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Current state and productivity of Scots pine modal stands of the Forest Steppe of Ukraine

Andrii Terentiev*

PhD in Agricultural Sciences, Associate Professor
Educational and Research Institute of Forestry and Landscape-Park Management
National University of Life and Environmental Sciences of Ukraine
03041, 19 Horikhuvatskyi Shliakh Str., Kyiv, Ukraine
https://orcid.org/0000-0001-9845-3638

Oleksandr Bala

PhD in Agricultural Sciences, Associate Professor
Educational and Research Institute of Forestry and Landscape-Park Management
National University of Life and Environmental Sciences of Ukraine
03041, 19 Horikhuvatskyi Shliakh Str., Kyiv, Ukraine
https://orcid.org/0000-0001-6538-8876

Petro Lakyda

Doctor of Agricultural Sciences, Professor
Educational and Research Institute of Forestry and Landscape-Park Management
National University of Life and Environmental Sciences of Ukraine
03041, 19 Horikhuvatskyi Shliakh Str., Kyiv, Ukraine
https://orcid.org/0000-0003-3639-2969

Hennadii Bondar

Postgraduate Student
Educational and Research Institute of Forestry and Landscape-Park Management
National University of Life and Environmental Sciences of Ukraine
03041, 19 Horikhuvatskyi Shliakh Str., Kyiv, Ukraine
https://orcid.org/0009-0004-3588-507X

Abstract. The development of regulatory and reference support for the inventory assessment of the state of modal stands is an urgent issue, since it allows obtaining reliable and up-to-date information on the current state of existing forests. The purpose of the study was a statistical substantiation of the division of pine stands into groups by region of growth and stand composition,

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*Corresponding author

and their detailed inventory characteristics with an analysis of the distribution in the Forest-Steppe and their productivity. To conduct the study, a stand-wise database of the Production Association "Ukrderzhlisproekt" for Forest-Steppe zone of Ukraine was used. Using a number of non-parametric criteria for evaluating samples (Kruskal-Wallis one-way analysis of variance, the median criterion, Jonckheere-Terpstra test), the study established a difference in the stands parameters of the samples under study and divided the stands of the Forest-Steppe zone into four groups. The main task was to describe the current state of modal pine stands of the Forest-Steppe zone of Ukraine for selected groups, with a detailed distribution of areas and stocks according to the main stand parameters According to the results of the database analysis, it was found that about 92% of the total area of pine stands of the Forest-Steppe zone are artificial forests. Depending on the region of growth, the stands were divided into the left- and right-bank parts of the Forest-Steppe, in composition – into pure and mixed stands. Within the groups under study, the distribution of areas and stocks of pine stands was analysed according to site index classes, types of forest-growing conditions, forest types, relative stand density, and age groups. Site index classes in all groups are dominated by high site index stands of I and I^a site index classes. The proportion of high-grade mixed stands is greater compared to pure stands. In terms of the forest-growing conditions, stands in condition B_2 dominate in all groups under study. From the left bank to the right bank, there is an increase in soil fertility from condition B to condition C, and this dependence is also observed from pure to mixed stands. Productivity in terms of the average growing stock of mixed stands of the right-bank and left-bank parts of the Forest-Steppe is very close and considerably less than the stocks of pure stands. The presented research results can be used by scientists as a description of the modal inventory characteristics of the Forest-Steppe region and for the grouping of experimental data when compiling forestry and forest inventory standards

Keywords: stand-wise database; non-parametric criteria; average growing stock; site index; stand species composition; site condition; relative stand density

Introduction

The improvement of the system of information support for the inventory assessment of forest resources of Ukraine is a significant issue that requires a detailed investigation, estimation, description, and development of relevant normative and reference support to assess the condition and forecast the growth of the main forest-forming tree species, considering the specific features of their growth depending on the region, forest-growing conditions, origin, and composition. An important stage of research is to establish, for a particular tree species, which stands by origin and composition are the most common in a given region for the subsequent compilation of growth charts for modal stands.

Scots pine (*Pinus sylvestris* L.) occupies the largest share of forests in Ukraine, they make up over 33%, or 3,130 thous. ha of forest areas covered with forest vegetation (Lovynska *et al.*, 2021). Scots pine stands are found in all natural areas of Ukraine. Such a wide area is explained by the unpretentiousness of this tree species to the temperature regime, the ability to withstand significant frosts up to -50 °C, soil – up to -24 °C, and heat – up to +40 °C. Scots pine is one of the key species in Europe and extends from the boreal region of Northern and Eastern

Europe to the Mediterranean mountains of Southeastern Europe (Socha *et al.*, 2021). Scots pine belongs to xerophytic and oligotrophic tree species, and therefore it can grow both on poor-fertility sands and on rich chernozems, it can be found even on stony soils, in the steppe zone and swamps.

Pine forests play a vital ecological role, namely, water protection, water regulation, soil protection, and anti-erosion. Pine stands regulate surface runoff, protect soil from erosion, and water sources from pollution, which is especially important on the sandy soils of Polissia (Yukhnovskyi *et al.*, 2021). Given the unpretentiousness of pine to soils, it is often used in the afforestation of anthropogenically disturbed landscapes (Brovko *et al.*, 2021), ravines and gullies, on poor and eroded soils, and can also be the main species in the afforestation of old arable land (Lakyda *et al.*, 2011). The ability of pine to release a considerable amount of volatile phytoncides has ensured its widespread use for recreational and sanitary purposes. On the territory of Ukraine, there are a significant number of health facilities located directly in pine forests.

Pine timber is important for the national economy of the country, especially widely used in construction, suitable for the manufacture of ore risers necessary for the development of mineral deposits. The presence of resinous substances provides increased resistance of wood to rot and has the property of creaking when the load increases, which is useful for labour protection of miners.

