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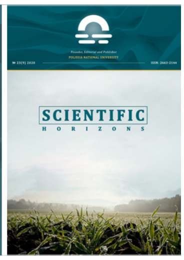

Forest inventory assessment of plus trees of hornbeam-oak and pine forests within the Malopolissia district

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Abstract. Improvement of the selection criteria and further testing of plus trees of Scots pine requires systematic updating of measurement data, their detailed analysis, and constant monitoring of the created sites. A significant task is to create new experimental plots to investigate the hereditary characteristics of trees, especially in the context of forestry adaptation to climate change. A forest inventory assessment of plus trees of hornbeam-oak and pine forests within the Malopolissia district was conducted to establish the relationship between the height-diameter ratio at 1.3 m and the age of trees in different forest types based on the results of their selection. Standard statistical methods were employed to establish reliable results of analytical and comparative conclusions. Two indices were calculated for the analysis: I_1 – an indicator of age-related changes in the A/H/DbH ratio, and I_2 – an indicator

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of changes in the H/DbH/A ratio depending on age. These indices were calculated for plus trees, considering their age (A), height (H), and trunk diameter at a height of 1.3 m (DbH). The dependencies of changes in the height and diameter of plus trees with age were studied, the speific features of these dependencies for the two most widespread forest types were determined, two types of indices of these dependencies were analysed, and the conclusions about their statistically reliable suitability for modelling the parameters of plus tree selection within the study area were summarised. The parametric dependencies of the plus trees of the Malopolissia district of pine forests of this region of origin established in the study can be used as additional criteria for selecting trees for productivity with a sufficient level of their biotic stability. The study summarised the possibility of establishing the regions of origin of forest reproductive material based on parametric assessment of stands and plus trees within the Malopolissia district based on their belonging to autochthonous forest stands by origin. The relevance of the study was enhanced by the introduction of approaches to regionalisation of forest reproductive material, which involves determining the boundaries of the regions of origin and the boundaries of the corresponding distribution of forest reproductive material from them. The proposed approach to regionalisation is a prerequisite for obtaining and putting into circulation forest reproductive material based on the implementation of Directive 1999/105/EC of 22 December 1999 on the marketing of forest reproductive material in the regulatory framework of forest seed production and nursery stock

Keywords: plus trees; forest reproductive material; regionalisation of forest reproductive material; regions of origin and distribution; taxonomic indicators; forest types; geobotanical zoning

INTRODUCTION

The issue of identification of Scots pine plus trees by region of origin is of particular relevance in the context of intensified use of selectively improved plantation forest seeds for reforestation. Such studies of the dynamics of the parameters of plus trees with age, along with long-term tests of their offspring for selected traits, will allow further assessing the potential transfer of biotic resistance to offspring in the region of origin. The significance and relevance of updating the origin of plus trees is supported by the need to adapt existing regulatory documents on forest seed production and nursery farming to the level of European integration requirements in the field of forest reproductive resources. Plus trees form the basis of plantation forest seed production, and their offspring play an essential role in forest reproduction, influencing the development of genetically balanced populations. Determining the boundaries of regions of origin and distribution areas for the creation of mapping schemes of regionalisation of forest reproductive material (FRM) is currently an urgent and at the same time unresolved task. Clarification of the boundaries of the regions of origin and distribution based on available silvicultural data and materials obtained during forest management, as well as certification of permanent forest seed stock (PFS), their monitoring and inventory, if properly analysed, will help to solve the problem in the context of the urgent need to regulate the regionalisation of forest reproductive material (FRM) of the main forest-forming species using forest basic material (FBM) in Ukraine. This study was based on the analysis of the correlation between height (H) and diameter at breast height (DbH), which is commonly used in foreign scientific literature. No information on the above issues related to plus trees was found in the public domain, but in other areas of modelling tree and stand characteristics based on H/DbH relationships, this approach is widely used. V. Blystiv *et al.* (2021a) considered the dependencies of the ratios of growth in height to diameter and the growth of tree crown habitus to be organically related processes of tree development in a stand, which can be assessed by the potential for a tree to use living space. This opens the possibility of developing the area of plus selection to increase the biotic stability of individual trees and stands and its verification, which was also noted by H. Krynytskyy *et al.* (2023).

The ratio of H and DbH during tree growth is a complex consequence-dependent process, which is also regulated by edaphic and climatic stress factors, according to F. Sağlam and O. Sakici (2024). However, these issues of forestry motivation have not been sufficiently studied to date. J. Wang *et al.* (2023) covered the prediction of the H/DbH relationship in the future due to the influence of climate factors under conditions of multifactorial uncertainty and is often linked to projection size and crown diameter (CD). The findings indicated close links between the indicators in the dynamics and the possibility of their forecasting, provided that concrete parameters of the influencing factors in a particular region are chosen (mainly an increase in average temperatures and a decrease in precipitation). J. Wang *et al.* (2023) established the dependencies of the H/DbH/DC allometry for indigenous and derived stands under varying edaphic and climatic conditions. The results were mostly verified for the issues under study, however, the prospect of forecasting for derivative (secondary) forests is not entirely certain and unambiguous, especially against the background of increased stress factors. This raises the issue of forest reproduction using the potential of plus trees and the identification of their autochthonousness in the region of origin. On this issue, O. Danchuk *et al.* (2024) propose to establish the boundaries of the regions of origin based on geobotanical zoning, which is based on the distribution of autochthonous forest cover, considering the potential of forest typology. The basic area for identifying regions of origin by the main forest-forming species is to assess the growth characteristics of provenance in test (geographical) cultures. I. Neyko *et al.* (2020) presented the results of such long-term trials, indicating the comparative characteristics of representatives of different origins, which is significant for developing an algorithm for establishing the boundaries of local and geographical populations. An actual area under study is the secondary selection of plus trees in the tested progeny of plus Scots pine trees for the reasons of recognising elite characteristics. V. Voitiuk *et al.* (2020) indicates the age of 38-40 years at which the elite status of plus Scots pine trees can be verified in Polissia, and therefore if the ortet is preserved at this time, the dynamics of its H/DbH with age and the correspondence to the forest type are significant for modelling selection rates in the region of its origin. According to H. Krynytskyy *et al.* (2021), one of the promising areas for determining the vitality (biotic stability) of trees is the determination of their dielectric properties, which can be used for rapid assessment of plus trees. J. Brichta *et al.* (2023) emphasises that an essential form of conservation of the forest genetic fund is the archives of clones and families, the purpose of which is to concentrate in one place and preserve the characteristics of plus trees in the form of offspring. Prompt recognition of elite characteristics, considering the analysis of H/DbH dynamics with age, including autochthonousness and biotic stability, allows ensuring their preservation in the archives of the forest gene pool. One of the key tasks of modern selection of plus trees from defined plastic populations is to create new forest seed plantations capable of providing a yield of genetically improved seeds. According to J. Quegwer *et al.* (2024), this will contribute to the development of the adaptive potential of newly created forests to climate change through the use of suitable forest reproductive material.

When selecting and certifying plus trees, the key parameters are diameter, height, and age, and therefore it is their ratio and dynamics that are the object of assessment and analysis in this study. In this context, the study was aimed at establishing relationships between the above biometric characteristics of Scots pine plus trees selected and certified within the geobotanical region – Malopolissia district of hornbeam-oak and pine forests.

MATERIALS AND METHODS

In this study, the assessment covers plus trees of Scots pine selected by phenotype according to the requirements of the Forest Seed Production Guidelines (Los *et al.*, 2017). The trees were selected in forestry enterprises located within the Malopolissia geobotanical district of hornbeam-oak and pine forests. Most of the sampling dates back to 1973, 1974, 1978, and the 2015 sampling in the eastern part of the district, where the trees of the 1980s sampling have not been preserved, was also considered. The taxation indicators of individual trees and the characteristics of forest stands at the time of selection were obtained from tree certification passports maintained by the Lviv Forestry and Seed Laboratory and verified by the state register of plus trees in Lviv and Ternopil regions. Data for the following periods were obtained from the results of inventory work reported in Yu. Debryniuk *et al.* (2021), simultaneous inventory of PFSBs in Ternopil (2022) and Lviv (2024) oblasts coordinated by the State Organisation “Ukrainian Forest Breeding Centre” (SO “UkrFSC”) (n.d.). The data of the latest inventories were verified using auxiliary monitoring materials and the electronic accounting database of SO “UkrFSC”, forest management materials of the branches of the State Enterprise “Forests of Ukraine”, information data from the Relational Database (RDB) and Geographic Information and Analytical System (GIAS), Ukrainian State Forest Management Project and Production Association (PA “Ukrderzhisproekt”) (n.d.), as well as a publicly available map of geobotanical zoning of Ukraine, adapted to the regionalisation of FRM. The location of the plus trees in the plots where they were sampled is presented in Table 1.

