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Silvicultural and mensurational structure of *Pinus nigra* Stands in Ukraine based on the 2011 state forest inventory data

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Abstract. The study aimed to identify the territorial, forest-site, silvicultural, and mensurational patterns governing the formation of Crimean pine and Austrian pine stands in Ukraine. The analysis was based on a compartment-level database of the State Forest Inventory as of 2011. Structured queries in the Microsoft SQL Server database management system, weighted mean calculations, and regression analysis of age-related changes in stand mensurational characteristics were applied. The total area of the studied stands amounted to 134.1 thousand ha, of which 99.8% was occupied by Crimean pine (*P. nigra* var. *pallasiana*) and 0.2% by Austrian pine (*P. nigra* var. *austriaca*). Most Crimean pine stands were concentrated in the southern and eastern regions of Ukraine, whereas Austrian pine stands had a local distribution, predominantly in the western part of the country. Very dry and dry forest-site conditions accounted for 84.8% of the total area of Crimean pine stands, primarily in dry fairly fertile site types and dry poor site types. Austrian pine occurred more frequently in fresh fairly fertile and fertile site types. Artificially established and pure stands predominated in the structure of both taxa. Under dry site conditions, artificially established stands accounted for 91.5% of Crimean pine stands and 98.5% of Austrian pine stands. The highest site-quality classes, mean heights, mean diameters, growing stock volumes, and proportions of merchantable timber were generally recorded in fairly fertile and fertile site types. By

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contrast, the productive potential of stands growing in dry poor site types was constrained by moisture deficiency and low soil fertility. The diversity of associated tree species increased with increasing site trophicity: *P. sylvestris* predominated in poor site types, whereas the contribution of broadleaved hardwood species increased in fairly fertile and fertile site types

Keywords: Crimean pine; Austrian pine; forest-site types; growing stock volume; productivity; merchantable timber; growth dynamics

INTRODUCTION

Black pine (*Pinus nigra* J.F. Arnold) is an ecologically and intraspecifically differentiated coniferous species whose natural range encompasses the mountainous regions of Southern and Central Europe, the Balkan Peninsula, the Mediterranean region, and Asia Minor. The spatial fragmentation of its range and the long-term isolation of individual populations have led to the formation of several geographical subspecies and ecotypes differing in morphological traits, growth rates, drought tolerance, and responses to site conditions. The eastern part of this taxonomic complex includes Pallas pine, also known as Crimean pine, which is most commonly classified as *P. nigra* subsp. *pallasiana* (Lamb.) Holmboe, whereas the name *P. pallasiana* D. Don is used less frequently.

The silvicultural importance of black pine is determined by its ability to form stands on dry, rocky, nutrient-poor, eroded, and anthropogenically disturbed lands. Owing to the plasticity of its root system, relatively efficient water use, and tolerance of adverse soil conditions, the species is widely used for erosion-control afforestation, the stabilisation of sands and slopes, the reclamation of disturbed lands, and the establishment of protective forest plantations. M.E. Lucas-Borja et al. (2022), investigating Spanish black pine along an elevation gradient, demonstrated that afforestation success depends strongly on plantation-site conditions and seed origin, with severe drought at low-elevation sites substantially reducing seedling survival. Z. Vacek et al. (2023), based on a systematic review of European studies, also confirmed the considerable potential of black pine for forest restoration, timber production, and climate-change adaptation in forestry. At the same time, these authors revealed substantial variation in cultivation outcomes depending on seed provenance, stand age and density, and local environmental conditions.

Current research on *P. nigra* increasingly focuses on identifying relationships among stand structure, climate, and productivity dynamics. S. Versace et al. (2022), studying populations of *P. nigra* subsp. *laricio* in Corsica, Sardinia, Sicily, and Calabria, further confirmed that resistance, recovery, and resilience following drought events depend on the local environment and tree age. According to their findings, older trees showed greater resistance to individual drought periods, although responses differed among populations. The importance of geographic origin for black pine growth has recently

been demonstrated by G. Giovannelli et al. (2026) in common-garden trials involving 16 provenances from four subspecies. The authors found that provenance effects on radial growth were stronger than subspecies effects and recorded substantial phenotypic plasticity and genotype-by-environment interactions among contrasting sites.