It was important to investigate the statistical substantiation of the possibility of grouping data on the Forest Fund, which will later be used as source data, into homogeneous groups. It is necessary to statistically confirm the similarity or difference between stands of different tree species in composition and origin. Pine stands of Ukraine are mostly concentrated in the Polissia zone (73.3% of the area of all pine stands (Bala *et al.*, 2017)) and a considerable number of scientific forestry studies, including forest inventory studies, have been devoted to their investigation, while the study of the growth of pine stands in the Forest Steppe of Ukraine has received less attention. Of the currently available ones, studies of pine stands in the Forest-Steppe were conducted mainly on its left-bank part. This can be explained by the territorial location of the H.M. Vysotsky Ukrainian Research Institute of Forestry and Agroforestry (Kharkiv), whose scientists addressed various silvicultural problems of pine stands. Thus, at different times, studies of the productivity of pine stands on the left bank of the Forest-Steppe were conducted by O.V. Tovstukha (2012), V.V. Nazarenko & V.P. Pasternak (2016), V.Yu. Yarotsky *et al.* (2016), V.P. Tkach *et al.* (2018), A.V. Harmash (2019) and S.I. Musienko *et al.* (2021) investigated the current state of pine stands within the left-bank Forest-Steppe of Ukraine and their age structure. The study of radial increment and the influence of climate changes on it is described in the studies of researchers I.M. Koval *et al.* (2018), I.M. Koval & V.O. Voronin (2019), O.A. Mikhaylichenko *et al.* (2021). V.P. Chigrinets *et al.* (2012) investigated forestry issues of the typological structure of pine forests of the left-bank Forest-Steppe, O.M. Tarnopilska & O.A. Ponomarev (2008) examined the impact of forestry measures, namely maintenance felling of various intensities, on their growth. The vast majority of these studies concerned Scots pine stands growing in the Kharkiv and Sumy regions. Some studies were limited to the territory of separate forestry enterprises.

The purpose of this study was statistical confirmation or refutation of the null hypothesis about the significance of the difference between the average stand parameters in modal pine stands of the Forest-Steppe zone of Ukraine in terms of groups of stands differing in growth region, origin, and composition, as well

as determining the groups according to which further forest inventory standards for modal Scots pine stands should be compiled and their detailed inventory characteristics.

The main tasks were to conduct a detailed analysis of the growing stands of Scots pine on the territory of the Forest-Steppe of Ukraine; to determine the main groups according to growth region (left or right bank of the Forest-Steppe), origin (artificial or natural) and composition (pure or mixed) for further statistical and inventory research; to conduct a statistical comparison of the selected groups on the subject of similarity or difference in their stand parameters; to describe the current state of modal pine stands of the Forest-Steppe zone of Ukraine for selected groups with a detailed distribution of areas and stocks according to the main stand parameters.

Materials and Methods

The calculations were performed using the sub-compartment forest inventory data of the database of the Production Association (PA) "Ukrderzhlisproekt" for the forest-growing zone of the Forest-Steppe with a division into groups according to the composition and origin of the tree stands (Ukrainian State Project..., n.d.). Stands of all departmental subordinations involving Scots pine in the stand composition of 2 or more units were selected for analysis. Therewith, almost 95% of all tree stands consisted of 6 or more units of Scots pine. Before using the database, it was verified to search for and filter out gross errors in the analysed inventory features of tree stands. As a result, an array of 133,540 forest stands with a total area of 451.3 thous. ha was used for further work.

For further statistical process ing, the database was divided into four groups:

1. artificial pure stands of the right-bank part of the Forest-Steppe, with 10 units of the main species in the stand composition (hereinafter – PR);

2. artificial pure stands of the left-bank part of the Forest-Steppe, with 10 units of the main species in the stand composition (hereinafter – PL);

3. artificial mixed stands of the right-bank part of the Forest-Steppe, with less than 10 units of the main species in the stand composition (hereinafter – MR);

4. artificial mixed stands of the left-bank part of the Forest-Steppe, with less than 10 units of the main species in the stand composition (hereinafter – ML).

The distributions of age, average height, average diameter, density, and average stock per 1 ha were used for statistical processing of samples.

The study was based on the principles of a system approach using modern information technologies and software (program for statistical data processing – IBM SPSS Statistics). During the study, general scientific (analysis, synthesis, hypothesis) and special (forestry, inventory, biometric) methods of cognition were combined. Analysis and synthesis were used to process, analyse, and group input information from the forest inventory characteristic database. The hypothesis was used to predict the division of experimental material into groups in the context of the stand composition and geographical location. Forestry methods in combination with inventory methods were used to group and analyse experimental data by types of forest conditions and average parameters of stands. Biometric methods were used in statistical data processing and calculation of criteria for estimating sample similarity.

Considering the data of previous studies (Bala *et al.*, 2019), namely the difference of the distribution of forestry information from the normal distribution, as well as the possibility of simultaneous comparison of several groups under study, it was decided to use non-parametric methods. Non-parametric methods that allow comparing the level of expression of a variable include Kruskal-Wallis one-way

analysis of variance (Kruskal, 1952); criterion of medians (Friedlin & Gastwirth, 2000); Jonckheere-Terpstra criterion of ordered alternatives (Jonckheere, 1954).

The Kruskel-Wallace test is used to assess differences between the groups under study with medians and is a generalization of the Mann-Whitney *U*-test (Mann & Whitney, 1947) for two independent samples. Thus, the Kruskel-Wallace test is a non-parametric alternative to the *F*-test in univariate analysis of variance and uses the total variance when comparing two independent samples (Agresti, 2019). If the conditions necessary for the application of the *F*-test in univariate analysis of variance are met, the Kruskel-Wallace test has analogous capabilities. The Kruskel-Wallace test is used to test the hypothesis about the equality of the medians of independent samples that belong to the same general population.

The median criterion is a non-parametric statistical criterion that belongs to the class of rank bias criteria. It allows testing the hypothesis that the shape of the distributions of two samples is identical and that there is a difference between them by a certain constant value (Friedlin & Gastwirth, 2000). Therewith, the total median is calculated for all independent samples, after which the number of measured values that are larger or smaller than the median is calculated. The result is the construction of a field table containing 2·k fields, which is then subjected to a chi-square test. In general, the median criterion is not very effective.

The Jonckheere-Terpstra criterion for ordered alternatives is a better alternative to the Kruskel-Wallace criterion, in the case when the samples under study are naturally ordered. Important is not only the fact that there are differences between several samples, but also the direction of change (increase or decrease) of differences when moving from sample to sample. To solve problems of this type, the Jonckheere-Terpstra criterion is used with an alternative hypothesis: "there are differences between samples, and the medians of samples are arranged in ascending order". To use this criterion, samples must be ordered according to the expected growth of the factor effect (e.g., average values). The Jonckheere-Terpstra criterion allows for a more detailed analysis and often reveals differences in cases where the Kruskel-Wallace criterion is ineffective (Bala *et al.*, 2019).