***Table 1**. Characteristics of the plots where plus trees were selected (as of 2020)*

Branch of FHE, FE	Forestry	Quarter	Allotment	Area, ha	Trees, pcs.	Number of measurements, times
Radekhivske	Lopatynske	64	13	19.0	10	3
Radekhivske	Vytkivske	15	1	4.9	6	3
Buske	Hrabivske	14	1	2.4*	13	2
Brodivske	Berlynske	83	4	0.6*	4	2
Kremenetske	Stizhotske	42	2	13.0	10	2

***Note:** *the areas of the allotments during tree selection were much larger and decreased due to the fragmentation of allotments during the next forest management*
***Source:** Ukrainian State Forest Management Project and Production Association (n.d.)*

Generally accepted forest inventory methods were employed to collect and process experimental, documentary materials, and electronic databases. For comparison and modelling, analytical and comparative methods were employed, based on the modal characteristics presented by A. Bilous *et al.* (2022), as well as age-appropriate inventory data. The basis of the comparative analysis included the inventory dependencies between the heights and diameters of tree trunks and their age, the correspondence between the site classes and forest vegetation conditions (forest types), the established dynamics of inventory indicators depending on age (stand growth), correlations, and the establishment of reliable differences between the indicators between plus trees and forest plots within the defined forest fund areas. The proposed research algorithm involves comparing the plus features with average and model indicators, as well as assessing their compliance within a certain territory – the region of origin.

The following algorithm for analysing data conformity was employed in the study: plots (allocations) were selected within the regions of origin (geobotanical districts), where on average about five plus trees were identified on an area of more than 5 ha. The number of trees and area were refined using the RDB and GIAS data of the SE "Ukrderzhlisproekt". At the next stage, the initial data for the plus trees were prepared at the time of their allocation (certification), including the height, diameter, age, site class, and average inventory indicators of the respective allocation. Subsequently, analogous inventory data were obtained for these trees in subsequent periods, with geolocation clarification and confirmation of parameters using photographic documentation. As a result, the estimated ratios for the model plots were established at the time of allocation of plus trees (according to the data of passports) and after a certain period (based on the results of measurements and taxation characteristics), with comparison of indicators for normal (full) stands. The key element of the analytical and comparative method was the calculation of the indices I_1 and I_2, which were calculated as the ratio of age (A), height (H), and diameter at 1.3 m (DbH) for the plus trees:

$$I_1 = A/H/DbH, \quad (1)$$

$$I_2 = H/DbH/A, \quad (2)$$

where I_1 is the index of age change by the H/DbH ratio; I_2 is the index of change in the H/DbH ratio by age; A is the age of the tree, years; H is the height of the tree, m; DbH is the diameter of the tree at a height of 1.3 m, cm.

Formulas 1 and 2 are considered basic. They are also used for average and model stand indices, to compare the respective indices. The indices are used to determine the indicators of compliance with the region of origin and its identification within the region of distribution. Specifically, the correlation of H/DbH values for plus trees by forest type was estimated. The proposed methodology of H/DbH index analysis was considered for comparing inventory data between plots of different local ecopopulations. This allows establishing reliable differences for their identification by the criteria of origin, forest types, and to ensure further selection of plus trees.

RESULTS

The study was conducted for the plus trees of Scots pine according to the proposed sampling option within the Western Ukrainian forest-steppe region of broadleaf-mixed forests belonging to the Malopolissia district of hornbeam-oak and pine forests. The motives and necessity of its separation were presented in V. Blystiv *et al.* (2021b). Five model plots were identified in pure pine forests, where the number of plus trees was four or more per plot. The study established the allometry dependencies (A/H/DbH) for these plus trees in native and derivative stands under different edaphic and climatic conditions. The results were presented for two types of forest – C_2-h-oP and C_3-h-oP, which differ in the hygrotope of the habitat. The assessment results for the wet hornbeam-oak-pine forest (C_3-h-oP) are presented in Tables 2, 3, 4 and Figs. 1, 2, 3 – for plots in Radekhivse and Buske branches of the SE "Forests of Ukraine". The results for a fresh hornbeam-oak-pine forest (C_2-h-oP) are presented in Tables 4, 5 and Figs. 3, 4 for the plots in Brodivske and Kremenetske branches. For each site, in the sections of discussion and general conclusions on the dynamics of inventory indicators and the use of the A/H/DbH index, shared characteristics, specific features, and suggestions were noted.

Evaluation results for a wet hornbeam-oak-pine forest (C3-h-oP). The estimation of plus trees based on the results of measurements and analysis is presented in Table 2 and Fig. 1.

Table 2. *Dynamics of morphometric parameters of plus trees of Scots pine (Pinus sylvestris L.) in the trial area of Lopatynske forestry of the Radekhivske forestry and hunting enterprise*

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/DbH*100	Model value of the index	Difference with the model
Model data, 1973		85	33.9	39.2		6.396	0
1	Plus features	84	34.0	46.0	5.371	6.396	-1.025
2	Plus features	84	39.0	50.0	4.308	6.396	-2.088
3	Plus features	84	34.0	48.0	5.147	6.396	-1.249

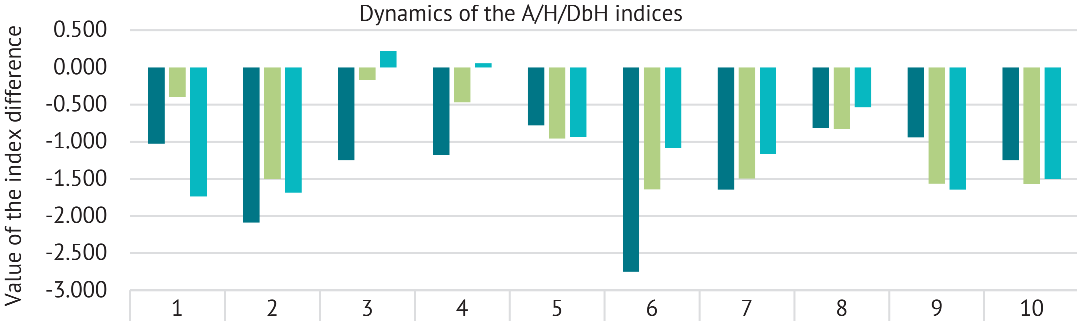
Table 2. Continued

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/DbH*100	Model value of the index	Difference with the model
4	Plus features	84	35.0	46.0	5.217	6.396	-1.179
5	Plus features	84	34.0	44.0	5.615	6.396	-0.781
6	Plus features	84	36.0	64.0	3.646	6.396	-2.750
7	Plus features	84	34.0	52.0	4.751	6.396	-1.645
8	Plus features	84	35.0	43.0	5.581	6.396	-0.815
9	Plus features	84	35.0	44.0	5.455	6.396	-0.941
10	Plus features	84	34.0	48.0	5.147	6.396	-1.249
Mean			35.0	48.5			
	Model data, 2004	115	38.2	47.5			
1	Satisfactory	115	36.9	52.5	6.338	6.338	0.000
2	Satisfactory	115	41.0	58.0	5.936	6.338	-0.402
3	Satisfactory	115	35.5	52.5	4.836	6.338	-1.502
4	Satisfactory	115	40.0	49.0	6.170	6.338	-0.168
5	Satisfactory	115	41.5	51.5	5.867	6.338	-0.471
6	Satisfactory	115	39.5	62.0	5.381	6.338	-0.957
7	Satisfactory	115	38.0	62.5	4.696	6.338	-1.642
8	Satisfactory	115	36.0	58.0	4.842	6.338	-1.496
9	Satisfactory	115	39.5	61.0	5.508	6.338	-0.830
10	Satisfactory	115	36.0	67.0	4.773	6.338	-1.565
Mean			38.4	57.4			
	Model data, 2024	135	40.1	51.1	6.588	6.588	0.000
1	Satisfactory	135	37.0	75.2	4.852	6.588	-1.736
2	Satisfactory	135	40.5	68.0	6.207	6.588	-1.686
3	Satisfactory	135	33.5	59.2	6.807	6.588	0.219
4	Satisfactory	135	34.5	58.9	6.644	6.588	0.056
5	Satisfactory	135	37.5	63.7	5.651	6.588	-0.937
6	Dries out	135	35.5	69.1	5.503	6.588	-1.085
7	Satisfactory	135	34.0	73.2	5.424	6.588	-1.164
8	Satisfactory	135	33.5	66.6	6.051	6.588	-0.537
9	Satisfactory	135	36.5	74.8	4.945	6.588	-1.643
10	Satisfactory	135	35.5	74.8	5.084	6.588	-1.504
Mean			35.5	67.4			

