forestry initiatives.

The examination of carbon fluxes in forest ecosystems is now the object of study by both Ukrainian and foreign researchers. In particular, a comprehensive assessment of the carbon deposition capacity of forest phytocenoses and the impact of disturbances in the forests of Polesia of Ukraine on their carbon budget was conducted by researchers of the Department of Forest Mensuration and Forest Management of the National University of Life and Environmental Sciences of Ukraine together with colleagues from the International Institute for Applied Systems Analysis (Lakyda et al., 2018, 2019).

The updated assessment of the carbon budget of the forests of Ukraine was made in 2019 based on the forest map of Ukraine with a resolution of 60 m, according to which the capacity of forest ecosystems of Ukraine is estimated at 90 million tonnes of organic matter per year, or 504 g of carbon per 1 m² (Lesiv et al., 2019).

Considering the consequences of future climate changes on the territory of EU countries and their impact on the regional balance of carbon emissions, individual researchers (Fady et al., 2020) believe that it is necessary to avoid creating forests in places of a high probability of fires and drought-prone areas, which are now substantially expanding throughout Europe. Therewith, to mitigate the consequences of natural disturbances in forest ecosystems, researchers from Central Europe (Zimova et al., 2020) used the iLand model for the modelling of the impact of logging turnover on the vulnerability of 16 thousand hectares of forest landscape damaged by windbreaks and affected by bark beetles. As a result of the study, a clear relationship was established between forest carbon reserves, biodiversity indicators and the duration of logging turnover. In particular, reducing the turnover of logging by 40% allowed reducing the mentioned violations by 14%.

Monitoring studies also play an important role in ensuring effective management of the carbon-saving capacity of forest stands. An example of such writings is the papers of Romanian (Dumitrascu et al., 2020) and Spanish (Gomez-Garcia, 2020) researchers who successfully combine field research data with a forest cadastre data to establish predictive estimates of annual amounts of carbon deposited in forest ecosystems.

The presence of a substantial number of scientific papers in this area of research indicates the importance and relevance of further research on carbon uptake and emission processes in forest ecosystems.

The purpose of the study is to estimate the volume of organic carbon in the components of phytomass and mortmass of forests in the Kyiv region and the city of Kyiv.

Materials and Methods

The information basis of the study was information from the database of the Ukrainian State Forest Management Planning Association, formed according to the data of the current accounting of forests of Ukraine, which contains a specific tax characteristic of plantings (more than 200 thousand forest plots) of the studied region (Table 1).

Table 1. Distribution of the number and area of forest plots in the Kyiv region by the dominant forest-forming species

Type of woody plants	Quantitative indicator		Type of woody plants	Quantitative indicator	
	pcs.	thousand ha		pcs.	thousand ha
Silver birch	24 078	68.97	Robinia pseudoacacia	3708	10.15
Common alder	13 002	36.04	Scots pine	122,494	384.65
Common hornbeam	2129	7.26	Common ash	1964	6.77
Common oak	24 788	82.64	Other tree species	11 797	19.11
Total				203,960	615.59

The methodology for estimating the volume of organic carbon in plant biomass components is based on the division estimation of phytomass and mortmass reserves using a system of mathematical models (Bilous, 2018; Schepaschenko et al., 2017; Shvidenko et al., 2014) and subsequent assessment of deposited carbon by quantitative parameters of its content in absolutely dry organic matter components of biomass plantings of the main forest-forming species of the region (Lakyda et al., 2018). For other wood species, the mentioned indicators of deposited carbon are established based on the weighted average values of these species.

Results and Discussion

The carbon capacity of forest stands now not only serves as a measure of the impact of climate

change on forest ecosystems but also determines the possibility of a positive impact of forests on the concentration of greenhouse gases in the Earth's atmosphere.

In the course of the study, it was established that the estimate of the total amount of carbon deposited in the plant biomass of forests in the Kyiv region (123.1 million tonnes of absolutely dry matter, in particular, 111.0 – phytomass; 13.1 – mortmass) is 61.8 million tonnes, including 55.3 million tonnes in phytomass (Table 2). In general, more than 65% of the deposited carbon is accumulated in the plant biomass of coniferous plantations in the region. Hard-leaved stands account for about 20%, and almost 14% is concentrated in phytomas and mortmass of soft-leaved stands.

Table 2. Total carbon content in plant biomass of forests of the Kyiv region

Species group	Deposited carbon in plant biomass, thousand tonnes	
	phytomass	mortmass
Coniferous trees	36 592,6	4097.0
Hard-leaved	10 974,0	1527.7
Soft-leaved	7688.8	872.4
Other tree species	28.5	9.5
Total	55 284,0	6506.6

The share of mortmass in the total structure of accumulated organic carbon in the plant biomass of forests in the Kyiv region is 10.5%.

In the overall structure of organic carbon of the forests of the studied region, the dominant positions are occupied by pine stands, in which more

than 60% (38.1 million tonnes) of its volumes are accumulated. The following positions belong to oak and birch stands with an indicator of 15.5% and 7.8%, respectively. The share of alder stands is about 4.5%, while the share of hornbeam, sedge, and ash stands slightly exceeds 1% (Fig. 1).

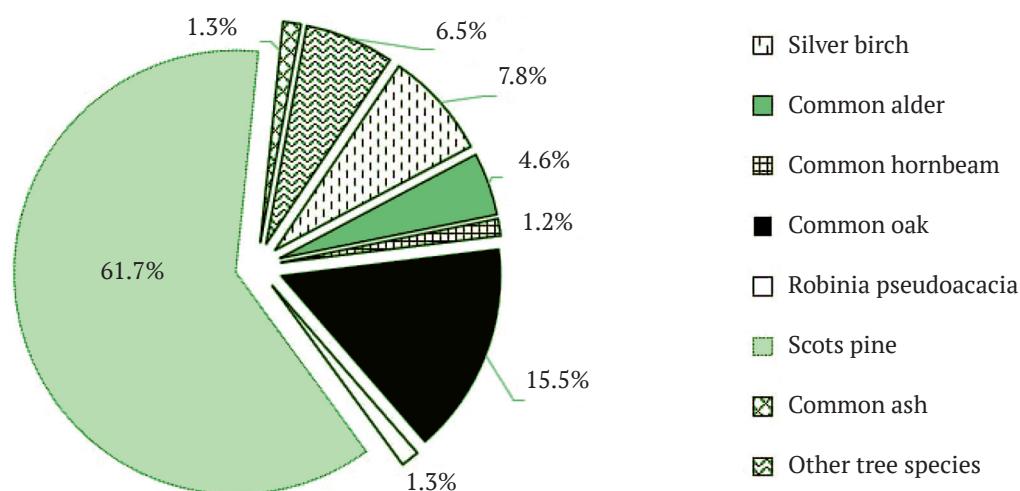


Figure 1. Structure of organic carbon reserves in plant biomass of forests of Kyiv region

It is established that ash and oak stands are characterised by the highest density of deposited carbon per unit area (Table 3). Quantitative values of the carbon density index in phytomass for these plantings reach 10,08 and 9,921 $\text{kg}^*(\text{m}^2)^{-1}$ accordingly. In general, the mentioned indicator within the plantings of the dominant forest-forming species varies from 6,52 $\text{kg}^*(\text{m}^2)^{-1}$ for alder stands up to 10,08 $\text{kg}^*(\text{m}^2)^{-1}$ for ash trees. The average value of the density index of carbon deposited in phytomass within the plantings of the region is at the level of 8.82 $\text{kg}^*(\text{m}^2)^{-1}$. For mortmass, the mentioned indicator

is much lower and amounts to about 1.1 $\text{kg}^*(\text{m}^2)^{-1}$, while the dominant positions in terms of carbon density accumulated in mortmass belong to oak and ash stands. The indicators of deposited carbon density in the plant biomass of forests in the region obtained in the process of separate assessment are almost 8% higher compared to the values obtained by researchers based on consolidated data from current forest accounting (Shvidenko et al., 2014). Therewith, according to the absolute values of organic carbon volumes in the plant biomass of forests in the Kyiv region, the mentioned deviation does not exceed 7%.

Table 3. Species differentiation of deposited carbon density in plant biomass of forests of the Kyiv region

Dominant tree species in the plantation	Deposited carbon density, $\text{kg}^*(\text{m}^2)^{-1}$	
	phytomass	mortmass
Silver birch	6.65	0.55
Common alder	6.52	0.96
Common hornbeam	8.51	1.05
Common oak	9.92	1.42
Robinia pseudoacacia	6.54	0.54
Scots pine	9.36	1.07
Common ash	10.08	1.40
Average within the region	8.82	1.06

In the study region, more than% of organic carbon is accumulated in the plant biomass of stands of the I class of bonitet (Table 4).

Almost 30% are in class II bonitet stands, and a quarter is accounted for by high-performance

plantings of Ia and above classes. This distribution is quite naturally determined by the regional bonitet and age structure of stands within the forest areas covered with forest vegetation of the Kyiv region.

Table 4. Distribution of carbon reserves in the plant biomass of forests of the Kyiv region within the bonitet classes

Bonitet class	Deposited carbon in plant biomass, thousand tonnes	
	phytomass	mortmass
I ^a and above	13 324,8	1548.1
I	23 378,6	2637.0
II	15 062,5	1786.7
III	2914.7	413.4
IV	425.3	81.6
V and below	178.0	39.7
Total	55 284,0	6506.6

Therewith, analysing the distribution of organic carbon within the categories of forests, which is presented in Table 5, it is worth paying attention to the dominance of recreational forests – over 50% of the volume of carbon deposited. The

share of operational forests does not exceed 25%. Regarding the density of organic carbon per unit area, the highest values in the region are typical for recreational and protective forests – 10.53 and 10.49 kg*(m²)⁻¹ accordingly.

Table 5. Distribution of carbon reserves in plant biomass of forests of Kyiv region within forest categories

Category of forests depending on their functions	Deposited carbon in plant biomass, thousand tonnes	
	phytomass	mortmass
Forests for conservation, scientific, historical-cultural purposes	6470.2	731.3
Recreational forests	27 850,0	3137.2
Protective forests	7244.7	946.1
Operational forests	13 719,1	1692.0
Total	55 284,0	6506.6

Objects of the nature reserve fund (NRF) also play an important role in the process of forming the carbon storage capacity of forests in a particular region. In the region under study, the share of organic carbon in the phytomass and mortmass of forests within

the mentioned sites is almost 9%, which is 5.5 million tonnes. Among the objects of the NRF, the dominant positions in terms of the volume of the studied indicator belong to nature reserves – 82.7% and about 8% is accounted for by national nature parks (Fig. 2).