Using the above methods in the present study, hypothesis testing matrices were constructed, which allowed determining the similarity of the tree stands under study and identifying homogeneous groups of stands according to their composition and geographical location.

During the study of the distribution of pine stands according to the type of forest-growing conditions (FGCT), the scale of P.S. Pogrebnyak (1955) was used, according to which plots are divided according to soil fertility and denoted by the letters A, B, C, and D from poor to rich in terms of fertility. In addition, an index is added to the letter that characterizes soil moisture and is indicated by numbers from 0 to 5, where 0 is very dry, and 5 is very wet growing conditions.

Results and Discussion

Analysis and modelling of stand parameters of modal stands of Scots pine in the Forest-Steppe of Ukraine requires a clear division of the latter into statistically substantiated homogeneous structural elements (groups), which further allows finding adequate models to predict their growth and development, identify natural factors of influence on the growth and development of tree stands, and reduce the variance of input research data. For this, the special stand-wise database provided by PA "Ukrderzhlisproekt" (Ukrainian State Project..., n.d.) was analysed, which characterizes Scots pine stands that differ in composition and origin. As a result, the distri-

bution of the areas of the stands under study according to these parameters was obtained (Table 1). Pure stands included stands with 10 units of the main species in the stand composition, which was substantiated in the study of P.I. Lakyda *et al.* (2012).

Table 1. Distribution of Scots pine stands in the Forest-Steppe of Ukraine

Origin	Composition	Forest-Steppe natural area							
		left-bank				right-bank			
		area		total stock		area		total stock	
		ha	share	thous. m³	share	ha	share	thous. m³	share
Natural	Pure	10448.3	60.1	3471.69	65.4	8464.2	42.8	2633.94	44.9
	Mixed	6951.0	39.9	1837.39	34.6	11320.6	57.2	3226.65	55.1
	Total	17399.3	7.2	5309.08	7.1	19784.8	8.0	5860.59	8.7
Artificial	Pure	172402.3	76.7	56484.83	81.5	134026.6	59.2	39297.79	64.0
	Mixed	52290.4	23.3	12842.49	18.5	92559.3	40.8	22119.47	36.0
	Total	224692.7	92.8	69327.32	92.9	226585.9	92.0	61417.26	91.3
Total		242092.0	100.0	74636.4	100.0	246370.7	100.0	67277.9	100.0

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

Scots pine stands in the Forest-Steppe of Ukraine cover an area of 488,462 thous. ha and have a total stock of 141.914 million m³ (Table 1). They are distributed almost evenly in the left-bank and right-bank parts (49.6% in the left-bank and 50.4% in the right-bank part of the areas of pine stands of the Forest-Steppe). Therewith, these stands are mainly of artificial origin. Thus, in the left-bank part of the Forest-Steppe, the share of artificial stands is 92.8% (224,692 thous. ha) of the area of pine stands in the left-bank part; for the right-bank part, this figure is 92% (226,586 thous. ha), respectively. Considering the small share of natural tree stands, it was decided to conduct further analysis for artificial tree stands. The share of artificial pure stands in the composition in the left-bank part is quite high and amounts to 172,402 thous. ha (76.7% of the area of artificial pine stands in the left-bank part of the Forest-Steppe); for the right-bank part, this figure is 134,027 thous. ha (59.2%).

The groups under study were compared using the statistical methods described above, and the null hypothesis about the similarity of the compared groups was accepted. In the obtained results, the *p*-value of the calculated indicator exceeds 0.001, which proves the existence of a relationship between the stand parameters of the groups under study and confirms their similarity. In addition, in comparison diagrams of calculated values, the equidistance of points from each other indicates that there is no relationship between the stand parameters of the groups under study.

The results of hypothesis testing using various methods are presented in Table 2.

Table 2. Result of testing hypotheses about sample equality

Stand parameters	Criteria for independent samples	Result
Age	Median criterion	Hypothesis rejected
	Kruskal-Wallace test	Hypothesis rejected
	Jonckheere–Terpstra test	Hypothesis rejected

Table 2, Continued

Stand parameters	Criteria for independent samples	Result
Average height	Median criterion	Hypothesis rejected
	Kruskal-Wallace test	Hypothesis rejected
	Jonckheere–Terpstra test	Hypothesis rejected
Average diameter	Median criterion	Hypothesis rejected
	Kruskal-Wallace test	Hypothesis rejected
	Jonckheere–Terpstra test	Hypothesis rejected
Relative density	Median criterion	Hypothesis rejected
	Kruskal-Wallace test	Hypothesis rejected
	Jonckheere–Terpstra test	Hypothesis rejected
Stock per 1 ha	Median criterion	Hypothesis rejected
	Kruskal-Wallace test	Hypothesis rejected
	Jonckheere–Terpstra test	Hypothesis rejected

Source: compiled by the authors

An example of paired comparisons of the median criterion is presented in Figure 1. Thus, the data in Table 2 and Figure 1 demonstrate that for all comparison groups, the null hypothesis of sample similarity is not confirmed by statistical criteria and should be rejected. Further analysis should be carried out for the groups under study, which factor in their statistical differences.

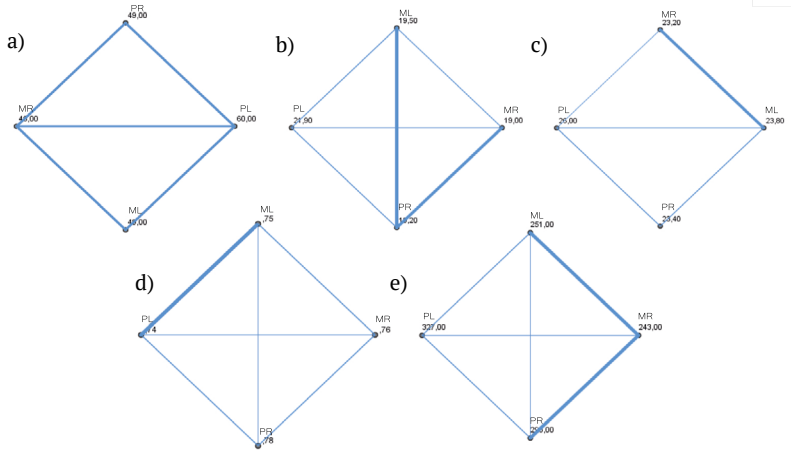

Figure 1. Comparison diagrams for the values of paired criteria for the median stands of Scots pine: a) age, b) average height; c) average diameter; d) density, e) stock per 1 ha

Source: compiled by the authors

Based on data from the stand-wise database, average stand parameters for artificial pine stands were calculated by groups according to natural zones and composition. The obtained parameters are presented in Table 3.