Source: *developed by the authors of this study*

The trees are located on a plot in the Lopatynske forestry, quarter 64, allotment 13. The inventory characteristics of the allotment according to the forest inventory as of 2010 were as follows: area – 19.0 ha; stand composition – 10Ps + Qr, Cb; age – 113 years; reserve – 400 $m^3 \cdot ha^{-1}$; relative density – 0.55; forest type – C_3-h-oP. According to the results of the last forest management, due to uneven density (reserve), the allotment was divided into several plots: quarter 64, allotment 19 – area of 4.1 ha; stand composition – 10Ps; age – 113 years; reserve – 200 $m^3 \cdot ha^{-1}$; relative density – 0.3. Quarter 64, allotment 24 – area 3.3 ha; stand composition – 10Ps; age – 113 years; reserve – 285 $m^3 \cdot ha^{-1}$; relative density – 0.4. Quarter 64, allotment 25 – area 3.3 ha; stand density – 10 Ps; age – 113 years; reserve – 260 $m^3 \cdot ha^{-1}$; relative density – 0.4. Quarter 64, allotment 26 – area 15.8 ha; stand composition – 10Ps + Qr, Cb; age – 113 years; reserve – 420 $m^3 \cdot ha^{-1}$; relative density – 0.55. The same forest type is preserved for all plots – C_3-h-oP. Over the past decade, there has been a decrease in reserves and a decrease in stand density.

The results of the analysis for the plot located in the Lopatynske forestry of the Radekhivske Forestry and Hunting Enterprise branch showed that the stands of Scots pine are original and of the same age. On the test site, in a 107-year-old stand, the stand had a stock of 481 $m^3 \cdot ha^{-1}$ with an average height of 34 m and a diameter of 44.3 cm, with a density of 0.55 and belonging to the I^b class. The origin of the stand is not known, but it is likely to be autochthonous. The local population of Scots pine has been preserved due to the site's belonging to the permanent forest seed base and the nature reserve fund and is characterised by a small participation of common beech in the stand. Its distribution area is at altitudes of 220-230 m. The analysis of the dynamics of H/DbH indices showed that during growth, plus trees effectively use the forest-typological potential of the habitat conditions. At the same time, at the age of about 135 years, there is a certain lagging behind the modal indicators of the I^b class, which is conditioned by a substantial decrease in the stand density. This trend is confirmed by the data for trees No. 1, 2, 5, 7, 8, 9, and 10, which have almost not lost their relative growth rates in height and diameter. The second group of trees – Nos. 3, 4, and 6 – demonstrates a deceleration in growth, with tree No. 6 weakened to the IV category of sanitary condition. Plus trees No. 1, 2, 5, 7, 8, 9, and 10 require urgent cloning to preserve and consolidate their genetic potential in archives or on forest seed plantations within the region of origin. It is also necessary to clarify the information on the participation of the descendants of these trees in existing forest-seed plantations and test crops within the distribution area.



	1	2	3	4	5	6	7	8	9	10
84 years	-1.025	-2.088	-1.249	-1.179	-0.781	-2.750	-1.645	-0.815	-0.941	-1.249
115 years	-0.4018	-1.502	-0.1676	-0.4707	-0.9573	-1.6422	-1.4959	-0.8303	-1.5652	-1.57
135 years	-1.7361	-1.686	0.21918	0.05554	-0.9365	-1.0846	-1.1637	-0.5372	-1.6433	-1.504

***Figure 1**. Difference in the values of the plus tree indices compared to the modal values (according to Table 2)*
***Source:** developed by the authors of this study*

Overall, the biotic stability of plus trees is not always determined by the initial phenotypic traits but is largely determined by hereditary factors and the effect of interactions within the forest ecosystem. Thus, the native stands of Scots pine in C_3-h-oP conditions of Small Polissia may be of autochthonous origin and, accordingly, have the potential for high biotic stability, provided that complex multi-age stands with an admixture of oak, beech, and hornbeam are formed. The assessment of plus trees based on the results of measurements and analysis (Table 3) is presented in Fig. 2. The studied trees are located on the plot of Vytkivske forestry, quarter 15, allotment 1. The inventory characteristics of the plot according to the forest management data as of 2010 were as follows: area – 4.9 ha; stand composition – 10 Ps + Bp, Cb; age – 113 years; reserve – 391 $m^3 \cdot ha^{-1}$; relative density – 0.55; forest type – C_3-h-oP. The stand is native, single-aged, of unknown origin, with a low probability of autochthonousness. The analysis of the dynamics of H/DbH indices revealed that during growth, plus trees effectively used the forest-typological potential of forest-plant conditions up to the age of 105 years, reaching values close to the modal indicators of the I^a class.

***Table 3**. Dynamics of morphometric parameters of plus trees of Scots pine (Pinus sylvestris L.) in the trial area of Vytkivske forestry of the Radekhivske Forestry and Hunting Enterprise branch*

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/DbH*100	Model value of the index	Difference with the model
Model data, 1973		75	31.8	35.8		6.588	
1	Plus features	75	31.0	41.0	5.901	6.588	-0.687
2	Plus features	75	31.0	43.0	5.626	6.588	-0.962
3	Plus features	75	31.0	48.0	5.040	6.588	-1.548
4	Plus features	75	31.0	48.0	5.040	6.588	-1.548
5	Plus features	75	32.0	43.0	5.451	6.588	-1.137
6	Plus features	75	34.0	44.0	5.013	6.588	-1.575
Mean			31.6	44.5			
Model data, 2004		105	33.3	40.0			
1	Satisfactory	106	38.0	51.0	5.470	7.783	-2.313
2	Satisfactory	106	31.5	54.5	6.174	7.783	-1.609
3	Satisfactory	106	36.0	60.5	4.867	7.783	-2.916
4	Satisfactory	106	38.5	61.5	4.477	7.783	-3.306

Table 3. Continued

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/DbH*100	Model value of the index	Difference with the model
5	Satisfactory	106	34.5	51.5	5.966	7.783	-1.817
6	Satisfactory	106	34.5	54.0	5.690	7.783	-2.093
Mean			35.5	36.5			
Model data, 2024		125	35.3	44.3			
1	Dries out	126	38.1	54.6	6.057	7.993	-1.936
2	Dries out	126	33.8	58.2	6.405	7.993	-1.588
3	Dries out	126	36.6	66.5	5.177	7.993	-2.816
4	Satisfactory	126	39.0	70.4	4.589	7.993	-3.404
5	Dries out	126	34.6	62.4	5.836	7.993	-2.157
6	Dries out	126	35.0	56.5	6.372	7.993	-1.621
Mean			36.2	61.4			

Source: *developed by the authors of this study*

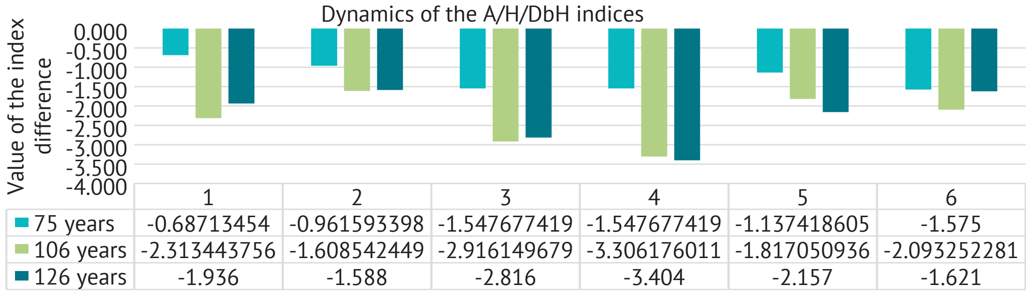


Figure 2*. Difference in the values of the plus tree indices compared to the modal values (according to Table 3)*
Source: *developed by the authors of this study*

At the age of 126 years, with a slight decrease in stand completeness, the best (plus) trees are observed to be weakened and dry out, indicating that the growth potential in these forest vegetation conditions is at its maximum. For plus trees, information on the participation of their breeding heritage in forest seed plantations and test crops within the region of distribution needs to be clarified. The increased biotic stability of these plus trees cannot be considered a confirmed stable plus hereditary trait. Thus, highly productive indigenous stands of Scots pine in the edaphic climatic conditions of Malopolissia may not be of autochthonous origin. It is advisable to use their offspring to create plantation-type forest crops to accelerate the production of business varieties. However, to substantiate this conclusion, it is necessary to conduct a detailed study of the factual state of the stand in this area, as well as its forest vegetation conditions.

