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

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

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

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Introduction

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

According to the State Forest Register of Ukraine, as of January 1, 2011, black (sticky) alder (*Alnus glutinoza* (L.) Gaertn) is one of the most common softwood species in Ukraine: it occupies an area of almost 255 thousand hectares, or 4.2% of the forest fund of Ukraine, reserves of alder stands amount to about 27 million m^3 (Forest Fund of Ukraine, 2011). Alder wood is valuable for the national economy, primarily due to the possibility of harvesting plywood boards. Therefore, it is important to determine the indicators of marketability dynamics in the study of alder stands.

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

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

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

Our previous studies (Pasternak & Buhaiov, 2016; Buhaiov, 2017) established that in alder stands of I and I^a site index classes, the distribution of trunks by thickness degrees differs substantially. At the age of 30, alder stands that grow according to I site index class have a smaller average diameter, and about 80% of trees belong to the three smallest thickness degrees. In stands of I^a site index class, the number of stages of thickness is greater, and the distribution by stages is more uniform. With age, the distribution of trunks in tree stands of I site index class evens out, with most trunks concentrated in three medium degrees of thickness. Tree stands of I^a site index class are more differentiated, and trunks with a diameter significantly larger than the average appear in their structure earlier.

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

Materials and Methods

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

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

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

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

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

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

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

Analysis of statistical indicators shows that for age (*A*), average diameter (*D*), average height (*H*), sum of cross-sectional areas (*G*), indicators of asymmetry and kurtosis in natural values do not exceed permissible values *(As*<1.0; *Es* <1.2). Left-sided asymmetry was determined for height, while right-sided asymmetry was determined for the other indicators under study. The distribution of the values of age and average height is characterized by a sharp-peaked curve, other indicators – by a blunt-peaked curve. The studied database of experimental plots describes black alder stands quite fully and is suitable for modelling the inventory and commodity structure.

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

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

Indicator	***A*, years**	***H*, m**	***D*, cm**	***N*, pcs.**	***P***	***G*, $m^2 \cdot ha^{-1}$**
A, years	1.00	0.84	0.91	-0.66	-0.43	0.48
H, m		1.00	0.86	-0.78	-0.42	0.67
D, cm			1.00	-0.71	-0.43	0.53
N, pcs.				1.00	0.47	-0.45
P					1.00	0.35
G, $m^2 \cdot ha^{-1}$						1.00

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

The theoretical series of diameter distribution was constructed according to the methodology developed at the Department of Forest Inventory and Forest Management of the National University of Life and Environmental Sciences of Ukraine. After the list database was created, the parameters of their structure were obtained using the STRUK program.

Results and Discussion

According to the data of the "Forest Fund" database as of January 1, 2011, in the region under study, black alder forests cover an area of more than 26.6 thousand hectares with a wood stock of 4,789.0 thousand m^3. By origin, 68% of black alder stands are of vegetative origin and 32% are of seed origin. In the region

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

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

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

The simulation results are represented by the following formulas:

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

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

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

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

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

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

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

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

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

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

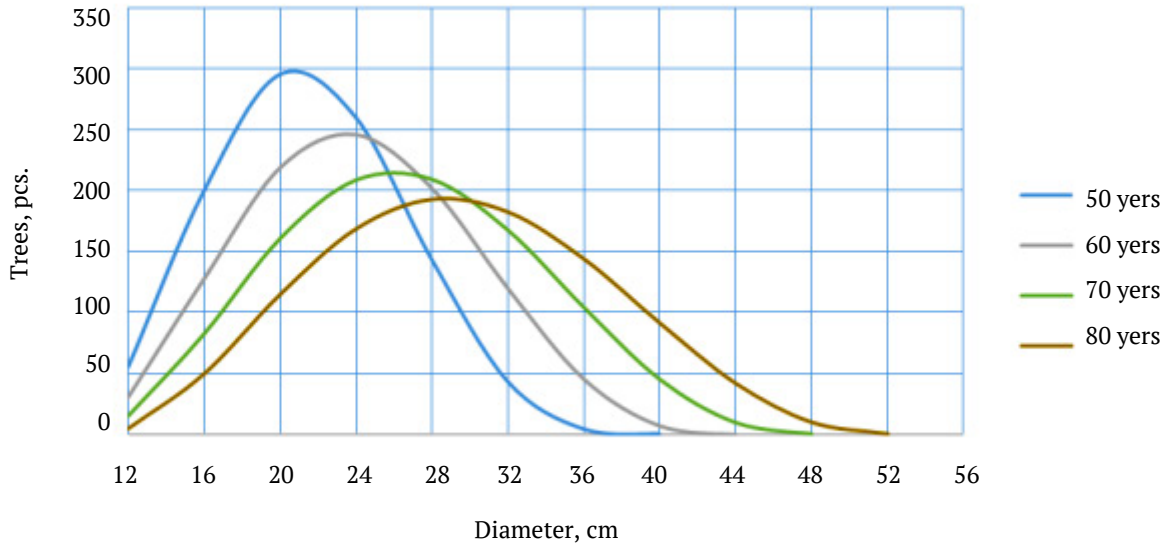

Figure 1. Distribution of trunks by diameter in modal alder stands of vegetative origin

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

Regularities of the inventory structure form the theoretical basis for constructing standards (tables of commodity structure and marketability dynamics). Regional growth tables (Buhayev & Pasternak, 2020), tables of volume distribution of commercial alder trunks by thickness classes and subclasses (Forest inventory handbook, 2020) and the above parameters of the structure by diameter were used to model the dynamics of the commodity structure of alder stands of vegetative origin. Classes and subclasses of thickness of commercial timber were set according to the average diameter

of logs without bark: D1b – 14.5-19.4 cm, D2a – 19.5-25.4 cm, D2b – 25.5-29.4 cm, D3a – 29.5-34.4 cm, D3b – 34.5-39.4 cm, D4 – 39.5-49.4 cm. Norms were calculated according to the methodology developed at the Department of Forest Inventory and Forest Management of the National University of Life and Environmental Sciences of Ukraine (Kashpor, 1999).

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

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

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

Notably, the norms of the dynamics of the commodity structure of modal alder stands are based on fundamentally new data on the distribution of the volume of commercial trunks of 16 cm and more by thickness classes and subclasses (Forest inventory handbook, 2020), consistent with European approaches to the inventory of round timber (DSTU EN 1315-1: 2001, 2002). The volume of timber was set as the sum of the volume of wood trunks and wood from commercial trees. The authors also conducted a comparative analysis of the dynamics of commercial timber yield in modal alder stands according to various standards (inventory of business wood by upper and middle diameters) (Table 4).

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

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

Table 4, Continued

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

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

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

Conclusions

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

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

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

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

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