Table 3. Average stand parameters of artificial pine stands in the Forest-Steppe of Ukraine

Forest-Steppe natural area	Composition	Age, years	Height, m	Diameter, cm	Relative density	Stock, $m^3 \cdot ha^{-1}$
Left-bank	Pure	60	20.6	25.3	0.74	310
	Mixed	48	17.8	22.4	0.74	235
	Total	57	19.8	24.6	0.74	290
Right-bank	Pure	51	18.7	23.4	0.76	284
	Mixed	46	17.6	22.4	0.75	232
	Total	49	18.2	22.9	0.76	262
Total		53	19.1	23.8	0.75	276

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

The data in Table 3 suggests that the pine stands of the left-bank part of the Forest-Steppe of Ukraine are older compared to the stands of the right-bank part, and their age is 57 years and 49 years, respectively. Notably, pure tree stands are older than mixed ones throughout the Forest-Steppe. Analysing the data in the table, it should be noted that the average stand parameters of the pine stands of the left bank part are higher than the corresponding parameters of the stands of the right-bank part, such results can primarily be explained by the different age structure, which could affect the difference in parameters. Pure stands are characterized by greater productivity than mixed ones, the average stock per 1 ha for the left-bank part is 310 m^3 and for the right-bank part – 284 m^3.

The distribution of pine stand areas according to site index classes is presented in Table 4 and Figure 2.

Table 4. Distribution of areas of pine stands in the Forest-Steppe of Ukraine according to site index classes

Composition	Site index	Forest-Steppe natural area					
		left-bank			right-bank		
		area		stock, $m^3 \cdot ha^{-1}$	area		stock, $m^3 \cdot ha^{-1}$
		ha	share		ha	share	
Pure	I^c and above	265.7	0.2	360	384.7	0.3	357
	I^b	6041.1	3.5	396	5546.0	4.1	370
	I^a	43348.4	25.1	366	40737.5	30.4	348
	I	84000.8	48.7	309	60270.9	45.0	276
	II	28732.1	16.7	262	21108.3	15.7	211
	III	7404.4	4.3	184	4986.6	3.7	144
	IV and below	2609.8	1.5	129	992.6	0.7	97
	Total	172402.3	100.0		134026.6	100.0	
Mixed	I^c and above	285.0	0.5	336	514.4	0.6	299
	I^b	4217.3	8.1	347	6823.7	7.4	311
	I^a	15808.0	30.2	300	33016.7	35.7	289
	I	23708.1	45.3	201	38030.3	41.1	201
	II	6573.5	12.6	172	11005.6	11.9	152
	III	1376.9	2.6	117	2803.3	3.0	99
	IV and below	321.6	0.6	96	365.3	0.4	64
	Total	52290.4	100.0		92559.3	100.0	

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

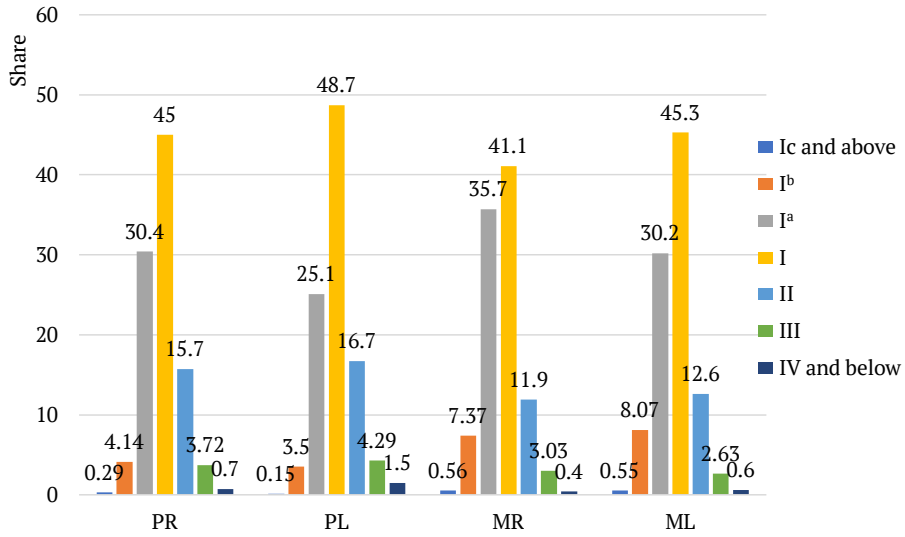

Figure 2. Distribution of pine stand areas according to site index classes

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

The above data suggests that the share of tree stands that grow according to site index class I and higher, pure stands of the left-bank part of the Forest-Steppe is 77.5% (133,656 thous. ha, from the area of pure Scots pine stands of the left-bank part of the Forest-Steppe). For the right-bank part of the Forest-Steppe, this figure was 79.8% (106,939 thous. ha). Notably, the proportion of high-purity mixed stands is higher compared to pure stands. Thus, the share of mixed stands with high site index class of the left-bank part of the Forest-Steppe is 84.2% (44,018 thous. ha, from the share of mixed Scots pine stands of the left-bank part of the Forest-Steppe), for the mixed stands of the right-bank part of the Forest-Steppe, this share was 84.7% (78,385 thous. ha). The average site index class of mixed stands for both regions is I^a, 7; for the left-bank part, pure stands have an average site index class I,0, for the right-bank part – I^a, 9.