An equally important research direction concerns the effects of stand density and silvicultural interventions on the response of black pine plantations to drought. From the perspective of timber utilisation, A. Dias et al. (2020) analysed the physical, chemical, and mechanical properties of *P. nigra* wood from six Portuguese sites. The authors found that its mechanical properties were broadly comparable to those of *P. pinaster*, while several wood characteristics indicated potential advantages for industrial use. These findings provide additional grounds for considering black pine not only as a protective or land-reclamation species but also as a potentially valuable timber-producing species.

These findings demonstrate the need for a comprehensive approach to assessing black pine stands. Their silvicultural potential cannot be substantiated solely on the basis of total area or stand survival. Their distribution by forest site conditions, origin, age, species composition, relative density, and site-quality class must also be considered, together with the dynamics of mean height, mean diameter, growing stock, and timber merchantability. Identifying these relationships makes it possible to distinguish realised productivity from the potential productive capacity of the species and to determine the conditions under which its cultivation is both ecologically and economically justified. In Ukraine, black pine in the broad taxonomic sense is represented primarily by Crimean pine and by substantially smaller areas of Austrian pine stands. Crimean pine occurs naturally in the Crimean Mountains, whereas in the Steppe, Forest-Steppe, and partly in the Polissia zones, it is grown predominantly in artificially established stands. Austrian pine is an introduced taxon whose cultivation centres are located mainly in the western, central, and north-eastern regions of the country.

The analysed dataset covers their distribution across administrative regions and forest site conditions, the proportions of natural and artificially established stands, pure and mixed stands, site-quality classes, growing stock, mean heights and diameters, the proportion

of merchantable timber, and the composition of associated tree species. The adaptive capacity of Crimean pine under the steppe conditions of Ukraine has also been assessed through physiological indicators. V. Besonova & T. Yusyypiva (2021) found that tree and shoot growth, needle surface development, and needle water content in anti-erosion plantations varied markedly with forest-growth conditions, with the lowest values generally occurring under arid and semi-arid slope conditions. Their findings demonstrate that physiological adaptation to drought does not eliminate the growth constraints associated with limited water availability.

Despite considerable scientific interest in the ecology, climatic sensitivity, introduction, and productivity of *P. nigra*, most studies have been conducted on individual experimental sites, regional networks of sample plots, or within a single subspecies. In Ukraine, the relationships among the territorial distribution of Crimean and Austrian pine, forest site conditions, stand origin and species composition, age structure, productivity, and timber merchantability remain insufficiently investigated. Addressing this knowledge gap is particularly relevant in the context of adapting forest management to increasing climatic aridity, restoring degraded lands, and scientifically substantiating the expansion of the range of tree species used in protective afforestation. The aim of the study was to provide a comparative assessment of Crimean pine and Austrian pine stands in Ukraine and to determine how their distribution, stand structure, and productivity vary in relation to forest site conditions.

To achieve this aim, the following objectives were established to assess the regional distribution of stand areas and determine their forest-site and age structure, origin, and proportions of pure and mixed stands; to analyse stand productivity and merchantability, as well as the dynamics of mean height, mean diameter, and growing stock in relation to site conditions; to determine the species composition of associated tree species in Crimean pine and Austrian pine stands. The scientific novelty of the study lies in the development of an integrated nationwide assessment of black pine stands by simultaneously combining spatial, forest-typological, age-related, coenotic, and mensurational characteristics. Unlike local studies of individual populations or experimental plantations, the present study compares Crimean pine and Austrian pine stands within a unified information framework in terms of their area, origin, species composition, productivity, and the qualitative structure of growing stock.