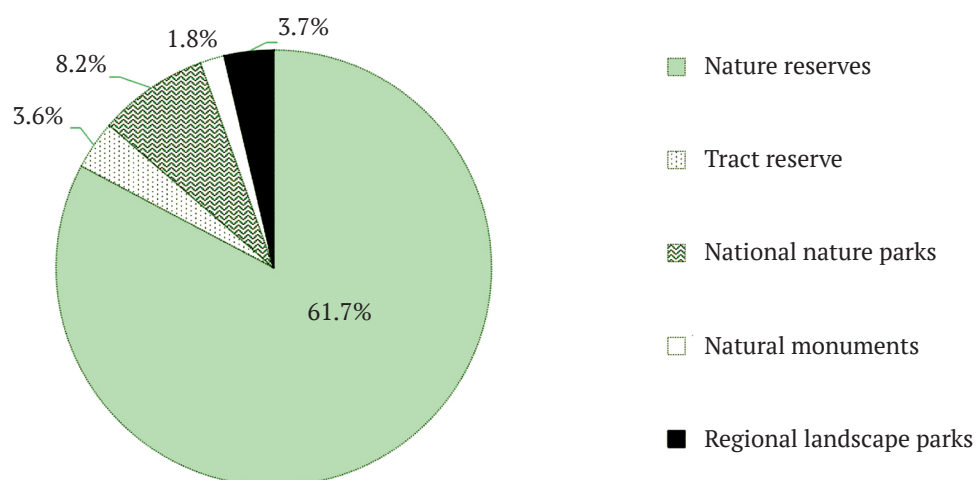


Figure 2. Structure of organic carbon reserves in plant biomass of forests within the objects of the nature reserve fund of the Kyiv region

The intensity of carbon deposition of forest stands substantially depends on the types of forest conditions in which they grow. In the course of the study, it was identified that the highest values of organic carbon density in phytomass are characteristic of plantings in fresh su-hruds (C_2) and wet hruds (D_3), where its values are more than $10 \text{ kg}^*(\text{m}^2)^{-1}$. Therewith, the minimum values of this indicator are inherent in very dry and wet barren forests – 3.22 and $3.32 \text{ kg}^*(\text{m}^2)^{-1}$ accordingly.

In total, about 10% of the organic carbon of plant biomass is accumulated in the barrens of the Kyiv region (Table 6). Therewith, about 50% of its reserves are concentrated in the biomass of plantings in su-barrens (conditions, similar to barrens but with more pronounced oligotrophic vegetation), where Scots pine stands dominate. As for the density of deposited carbon, here the highest values are characteristic of stands in hruds (D) and su-hruds (C) – over 9.84 and $9.27 \text{ kg}^*(\text{m}^2)^{-1}$ accordingly.

Table 6. Distribution of carbon reserves in plant biomass of forests of Kyiv region within trophotopes

Trophotop	Deposited carbon in plant biomass, thousand tonnes	
	phytomass	mortmass
Barrens (A)	5975.4	700.1
Su-barrens (B)	25650.8	2842.5
Hruds (C)	17933.0	2207.1
Su-hruds (D)	5724.8	757.0
Total	55284.0	6506.6

The component structure of carbon deposited in the phytomass of forests in the Kyiv region is dominated by tree trunks, the share of which is 71.4%

(Table 7). This component of wood biomass is now the most important in terms of ensuring long-term accumulation and retention of atmospheric carbon.

Table 7. Distribution of carbon reserves in the phytomass of forests of the Kyiv region by components

Species group, tree type	Deposited carbon in phytomass, thousand tonnes						
	wood and trunk bark	wood and the bark of branches	needles (leaves)	roots	understory undergrowth	live ground cover	total
Coniferous trees	27 106,8	2307.4	524.0	5812.2	241.8	600.4	36 592,6
<i>including Scots pine</i>	25 391,5	2149.3	486.1	5461.8	228.5	567.9	34 285.1
Hard-leaved	7437.6	1493.7	156.9	1581.0	130.9	173.9	10 974,0
<i>including common oak</i>	5812.4	1144.5	106.6	1176.1	106.7	134.1	8480.5
Soft-leaved	4899.6	877.6	232.6	1439.3	81.6	158.1	7688.8
<i>including silver birch</i>	2774.3	605.0	168.2	786.3	43.5	89.6	4466.9
<i>common alder</i>	1681.7	179.6	33.0	488.0	30.3	52.1	2464.8
Other tree species	17.1	3.3	0.4	6.0	0.5	1.1	28.5
Total	39 461.1	4682.0	914.0	8838.5	454.8	933.6	55 284.0

8.5% of organic carbon is concentrated in the phytomass of branches, and more than 15% is concentrated in the phytomass of roots.

Components of the forest mormass of the region, such as tree stand, coarse woody debris, and forest litter, also serve as a fairly substantial carbon

depot within forest ecosystems. In total, more than 6.5 million tonnes of organic carbon are accumulated in the forests of the Kyiv region, of which 64.3% are in the forest litter (Table 8). Notably, mortmass is also a substantial source of carbon emissions, especially during forest fires and its biodegradation.

Table 7. Distribution of carbon reserves in the phytomass of forests of the Kyiv region by components

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Total	39 461,1	4682.0	914.0	8838.5	454.8	933.6	55 284,0

In the total carbon structure of mortmass of the forests in the region, an important place belongs to dry branches – 1.3 million tonnes, or about 19%, but the mentioned component of mortmass is subject to rapid biodegradation under certain conditions.

In the region of the study, the carbon content of mortmass of coniferous tree stands is 4.1 million tonnes, or 62.9%, while the share of mortmass components of the studied stands, which can potentially hold organic carbon for a long time (tree stand, forest litter), reaches about 75% of the total mortmass of coniferous stands. For hard-leaved and soft-leaved plantings, this ratio is 80.0% and 72%, respectively.

Conclusions

According to the results of the conducted studies, it was established that the total volume of organic carbon deposited in the plant biomass of forests in the Kyiv region is 61.8 million tonnes, including 55.3 million tonnes in phytomass. The share of mortmass in the total structure of accumulated or-

ganic carbon in the plant biomass of forests in the Kyiv region is 10.5%.

The structure of organic carbon deposited in the region's plant biomass is dominated by pine stands, which accumulate more than 60% of the total reserve. The component structure is dominated by tree trunks, the share of which is 71.4%. In the total carbon structure of mortmass (6.5 million tonnes), more than 60% belongs to forest litter. Therewith, the carbon content of mortmass plantings of coniferous tree species is 4.1 million tonnes, or 62.9%.

The forest categories are dominated by recreational forests, which account for more than 50% of the volume of carbon deposited. The share of operational forests does not exceed 25%. Recreational and protective forests are also characterised by the highest organic carbon densities per unit area – 10.53 and 10.49 kg*(m²)⁻¹ accordingly.

The results obtained in the course of the study will serve as an information basis for forming a strategy for regional low-carbon development.

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Органічний вуглець у рослинній біомасі лісів Київщини

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Анотація. Вуглецедепонувальна здатність лісових фітоценозів слугує одним із базових критеріїв потенційних можливостей забезпечення низьковуглецевого розвитку країни та виконання міжнародних зобов'язань у контексті Паризької кліматичної угоди. Інформаційною базою дослідження слугувала інформація з бази даних ВО «Укрдержліспроєкт», що містить повидільну таксаційну характеристику деревостанів Київщини, а також система математичних моделей для кількісного оцінювання фітомаси й мормаси лісів.

У результаті встановлено кількісні значення обсягів органічного вуглецю у фітомасі та мортмасі лісів Київської області та м. Києва. Загальний обсяг вуглецю, акумульований у рослинній біомасі лісів регіону, становить 61,8 млн т, з яких 60 % припадає на соснові деревостани. Частка вуглецю, накопиченого у мортмасі лісів Київщини, складає 10,5 %. Найвищою щільністю депонованого вуглецю на одиниці площі характеризуються ясеневі та дубові насадження з показниками 10,08 і 9,921 кг·(м²)⁻¹ відповідно. Понад 40 % органічного вуглецю акумульовано у рослинній біомасі деревостанів I класу бонітету, які переважно ростуть у порівняно бідних лісорослинних умовах (суборах). Рекреаційно-оздоровчі та захисні ліси регіону мають найвищі показники щільності органічного вуглецю на одиниці площі – 10,53 та 10,49 кг·(м²)⁻¹ відповідно. Серед об'єктів природно-заповідного фонду домінантні позиції за обсягами досліджуваного показника належать заказникам – 82,7 %, ще близько 8 % припадає на національні природні парки. У загальній структурі вуглецемісткості мормаси (6,5 млн т) понад 60 % становить лісова підстилка. Водночас вуглецемісткість мормаси насаджень хвойних деревних видів складає 4,1 млн т, або 62,9 %.

Одержані в процесі дослідження результати слугуватимуть інформаційною основою для формування стратегії регіонального низьковуглецевого розвитку

Ключові слова: біомаса, вуглець, депонування, екологічний моніторинг, мортмаса, насадження, фітомаса

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Structure and Morphogenesis of Shoots of Species of the *Viburnum* L. Genus in the Right-Bank Forest-Steppe of Ukraine

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Abstract. A study of the growth features and structure of shoots of species of the *Viburnum* L genus was conducted. Determination of features of the structure of shoots of species of the *Viburnum* genus is relevant because there are substantial differences in the structure and dynamics of growth within the genus. The study of the dynamics of shoot growth was conducted according to the method of A.A. Molchanov and V.V. Smirnov (1967). The studied species belong to three sections of the *Viburnum* L. genus. In the species of each of the sections, the features of the bud structure largely determine the structure of shoots. It is determined that the species of each of the three sections of the genus have a special structure of shoots. The rhythms of growth and development of plants of native and introduced species of the *Viburnum* genus are studied.

The timing of shoot growth of species of the *Viburnum* genus is analysed, and the length of annual shoot growth is determined. Phenodates of the beginning and end of shoot growth were established. It is identified that the onset of individual phenophases quite clearly correlates with the sum of effective temperatures above +5°C. For species of the *Viburnum* genus the following types of shoots are characteristic: tillering, stem, generative. Intensive growth of shoots of all the studied species occurs in May – mid-June. In Lantana section species there are two peaks of shoot growth – May and mid-July. According to the duration of growth, *viburnum* shoots can be divided into two groups: 1) with a short growth period (65-75 days): *V.opulus* L., *V.sargentii* Koehne, *V.prunifolium* L., *V.rufidulum* Raf., *V.lentago* L.; 2) with a long growth period (100 or more days): *V.lantana* L., *V.carlesii* Hemsl., *V.veitchii* C.H. Wright, *V.rhytidophyllum* Hemsl., *V.buddleifolium* C.H. Wright, *V.burejaeticum* Rgl. et Herd.

The data obtained indicate that the greatest annual growth of shoots of all *Viburnum* species was received at the age of 4-7 years. A decrease in the annual growth of axial shoots signals the need for preliminary rejuvenation of the plant

Keywords: shoots, annual growth, phenophase, phenodate, *Viburnum*

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Introduction

The growth of plants of introduced species, the ability to give annual growth is one of the indicators of success in the introduction of a species.