According to the type of forest-growing conditions for different groups, pine stands in the Forest-Steppe of Ukraine are distributed unevenly (Table 5 and Fig. 3). Specifically, 19.5% (33,619 thous. ha of the area of pure pine stands of the left-bank part of the Forest-Steppe) of pure pine forests of the left-bank part are distributed in conditions A, 61.9% (105,943 thous. ha) – in conditions B, 17.8% (30,732 thous. ha) – in conditions C and D. Mixed pine stands of the left-bank part grow in richer forest-growing conditions, the share of growth in conditions C and D was 46.2% (24,147 thous. ha of the area of mixed pine stands of the left-bank part of the Forest-Steppe), the share of pine growth in conditions B – 45.6% (23,854 thous. ha) and conditions A – 7.6% (3,996 thous. ha). Mixed pine stands of the right-bank part of the Forest-Steppe are common in much richer forest-growing conditions than others. Thus, the share of growth conditions C and D was 64.8% (59,940 thous. ha, from the area of mixed pine stands in the right-bank part of the Forest-Steppe), the share of conditions B – 27.2% (25,177 thous. ha) and conditions A – 2.5% (2,321 thous. ha). Pure pine stands of the right-bank part of the Forest-Steppe were distributed as follows: A – 10.6%; B – 44.4%; C and

D – 42.6%. According to the analysis results, the following dependence of Scots pine growth in the Forest-Steppe is observed: in the left-bank part, poorer conditions B dominate; on the right bank, from pure to mixed stands, there is a change in growth from conditions B to conditions C; in all areas, fresh growth conditions predominate in terms of humidity (index 2).

Table 5. Distribution of areas and stocks of pine stands in the Forest-Steppe of Ukraine according to types of forest-growing conditions (FGCT)

FGCT	Forest-Steppe left-bank zone				Forest-Steppe right-bank zone			
	pure		mixed		pure		mixed	
	area, ha	stock, $m^3 \cdot ha^{-1}$	area, ha	stock, $m^3 \cdot ha^{-1}$	area, ha	stock, $m^3 \cdot ha^{-1}$	area, ha	stock, $m^3 \cdot ha^{-1}$
A_1	6,529.8	182	571.5	147	3,955.7	170	294.2	83
A_2	27,089.2	259	3,424.6	157	10,310.8	246	2,026.6	128
B_1	1,776.9	259	272	181	5,104.8	248	999.1	139
B_2	105,008.4	324	22,804.9	218	50,943.5	303	22,003.2	212
B_3	934.9	350	776.6	243	3,485.6	246	2,174.5	202
C_2	27,579.9	333	20,085.4	262	42,158.7	299	39,042.6	243
C_3	1,833.3	370	1,966.4	286	4,480.3	321	8,126.9	252
D_2	1,319.2	297	2,095.1	269	10,506.6	260	12,770.8	242
Other FGCTs	330.7	210	293.9	165	3,080.6	232	5,121.4	230
Total	172,402.3		52,290.4		134,026.6		92,559.3	

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

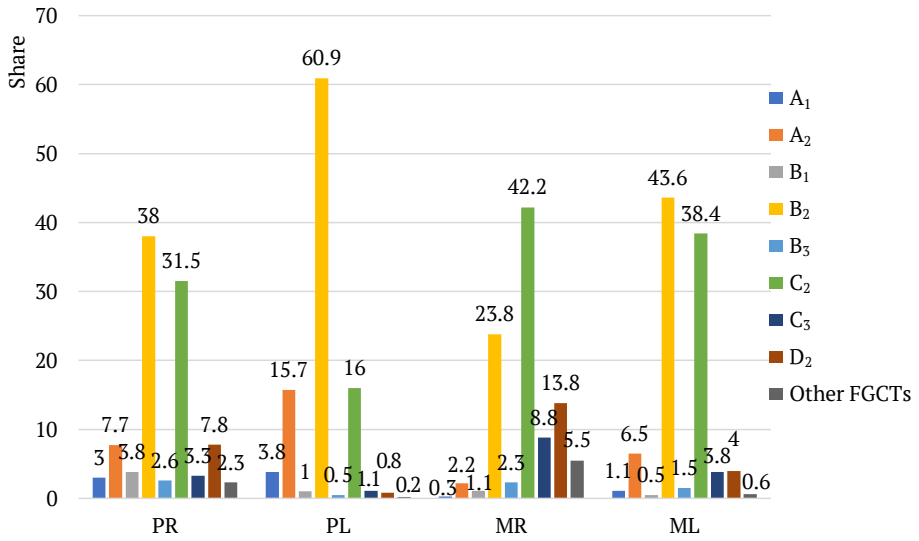

Figure 3. Distribution of areas of pine stands in the Forest-Steppe of Ukraine according to types of forest-growing conditions

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

Analysing the average stock of pine stands, the greatest productivity in terms of stock in all groups is observed in conditions C_3. The largest margin in pure stands: 370 $m^3 \cdot ha^{-1}$ for

the left-bank part and 321 $m^3 \cdot ha^{-1}$ for the right-bank part. Mixed stands in these conditions have an average margin for the left-bank part of 286 $m^3 \cdot ha^{-1}$, and for the right-bank – 252 $m^3 \cdot ha^{-1}$.

Over 86% of the area of pine stands in the Forest-Steppe of Ukraine has a relative completeness of 0.7-0.9 (Table 6 and Fig. 4). There is a difference in the distribution of relative stand density for the left- and right-bank parts of the Forest-Steppe, there is no significant difference in the distribution of tree stands for pure and mixed stands. In general, pine stands of the right-bank part are described by a higher proportion of high-density stands (with a density of 0.9-1.0) and, accordingly, a lower proportion of stands with a density of 0.7. There is also a share of stands (up to 14%), which grow with a reduced density of 0.6 and below. The most productive according to average margin are stands with a density of 0.9 for all groups of pine stands.