LITERATURE REVIEW

Scientific research on black pine encompasses its taxonomy, natural and secondary distribution, introduction, forest-site affinity, growth, productivity, natural regeneration, health condition, and economic value. Comparisons among published findings are complicated by inconsistent interpretations of the intraspecific

structure of *P. nigra*. Different sources use the names *P. nigra* var. *austriaca*, *P. nigra* subsp. *nigra*, *P. nigra* subsp. *pallasiana*, and *P. pallasiana* D. Don. These differences in taxonomic approaches have also affected forest inventory records, in which Crimean pine and Austrian pine may have been registered as separate tree species, varieties of black pine, or, in some cases, mistakenly assigned to Scots pine.

One of the first comprehensive studies of introduced black pine stands in Ukraine was conducted by T.B. Skrobach (2006). The author characterised the distribution of the species in the lowland and mountainous parts of western Ukraine, its bioecological properties, silvicultural and mensurational characteristics, health condition, seed production, and capacity for natural regeneration. The findings provided a positive assessment of the effectiveness of black pine introduction and substantiated its potential for use in forest plantations and phytomeliorative stands. At the same time, it was emphasised that the longevity and productivity of the species are determined by the correspondence of specific sites to its ecological requirements rather than solely by its generally recognised drought tolerance.

Environmental differentiation within the natural Crimean range of *P. nigra* subsp. *pallasiana* was examined by N.M. Devi *et al.* (2023) along an elevational transect on Mount Ai-Petri. Using four tree-ring chronologies, the authors demonstrated substantial differences in climate–growth relationships along the altitudinal gradient. These differences were associated not only with climatic variation but also with topography, soil, and bedrock characteristics. Precipitation during the growing season, particularly in July, was identified as an important factor affecting radial growth. The study therefore confirms that even within a relatively compact natural range, Crimean pine growth is strongly site dependent and should be interpreted within a combined climatic-edaphic framework.

The complex intraspecific differentiation of European black pine has also been investigated using genomic approaches. S. Olsson *et al.* (2020) developed transcriptomic resources representing major biogeographical regions of the natural range and used nuclear orthologous genes and single-nucleotide polymorphisms to examine evolutionary relationships within *P. nigra*. Their results supported the existence of two broad geographical population groups while also demonstrating that conventional subspecific classifications do not fully reflect the genetic structure of the species. These findings emphasise the need for caution when interpreting the taxonomic identity and provenance of introduced stands solely from historical planting records or conventional forest inventory classifications.

The adaptation of black pine to conditions within its secondary range was investigated by M. Soroka & T. Yuskevych (2011). In the Holohory region, the authors recorded successful seed regeneration and the

formation of a third generation of black pine without direct human intervention, which was interpreted as evidence of its complete naturalisation. Phytosociological surveys showed that the species had formed an ecological niche similar to that of natural black pine forests belonging to the eastern ecological group. Nevertheless, the capacity of this introduced species for autonomous spread requires monitoring near natural steppe and meadow-steppe communities, because successful naturalisation from a forestry perspective does not always correspond with the objectives of conserving native vegetation.

The climatic sensitivity of Crimean pine within its natural range was assessed by I. Koval (2013). A dendrochronological analysis of a 110-year-old stand on the southern slope of the Crimean Mountains revealed differences in the responses of earlywood, latewood, and total annual ring width to temperature and precipitation. Latewood was the most sensitive component to climatic variation. Reduced precipitation during the warm season and increasing summer water deficits resulted in decreased radial growth. Thus, even in natural stands of the subspecies *pallasiana*, drought tolerance does not prevent productivity losses under prolonged shortages of available moisture.

The phenological characteristics of introduced black pine under the conditions of the Right-Bank Forest-Steppe were studied by S. Adamenko *et al.* (2018). The authors identified an early onset of vegetation and a pronounced dependence of shoot growth intensity on air temperature. Needle growth began later than shoot elongation, while growth intensity increased from the lower part of the crown towards the apex. The correspondence of seasonal rhythms to the local climate indicates a sufficient level of species adaptation; however, phenological observations alone do not characterise the long-term productivity and stability of established stands.