The assessment of plus trees based on the results of measurements and analysis presented in Table 4 and Fig. 3. The trees are located on the plot in the Berlynske forestry, quarter 83, allotment 4, and were collected in 1974 at the age of 80 years. Inventory characteristics of the stand according to forest management materials as of 2010 were as follows: area – 0.7 ha (at the time of selection, the area was larger); stand composition – 10 Ps + Fs, Qr; age – 117 years; reserve – 390 $m^3 \cdot ha^{-1}$; relative density – 0.6; forest type – C_3-h-oP. As of 2024, new plus trees were selected on the adjacent allotment (quarter 83, allotment 4) with an area of 3.8 ha, with a stand composition of 10Ps + Qr + Cb, age 113 years, reserve of 391 $m^3 \cdot ha^{-1}$, relative density 0.55 and forest type B_3-oP.

Table 4*. Dynamics of morphometric parameters of plus trees of Scots pine (Pinus sylvestris L.) on the trial area of the Berlynske forestry of the Brodivske Forestry Enterprise branch*

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/DbH*100	Model value of the index	Difference with the model
Model data, 1974		80	29.4	33.4	8.147		
1	plus features	80	29.0	44.0	6.270	8.147	-1.877
2	plus features	80	30.0	38.0	7.018	8.147	-1.129
3	plus features	80	30.0	47.0	5.674	8.147	-2.473
4	plus features	80	30.0	41.0	6.504	8.147	-1.643

Table 4. Continued

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/ DbH*100	Model value of the index	Difference with the model
Mean			29.75	42.5			
	Model data, 2004	110	32.6	38.9	8.674	8.674	
1	satisfactory	110	32.0	46.0	7.473	8.674	-1.201
2	satisfactory	110	32.0	40.0	8.594	8.674	-0.080
3	satisfactory	110	30.5	49.0	7.514	8.674	-1.160
4	satisfactory	110	31.6	46.0	7.567	8.674	-1.107
Mean			31.5	45			

Source: *developed by the authors of this study*

The stand was native in composition, single-aged. The stand was of unknown origin, with a low probability of autochthonousness. The nature of the dependence of changes in the A/H/DbH indices suggests that during growth, the plus trees effectively used the forest-typological potential of forest-plant conditions up to 110 years of age, close to the modal indicators of the I^a class. By the age of 130 years, with a relatively slight decrease in stand completeness, the best (plus) trees are significantly weakened and dry out, indicating that the growth potential under these conditions is at its limit. In 2020, trees were excluded from the register of plus trees due to their drying out in previous years.

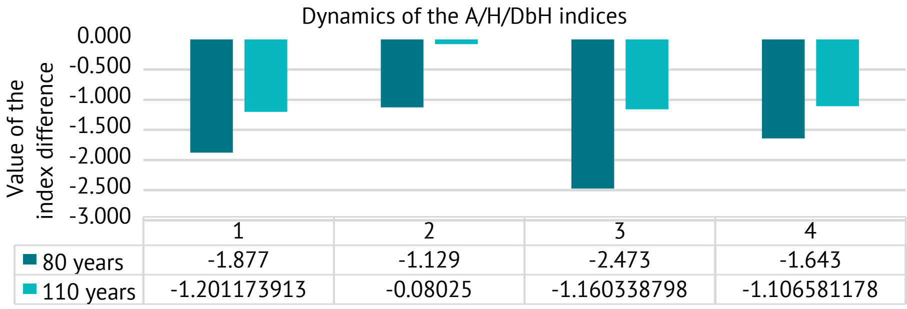


***Figure 3**. Difference in the values of the plus tree indices compared to the modal values (according to Table 4)*
Source: *developed by the authors of this study*

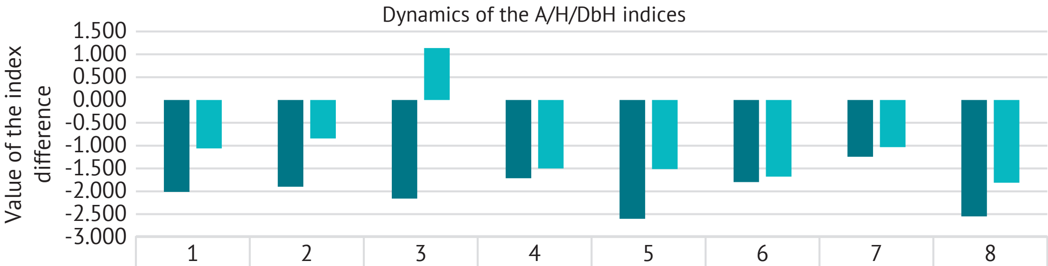
For plus trees, information on the involvement of their heredity in forest-seed plantations and test crops in the region of distribution needs to be clarified, since these trees did not have pronounced plus traits in terms of productivity and proved to be biotically unstable. Overall, there is reason to believe that the biotic stability of plus trees within this area does not manifest itself as a hereditary trait that determines their plus value when they reach a height of 30 m or more. Such native stands of Scots pine in the edapho-climatic conditions of Malopolissia may not be of autochthonous origin. At the age of 120 years, they cannot withstand a sharp change in forest and vegetation conditions (e.g., the emergence and development of forest beech under the canopy) or changes in the functional properties of the forest environment. The targeted use of plantation offspring of such trees during reforestation requires further analysis of their evaluation in test cultures or more detailed specification of their origin.

Evaluation results for a fresh hornbeam-oak-pine forest (C_2-h-oP). The estimation of plus trees based on the results of measurements and analysis presented in Tables 5 and 6 and in Figs. 4 and 5. Data for one sample plot at the time of tree selection are presented in two tables with a five-year interval. The trees were located in the plot of Hrabivske forestry, quarter 18, allotment 3, and were collected in 1973 and 1978, which led to a separate analysis for each group. Inventory characteristics of the allotment according to forest management materials as of 2020 were as follows: area – 10.5 ha; stand composition – 10Ps; reserve – 400 $m^3 \cdot ha^{-1}$; density – 0.7; forest type – C_2-h-oP. The stand was of the native type, single-aged, and its composition corresponded to the forest and vegetation conditions of the site. The origin of the stand was not reliably established, with a low probability of autochthonousness. In 2018–2020, the trees were excluded from the registers due to the drying process. According to the data presented in Tables 4 and 5 and in Figs. 3 and 4, the nature of the dependence of changes in the A/H/DbH indices indicates that plus trees in the fresh forest are more vulnerable to prolonged periods of drought compared to trees growing in wet hygrotopes. For these plus trees, information on the involvement of their breeding heritage in forest seed plantations in the region of distribution needs to be clarified, as they have not been tested in test crops. The biotic stability of these plus trees is probably not a heritable plus trait in these forest conditions after they reach 100 years of age and a height of 30 m or more.

***Table 5**. Dynamics of morphometric parameters of plus trees of Scots pine (Pinus sylvestris L.) on the trial area of Hrabivske forestry of the Buske Forestry Enterprise branch (1973 selection)*

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/DbH*100	Model value of the index	Difference with the model
Model data, 1973		85	33.9	39.2			
1	Plus features	85	34.0	57.0	4.386	6.396	-2.010
2	Plus features	85	35.0	54.0	4.497	6.396	-1.899
3	Plus features	85	34.0	59.0	4.237	6.396	-2.159
4	Plus features	85	33.0	55.0	4.683	6.396	-1.713
5	Plus features	85	35.0	64.0	3.795	6.396	-2.601
6	Plus features	85	33.0	56.0	4.600	6.396	-1.796
7	Plus features	85	33.0	50.0	5.152	6.396	-1.244
8	Plus features	85	34.0	65.0	3.846	6.396	-2.550
Mean			33.9	55.5			
Model data, 2004		115	38.3	47.5			
1	Satisfactory	116	35.0	63.0	5.261	6.321	-1.060
2	Satisfactory	116	35.0	60.5	5.478	6.321	-0.843
3	Satisfactory	116	30.5	51.0	7.457	6.321	1.136
4	Satisfactory	116	38.5	62.5	4.821	6.321	-1.500
5	Satisfactory	116	36.0	67.0	4.809	6.321	-1.512
6	Satisfactory	116	37.0	67.5	4.645	6.321	-1.676
7	Satisfactory	116	37.5	58.5	5.288	6.321	-1.033
8	Satisfactory	116	35.0	73.5	4.509	6.321	-1.812
Mean			35.9	61.2			

***Source:** developed by the authors of this study*



	1	2	3	4	5	6	7	8
85 years	-2.010035	-1.898646	-2.158712	-1.712804	-2.601357	-1.796	-1.244485	-2.549846
116 years	-1.060229	-0.842842	1.1364092	-1.500221	-1.511713	-1.676355	-1.033251	-1.811768

***Figure 4**. Difference in the values of the plus tree indices compared to the modal values (according to Table 5)*
***Source:** developed by the authors of this study*

Therefore, such native stands of Scots pine in the edapho-climatic conditions of Lesser Polissia may be of both autochthonous and, for the most part, non-autochthonous origin. Considering this, the selected new trees require more detailed monitoring of the state and dynamics of the parametric characteristics of the plus traits (Table 6, Fig. 5).