The age structure of stands is not uniform (Table 7 and Fig. 5). The share of young ani-

Table 6. Distribution of areas and stocks of pine stands in the Forest-Steppe of Ukraine according to relative stand density

Density classes	Forest-Steppe left-bank zone				Forest-Steppe right-bank zone			
	pure		mixed		pure		mixed	
	area, ha	stock, $m^3 \cdot ha^{-1}$	area, ha	stock, $m^3 \cdot ha^{-1}$	area, ha	stock, $m^3 \cdot ha^{-1}$	area, ha	stock, $m^3 \cdot ha^{-1}$
0.4 and under	1,375.9	175	392.9	142	833.5	140	503.0	136
0.5	3,681.1	226	1,365.0	162	2,675.9	197	1,793.0	173
0.6	17,591.5	283	5,111.1	188	11,493.7	240	7,907.0	202
0.7	59,712.8	314	16,930.0	231	37,621.6	266	27,018.1	215
0.8	66,494.3	320	21,273.9	251	53,577.7	297	39,483.3	249
0.9	22,695.1	329	6,826.8	272	27,049.2	317	15,155.5	254
1.0	851.6	249	390.7	254	775.0	263	699.4	196
Total	172,402.3		52,290.4		134,026.6		92,559.3	

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

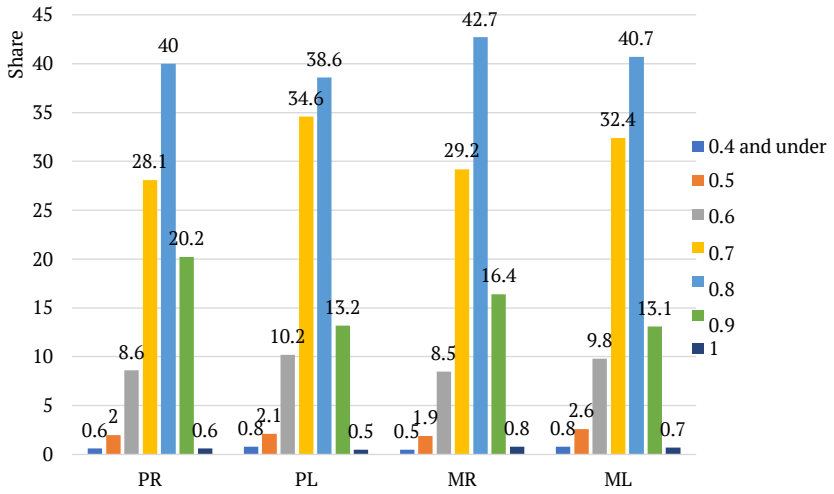

Figure 4. Distribution of areas of pine stands in the Forest-Steppe of Ukraine according to relative stand density

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

mals in pure pine stands of the left-bank part of the Forest-Steppe is 20.13 thous. ha (11.7% of the area of pure pine stands of the left-bank part), a considerable share of middle-aged stands –115.823 thous. ha (67.2%) and mature 30.742 thous. ha (17.8%) and a small area of mature and over-mature stands 5,663 thous. ha (3.3%). Mixed stands of the left-bank part of the Forest-Steppe are described by a large share of young animals – 35.7% (18,659 thous. ha) of the area of mixed stands of the left-bank Forest-Steppe and, accordingly, smaller shares of middle-aged stands (47.6% or 24,873 thous. ha) and maturing (13.9% or 7,289 thous. ha) and a small share of mature and over-mature 2.8% (1,469 thous. ha). In contrast to the pure pine stands of the left-bank part, the stands of the right-bank part have a large share of young animals, which make up 25.2% of the area of pure pine stands of the right-bank part of the Forest-Steppe (33,714 thous. ha), a considerable share of middle-aged – 61.2% (81,984 thous. ha) and maturing – 10.6% (14,152 thous. ha) as well as for other stands, the share of mature and over-mature is insignificant – 2.8% (1,469 thous. ha). The largest part of young animals is observed in mixed stands of the right-bank part of the Forest-Steppe, their share is 40.2% (37,216 thous. ha) of the area of mixed stands of the right-bank Forest-Steppe. The share of middle-aged stands is 47.5% (44,003 thous. ha) and maturing stands – 9.1% (8,449 thous. ha). The share of mature and over-mature stands is 2.8% (2,890 thous. ha).

Table 7. Distribution of areas and stocks of pine stands in the Forest-Steppe of Ukraine according to age groups

Age group	Forest-Steppe left-bank zone				Forest-Steppe right-bank zone			
	pure		mixed		pure		mixed	
	area, ha	stock, $m^3 \cdot ha^{-1}$	area, ha	stock, $m^3 \cdot ha^{-1}$	area, ha	stock, $m^3 \cdot ha^{-1}$	area, ha	stock, $m^3 \cdot ha^{-1}$
Young	20,173.0	127	18,658.7	95	33,714.2	152	37,216.4	106
Middle-aged	115,823.2	330	24,873.4	302	81,983.5	324	44,003.3	305
Maturing	30,742.3	388	7,289.1	367	14,152.4	401	8,449.4	373
Mature	5,593.9	385	1,458.0	358	4,137.3	374	2,863.1	344
Over-mature	69.9	317	11.2	298	39.2	314	27.1	339
Total	172,402.3		52,290.4		134,026.6		92,559.3	

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

Figure 6 shows the dynamics of the average stock for the researched groups of pine stands in the Forest-Steppe of Ukraine.

Analysing the dynamics of stock changes per 1 ha (Fig. 6), it should be noted that the most productive stands are pure Scots pine stands in the right-bank part of the Forest-Steppe. Therewith, starting from the age group of the mature ones, there is a decrease in the stock on average from 388 to 317 $m^3 \cdot ha^{-1}$. The productivity of pure pine stands of the left-bank part of the Forest-Steppe is lower than the stock of pure stands of the right-bank part, in the age group, mature and over-mature stocks per 1 ha exceed pure stands of the right-bank part. In general, the stocks of mixed stands in the right-bank and left-bank parts of the Forest-Steppe are very close and significantly less than the stocks of pure stands. Notably, a decrease in stocks after the maturing age group is observed for all groups of stands.