The importance of planting-material provenance for the adaptation of black pine to contrasting environmental conditions was investigated by V. Ivetić *et al.* (2021). The authors compared seedlings originating from southern Greek and northern Serbian provenances and assessed their tolerance to freezing, heat, and drought. Seedlings from the northern provenance showed the highest tolerance to severe freezing, although differences among provenances were not statistically significant, while the combined effects of heat and drought caused greater foliar damage than drought alone. The authors emphasised that the use of black pine in reforestation and restoration should not be based on the search for a single universally adapted provenance but should consider genetic diversity and the correspondence of reproductive material to projected environmental conditions. These findings highlight the importance of provenance selection when black pine is introduced beyond its natural range.

The productivity of semi-arid Crimean pine stands was assessed by S. Bulut *et al.* (2023) using an integrated approach combining field measurements, biogeochemical modelling, remote sensing, and machine-learning techniques. Net primary productivity showed significant temporal relationships with vegetation indices, temperature, and solar radiation, while the integration of satellite-derived texture characteristics with support vector machine modelling provided high predictive accuracy. The study demonstrates that Crimean pine productivity is spatially and temporally variable and is controlled by the interaction of stand characteristics, climatic factors, and environmental conditions. It also highlights the potential of combining conventional forest inventory data with remote-sensing information for assessing the productive capacity of black pine stands over larger areas.

The interaction between forest management and climatic stress in black pine stands was examined by E. Collado *et al.* (2026) across several Mediterranean regions in Spain and Slovenia. Based on dendrochronological, mensurational, and soil data from managed and unmanaged stands, the authors found that silvicultural treatments, particularly moderate thinning, generally enhanced radial growth and reduced tree drought stress. The effects varied with stand age, climatic conditions, and regional context and were particularly pronounced in warmer and drier areas. These results demonstrate that stand structure and management intensity are important determinants of black pine growth responses under increasing climatic aridity.

The influence of ecological regionalisation on Crimean pine growth was quantified by M. Seki & O.E. Sakici (2022) using data from 274 sample plots and 293 stem analyses in north-western Türkiye. The authors found significant ecoregional differences in dominant-height, tree-number, basal-area, and stand-volume growth. Ecoregion-specific models provided more reliable predictions than a single regional model, whereas ignoring ecological differentiation resulted in systematic biases in estimates of stand characteristics. The findings demonstrate that growth and yield assessment of *P. nigra* subsp. *pallasiana* should explicitly account for ecological regionalisation rather than assuming uniform stand development across contrasting environments.

A. Dias *et al.* (2022) analysed the long-term growth of introduced black pine stands in Portugal located near the western limit of its current distribution. Six stands aged 50-90 years showed differences in diameter-growth dynamics that did not form a clear latitudinal or longitudinal gradient. Low mortality and the satisfactory condition of most stands indicated the high adaptive capacity of the species, while differences among growth trajectories confirmed the influence of local site conditions and, potentially, the provenance of planting material. The proposed models may be used to predict diameter growth when planning new forest plantations.

Mensurational modelling of natural even-aged black pine stands was performed by D.I. Raptis *et al.* (2021). Based on 3,442 pairs of height and diameter observations, the authors developed nonlinear mixed-effects models describing the relationship between these variables. The inclusion of dominant height and dominant diameter as predictors improved the accuracy of tree-height estimates. Such models are of practical importance for calculating growing stock and aboveground biomass and demonstrate that the interpretation of mean mensurational characteristics should account for between-site variability and the structure of the individual stand.

The regeneration dynamics of black pine forests following severe disturbance were analysed by S. Martín-Alcón & L. Coll (2016) in *P. nigra* subsp. *salzmannii* forests affected by a large wildfire in north-eastern Spain. The authors found that post-fire trajectories were determined jointly by pre-fire vegetation structure, burn severity, the proximity of unburned patches, topography, and site quality. Pine regeneration was favoured near surviving forest patches, whereas transitions towards shrub-dominated vegetation occurred more frequently on xeric sites. These findings demonstrate that the long-term persistence and structural development of black pine forests depend strongly on disturbance history and site context and that their regeneration trajectories can be influenced by silvicultural management.