The results of the assessment of plus trees based on measurements and analysis are presented in Table 7 and Fig. 6. The trees are located on a plot of 13.0 ha belonging to the Kremenetske Forestry Enterprise branch, Stizhotske Forestry, quarter 42, allotment 2. The trees were selected in 2015 at the age of 88 years. Inventory characteristics of the stand according to forest management materials as of 2018 were as follows: stand composition – 10Ps + Cb; age – 90 years; reserve – 382 $m^3 \cdot ha^{-1}$; relative density – 0.62; forest type – C_2-h-oP. The stand of Scots pine is native in composition, single-aged, complex in structure, with a predominance of common hornbeam in the second tier. The origin of the stand has not been reliably established, but there is a high probability of its autochthonous nature.

Table 6. Dynamics of morphometric parameters of plus trees of Scots pine (Pinus sylvestris L.) in the trial area of Hrabivske forestry of the Buske Forestry Enterprise branch (1978 selection)

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/DbH*100	Model value of the index	Difference with the model
Model data, 1978		90	34.8	40.8		6.339	
1	Plus features	90	33.0	56.0	4.870	6.339	-1.469
2	Plus features	90	32.5	50.0	5.538	6.339	-0.801
3	Plus features	92	32.0	48.0	5.990	6.339	-0.349
4	Plus features	92	33.0	50.0	5.576	6.339	-0.763
5	Plus features	92	32.5	48.0	5.897	6.339	-0.442
Mean			32.6	50.4			
Model data, 2004		115	38.3	47.5			
1	Satisfactory	116	39.5	59.0	4.977	6.321	-1.344
2	Satisfactory	116	38.0	60.0	5.088	6.321	-1.233
3	Satisfactory	116	40.5	63.5	4.511	6.321	-1.810
4	Satisfactory	116	44.0	59.0	4.468	6.321	-1.853
5	Satisfactory	116	42.0	61.0	4.528	6.321	-1.793
Mean			40.8	60.5			

Source: *developed by the authors of this study*

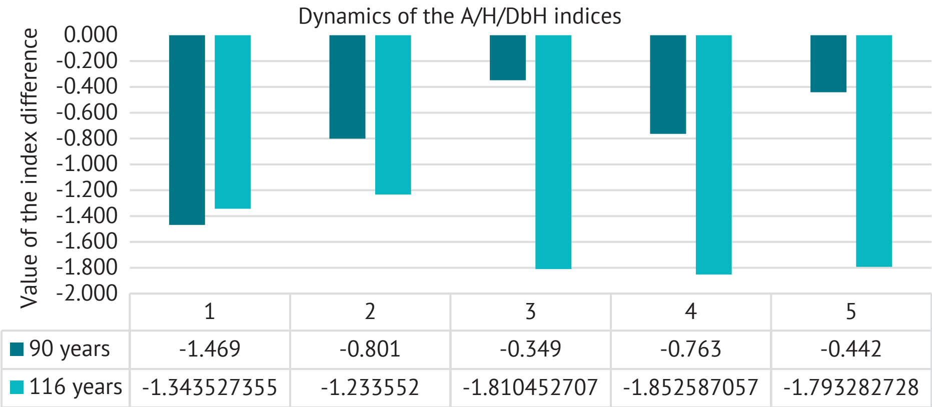


Figure 5*. Difference in the values of the plus tree indices compared to the modal values (according to Table 6)*
Source: *developed by the authors of this study*

Table 7. Dynamics of morphometric parameters of plus trees of Scots pine (Pinus sylvestris L.) on the trial area of Stizhotske forestry of the Kremenetske Forestry Enterprise branch

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/DbH*100	Model value of the index	Difference with the model
Model data, 2015		90	31.2	36.3		7.947	
1	Plus features	88	32	52	5.288	7.947	-2.659
2	Plus features	88	31	45	6.308	7.947	-1.639
3	Plus features	88	32	52	5.288	7.947	-2.659
4	Plus features	88	32	52	5.288	7.947	-2.659
5	Plus features	88	31	52	5.459	7.947	-2.488
6	Plus features	88	33	52	5.128	7.947	-2.819
7	Plus features	88	32	44	6.250	7.947	-1.697
8	Plus features	88	31	46	6.171	7.947	-1.776
9	Plus features	88	30	44	6.667	7.947	-1.280
10	Plus features	88	31	54	5.257	7.947	-2.690

Table 7. Continued

Plus tree No.	Year of selection, examination, Condition	Age at the time of selection and examination	Height, m	Diameter, cm	Index A/H/DbH*100	Model value of the index	Difference with the model
Mean			31.5	49.3			
Model data, 2024							
1	Satisfactory	97	31	62	5.047	7.886	-2.839
2	Satisfactory	97	33	52	5.653	7.886	-2.233
3	Satisfactory	97	33	60	4.899	7.886	-2.987
4	Satisfactory	97	32	62	4.889	7.886	-2.997
5	Satisfactory	97	33	56	5.249	7.886	-2.637
6	Satisfactory	97	33	64	4.593	7.886	-3.293
7	Satisfactory	97	32	52	5.829	7.886	-2.057
8	Satisfactory	97	31	52	6.017	7.886	-1.869
9	Satisfactory	97	33	54	5.443	7.886	-2.443
10	Satisfactory	97	33	62	4.741	7.886	-3.145
Mean			32.4	57.6			

Source: *developed by the authors of this study*

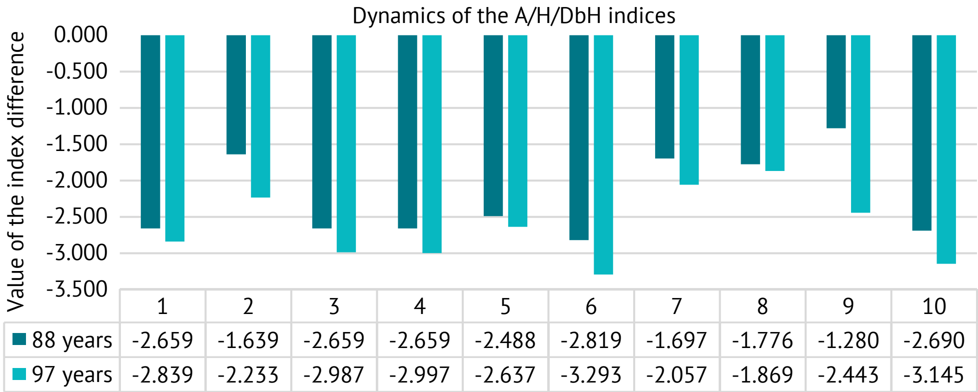


Figure 6*. Difference in the values of the plus tree indices compared to the modal values (according to Table 7)*
Source: *developed by the authors of this study*

The nature of the dependence of changes in the A/H/DbH indices suggests that plus trees during growth effectively use the forest-typological potential of forest-vegetation conditions in the age range of 90-100 years, approaching the modal values of the I^{a} class. At the age of up to 98 years, under conditions of a relatively slight decrease in the relative completeness of the stand, there is a uniform dynamics of deviations of indicators compared to the modal values, with the exception of tree No. 9. For the plus trees listed in Table 7, information on their heredity in the formation of forest-seed plantations in the region of distribution needs to be clarified, since the progeny of these trees were not tested in test crops. The increased biotic stability of these plus trees is not a reliably established heritable plus trait after they reach 100 years of age and a height of more than 30 metres. However, further monitoring and testing of their offspring in more extreme conditions may confirm or refute this assumption. Thus, indigenous stands of Scots pine in the edaphic and climatic conditions of Malopolissia may be of both autochthonous and non-autochthonous origin, which necessitates further monitoring of their condition and parametric characteristics of plus traits.

The summary information of the assessment of the development of plus trees by plots allows discussing and identifying the key features of the results. The growth of a plus tree in height and thickness with age and its condition under certain parameters specific to each forest-forming tree species can serve as an assessment of the use of forest vegetation conditions and one of the indicators of confirmation of the assignment of forest stands to the established forest types and stand types, O. Danchuk *et al.* (2024). Another area of research is the analysis and comparison of the dynamics of the H/DbH ratio by dominant height, which can use both data on plus trees and average taxonomic characteristics of stands in model plots. Analogous relationships (regression models) were described by F. Sağlam *et al.* (2024) to predict timber reserves for certain time intervals in different forest-ecological conditions, which allows refining the data of growth tables. The ratio of tree heights and diameters in the dynamics with age is presented in Fig. 7. The results confirmed that the correlation between tree height and age is the lowest among the studied indicators. This indicates a substantial dependence of the height of Scots pine plus trees on habitat conditions and forest type, as well as a pronounced heterogeneity of stands of this species, where trees were selected based on their origin.