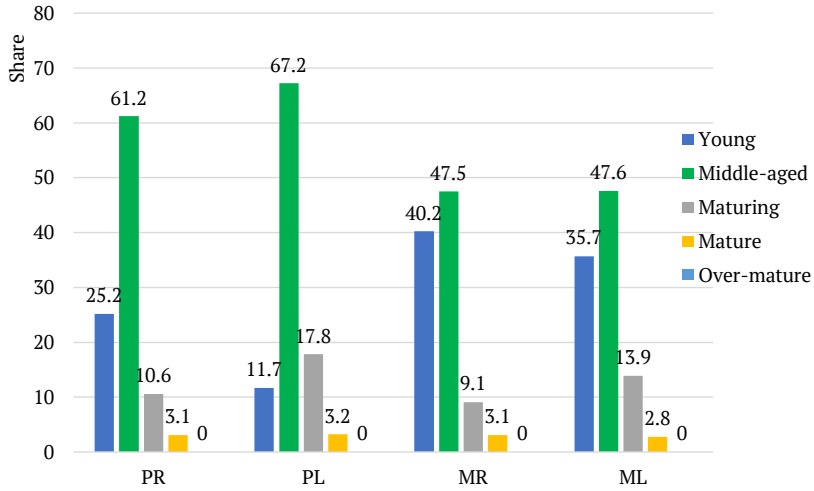

Figure 5. Distribution of areas of pine stands in the Forest-Steppe of Ukraine according to age groups

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

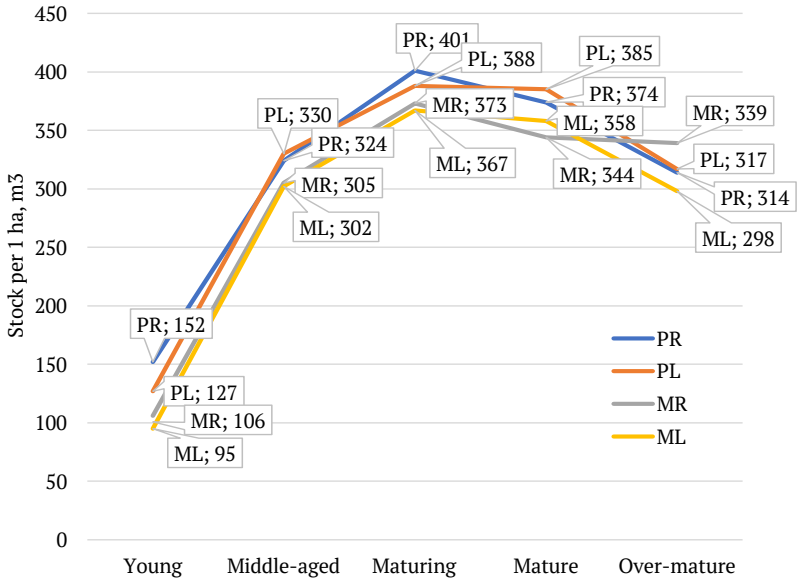

Figure 6. Dynamics of the average stock of pine stands in the Forest-Steppe of Ukraine

Source: developed by the authors based on data (Ukrainian State Project..., n.d.)

To verify the conducted research, we will compare it with the data obtained by other scientists. As mentioned earlier, scientists paid little attention to Scots pine stands in the Forest-Steppe of Ukraine, so we compared the dynamics of changes in the average stock per 1 ha with the data of S. Musienko *et al.* (2021) for the left-bank part of the Forest Steppe, as well

as with collective studies of natural pine stands of Polissia (Lakyda *et al.*, 2018) and the Northern Steppe of Ukraine (Lovynska *et al.*, 2021). In their research, the authors determined the productivity of pine stands without dividing them into pure and mixed ones, so we present the data for both of these groups. The results obtained are presented in Table 8 and Figure 7.

Table 8. Average stock per 1 ha of pine stands in the left-bank part of the Forest-Steppe

Age classes	Average stock per 1 ha, m³				
	pure stands	mixed stands	according to S. Musienko *et al.* (2021)	according to (Lakyda *et al.*, 2018) for Polissia	according to (Lovynska *et al.*, 2021) for the Northern Steppe
I	14	14	13	11	9
II	57	48	47	30	31
III	128	109	115	67	99
IV	209	183	210	109	160
V	272	256	296	167	242
VI	323	307	331	251	270
VII	354	343	352	298	313
VIII	383	363	384	323	360
IX	388	366	389	324	376
X	358	336	378	313	356
XI	374	350	336	286	366
XII	363	365	321	279	363
XIII	342	340	276	-	-
XIV	346	293	260	-	-
XV and above	289	289	250	-	-

Source: developed by the authors based on (Lakyda *et al.*, 2018; Lovynska *et al.*; 2021; Musienko *et al.*, 2021; Ukrainian State Project...,n.d.)

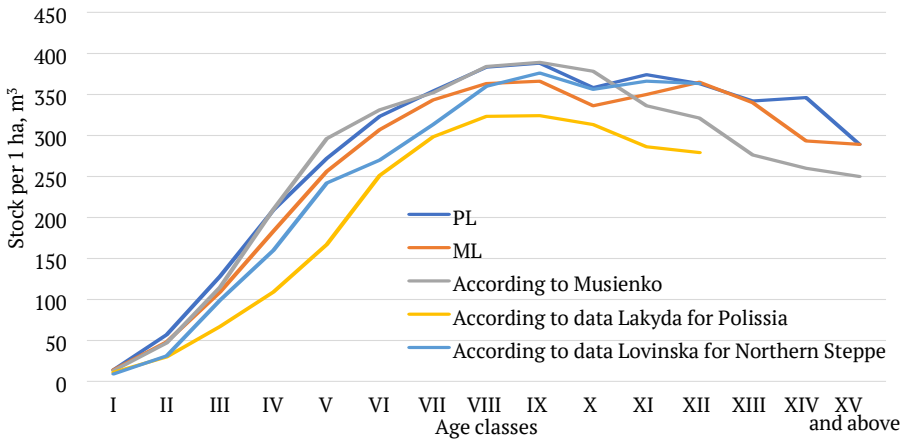

Figure 7. Dynamics of the average stock of pine stands in the left-bank part of the Forest-Steppe of Ukraine

Source: developed by the authors based on (Lakyda *et al.*, 2018; Lovynska *et al.*; 2021; Musienko *et al.*, 2021; Ukrainian State Project...,n.d.)

According to the presented data, in general, the dynamics of stocks per 1 ha of the compared data is close to the pure tree stands of the left-bank part of the Forest-Steppe of Ukraine. This is also confirmed by the average value of Scots pine presence in stands – 9.7 units. After the IX age class, there is a significant decrease in the average stock per 1 ha according to S. Musienko's data, which can be explained by the small area of the researched object (State Enterprise "Zhovtneve Forestry") and the specific features of forestry activities. For the conditions of the Northern Steppe (Lovynska *et al*., 2021), the average stock per 1 ha is slightly lower than the stocks for the Forest-Steppe zone. Therewith, in the VIII class of age, they increase sharply and correspond to the stocks of the Forest-Steppe zone, which is explained by the presence of such stands mainly in the composition of protective stands of green zones and sanitary zones and their insignificant representation. In addition, the productivity of natural pine stands of Polissia is significantly less than in the Forest-Steppe and Steppe.