Shrubs differ from trees in that they have not one, but several skeletal axes (stems) connected to each other at the base of the bush or in its underground part. The age of individual stems is relatively small, but the total age of the entire plant can be quite substantial, its life is extended due to new axes that grow from aboveground and underground renewal buds, replacing old ones that die off (Mazurenko & Hohryakov, 1977). The stem of perennials, and shrubs as well, consists of separate distinct structural elements called annual shoots (metamers). Annual bush shoots are young central or lateral axes of the stem that have developed during a single growing season from buds located on stems, rhizomes, or roots. Adjacent annual shoots (growths) are separated from each other by scars left over from bud scales, and shortened internodes. Thus, the stem of the shrub consists of a series of generations of shoots that are formed annually, and is characterised by a special type of growth and branching characteristic of this species.

The study of the phase of growth and development of shoots of introduced plants is of particular importance, because the degree of their lignification depends on the time of their growth and development, and therefore the frost resistance and winter hardiness of plants. Simultaneously with the study of the duration of growth of shoots, the dynamics of their growth was also investigated, which is also important for determining the winter hardiness of plants, because it is known that winter-hardy can be not only those shoots that complete growth and development early, but also those that grow for a long time, but rather slowly.

Determining the features of the structure and dynamics of shoot growth is extremely relevant for species of the *Viburnum* genus because there are substantial differences in structure and dynamics in different species. The dynamics (duration) of growth and development of plant shoots of a certain species is directly related to the annual (phenological) cycle of plant development of a certain species. Information on the phenology of species of the *Viburnum* genus is submitted in the paper (Demchenko, 2017). Shoots of plants of

the genus species as an integral part of the crown of plants directly affect the decorative effect of plants (Demchenko, 2016). Features of the growth of shoots of various types of woody plants on the example of the *viburnum* genus in the United States are considered in the paper (Donoghue, 1981). Investigation of the reaction of a number of species of forest shrubs, in particular, witherod *viburnum* (*Viburnum cassinoides* L.), on the bending of the stem is given in the paper (Wilson, 1997). According to the author, the formation of epicormal shoots is the main reaction of the studied species *Cornus amomum* Mill., *V. cassinoides* and *Gaylussacia baccata* (Wang.) K. Koch on bending. Information on the structure of shoots and the formation of the crown structure of *Viburnum lantana* and *Viburnum opulus* is collected in the paper (Kollmann & Grubb, 2002).

The purpose of the study is a comparative analysis of the features of the structure and dynamics of growth and development of plant shoots of species of the *Viburnum* genus due to their phenological development in the conditions of the Right-bank forest-steppe of Ukraine and their consistency with the natural and climatic conditions of this region.

Materials and Methods

Bioecological, biomorphological, biometric, and statistical research methods were applied.

The objects of the study were plants of the *Viburnum* genus of collections of the NM. M. Hryshko National Botanical Garden of the National Academy of Sciences of Ukraine (NBG of the NASU) and the A.V. Fomin Botanical Garden of the Taras Shevchenko National University of Kyiv (BG of the NUK).

Stationary studies of 11 species and 5 varieties of introduced and native *Viburnum* species were conducted in 2009-2013 in Kyiv on the territory of the NBG of the NASU and BG of the NUK. The studied species belong to 3 of the 9 isolated species in the *Viburnum* genus sections: *Lantana* Spach. (*V. lantana* L., *V. lantana* 'Aureum', *V. lantana* 'Variegatum', *V. carlesii* Hemsl., *V. rhytidophyllum* Hemsl., *V. burejaeticum* Rgl. et Herd., *V. veitchii* C.H.Wright., *V. buddleifolium* C.H.Wright), *Lentago* DC. (*V. lentago* L., *V. prunifolium* L., *V. rufidulum* Raf.), *Opulus* DC. (*Viburnum opulus* L., *V. opulus* 'Roseum', *V. opulus* 'Nanum', *V. sargentii* Koehne, *V. sargentii* 'Flavum').

The dynamics of seasonal shoot growth was determined by the method of A.A. Molchanov and V.V. Smirnov (Molchanov & Smirnov, 1967). Phenological observations were conducted according to the "Technique of phenological observations in botanical gardens of the USSR" (1975). Phenospectors were compiled according to the method of N.E. Bulyigin (Bulyigin, 1985). Field data expressed as ordinary calendar dates were converted to a continuous series of numbers as the number of days from March 1 according to G.M. Zaytsev (Zaytsev, 1981). Statistical processing of research results was conducted according to the methods of G.M. Zaytsev (Zaytsev, 1981, 1984).

Results and Discussion

For *Viburnum* species the following types of shoots are typical.

1. Tillering shoots – vegetative shoots formed most often from the lower or middle part of the crown and delayed for a long time at the second stage of organogenesis. They are characterised by increased growth (in 1-2 years they reach a length corresponding to the habit of the species) and slow development (they enter the generative phase for 2-3 years of growth and development). It was determined that up to 20% of these shoots freeze or stop growing and die off in the first year.

2. Stem shoots – the most numerous among all types of shoots that are distinguished in the crown of the bush. They are formed from lateral buds located at the base of leaf petioles in the middle and upper parts of the crown. They are characterised by slower growth and the rate of transition to the generative phase.

3. Generative shoots – they are characterised by slow growth and rapid development. Such shoots stop growing with the beginning of flowering.

Shoots of the first two types continue to develop even after flowering. Their growth rate slows down during flowering, and after it ends, the shoots activate growth processes. The complexes of conditions necessary for passing a particular phase are determined by the ecological factors in which the species were formed.

The internal rhythm of growth and development, changes in the needs of plants in various complexes of environmental conditions are due to the heredity of organisms and are largely a reflection of seasonal phenomena.

The period from the beginning of bud opening to the beginning of leaf fall or leaf death from autumn frosts in summer green plants can be roughly taken as vegetative, in evergreens – the transition of plants to a state of organic dormancy can be conditionally accepted for the termination of vegetation.

The structure of viburnum shoots, although differs from one another, but also has a lot in common. At the border between adjacent annual shoots, they do not have the typical bud rings consisting of scars of bud scales, as in many trees and shrubs. However, the first internode of the annual shoot in all species of the *Viburnum* genus is usually shorter than the following ones. All nodes on the shoots of viburnum have two opposite leaves. In all species, inflorescences are formed on the tops of shoots.

There is a clear relationship between the structural features of viburnum shoots and their systematic position. The studied species belong to three sections of the *Viburnum* genus, the species of each section have a special structure of shoots.

Among the studied plants, the most distinctive features of their shoots are the species of *Opulus* sections: they usually die and fall off of the tip, the apical bud is not formed. Instead, at the top of the shoot there are two axillary buds of the upper node with a small scar from the dead tip between them. These buds can be either vegetative or generative. In isolated cases, an apical bud is formed on particularly strong shoots, and then a monopodial increase in the axis of the perennial shoot is observed. This occurs more often on intensively growing tillering shoots or in young plants. Sympodial branching is observed in stem shoots. In generative shoots, which usually die off after fruiting, their first metamer remains alive, axillary buds develop on it and give new shoots. In the crown of *Opulus* section species on perennial axial shoots, strongly thickened nodes can be identified, consisting of the first metamers of dead shoots of several orders of branching. Border between adjacent annual shoots of *Opulus* section species, it is easily determined behind the short first internodes of the shoot.

Notably, the dwarf cultivar of *Viburnum opulus* (*Viburnum opulus* 'Nanum') it is distinguished by a peculiar form of growth and development of shoots: the vegetation of the plant is conducted at the expense of lateral shoots, apical shoots grow very slowly.

It is much more difficult to establish a boundary between the annual shoots of the *Lantana* section

species. It does not have specialised bud scales, the buds are protected by the outer rudiments of leaves, which are covered with dense pubescence, which forms a dense layer, like felt. Under the outer rudiments there are one or two more pairs of also densely pubescent leaf rudiments. In spring, when the buds open, the outer rudiments unfold and grow into normal green leaves, although slightly smaller in size compared to those located above. The internodes under this first pair of leaves lengthen when the bud opens and become almost as long as the internodes located above. After leaf fall in autumn, the border between adjacent annual shoots is almost impossible to determine. Unlike the *Opu-* *lus* section, shoots of *Lantana* section species form an apical bud. Therefore, most perennial axes grow monopodially. Sympodial growth is observed only in generative shoots, the apical bud of which forms the rudiment of the inflorescence.

In *Lentago* section species an apical bud develops on all shoots. From the outside, it is protected by a pair of scales. When the buds open in spring, these scales move apart and their upper parts grow, forming small green leaf blades. These first leaves of the shoot are transitional forms from scales to leaves. The internodes under these leaves lengthen only during the opening of the bud. Therefore, it will not be like the *Lantana* section species, simul-

taneously the last internodes of the previous summer shoot. This first shortened Internode serves as a well-defined border between adjacent annual shoots.

In most of the studied species of the viburnum genus, stem shoots most often consist of three metamers. Tillering shoots contain much more metamers. For example, in *V.opulus* there can be 7-8 of them, in *V.lantana*, *V.lentago* – 8-9. Internodes on these shoots are always much longer than on stem shoots.

Thus, a comparison of the structure of shoots of different types of viburnum shows that in the species of each of the sections, the features of shoots are mutually predetermined, that the features of the structure of buds largely determine the structure of shoots, and all this is due to external conditions in the areas of the natural distribution of species.

Intensive growth of shoots of all the studied species occurs in May – mid-June (Fig. 1). In *Lantana* section species there are two peaks of shoot growth – May and mid-July, which is associated with climatic conditions.

It is established that the objects of research on the duration of shoot growth can be divided into two groups (Table 1): 1) with a short growth period (65-75 days) – *V.opulus*, *V.sargentii*, *V.prunifolium*, *V.rufidulum*, *V.lentago*; 2) with a long growth period (100 or more days) – *V.lantana*, *V.carlesii*, *V.veitchii*, *V.rhytidophyllum*, *V.buddleifolium*, *V.burejaeticum*.