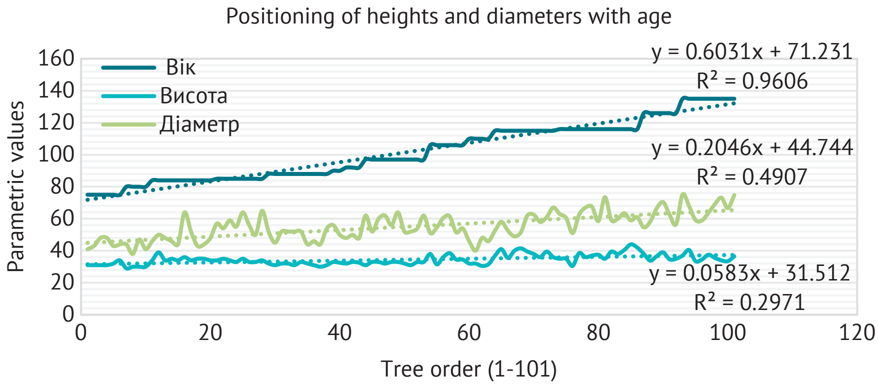


Figure 7. *Ratio of heights and diameters of plus trees with increasing stand age*
Source: *developed by the authors of this study*

Table 8 presents the correlation matrix between age, height, diameter and I_1 indices for the entire array of plus trees in the study area.

The correlation analysis shows that the I_2 index has a negative relationship with tree age, with a total correlation coefficient of -0.87, which indicates the presence of an inverse relationship of a significant level. For forest type C_2-h-oP, this indicator is -0.785, and for C_3-h-oP – -0.948, indicating that the I_2 index is more informative about the parametric characteristics of trees than the I_1 index. The I_1 index, on the other hand, proved to be more suitable for analysing the growth process (dynamics) of trees and was used to assess the biotic stability of plus trees. Figs. 8, 9, and 10 show the variance of height, diameter, I_1 index, and age of plus trees with the corresponding linear regression equations.

Table 8. *Correlation matrix of parameters of plus trees and their indices I_1*

Correlation matric	Age	Height	Diamere	Index I_1
Age	1	0.554	0.769	0.136
Height	0.554	1	0.506	0.330
Diameter	0.769	0.769	1	0.398
Index	0.136	0.330	0.398	1

Source: *developed by the authors of this study*

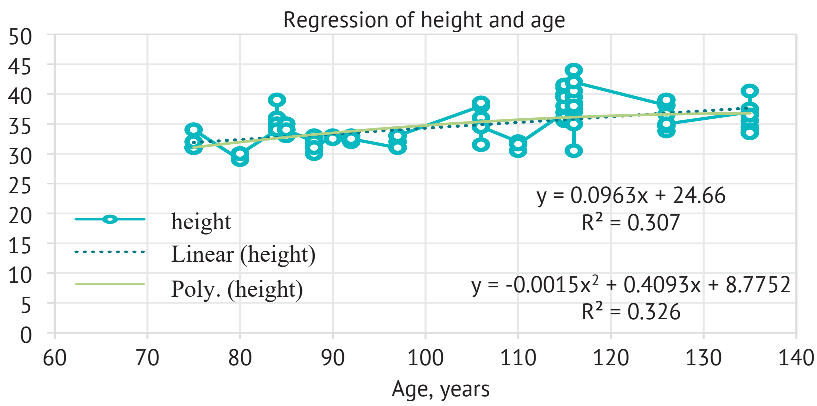


Figure 8. *Positioning heights and ages of plus trees with stand age*
Source: *developed by the authors of this study*

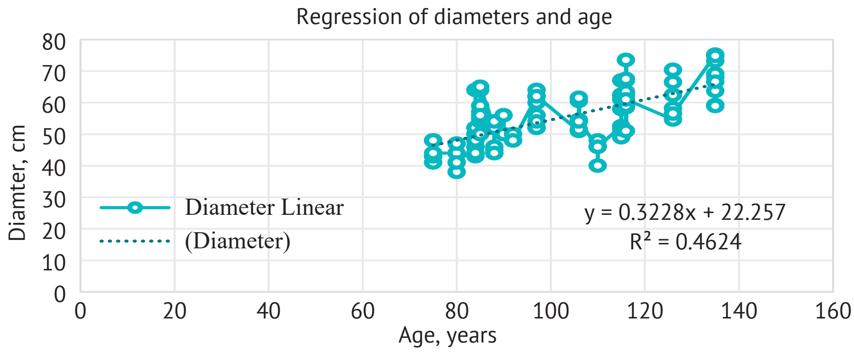


***Figure 9**. Positioning diameters and ages of plus trees with stand age*

***Source:** developed by the authors of this study*

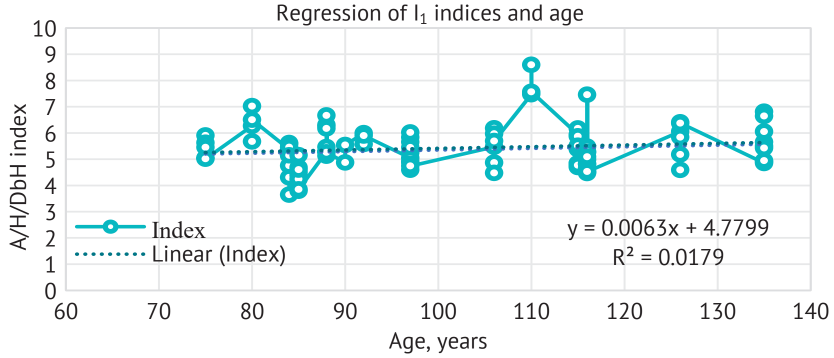


***Figure 10**. Positioning of indices and age of plus trees with stand age*

***Source:** developed by the authors of this study*

Figs. 8, 9, 10 show the trend lines of the one-factor linear regression with the corresponding coefficients of determination. Fig. 10 visualises the variance of indices and age, and Table 8 presents the statistical indicators of these series.

The analysis of variance based on Fisher's criterion and its significance ($F = 1.802083$; $p = 0.182531$) with a low correlation coefficient does not allow proposing an adequate model of the parametric indicators of plus trees according to the I_1 index. It also does not make practical sense due to the variability of forest-typological conditions of stand growth. Clearly, the use of indices is suitable only for modelling within specific forest types. In this regard, Table 10 shows the distribution of values of the I_1 index (A/H/DbH) by forest type, and adds the value of the I_2 index (H/DbH/A), which turned out to be more suitable for modelling tree parameters depending on age.

***Table 9**. Statistical information on age estimation and I_1 index for plus trees*

Statistical indicators	Age, years	Index I_1
Mean value	102	5.425054
Standard error	1.8	0.084873
Standard deviation	18.0	0.852963
The greatest value	135	8.593750
The smallest value	75	3.645833

***Source:** developed by the authors of this study*

***Table 10**. Values of I_1 (A/H/DbH) and I_2 (H/DbH/A) indices in different forest types*

Index	Forest type	Average value by forest type	Average value of all	The smallest of all	The greatest of all
I_1	C_3-h-oP	5.618	5.425	3.645	8.593
	C_2-h-oP	5.182	5.425	3.645	8.593
I_2	C_3-h-oP	0.654	0.644	0.344	1.030
	C_2-h-oP	0.632	0.644	0.344	1.030

***Source:** developed by the authors of this study*

Figs. 11 and 12 show the regression dependencies of tree age on the I_2 index by forest type. The obtained relatively high coefficients of determination ($R^2 = 0.617$ and $R^2 = 0.897$) indicate a significant relationship, which allows proposing suitable models for predicting tree parameters depending on age.