Conclusions

As a result of the conducted study, forest inventory dependencies were established that characterize the growth of Scots pine stands in the Forest-Steppe zone of Ukraine. In the research of Ukrainian scientists, when investigating the growth of Scots pine stands, preference is given to stands growing in the natural zone of Polissia of Ukraine. This is primarily because in these conditions this species is considered as a priority. But in the Forest-Steppe zone, more attention is paid to oak stands. Much less attention is paid to the growth of Scots pine in other natural areas; specifically, studies were conducted for the Forest-Steppe, but were limited exclusively to its eastern part (Kharkiv and Sumy regions). The originality of the conducted study was the coverage of the entire territory of the Forest-Steppe zone of Ukraine using the stand-wise database of PA "Ukrderzhlisproekt". In fact, the provided database is a general set of forest inventory data of stands that include Scots pine growing in the Forest-Steppe zone of Ukraine. Having conducted an initial analysis of the database, it was decided to investigate only artificial Scots pine stands, since they occupy about 92% of the total area of pine stands in the Forest-Steppe of Ukraine. Using several non-parametric statistical criteria to estimate the similarity of samples, the difference in stand parameters of pine stands was established and divided into four groups depending on the geographical location and participation of the main species in the stand composition. The analysis of the groups under study proved that Scots pine on the territory of the Forest-Steppe zone of Ukraine grows relatively evenly within its left-and right-bank parts. Pure tree stands are older than mixed ones and, accordingly, have a higher productivity (about 300 $m^3 \cdot ha^{-1}$ in pure and 235 $m^3 \cdot ha^{-1}$ in mixed stands). However, the highest middle site index class is characterized by mixed stands in both regions, the lowest middle site index class – in pure stands of the left-bank Forest-Steppe. By types of forest vegetation conditions, poorer conditions B dominate in the left-bank part, while on the right bank, from pure to mixed stands, there is a change in growth from conditions B to C. In terms of productivity, pure stands of the right-bank part of the Forest-Steppe of Ukraine dominate. The description and generalization of the current state and analysis of the productivity of pine stands in the Forest-Steppe zone of Ukraine can be used for further grouping of experimental material in the preparation of forestry and forest inventory standards. The obtained description is the most complete since it was based on the entire sub-compartment inventory characteristic of Scots pine stands in the region under study.

Conflict of Interest

The authors declare no conflict of interest.

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None.

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Сучасний стан та продуктивність модальних насаджень сосни звичайної Лісостепу України

Андрій Юрійович Терентьєв

Кандидат сільськогосподарських наук, доцент
Навчально-науковий інститут лісового і садово-паркового господарства
Національний університет біоресурсів і природокористування України
03041, вул. Горіхуватський шлях, 19, м. Київ, Україна
https://orcid.org/0000-0001-9845-3638

Олександр Петрович Бала

Кандидат сільськогосподарських наук, доцент
Навчально-науковий інститут лісового і садово-паркового господарства
Національний університет біоресурсів і природокористування України
03041, вул. Горіхуватський шлях, 19, м. Київ, Україна
https://orcid.org/0000-0001-6538-8876

Петро Іванович Лакида

Доктор сільськогосподарських наук, професор
Навчально-науковий інститут лісового і садово-паркового господарства
Національний університет біоресурсів і природокористування України
03041, вул. Горіхуватський шлях, 19, м. Київ, Україна
https://orcid.org/0000-0003-3639-2969

Геннадій Сергійович Бондар

Аспірант
Навчально-науковий інститут лісового і садово-паркового господарства
Національний університет біоресурсів і природокористування України
03041, вул. Горіхуватський шлях, 19, м. Київ, Україна
https://orcid.org/0009-0004-3588-507X

Анотація. Розробка нормативно-довідкового забезпечення для таксаційної оцінки стану модальних деревостанів є нагальним питанням оскільки дає можливість отримати достовірну та актуальну інформацію про сучасний стан існуючих деревостанів. Метою роботи було статистичне обґрунтування поділу соснових деревостанів на групи за регіоном зростання та складом, та їх детальна таксаційна характеристика з аналізом поширення на території Лісостепу та їх продуктивності. Для проведення досліджень використовувалась база даних повидільної таксаційної характеристики лісів виробничого об'єднання «Укрдержліспроект» для лісостепової зони України. Використовуючи ряд непараметричних критеріїв оцінки вибірок (ранговий однофакторний *H*-критерій Краскела-Уоллеса, критерій медіан, критерій впорядкованих альтернатив Джонкіра-Терпстра) було встановлено відмінність в таксаційних показниках досліджуваних вибірок та розділено деревостани лісостепової зони на чотири групи. Було описано сучасний стан модальних соснових деревостанів лісостепової зони України для обраних груп з детальним розподілом площ та запасів за основними таксаційними показниками. За результатами проведеного аналізу бази даних було встановлено, що близько 92 % від загальної площі соснових деревостані лісостепової зони

становлять штучні ліси. Залежно від регіону зростання – на ліво- та правобережну частину Лісостепу, за складом – на чисті та мішані. В межах досліджуваних груп було проведено аналіз розподілу площ та запасів соснових деревостанів за класами бонітету, типами лісорослинних умов, типами лісу, відносними повнотами та групами віку. За класами бонітету у всіх групах домінують високобонітетні насадження I та I^a класів бонітету. Частка високобонітетних мішаних насаджень більша в порівнянні з чистими насадженнями. За типом лісорослинних умов домінують насадження B_2 у всіх досліджуваних групах. Із лівобережжя до правобережжя спостерігається зростання родючості ґрунтів із умов В на умови С, також така залежність спостерігається від чистих до мішаних насаджень. Продуктивність за середнім запасом мішаних насаджень правобережної та лівобережної частини Лісостепу дуже близькі і значно менше запасів чистих деревостанів. Наведені результати досліджень можуть бути використані науковцями в якості опису модальних таксаційних характеристик регіону Лісостепу та для групування експериментального матеріалу при складанні лісівничих та лісотаксаційних нормативів

Ключові слова: повидільна база даних; непараметричні критерії; середній запас; клас бонітету; склад насадження; тип лісорослинних умов; відносна повнота