Table 1. Average annual phenodates of species of the *Viburnum* genus (average phenodates in days from March 1, Kyiv, 2009-2013)

Species cultivar	Appearance of a green leaf cone	Duration of shoot growth, days	Beginning of November	Duration of vegetation, days
<i>Viburnum opulus</i>	33.13	68.18	213.20	180.07
<i>V. o. 'Roseum'</i>	31.47	67.62	232.27	200.80
<i>V. O. 'Nanum'</i>	42.20	71.14	227.13	184.93
<i>V. lantana</i>	30.60	105.28	234.07	203.47
<i>V.l.'Aureum'</i>	29.67	108.49	247.33	217.66
<i>V. l. 'Varie-gatum'</i>	29, 00	100.35	238.67	209.67
<i>V. sarlesii</i>	29.87	96.14	240.27	210.40
<i>V. rhytidophyllum</i>	30.27	112.36	---	---
<i>V. lentago</i>	37.33	69.32	241.67	204.34
<i>V. rufidulum</i>	34.33	73.24	240.67	206.34
<i>V. prunifolium</i>	36.67	70.76	238.22	201.55
<i>V. veitchii</i>	26.89	115.84	239.22	212.33
<i>V. burejaeticum</i>	25.33	109.28	250.67	225.34
<i>V. buddleifolium</i>	39.33	114.16	---	---
<i>V. sargentii</i>	34.11	68.25	248.33	214.22
<i>V. sargentii 'Flavum'</i>	33.67	69.18	245.22	211.55

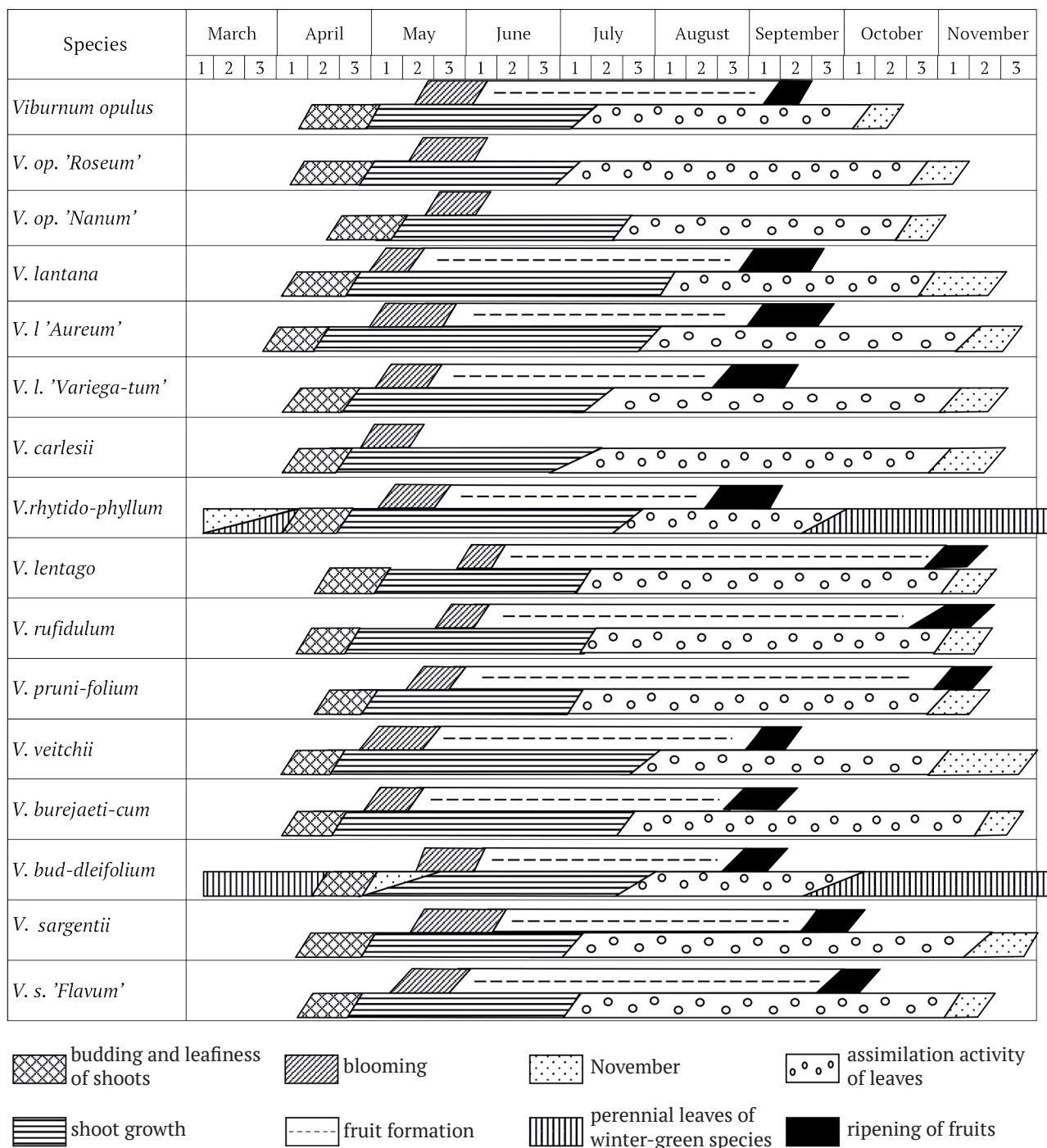


Figure 1. Phenospectre of seasonal development of *Viburnum* species in Kyiv (NBG of the NASU, BG of the NUK)

The average increase per day during the period of intensive growth in *V.lantana* is 10-16 mm, in other viburnums – up to 5 mm. The value of the annual growth of *Viburnum* ranges from 16.6 cm to

64.7 cm, only in *V.opulus 'Nanum'* it does not exceed 15 cm, more often 5-7 cm.

The greatest length of annual growth of stem shoots is observed in *V.opulus* (21.6 cm), *V.lantana*

(29.4 cm), *V.burejaeticum* (27.8 cm), *V.rufidulum* (19.7 cm).

The greatest annual growth of generative shoots is in *V.opulus* (15.3 cm) and *V.sargentii* (13.9 cm), the smallest – in *V.lantana* 'Variegatum' (2.4 cm) and *V.lantana* 'Aureum' (3.8 cm). The relationship between the timing of the beginning of flowering and the length of generative shoots is determined: the earlier flowering begins, the shorter the length of generative shoots and vice versa.

The data obtained indicate that the largest increase in all *Viburnum* species occurs at the age of 4-7 years. A decrease in the annual growth of axial shoots signals the need for preliminary rejuvenation of the bush: removal of old shoots, crown formation, if necessary – “planting on a stump”.

As a result of statistical treatment with phenodate, it was identified that the onset of individual phenophases quite clearly correlates with the sum of effective temperatures (above +5°C) (Table 2).

Table 2. Average dates of occurrence of the main phenophases of *Viburnum* species and the sum of effective temperatures, Kyiv (2009-2013)

Type, cultivar	Budding	Flowering	November	Duration of vegetation
<i>V. opulus</i>	$\frac{(2.04 \pm 4.0)}{(70.51 \pm 4.41)}$	$\frac{(9.05 \pm 3.6)}{(510.25 \pm 18.61)}$	$\frac{(29.09 \pm 5.8)}{(2074.39 \pm 27.11)}$	180.1 ± 4.58
<i>V.o. 'Roseum'</i>	$\frac{(31.03 \pm 5.3)}{(64.83 \pm 5.25)}$	$\frac{(5.05 \pm 3.1)}{(484.13 \pm 17.83)}$	$\frac{(18.10 \pm 6.3)}{(2210.14 \pm 30.26)}$	200.8 ± 3.39
<i>V.o. 'Nanum'</i>	$\frac{(11.04 \pm 4.0)}{(98.47 \pm 4.37)}$	$\frac{(15.05 \pm 4.1)}{(567.62 \pm 21.14)}$	$\frac{(13.10 \pm 8.1)}{(2154.29 \pm 32.15)}$	184.9 ± 3.63
<i>V. lantana</i>	$\frac{(30.03 \pm 5.3)}{(61.85 \pm 3.49)}$	$\frac{(27.04 \pm 2.3)}{(285.25 \pm 20.71)}$	$\frac{(20.10 \pm 4.1)}{(2278.38 \pm 34.29)}$	203.5 ± 4.48
<i>V.l. 'Aureum'</i>	$\frac{(19.03 \pm 4.6)}{(54.93 \pm 4.68)}$	$\frac{(27.04 \pm 2.5)}{(298.15 \pm 20.11)}$	$\frac{(2.11 \pm 4.9)}{(2562.49 \pm 40.28)}$	217.7 ± 4.34
<i>V.l. 'Variegatum'</i>	$\frac{(29.03 \pm 4.0)}{(59.94 \pm 5.43)}$	$\frac{(25.04 \pm 2.1)}{(229.21 \pm 17.16)}$	$\frac{(25.10 \pm 4.5)}{(2400.72 \pm 30.29)}$	209.7 ± 4.08
<i>V.carlesii</i>	$\frac{(29.03 \pm 3.8)}{(58.3 \pm 3.25)}$	$\frac{(20.04 \pm 2.6)}{(182.31 \pm 19.25)}$	$\frac{(26.10 \pm 3.7)}{(2416.67 \pm 39.25)}$	210.4 ± 3.13
<i>V. lentago</i>	$\frac{(6.04 \pm 6.2)}{(124.8 \pm 5.26)}$	$\frac{(22.05 \pm 4.1)}{(645.73 \pm 21.14)}$	$\frac{(28.10 \pm 5.2)}{(2485.51 \pm 36.29)}$	204.3 ± 6.53
<i>V.rufidulum</i>	$\frac{(3.04 \pm 5.2)}{(116.2 \pm 3.43)}$	$\frac{(15.05 \pm 3.2)}{(559.48 \pm 17.28)}$	$\frac{(26.10 \pm 6.5)}{(2462.85 \pm 33.28)}$	206.3 ± 7.78
<i>V.prunifolium</i>	$\frac{(6.04 \pm 5.1)}{(124.8 \pm 4.01)}$	$\frac{(7.05 \pm 2.1)}{(503.41 \pm 18.17)}$	$\frac{(24.10 \pm 8.1)}{(2439.64 \pm 34.24)}$	201.6 ± 5.59
<i>V.veitchii</i>	$\frac{(27.03 \pm 4.5)}{(83.1 \pm 3.25)}$	$\frac{(22.04 \pm 2.6)}{(195.12 \pm 18.28)}$	$\frac{(25.10 \pm 7.4)}{(2445.62 \pm 36.33)}$	212.3 ± 2.12
<i>V.burejae-ticum</i>	$\frac{(25.03 \pm 4.6)}{(80.6 \pm 4.47)}$	$\frac{(22.04 \pm 1.2)}{(193.25 \pm 17.02)}$	$\frac{(6.11 \pm 7.2)}{(2598.26 \pm 34.29)}$	225.3 ± 2.08
<i>V.sargentii</i>	$\frac{(30.04 \pm 4.7)}{(69.2 \pm 3.73)}$	$\frac{(9.05 \pm 2.8)}{(512.16 \pm 17.84)}$	$\frac{(3.11 \pm 8.9)}{(2577.34 \pm 32.26)}$	214.2 ± 4.44
<i>V.sargentii 'Flavum'</i>	$\frac{(2.04 \pm 5.1)}{(70.5 \pm 4.45)}$	$\frac{(2.05 \pm 2.2)}{(458.25 \pm 16.24)}$	$\frac{(31.10 \pm 7.0)}{(2489.74 \pm 32.25)}$	211.6 ± 5.24

Conclusions

The objects of research are divided into two groups according to the duration of shoot growth. By the end of the growing season, the shoots of most species of viburnum have time to lignify. Exceptions are some species with long growth (*V.rhytidophyllum*, *V.buddleifolium*, *V.veitchii*), the shoots of which

do not have time to completely lignify. However, the shoots of these species are protected by a thick layer of pubescence, and under the surface covers of the shoot with the onset of cold weather, a sufficient amount of fat is formed that prevents damage to the shoots by low temperatures, so these plants are quite hardy.