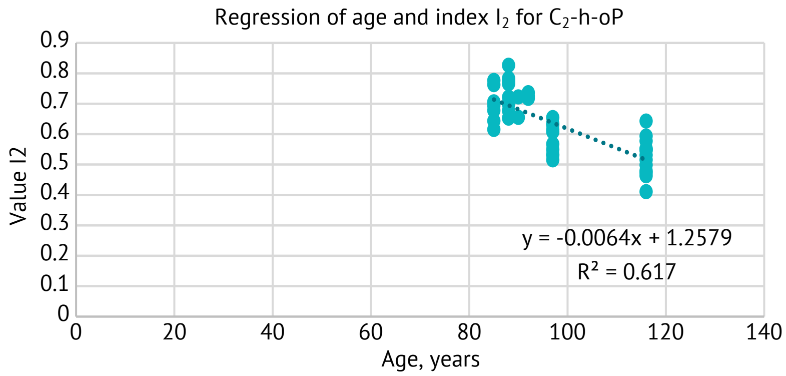


Figure 11*. Positioning of indices and ages of plus trees with the age of stands (average age of trees – 98 years)*
Source: *developed by the authors of this study*

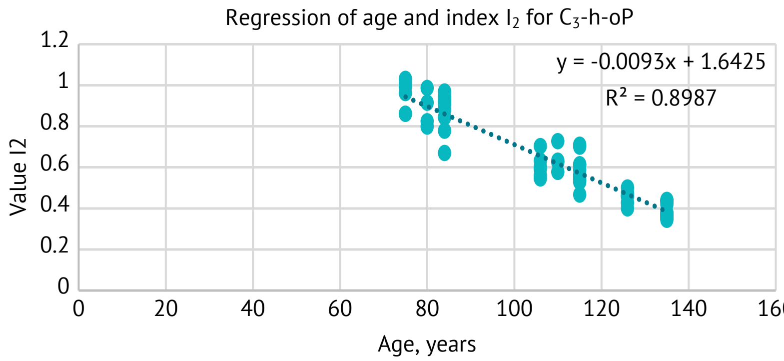


Figure 12*. Positioning of indices and ages of plus trees with the age of stands (average age of trees – 98 years)*
Source: *developed by the authors of this study*

The obtained equations can be used to form the parameters of plus trees by age through the value of the index I_2. Figs. 13 and 14 show the dynamics of the decrease in the values of the I_2 index as the age of the stands increases, separately for each forest type. The obtained equations of trend dependencies can be used to predict the parameters of plus trees by their age through the value of the I_2 index. The graph shows that as the age of trees in a given forest type increases, there is a gradual and stable decrease in the I_2 index, which illustrates the process of age-related deterioration of indicators related to tree growth or quality.

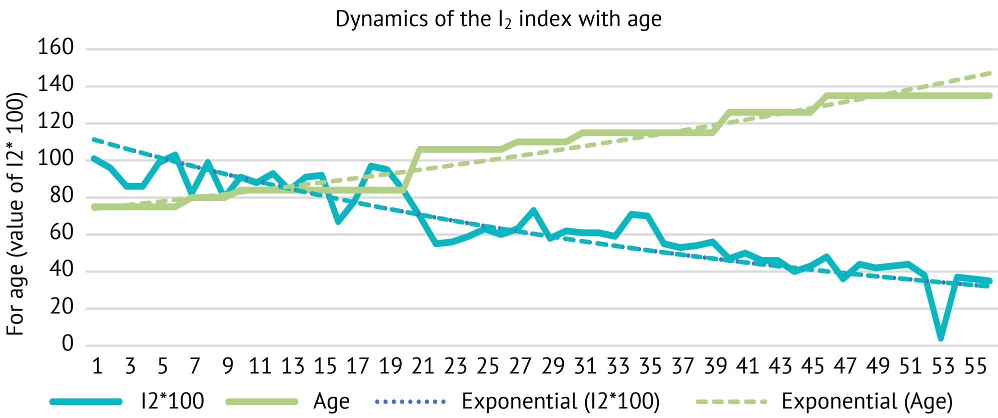


Figure 13*. Positioning of index reduction with increasing age of plus trees (in conditions of forest type C_3-h-oP)*
Source: *developed by the authors of this study*

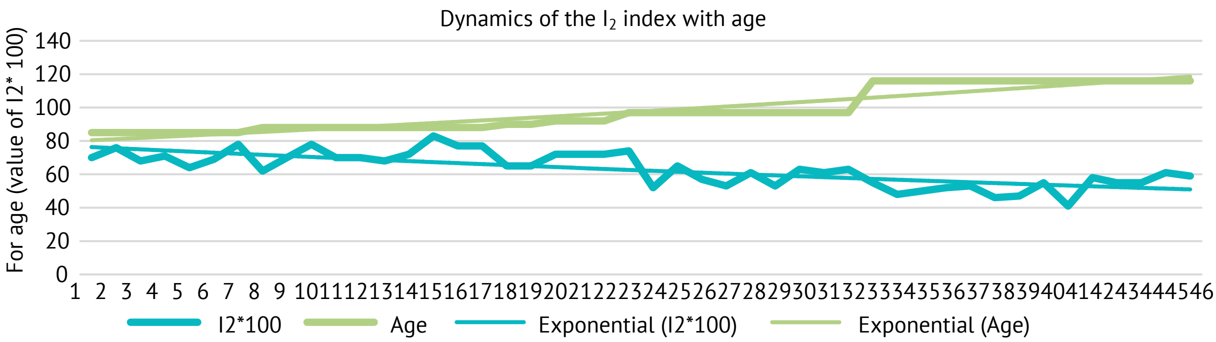


***Figure 14**. Positioning of index reduction with increasing age of plus trees (in conditions of forest type C2-h-oP)*
***Source:** developed by the authors of this study*

Analysing Figs. 13 and 14, it can be noted that for the C_3-h-oP conditions, the drop in the I_2 index is more dramatic than in the case of the C_2-h-oP forest type, where Scots pine grows in more optimal soil conditions. In both cases, the rate of index decline accelerates after the plantation reaches the age of about 100 years, when the risk of losing biotic stability increases sharply, especially under the influence of summer droughts. The increased sensitivity to a drop in the I_2 index in old-growth stands under fresher and drier conditions is explained by the development of a greater moisture deficit, which limits the adaptive capacity of trees at a later age. However, even in humid conditions, a sharp decline in the I_2 index is a negative factor, as it can lead to a weakening of old-growth stands and create prerequisites for the activation of stem pests. Thus, the graphical data confirm the need to consider the age threshold of about 100 years when planning silvicultural measures aimed at maintaining the biotic stability of pine stands in different types of forest vegetation conditions.

DISCUSSION

Assessment of the impact of abrupt changes in edaphic and climatic conditions on the condition of plus trees and determination of their further growth by parametric indices calculated by age dynamics is not sufficiently informative without a comprehensive analysis, including the dynamics of the spatial and age structure of the forest stands in which the trees were selected. At the same time, the impact of stress factors on Scots pine stands is a relevant topic in silvicultural research, and the results presented here are of both silvicultural and breeding value. The analysis of the identified correspondences and differences in H/DbH of plus trees at different ages allowed proposing an auxiliary area for practical validation of regionalisation of forest reproductive material by taxonomic parameters of research sites. Analogous studies were presented in O. Danchuk *et al.* (2024), where the assessment was conducted using a complex indicator – the site class, which reflects the dynamics of average heights with age. The proposed approach using the H/DbH ratio complements such assessments, expanding the possibilities of determining the vital status and ecological plasticity of trees, which are valuable criteria for the autochthonous nature of forest stands.

Analogous studies on adaptability were presented in P. Przybylski *et al.* (2020), where the dependence of crown defoliation on taxonomic parameters was assessed based on five-year monitoring of mature pine stands (> 130 years). No correlation was found between tree height and diameter and the degree of defoliation, which the researchers explained by the lack of analysis of the relationship with tree age, which could reduce the accuracy of the regression model. At the same time, the researchers found a dependence of defoliation on site moisture, which is consistent with current data on the hygrotope, as the main stress factor of the study period was a two-year drought.

Another study by P. Przybylski *et al.* (2021) assessed crown defoliation depending on the level of biodiversity, specifically, considering genetic analysis, which concluded that genotype is closely related to adaptability to stress factors. An analogous relationship can be observed in the findings of R. Matisons *et al.* (2021), where, based on a combination of dendrochronological analysis of trees and genotypic assessment of local populations that differ in taxonomic indicators, a response to changes in meteorological conditions was identified. These studies confirmed the significance of phenotypic evaluation (selection of plus trees) in further studies of their hereditary properties to determine the level of autochthonous forest stands of the metapopulation of the (local) region of origin. Therefore, when discussing the results of using the dynamics of the A/H/DbH index in the edaphic and climatic conditions of Malopolissia from the standpoint of establishing the region of origin of forest reproductive material for Scots pine, the primary task is to determine the autochthonousness of the forest stands in which plus trees are selected.