The structural development and natural regeneration of old-established black pine plantations were investigated by A. Bricca *et al.* (2025) in the eastern European Alps. The authors analysed the effects of climatic, topographic, and local environmental conditions together with interactions among the tree, shrub, herbaceous, and regeneration layers. They found that plant diversity and regeneration were influenced not only by site conditions but also by the structure of the upper vegetation layers, with tree composition exerting cascading effects on shrub, herbaceous, and juvenile woody communities. Old-established black pine plantations were characterised by relatively high plant diversity but limited natural regeneration, while the course of their passive transition towards more natural forest communities depended on environmental conditions and interactions among vegetation layers. These findings demonstrate that the long-term structural development of black pine plantations cannot be interpreted solely from the characteristics of the dominant tree species but requires consideration of stand structure, regeneration processes, and site-specific environmental filters.

A synthesis of the available scientific literature indicates that regional patterns of introduction, physiological adaptation, climatic sensitivity, natural regeneration, and black pine growth have been investigated most extensively. Nevertheless, most studies are based

on a limited number of sample plots or focus on an individual region, taxon, or aspect of stand functioning. Studies simultaneously comparing the territorial distribution, forest site conditions, origin, species composition, age structure, site quality, growing stock, mean height and diameter, and proportion of merchantable timber in Crimean pine and Austrian pine stands throughout Ukraine remain insufficient. The analysis of a nationwide forest inventory dataset makes it possible to extend existing regional findings and develop an integrated understanding of the silvicultural and mensurational structure of black pine stands.

MATERIALS AND METHODS

The analysis was based on the 2011 database of the Ukrderzhlisproekt Production Association (2012), which currently represents the most recent statistically reliable source of nationwide forest inventory information (Information from the State Forest Cadastre, 2019). The use of more recent nationwide data is constrained by the absence of a complete repeated forest inventory covering the entire territory of Ukraine and by restricted or unavailable access to forests located in temporarily occupied territories. Consequently, the results should be interpreted as representing the pre-war baseline condition of *P. nigra* stands rather than their current state. Nevertheless, this temporal limitation also gives the dataset particular value as a reference point for assessing subsequent changes and for planning post-war forest restoration and management. Since 2011, the actual condition, area, and structure of these stands may have been altered by wildfires, military activities, forest damage associated with hostilities, and logging or other disturbances in territories beyond the effective control of Ukrainian forest authorities. These factors should therefore be taken into account when extrapolating the results to the present-day condition of black pine stands. The study included the entire population of forest-covered inventory compartments managed by all categories of forest users, including those located within the temporarily occupied territories of Ukraine. Database queries and data analysis were performed using Microsoft SQL Server. At the first stage, the total population of inventory compartments dominated by the two black pine taxa—Crimean pine and Austrian pine—was identified using the “Count” query mode. Data grouping was performed using the operators *s* to calculate the total area and *g* to group the target variable, including administrative region, forest site conditions, and age group. This procedure was used to identify the most widely represented forest site types, the analysis of which encompassed the largest number of observations, i.e. forest inventory compartments. In the same query mode, mean site-quality classes were calculated for individual edatopes using the *v* operator to obtain the area-weighted mean site-quality class and the *g* operator to group records by forest site conditions