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Структура та морфогенез пагонів видів роду *Viburnum* L. у правобережному лісостепу України

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Анотація. Було проведено дослідження особливостей росту та будови пагонів видів роду *Viburnum* L. Визначення особливостей будови пагонів видів роду *Viburnum* є актуальним, оскільки існують суттєві відмінності структури та динаміки росту в межах роду. Дослідження динаміки росту пагонів проводили за методикою А.А. Молчанова і В.В. Смірнова (1967). Досліджувані види належать до трьох секцій роду *Viburnum* L. У видів кожної з секцій особливості структури бруньок багато в чому визначають структуру пагонів. Установлено, що видам кожної з трьох секцій роду властива особлива будова пагонів. Було вивчено ритми росту та розвитку рослин аборигенних та інтродукованих видів роду *Viburnum*.

Проаналізовано терміни росту пагонів видів роду *Viburnum*, а також визначено довжину річного приросту пагонів. Установлено фенодати початку і закінчення росту пагонів. Виявлено, що настання окремих фенофаз доволі чітко співвідноситься з сумою ефективних температур вище ніж +5 °С. Для видів роду *Viburnum* характерні такі типи пагонів: кущіння, стеблові, генеративні. Інтенсивний приріст пагонів усіх досліджуваних видів припадає на травень – середину червня. У видів секції *Lantana* спостерігається два піки росту пагонів – травень і середина липня. За тривалістю росту пагонів калини можна розділити на дві групи: 1) з нетривалим періодом росту (65–75 днів): *V. opulus* L., *V. sargentii* Koehne, *V. prunifolium* L., *V. rufidulum* Raf., *V. lentago* L.; 2) з тривалим періодом росту (100 й більше днів): *V. lantana* L., *V. carlesii* Hemsl., *V. veitchii* C.H. Wright, *V. rhytidophyllum* Hemsl., *V. buddleifolium* C.H. Wright, *V. burejaeticum* Rgl. et Herd.

Отримані дані свідчать, що найбільший річний приріст пагонів усіх видів *Viburnum* отримано у віці 4–7 років. Зниження річного приросту осьових пагонів сигналізує про необхідність робіт із попереднього омолодження рослини

Ключові слова: пагони, річний приріст, фенофаза, фенодата, *Viburnum*



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Optimisation of the Protocol for Sterilising Explants of Some Deciduous Woody Plants in Culture *in vitro*

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Abstract. One of the methods of obtaining planting material for deciduous woody plants, in particular, common ash (*Fraxinus excelsior* L.), large-leaved linden (*Tilia platyphyllos* Scop.), and the silver birch (*Betula pendula* Roth) is micropropagation. Explant asepsis – prerequisite for microclonal plant reproduction. For the most part, chemical sterilisation with liquid substances is used for this purpose. The decontamination regime is influenced by a number of factors, in particular, the genotype of the plant. The purpose of the study is to optimise the explant sterilisation protocol of *F. excelsior*, *T. platyphyllos*, and *B. pendula* for micropropagation. For the study, 20-30 cm parts of shoots isolated from a 12-year-old *T. platyphyllos*, 10-year-old *B. pendula*, and a 15-year-old *F. excelsior* were used in February-March 2021. Plant material was cultured according to the generally accepted method on an MS nutrient medium (Murashige & Skoog, 1962). MS Excel software tools were used to process the research data, the average, and its main error were calculated. Univariate analysis of variance (ANOVA) was performed to analyse the effect of explant sterilisation mode on asepsis. The expediency of keeping plant material for a day in fungicidal preparations, in particular, in 0.1% “Samshit” solution, is shown – *F. excelsior* and 0.3% Fundazol solution – *T. platyphyllos* and *B. pendula*. The protocol of sterilisation of experimental plants (efficiency over 50%) is optimised by using a step method using 70% ethyl alcohol, 1.0% and 2.0% AgNO₃, and 2.5% and 5.0% NaClO. It was identified that the effect of the sterilisation regime of experimental plants on asepsis is statistically substantial at the level of 5%. A MS nutrient medium with the addition of 0.25 mg·l⁻¹ kinetin and 2.0 g·l⁻¹ activated carbon was used to initiate explants. Further research is aimed at developing a protocol for the direct regeneration of plant microshoots of *F. excelsior*, *T. platyphyllos*, and *B. pendula* by the action of the components of the nutrient medium *in vitro*

Keywords: plant tissue culture *in vitro*, *Fraxinus excelsior* L., *Tilia platyphyllos* Scop., *Betula pendula* Roth, asepsis, explants, regeneration, nutrient medium, micropropagation

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Introduction

Obtaining high-quality planting material for deciduous woody plants, in particular, common ash (*Fraxinus excelsior* L.), large-leaved linden (*Tilia platyphyllos* Scop.), and the silver birch (*Betula pendula* Roth), is an urgent task for the forestry and gardening industry of Ukraine. One of the methods of obtaining plants while preserving valuable hereditary properties is micropropagation. In contrast to conventional reproduction methods, this method allows obtaining healthy genetically homogeneous plants throughout the year from a minimum amount of donor material and substantially increases the reproduction rate (Butenko, 1964; Lutova, 2003; Smith, 2012). One of the most important conditions for micropropagation is the preparation of plant material for introduction into the conditions *in vitro*, in particular, the selection of an effective sterilisation protocol (Kalinin et al., 1980; Kataeva & Butenko, 1983). The result of micropropagation depends on sterilisation as the first stage. Therewith, it is necessary to select the appropriate sterilising substances, their concentration and exposure to holding, which effectively neutralise the biota, do not damage plant tissues, and allow obtaining high viability in the conditions of *in vitro*.

Currently, chemical sterilisation with liquid substances, less often gaseous substances, and physical reagents (ultrasound, ultraviolet radiation) are used to achieve asepsis of explants (Butenko, 1964; Kalinin et al., 1980; Kataeva & Butenko, 1983). Analysis of studies shows that the most common is chemical sterilisation with substances containing active chlorine (sodium/calcium hypochlorite, chloramine, bleach lime), hydrargium (Sulema, ethylmercurchloride, thimerosal), oxygen (hydrogen peroxide), silver (silver nitrate), alcohols (Shabanova & Mashkina, 2015; Lebedev & Shestibratov, 2016; Podhaietsky et al., 2016; Shakhov et al., 2018, 2019). Antibiotics are used to neutralise the endogenous biota of objects, but they are characterised by a selective spectrum of action (Butenko, 1964). Biocides are also used, in particular, PPM (Plant Preservative Mixture™) (Podhaietsky et al., 2016). In particular, the authors of Lebedev & Shestibratov (2016) sterilised the parts of the escape from 2-3 buds isolated from 60-year-old plus *F. excelsior* trees, in 0.1% mercury chloride for 6 minutes, followed by three-time washing with sterile distilled water. Plant material was cultured on

an MS nutrient medium (Murashige & Skoog, 1962) with the addition of BAP (6-benzylaminopurine) and IAA (β -indolyl-3-acetic acid). Two-stage sterilisation was used to increase the percentage of sterilisation efficiency (Skálová et al., 2012). Authors Payamnour et al. (2014) optimised the shoot sterilisation protocol of *T. platyphyllos* using soapy water to neutralise surface contamination and pre-sterilisation, which consisted of holding in a solution of $600 \text{ mg} \cdot \text{l}^{-1}$ ascorbic acid, $4.0 \text{ g} \cdot \text{l}^{-1}$ fungicide “Captan”, 5.0% commercial solution of NaOCl (5.0% Cl) (20 min). The plant material was then washed under running water. A solution of $600 \text{ mg} \cdot \text{l}^{-1}$ was used for sterilisation of ascorbic acid and 10% NaOCl (5 min). For sterilisation of plant seeds of *Betula spp.* 1.0% hydrogen peroxide (H_2O_2) (48 h) at $T=+4^\circ\text{C}$, followed by exposure at 30.0% H_2O_2 (15 min) and washing in sterile distilled water (Gaidamashvili et al., 2015). Authors Shabanova & Mashkina (2015) conducted sterilisation of hybrid explants *Populus L.* considering the isolation season. In particular, shoots isolated in winter were pretreated under non-sterile conditions in 2.0% “Domestos” (10 min), then in a mixture of solutions of 0.025% merthiolate (10 min) and 7.0% “Bilyzna” (10 min); the exposure of explants isolated in summer was 7 minutes. Effective for sinus buds of *Populus maximowiczii* Henry was holding in 70% ethyl alcohol (1 min), followed by transfer to NaClO (2% active chlorine) (10-18 min) (Kärkönen et al., 2011). Other researchers (Delgadillo-Díaz et al., 2013) developed an effective mode for sterilising explants of *Quercus spp.* with the use of 70% ethyl alcohol and 5.25% sodium hypochlorite. A 0.1% solution of merthiolate or mercury bichloride (Shakhov et al., 2019) / 12,0 % H_2O_2 / NaClO with 95.2% active chlorine (Shakhov et al., 2018) was used for cherry explants isolated from the apical and lateral buds of annual shoots in March. Therewith, a number of authors note that the mode of explant sterilisation depends on a number of factors, in particular, the donor genotype, physiological state, age and type of explant, and the isolation season (Butenko, 1964; Kärkönen et al., 2011; Payamnour et al., 2014; Podhaietskyi et al., 2016; Shakhov et al., 2018, 2019).

The purpose of the study is to optimise the explant sterilisation protocol of F. excelsior, T. platyphyllos and B. pendula for micropropagation. The study provided for solving the following tasks: 1) determine

the effective mode of decontamination of explants in non-sterile conditions; 2) select sterilising substances and determine their optimal concentration, and exposure in sterile conditions; 3) select an effective nutrient medium at the *in vitro* initiation stage.