Notably, in conditions of wet hornbeam-oak woodland, plus trees have greater heights while maintaining an average diameter: plus trees in plots in Buske and Radekhivske branches (C_3-h-oP) show greater values of average height with a lower DbH/H ratio compared to trees in plots in Kremenetske and Brodivske branches (C_2-h-oP). There are some discrepancies with the findings of P. Lakyda *et al.* (2020) and V. Lovynska *et al.* (2021) in terms of biomass estimation. Comparing Polissia as a whole with the Northern Steppe, the researchers noted the greater productivity of pine stands for the C_2 edatope in Polissia. This may also indicate the specific features of the conditions of forest stand development in the Malopolissia district for pine forests in relation to the conditions of Polissia as a whole. The question of the autochthonous nature of forest stands by origin often continues to be open. This applies even to native pine stands. Defining the boundaries of the region of origin is more challenging when it comes to local populations of forest-forming species. In Ukraine, there are currently no opportunities to assess the genomes of such populations using genetic and molecular markers. Analogously, genetic assessment of plus trees is not available. Marker and genomic selection methods are considered to be promising, especially in the context of climate change. Their potential and features were summarised in Ch. Li *et al.* (2025). According to by B.É.D. Borges da Silva *et al.* (2021), it is advisable to combine genomic testing, field trials, and selection. M. Lstiburek *et al.* (2023) proposed a new concept of breeding evaluation, which involves the gradual determination of a set of genetic traits in forest stands depending on their age. This will help to improve approaches to the dynamics of phenotypic evaluation in a wide range of environmental conditions. The analysis of growth dynamics, provenance in test cultures, population stands, and plus stands, especially those with high performance (e.g., Lopatynska pine), in combination with genetic methods, will enable faster assessment of the adaptability of offspring. This applies to both individual trees and populations overall.

The study also considered the possibility of modelling the parameters of plus trees and the sustainable forest stands from which they are selected to improve their functional purpose in forest reproduction. This approach complements the results of modern ecopopulation studies in Ukraine, namely: V. Voitiuk *et al.* (2020) – assessment of the adaptability of local pine populations from Volyn; I. Neyko *et al.* (2020) – assessment of the adaptability of northern populations of Scots pine in the southern limit of the range; V. Blystiv *et al.* (2021) – assessment of the sustainability of stand development. The selection of plus trees in stands of autochthonous origin, as well as in populations that are plastic to stress factors, increases the significance of plus selection in the development of sustainable forests of the future. The massive damage to Scots pine (*Pinus sylvestris* L.) stands by stem pests, particularly bark beetles, which has become widely publicised in recent years, has even affected plus trees, which were conventionally considered more resistant. This has exacerbated the scientific and practical problem of prompt preventive assessment of the physiological state of plantations and identification of the principal causes of their weakening before large-scale phytophage invasions. K. Davydenko *et al.* (2021) addressed these issues in detail, but it should be noted that the effectiveness of pest prediction and the development of a forest ecosystem protection system largely depends on the integrated impact of a complex of stress factors (climatic, edaphic, anthropogenic) and the adaptive response of trees to them.

It was found that the assessment of the state of stands by the difference in changes in the A/H/DbH indices (the ratio of absolute height, mean diameter, and other morphometric parameters), illustrated in Figs. 1–6, is an informative indicator of stability dynamics. Specifically, smaller values of the difference in these indices correlate with increased biotic stability of plantations, while their growth indicates a gradual loss of stability, accelerated drying out of even plus trees and, accordingly, more intensive colonisation by bark beetles. The results are in line with the findings of earlier studies, specifically O. Danchuk *et al.* (2024), who substantiated the need to allocate the Malopolissia region of origin for pine forests based on geobotanical zonation. This emphasises the significance of regionally oriented approaches to assessing the resilience and adaptive potential of forest ecosystems.

CONCLUSIONS

The results of the regression analysis based on the measurements of 43 plus trees in five model plots (102 replications in total) showed that there are no direct statistically significant relationships between tree age (A), height (H), and diameter at 1.3 m (DbH) in the dynamics of age. Instead, a high inverse correlation was found between the I_2 index (H/DbH/A) and the C_2-h-oP forest type (correlation coefficient $r = -0.785$) and a very high inverse correlation for the C_3-h-oP forest type ($r = -0.948$). The coefficients of determination (R^2) for the respective linear regression models are 0.617 (C_2-h-oP) and 0.897 (C_3-h-oP). The equations of the obtained linear regressions are as follows: for forest type C_2-h-oP: $I_2 = -0.0064A + 1.2579$ ($R^2 = 0.617$, $P < 0.0001$); for forest type C_3-h-oP: $I_2 = -0.0093A + 1.6425$, ($R^2 = 0.899$, $P < 0.0001$). The proposed models can be used to predict the parameters of selection of plus trees within the Malopolissia district of hornbeam-oak and pine forests. The results of the analysis of growth dynamics and biotic stability (preservation) of plus trees showed that, despite greater taxonomic indicators in wet hygrotopes, they have lower adaptability to abrupt changes in humidity at the age of more than 100 years compared to fresh hygrotopes. In fresh hygrotopes, the critical effect is mainly manifested under conditions of prolonged moisture deficit. This difference is levelled out with the systematic increase in the dynamics and amplitude of climatic factors observed over the past decade. Notably, a significant part of the plus trees requires urgent cloning and preservation of their genetic potential in clone and family archives or on forest seed plantations.

The findings of the study of plus trees revealed high germination of stands in terms of productivity in the experimental plots. The productivity varies depending on the hygrotope in hornbeam-oak-pine stands, which is natural. At the same time, these forest stands can be attributed to the same region of origin of Scots pine forest reproductive material (FRM) – Malopolissia district, which covers autochthonous hornbeam-oak and pine forests. Clarification of the boundaries of this district is a necessary step for the development of a reliable forest seed base, particularly for the further selection of plus trees for plantations. The feasibility of such a designation is also confirmed by the fact that in the context of global climate change, intraspecific variability results in the development of local ecotypes of Scots pine, which should be considered as the most promising for reforestation. To effectively select plus trees that meet the forest vegetation potential of fresh and wet pine forest types in this region, it is necessary to clarify quantitative parameters. It is proposed to use regression models with the I_2 index (H/DbH/A).

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Лісівничо-таксаційна оцінка плюсових дерев у межах Малополіського округу грабово-дубових та соснових лісів

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Анотація. Удосконалення критеріїв добору та подальше випробування плюсових дерев сосни звичайної потребує систематичного оновлення даних обмірів, їх детального аналізу, а також постійного моніторингу створених об'єктів. Важливим завданням є формування нових експериментальних ділянок для дослідження спадкових характеристик дерев, особливо в умовах адаптації лісового господарства до кліматичних змін. Лісівничо-таксаційна оцінка плюсових дерев у межах Малополіського округу грабово-дубових та соснових лісів проведена з метою встановлення залежностей між співвідношенням висоти та діаметра на висоті 1,3 м і віком дерев у різних типах лісу за результатами їх добору. Для встановлення достовірних результатів аналітично-порівняльних висновків використовувалися стандартні статистичні методи. Для проведення аналізу було використано розрахунок двох індексів: I_1 – показник зміни віку у співвідношенні A/H/DbH, та I_2 – показник зміни співвідношення H/DbH/A залежно від віку. Обчислення цих індексів здійснювалося для плюсових дерев, з урахуванням їх віку (A), висоти (H) та діаметра стовбура на висоті 1,3 м (DbH). Досліджено залежності зміни висоти та діаметра плюсових дерев із віком, визначено особливості цих залежностей для двох найпоширеніших типів лісу, проаналізовано два види індексів зазначених залежностей та узагальнено висновки щодо їх статистично достовірної придатності для моделювання параметрів добору плюсових дерев у межах досліджуваної території. Встановлені у дослідженні параметричні залежності плюсових дерев Малополіського округу соснових лісів даного регіону походження можуть бути використані як додаткові критерії відбору дерев за продуктивністю із забезпеченням достатнього рівня їх біотичної стійкості. У статті узагальнена можливість встановлення регіонів походження лісового репродуктивного матеріалу на основі параметричної оцінки деревостанів і плюсових дерев в межах Малополіського округу на підставі їх приналежності до автохтонних лісостанів за походженням. Актуальність досліджень підсилюється впровадженням підходів до регіоналізації лісового репродуктивного матеріалу що, полягає у визначенні меж регіонів походження та меж відповідного поширення з них лісового репродуктивного матеріалу. Запропонований підхід до впровадження регіоналізації є передумовою отримання і введення в обіг лісового репродуктивного матеріалу на засадах імплементації у нормативну базу лісового насінництва і розсадництва Директиви 1999/105/ЄС від 22 грудня 1999 року «Про маркетинг лісового репродуктивного матеріалу»

Ключові слова: плюсові дерева; лісовий репродуктивний матеріал; регіоналізація лісового репродуктивного матеріалу; регіони походження та поширення; таксаційні показники; типи лісу; геоботанічне районування