Materials and Methods

For the study, 20–30 cm parts of shoots isolated from a 12-year-old *T. platyphyllos*, 10-year-old *B. pendula*, and a 15-year-old *F. excelsior* in February–March 2021 were used. Commercial fungicides were used to reduce the percentage of contamination of plant material under non-sterile conditions: 0.3% Fundazol and 0.1% Samshit (100 g^{*1}-1 cresoximethyl + 200 g^{*1}-1 diphenconazole). Shoots were treated by spraying/holding for a day / were not treated with fungicides (control). Sterilisation of plant material (4–8 cm fragments) consisted in holding (15–20 min) in a soapy solution (with the addition of a few drops of Tween-80 detergent), stirring constantly, washing in running water (15–20 min), rinsing in distilled water, immersion in 70% ethyl alcohol, sterilisation in solutions, and subsequent three-time washing in sterile distilled water (5–6 minutes in each serving). 2.5% and 5.0% NaClO, 1.0% and 2.0% AgNO₃ were used as sterilising agents. At the stage of introduction to culture *in vitro* an MS nutrient medium was used. The nutrient media was supplemented with 100 mg^{*1}-1 mesoinositol, 0.25 mg^{*1}-1 kinetin, 30 g^{*1}-1 sucrose, 2.0 g^{*1}-1 activated carbon, and 7.0–7.3 g^{*1}-1 microbiological agar. The acidity index of the medium (pH) was adjusted to the level of 5.7–5.9.

The plant material was cultivated according to the generally accepted method in a light room at a temperature of 24±1°C and illumination of 2.0–

3.0 klx with 16-hour photoperiod and relative humidity of 70–75%. Biotechnological methods were used, in particular, micropropagation using the culture of plant shoot fragments *in vitro* (Butenko, 1964; Kalinin et al., 1980; Kataeva & Butenko, 1983; Smith, 2012). The repeatability of experiments is fourfold. MS Excel software tools were used to process the research data, the average, and its main error were calculated. Univariate analysis of variance (ANOVA) was performed to analyse the effect of explant sterilisation mode on asepsis. The following abbreviations were used in the results: *F* – calculated value of the Fischer criterion; *F_{crit.}* – critical value of the Fischer criterion. The study was conducted in the research laboratory of plant biotechnology of the National University of Life and Environmental Sciences of Ukraine “Boyars’ka LDS” in 2021.

Results and Discussion

Explant asepsis – prerequisite for microclonal plant reproduction. One of the most common sterilising agents for the production of aseptic woody plant cultures is NaClO (Kärkönen et al., 2011; Delgado-Díaz et al., 2013; Payamnour et al., 2014; Shabanova & Mashkina, 2015). Therewith, the difficulty of obtaining a substantial proportion of aseptic material of woody plants is due to morpho-physiological features, so by analogy with other researchers, (Skálová et al., 2012; Payamnour et al., 2014; Gaidamashvili et al., 2015) two-stage sterilisation was used. Results of the authors’ research (Butenko, 1964; Payamnour et al., 2014) indicate the feasibility of using fungicides for pre-sterilisation. Action of fungicides and sterilising substances (ethyl alcohol, NaClO, AgNO₃) for explants are shown in Table 1.

Table 1. Efficiency of sterilisation of fragments of shoots of experimental plants in the conditions of *in vitro*

Variant	Species	Fungicide (pre-sterilisation)	Basic sterilisation mode	Explant sterilisation efficiency (mean ± standard error). %
1	<i>F. excelsior</i>	–	70% ethyl alcohol (1–2 min). 5% NaClO (10 min) followed by transfer to 2.0% AgNO ₃ (9–10 min)	27.5±3.0
2		spraying 0.1% “Samshit”		52.3±4.3
3		soaking in 0.1% Samshit (24 hours)		70.3±2.8
4	<i>T. platyphyllos</i>	–	70% ethyl alcohol (1–2 min). 5% NaClO (6–7 min) followed by transfer to 2.0% AgNO ₃ (9–10 min)	29.3±2.2
5		spraying 0.3% “Fundazol”		31.3±1.5
6		soaking in 0.3% “Fundazol” (24 hours)		65.0±2.6

Table 2, Continued

Variant	Species	Fungicide (pre-sterilisation)	Basic sterilisation mode	Explant sterilisation efficiency (mean \pm standard error). %
7	<i>B. pendula</i>	-	70% ethyl alcohol (1-2 min). 2.5% NaClO (5-6 min) followed by transfer to 1.0% AgNO ₃ (5-6 min)	22.0 \pm 3.4
8		spraying 0.3% "Fundazol"		57.3 \pm 2.2
9		soaking in 0.3% "Fundazol" (24 hours)		58.5 \pm 1.9

On day 4, the growth of biota (fungi/bacteria) at the base of the explant on the surface of the nutrient medium was recorded. This was caused by insufficient aseptic intake during surface sterilisation

of plant material (Buckley & Reed, 1994). It was visually established that the basis of contaminants was fungi (over 80 %, Fig. 1, c) bacteriosis occurred occasionally (up to 20 %).

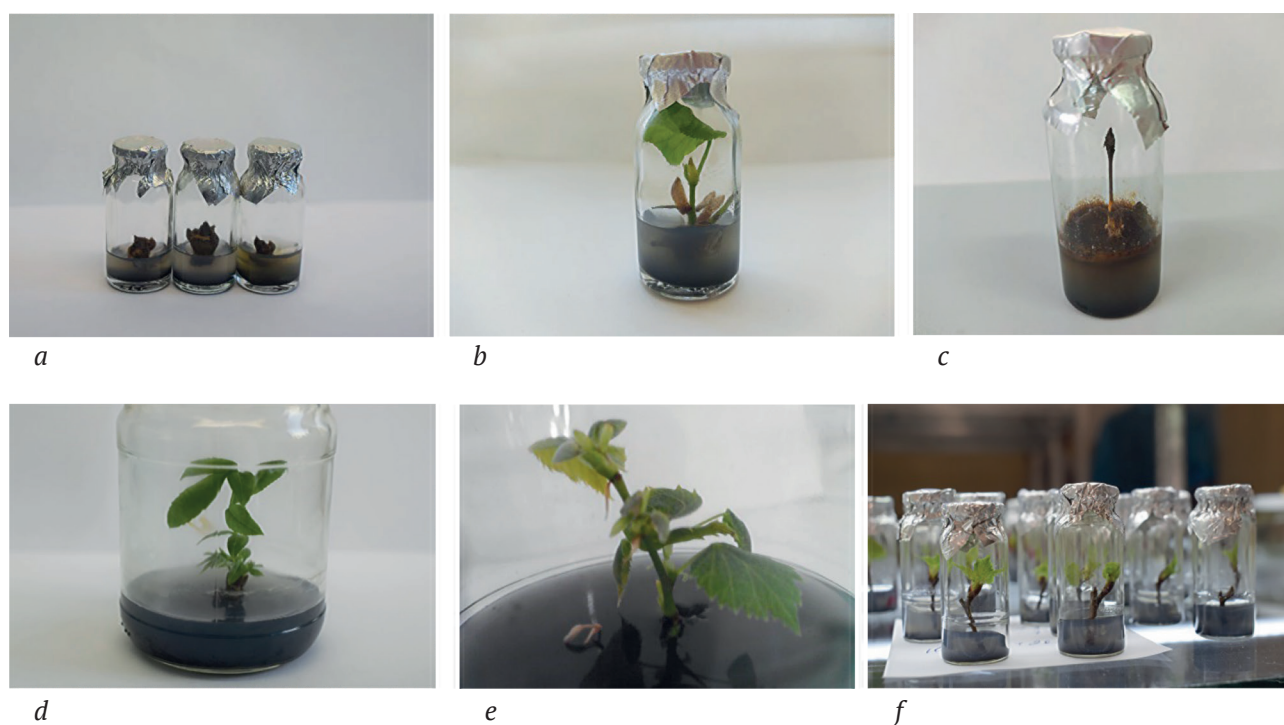


Figure 1. Results of explant sterilisation: aseptic explants of *F. excelsior* (a) and *T. platyphyllos* (b); infected with fungal mycelium *B. pendula* (c); viable micro-shoots *in vitro* *F. excelsior* (d), *T. platyphyllos* (e), *B. pendula* (f)

It is known that to minimise the toxic effects of sterilising agents and reduce the proportion of non-viable plants, their concentration and exposure should be minimal (Kalinin et al., 1980; Kataeva & Butenko, 1983). Responses of woody plant explants to decontamination regimes differed,

which is due to morpho-physiological features of genotypes. According to the results of univariate analysis of variance (ANOVA), the effect of the sterilisation regime of experimental plants on asepsis is statistically substantial at the level of 5% ($F > F_{crit}$, $P < 0.05$) (Table 2).

Table 2. Final results of univariate dispersion analysis for experimental plant tissues *in vitro*

<i>F. excelsior</i>						
Source of variation	SS	df	MS	F	P-value	$F_{crit.}$
Between groups	3731	2	1865.3333	39.2014	3.6077	4.2565
<i>T. platyphyllos</i>						
Between groups	3228	2	1614.0833	89.9489	1.1248	4.2565
<i>B. pendula</i>						
Between groups	3435	2	1717.5833	65.5705	4.3106	4.2565

where: *df* – number of degrees of freedom; *MS* - variances; *F* – calculated value of the Fischer criterion; *P-value* – calculated value of the minimum substantiality; $F_{crit.}$ – critical value of the Fischer criterion

The experimental results showed the feasibility of keeping plant material in fungicide solutions and using step-by-step sterilisation, which is consistent with the data of other authors (Skálová et al., 2012; Payamnour et al., 2014; Gaidamashvili et al., 2015). Effective sterilisation of plant shoot fragments of *B. pendula* was achieved by using step-by-step sterilisation (70% ethyl alcohol – 1-2 min, 2.5% NaClO and 1.0% AgNO₃ – 6-7 min) with preliminary exposure for a day in 0.3% Fundazol solution to obtain 58.5±1.9% asepsis (Fig. 1, *f*). The highest percentage of efficiency (65.0 ± 2.6 %) for explants of *T. platyphyllos* was obtained in the case of using 70% ethyl alcohol (1-2 min), 5.0% NaClO (6-7 min) and 2.0% AgNO₃ (9-10 min) and pre-holding in 0.3% Fundazol solution (Fig. 1, *b*).

For effective neutralisation of exogenous biota *F. excelsior* (70.3±2.8 %), it is advisable to apply an asepsis regime that provided for the use of 70% ethyl alcohol (1-2 min), 2.0% AgNO₃, and 5.0% NaClO (9-10 min) with preliminary exposure for a day in 0.1% “Samshit” solution (Fig. 1, *a*). On 30-50 of cultivation, viable microshoots with characteristic pigmentation without signs of vitrification and necrotisation were obtained on an MS nutrient medium with the addition of 0.25 mg*1⁻¹ kinetin and 2.0 g*1⁻¹ activated carbon (Fig. 1, *d*, *e*, *f*).

Conclusions

Protocol for sterilisation of plant shoot fragments of *F. excelsior*, *T. platyphyllos*, and *B. pendula*, isolated in February-March was optimised, and aseptic viable microshoots *in vitro* were obtained. The expediency of keeping plant material in fungicides for a day (0.1% Samshit solution) is shown. – *F. excelsior*; 0.3% solution of “Fundazol” – *T. platyphyllos*, *B. pendula*) and the use of step-by-step sterilisation using ethyl alcohol, AgNO₃ and NaClO. It was identified that the effect of the sterilisation regime of experimental plants on asepsis is statistically substantial at the level of 5%. It is advisable to use the following protocols (with preliminary exposure in a fungicide solution and 70% ethyl alcohol for 1-2 min): 1) 2.5% NaClO (6-7 min) and 1.0% AgNO₃ (6-7 min) – for *B. pendula*; 2) 5.0% NaClO (6-7 min) and 2.0% AgNO₃ (9-10 min) – for *T. platyphyllos*; 3) 2.0 % AgNO₃ and 5.0% NaClO (9-10 min) – for *F. excelsior* to obtain a substantial amount of aseptic viable microshoots (over 50%). An MS nutrient medium with the addition of 0.25 mg*1⁻¹ kinetin and 2.0 g*1⁻¹ activated carbon is applied to initiate explants. Further research is aimed at developing a protocol for the direct regeneration of microshoots under the action of components of the nutrient medium *in vitro*.

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Оптимізація протоколу стерилізації експлантатів деяких листяних деревних рослин у культурі *in vitro*

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Анотація. Одним із методів отримання садивного матеріалу листяних деревних рослин, зокрема ясена звичайного (*Fraxinus excelsior* L.), липи широколистої (*Tilia platyphyllos* Scop.) та берези повислої (*Betula pendula* Roth), є мікроклональне розмноження. Асептичність експлантатів – передумова мікроклонального розмноження рослин. Здебільшого для цього використовують хімічну стерилізацію рідкими речовинами. На режим деконтамінації впливає низка чинників, зокрема генотип рослини. Мета дослідження – оптимізація протоколу стерилізації експлантатів *F. excelsior*, *T. platyphyllos* та *B. pendula* для мікроклонального розмноження. Для досліджень використовували 20-30 см частини пагонів, ізольовані із 12-річної *T. platyphyllos*, 10-річної *B. pendula* та 15-річного *F. excelsior* у лютому-березні 2021 р. Рослинний матеріал культивували за загальноприйнятою методикою на живильному середовищі MS (Murashige & Skoog, 1962). Для опрацювання дослідних даних використовували програмні засоби MS Excel, розраховано середнє та його основну помилку. Для аналізу впливу режиму стерилізації експлантатів на асептичність проведено однофакторний дисперсійний аналіз (ANOVA). Показано доцільність витримування рослинного матеріалу упродовж доби у фунгіцидних препаратах, зокрема у 0,1 % розчині «Самшит» – *F. excelsior* та 0,3 % розчині «Фундазол» – *T. platyphyllos* і *B. pendula*. Оптимізовано протокол стерилізації дослідних рослин (ефективність понад 50 %) шляхом використання ступінчастого способу із застосуванням 70 % етилового спирту, 1,0 % і 2,0 % AgNO_3 та 2,5 % і 5,0 % NaClO . Установлено, що вплив режиму стерилізації дослідних рослин на асептичність є статистично значущим на рівні 5 %. Для ініціації експлантатів використовували живильне середовище за прописом MS із додаванням 0,25 мг·л⁻¹ кінетину і 2,0 г·л⁻¹ активованого вугілля. Подальші дослідження спрямовані на розроблення протоколу прямої регенерації мікропагонів рослин *F. excelsior*, *T. platyphyllos* та *B. pendula* за дії компонентів живильного середовища *in vitro*

Ключові слова: культура тканин рослин *in vitro*, *Fraxinus excelsior* L., *Tilia platyphyllos* Scop., *Betula pendula* Roth, асептичність, експлантати, регенерація, живильне середовище, мікроклональне розмноження

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Impact of Climate Change on Scots Pine Plantations: State, Problems, Challenges

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Abstract. It is identified that since the beginning of the 19th century, the degradation of pine stands has acquired a huge scale on all continents. In Ukraine, according to the Ministry of Environmental Protection and Natural Resources of Ukraine, the average annual temperature has increased by more than 2°C since the beginning of the 20th century, in particular, by 1.2°C for the last 30 years. In recent years, the number of days with maximum summer temperatures is more than 35°C and 40°C has almost doubled, meaning the extreme weather events are intensifying. In most parts of Ukraine, there is already a tendency to increase droughts and fire danger, repeating the years during which plantings will be exposed to water stress, pest damage, and degradation of forest ecosystems in general due to the increase in the number and duration of hot periods.

It was determined that dendrochronological methods are used to investigate the relationship between climate change and radial pine growth. The main methods for investigating radial increment are to take cores at a height of 1.3 m from two opposite radii, to exclude the influence of random factors on the radial increment. The width of year rings is determined using installations for dendrochronological studies, with automatic data recording. These values of annual rings are processed according to the programmes of the International Tree Ring Data Bank (ITRDB). A specialised COFECHA programme is used to synchronise the series with setting the calendar year of formation of each year's growth. It was identified that the growth of Scots pine is limited by the humidification of the climate and the presence of sufficient moisture in the soil, but in the case of extreme temperatures, a negative trend towards drying out of plantings still remains

Keywords: dendrochronology, pathological processes of the forest, climate changes, pine, radial growth

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Introduction

The biggest global problem today is the increase in the concentration of greenhouse gases in the atmosphere, in particular, carbon dioxide, which is the main cause of global climate change. Due to the anthropogenic impact of human activity, the impact of the greenhouse effect is constantly increasing, as a result of the burning of fossil fuels, and their less absorption due to deforestation. Human activity can substantially change abiotic factors that play a key role in the formation of forest phytocenoses, because the number, distribution, and productivity of plant and animal communities depend on limiting factors. Since the beginning of the 21st century, the phenomenon of previously unheard-of degradation of pine stands, which is gaining a huge scale on all continents, has already been an indisputable fact. It is necessary to know not only the mechanism of its course but also the factors and causes of its appearance in forest phytocenoses to successfully resist the phenomenon. A vision of the most dangerous manifestations and a professional interpretation of the essence of the processes will allow determining the mechanism of influence on these factors, and the principle of forestry management that will be most suitable for the new transformed conditions. A specific feature of the lowland part of Ukraine is the presence of a transition zone between the forest and steppe, in which the vulnerability of forests is extremely high, and there is a high probability that climate change can cause irreversible loss of forests here. Forest vulnerability can be substantially reduced by developing and implementing systematic actions aimed at adapting Ukraine's forests to climate change. The basic imperative is to understand that Ukrainian forests are not just a source of renewable resources, but one of the main factors for levelling the anthropogenic load and creating comfortable conditions for humans. The adaptive potential of Ukrainian forests and the regional sensitivity of forests have not been sufficiently investigated, which actualises the urgent need for research to prevent disruption of the balance of environmental components, loss of environmental sustainability, and destruction of the natural environment.

Climate change, which has taken on a global character, has attracted the attention of all mankind as one of the most pressing environmental problems. According to the World Meteorological Organisation, the warmest years on record were the last three. According to the report of the Intergovernmental Panel on Climate Change, studies show that since the end of the 19th century, anthropogenic impact on two-thirds is due to human activity, namely, an increase in the concentration of greenhouse gases in the planet's atmosphere (Ivaniuta et al., 2020). In 2015, during the preparation for the signing of the Paris Climate Agreement (Conference on Climate Change in Paris, 2015), it was planned to limit the global temperature rise below 2°C by the end of the century. However, at the moment, according to the United Nations, the world is heading for warming at the level of 3.2°C until 2100 (UN Environment programme, 2019).

In Ukraine, according to the Ministry of Environmental Protection and Natural Resources of Ukraine, the average annual temperature has increased by more than 2°C since the beginning of the 20th century, in particular, by 1.2°C for the last 30 years (How the climate, 2020). In recent years, the number of days with maximum summer temperatures is more than 35°C and 40°C has almost doubled, meaning the extreme weather events are intensifying. In most of Ukraine, there is already a tendency to increase droughts and fire danger due to an increase in the number and duration of hot periods. An increase in summer temperature extremes leads to the threat of extinction of certain species and the emergence of new and invasive species. Such changes pose a threat to reducing forest areas and changing the species composition. In particular, the study provides a forecast for Scots pine (Buksha et al., 2017). According to the study, it was determined that according to the forecast, in the period 2080-2100, there will be a substantial narrowing of the optimal growth zone in terms of climate humidity. Due to climate change, it is expected that by the end of the 21st century, there will be quite substantial areas with unfavourable climatic conditions for the growth of Scots pine.

Materials and Methods

The study is based on the analysis of papers that consider the impact of regional and national climate changes on the radial growth of Scots pine stands. The dependence of the radial growth of pine trees on the action of climatic factors, such as precipitation, temperature, humidity, and deep deformations, and depressions of the hydrological regime is determined.

Results and Discussion

Trees respond to any fluctuations in the external environment, which is manifested in changes in the width of year rings – well-defined and easily accessible anatomical features. Trees affected by various factors have the same order of alternation of wide and narrow rings, with narrow rings indicating years of drought and other limiting growth factors, and wide rings indicating favourable years (Bitvinskis, 1974).

As A.I. Getmanchuk notes in his work, based on departmental materials of forestry enterprises of the Polesia zone, which are subordinate to the Volyn Regional Department of Forestry and Hunting (Volyn RDFH), in relation to the foci of acute drying of pine forests over the past two years, a hypothesis was put forward about the climatic origin of its root causes (Getmanchuk et al., 2017). Archival data from meteorological observations of the Kovel weather station for the period from 1946 to 2015 were used to analyse general climate trends and patterns in the forest area. According to the results of research, it was identified that drying of a new type, which is based on the defeat of pine trees by aggressive stem pests and pathogenic fungi, in the territory of the Volyn region in substantial sizes began to manifest themselves over the past 2 years. As of October 3, 2016, according to experts of the Volyn RDFH, 8861 foci of characteristic acute drying with a total area of 3708.7 hectares were identified. Such activity of aggressive stem pests, which manifested itself during the dry period, according to the study conducted by A.I. Getmanchuk, can also be associated with a decrease in productive moisture in the soil; this relationship is described below in the materials of this study. During the survey of pine stands, it was

identified that recently they have been functioning in radically changed forest conditions. Analysis of the complex of characteristics of habitats and vegetation conditions showed that there are atypically deep deformations and depressions of the hydrological regime in forest areas. They are characterised by a sharp character and a powerful negative impact on forests, but until now the details of the mechanism of their formation and action remained uncertain. The climate of the area where enterprises of the Volyn RDFH are located in the materials of previous forest management is described as moderate, humid, with mild winters, unstable frosts, thaws, mild summers, substantial precipitation, and prolonged spring and autumn. The territory of the main woodlands was characterised by a close occurrence of ground water levels. Turf-podzolic soils are common, mainly of light mechanical composition. This is worth noting, because such soils are characterised by high water permeability and low moisture lifting capacity (capillarity). These circumstances contribute to the rapid formation of a crisis hydrological regime during droughts. In particular, in the acute drying year 2015, forest vegetation began to signal a lack of productive moisture in the second half of the growing season. Characteristic reactions were manifested in the form of wilting and early completion of vegetation of grass and tree-shrub flora, partial loss of leaves by individual species (birch, linden, sorbus, etc.), termination of growth processes, early discharge of older needles, defective fruiting, etc. The general mass weakening of the main stand was also accompanied by numerous thermal lesions of the leaf surface in the regrowth and the undergrowth.

In the course of this study, drying out of waterlogged and swampy areas was identified in plantings, and drying out of forest wells and digs due to an increase in the dry period. There was a drop in the water level in reservoirs inside woodlands and tracts, and a lack of water in land reclamation systems in forest and adjacent territories. A characteristic manifestation of the crisis hydrological regime is also the complete disappearance of typical surface water objects in various deepening, cavities, etc. Considering all the aspects

that were highlighted during the study, it can be argued that there is a direct link between dry periods and depressions of the hydrological regime in plantings. In turn, this affects the wilting and early cessation of vegetation of shrubby vegetation and partial loss of leaves of individual tree species. Due to the deterioration of the hydrological regime in the plantings, the activation of stem pests was observed, which is also associated with the weakening of plantings due to droughts.

The purpose of the study by I.M. Koval et al., "Dendroclimatological studies of Scots pine in the planting of the Left-Bank forest-steppe of Ukraine", was to identify the impact of climate change on the radial growth of pine in the left-bank steppe on the example of a 100-year-old pine plantation of the SE "Kharkiv Forest Research Station" (Koval et al., 2017). Dendrochronological methods were used. Based on the results, tree-ring chronologies were created, which helped to establish links between climatic factors and radial growth of pine trees for two periods: 1960-1988 and 1988-2016.

Correlation analysis and the response function for two periods showed that due to the increase in temperatures and precipitation (with the exception of winter precipitation), the response of forest ecosystems to climate change changed, in particular: in the first period (1960-1988), there was a positive effect of summer temperatures on radial growth, but the increase in radial rings was limited by April temperatures, in the second period (1988-2016), June temperatures already negatively affected the growth. With a positive spring temperature and hydrological regime, a radial increase can be observed that is not limited by these indicators, but it is levelled due to high July temperatures. Therewith, a slight increase in precipitation during the growing season could not mitigate the impact of the high temperatures of the growing season on radial growth.

The responses of radial growth of Scots pine to climate change and recreational load in the forest-steppe zone of Ukraine were also investigated (Koval, 2011). Generally accepted methods in forestry and forest taxation, methods of comparative ecology, and dendrochronological methods are applied. The cores were selected at a height of 1.3 m

of pine trunks by a Presler drill from the biogroups of trees. The values of summer wood layers were measured on a Henson digital instrument with an accuracy of 0.01 mm. The obtained series of individual values of tree rings are averaged for each plantation. Data on annual ring values were processed according to the programmes of the International Tree Ring Data Bank (ITRDB).

Data from the Komsomol weather station were used to analyse the influence of climate on the formation of tree rings. The calculation of growth change indices (GGt) for the year of damage (t), which are universal for all types of breeds and growing conditions is performed to identify violations in plantings under the influence of stress factors. As a result of the analysis of the dynamics of radial pine growth, three periods of stand development were identified for the periods 1967-2008. In the forest-steppe zone, warming and increased precipitation began to accelerate during 1989-2008. Temperatures rose particularly rapidly during the cold period, which led to a decrease in the trend of radial growth of pine trees due to a violation of the winter dormancy of trees in 1999-2008. Therewith, precipitation to a lesser extent began to limit the formation of rings in pines. Periods of stand development based on the dynamics of radial pine growth are identified: 1967-1975, 1976-1989, and 1990-2008, and years of minimal radial tree growth (1975, 1983, 1984, 1987, 1990, 1994, 1996, 2002, and 2007), which are characterised by droughts and low temperatures in winter and early spring, with the exception of 2007 with extremely warm winters and early spring. Pine radial growth maxima were established in 1980, 1989, 1997, and 2004 with a favourable heat-to-moisture ratio for tree growth.

In the course of the study, it was determined that the violation of winter dormancy of trees due to a rapid increase in temperature during the winter period in 1999-2008 led to a decrease in the trend of radial growth of pine trees. In addition, in years characterised by reduced precipitation, droughts, and low temperatures in winter and spring, minimal radial tree growth was determined. The maxima of radial growth were in years with a favourable ratio of temperature and hydrological conditions.

In their study, O.V. Zhukovskiy and O.V. Zborovska (Zhukovskiy & Zborovska, 2015) analysed the relationship between the radial growth indices of pine and climate for plantings of 61-80 years of age, which grow in fresh forest conditions on moraine and water-glacial deposits. For 1945-1976, a positive effect of precipitation on the radial growth of pine trees was identified for fresh pinewood plantings in places of water-glacial deposits, that is, in poor conditions and with low soil moisture capacity for the year and during the growing season. In 1977-2008, these connections decreased, which is explained by an increase in precipitation. Comparing the periods 1945-1976 and 1977-2008, it was identified that the amount of precipitation during the growing season increased by 5%, and for the year – by 7%. However, in 2001-2010, the amount of precipitation during the growing season, on the contrary, decreased by 10%. Precipitation had a positive effect on the radial growth of trees in fresh forest stands in places of water-glacial deposits.

The negative influence of growing season temperatures on the formation of wood layers was identified for plantings growing in the fresh forest on water-glacial deposits for 1945-1976. Later, in 1977-2008, this restriction was relaxed due to the fact that the temperature increased by 1.3% (0.21°C) compared to the previous period of 1945-1976. The rate of warming accelerated during 1999-2008 when the average annual temperature increased by 6% (by 0.9°C). March temperatures in the second period (1977-2008) increased the impact on the radial growth of pine trees for all plantings of fresh pine barrens and fresh sub-barrens on moraine and water-glacial deposits due to their increase by 62% (1.8°C) compared to 1945-1976. Winter temperatures rose by 66% (1.5°C) in 1977-2008 compared to 1946-1976. A positive effect on the radial increase in winter temperatures was identified for planting fresh pinewood on moraine for 1977-2008 and in plantings that grew on water-glacial deposits for 1946-1976. It is established that plantings in fresh forest conditions on water-glacial deposits are the most sensitive to climate. Radial growth in all plantings is limited by climatic factors such as precipitation, relative humidity during the growing season, and winter

and early spring temperatures. For 1977-2008, compared to 1945-1976, the dependence of radial growth of Pine on precipitation decreased, the amount of which increased by 7% during the growing season, but in 2001-2010, the opposite process occurred – a decrease in precipitation during the growing season and an increase in the dependence of radial growth on temperatures, which increased by 1.3% and 62%, respectively.

V.P. Ivanov in his study (Ivanov et al., 2021) proposed an approach for analysing the causes of a sharp decline in the radial growth trend under the influence of temperature and precipitation. The research was conducted on the territory of the Bryansk administrative district in the Educational-experimental forestry of the Bryansk State Engineering-Technological Academy. The climate situation was analysed for five years before the decline in growth and five years after that. Notably, the radial increase in the five years before the recession was not the same. During the study, it was identified that a more informative picture of the features of radial growth is given by detailing the influence of temperature at the level of the average monthly temperatures of the current and previous growing season and using indicators of the average monthly precipitation. Thus, the radial growth of Scots pine in the Bryansk region in dry and fresh forests occurs in years with cold January, warmer May, and August of this year, provided that January of last year is warmer. There was no substantial influence of the average monthly precipitation in conditions of violation of the hydrological regime.

Conclusions

The impact of climate change on the forests of Ukraine varies, depending on the geographical location, geomorphology, and topography of forest types and the forest management regime. The state and dynamics of forest ecosystems are the results of a complex interaction of environmental factors. Trend changes in the main climate indicators within the current and expected values are less dangerous than climate variability, frequency, and severity of extreme situations (heat waves or droughts). The growth of Scots pine in Ukraine is limited by climate humidification. In terms of humidity, favourable

conditions are very poorly represented, satisfactory conditions for pine trees in the West and to a small extent in the North, and in the rest of the territory – unsatisfactory and extreme. Unsuitable conditions are observed in the South of Ukraine.

The main limiting factors influencing the radial growth of Scots pine are the amount of precipitation, soil moisture, its capillarity, and the temperature regime at the beginning of the growing season of stands. The influence of summer temperatures also makes its adjustments to the development of plantings. Extreme summer temperatures can cause early leaf fall from woody and shrubby vegetation due to changes in the hydrological regime.

A change in the climatological situation can lead to a substantial transformation of forest covers, including a shift in the boundaries of pine ranges. It is climate change that is one of the most dangerous factors for the further destruction of forest covers and destabilisation of forestry.

It is necessary to know the mechanism of identification of changes in the types of plantings and stability of Scots pine in the future and conduct a retrospective analysis to establish the degree and mechanism of impact of climate change in the context of the progressive spread of depressions and digressions of plantings to successfully resist a negative phenomenon.

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**Вплив змін клімату на насадження сосни звичайної:
стан, проблеми, виклики**

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Анотація. Досліджено, що з початку XIX ст. деградація соснових деревостанів набуває величезного масштабу на всіх континентах. В Україні за даними Міністерства захисту довкілля та природних ресурсів України середня річна температура з початку XX ст. зросла більш ніж на 2°C, зокрема на 1,2°C за останні 30 років. Останніми роками кількість днів із максимальними температурами влітку понад 35°C та 40°C зросла майже вдвічі, тобто йдеться про екстремальні погодні явища. На більшій частині України вже спостерігається тенденція до посилення посух, збільшення пожежної небезпеки, повторюваності років, упродовж яких насадження зазнаватимуть водного стресу, ураження шкідниками, а також деградації лісових екосистем загалом унаслідок збільшення кількості та тривалості спекотних періодів.

Визначено, що при дослідженні зв'язку між зміною клімату і радіальним приростом сосни використовують дендрохронологічні методи. Основними методами дослідження радіального приросту є взяття кернів на висоті 1,3 м із двох протилежних радіусів, для унеможливлення впливу на радіальний приріст випадкових факторів. Ширину річних кілець визначають за допомогою установок для дендрохронологічних досліджень, з автоматичною реєстрацією даних. Дані величин річних кілець обробляють за програмами Міжнародного банку даних деревних кілець (ITRDB). Для синхронізації рядів зі встановленням календарного року утворення кожного річного приросту використовують спеціалізовану програму COFESHA. Виявлено, що ріст сосни звичайної лімітується зволоженням клімату та наявністю достатньої кількості вологи у ґрунті, проте у разі екстремальних температур все одно зберігається негативний тренд щодо всихання насаджень

Ключові слова: дендрохронологія, патологічні процеси лісу, кліматичні зміни, сосна, радіальний приріст

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