(Ukrderzhlisproekt Production Association, 2006). At the second stage, the distribution of stand area by species composition and origin was determined for the most widespread forest site types using the “Count” mode. The data were grouped using the *s* operator to sum stand areas and the *g* operator to classify records by forest site conditions, stand origin, pure or mixed stand status, and associated tree species. Forest site types were classified according to the Alekseev-Pogrebnyak edaphic grid, which differentiates forest site conditions along gradients of soil fertility (trophic status) and moisture regime (Krasnov *et al.*, 2009). Area-weighted mean mensurational characteristics were also calculated for the subsequent analysis of their age-related dynamics. The *v* operator was used to calculate the mean diameter, mean height, growing stock per hectare, and proportion of merchantable trees, whereas the *g* operator was used to group the data by forest site conditions and age class. Relationships between stand age and the principal mensurational characteristics of Crimean pine stands – mean diameter, mean height, and growing stock per hectare – within the most widely represented forest site types were assessed using regression

analysis. Model coefficients were estimated by the least-squares method. Goodness of fit was evaluated using the coefficient of determination, R^2 , which indicates the proportion of variation in the mean mensurational characteristics explained by changes in age class. Statistical processing and graphical presentation of the results were performed in Microsoft Excel 2024.

RESULTS AND DISCUSSION

The total area of Crimean pine and Austrian pine stands in Ukraine is 134.1 thousand ha; however, the proportion of the two studied taxa is highly uneven. Crimean pine accounts for 99.8% of the total area, whereas Austrian pine represents only 0.2%. This marked disparity indicates that black pine stands in Ukraine are represented predominantly by Crimean pine, while the data on Austrian pine describe only local centres of its introduction. The regional distribution of the stands is also distinctly asymmetric (Table 1). Kherson Oblast and the Autonomous Republic of Crimea account for 56.4% of the total area of Crimean pine stands, while their combined share with Mykolaiv and Odesa oblasts reaches 73.7%.

Table 1. Regional distribution of black pine stand area by taxon

Oblast / Region	Austrian pine, ha	Crimean pine, ha	Total, ha
Autonomous Republic of Crimea	16.4	36,916.5	36,932.9
Vinnitsia Oblast	–	3,578.5	3,578.5
Volyn Oblast	–	44.0	44.0
Dnipropetrovsk Oblast	–	1,562.8	1,562.8
Donetsk Oblast	–	6,324.7	6,324.7
Zhytomyr Oblast	1.3	7.5	8.8
Zakarpattia Oblast	8.2	0.7	8.9
Zaporizhzhia Oblast	–	5,681.8	5,681.8
Ivano-Frankivsk Oblast	24.3	6.2	30.5
Kyiv Oblast	–	143.0	143.0
Kirovohrad Oblast	23.9	976.0	999.9
Luhansk Oblast	–	7,701.0	7,701.0
Lviv Oblast	74.2	1.2	75.4
City of Kyiv	–	0.6	0.6
City of Sevastopol	–	6,961.8	6,961.8
Mykolaiv Oblast	–	13,922.7	13,922.7
Odesa Oblast	–	9,184.0	9,184.0
Poltava Oblast	–	206.3	206.3
Rivne Oblast	1.0	1.1	2.1
Sumy Oblast	3.0	28.6	31.6
Ternopil Oblast	98.5	25.6	124.1
Kharkiv Oblast	2.6	551.5	554.1
Kherson Oblast	–	38,528.2	38,528.2
Khmelnitskyi Oblast	4.5	977.4	981.9
Cherkasy Oblast	–	150.7	150.7
Chernivtsi Oblast	27.9	273.5	301.4
Chernihiv Oblast	2.1	17.2	19.3
Total for Ukraine	287.9	133,773.1	134,061.0

Source: developed by the authors

The concentration of most Crimean pine stands in southern Ukraine reflects the long-standing use of this

taxon for the afforestation of sandy areas, dry slopes, eroded soils, and low-productivity lands. This is consistent

with the conclusions of S. Ayan *et al.* (2021), who identified *P. nigra* subsp. *pallasiana* as one of the principal tree taxa used for afforestation in semi-arid steppe regions and on anthropogenically transformed lands in Türkiye. At the same time, the authors emphasised that the success of such plantations depends on matching the provenance of planting material to local environmental conditions.

Austrian pine exhibits a different spatial pattern, with its largest stand areas occurring in Ternopil, Lviv, Chernivtsi, and Ivano-Frankivsk oblasts. The concentration of this taxon in western Ukraine is associated with the history of its introduction and the establishment of forest plantations during the periods when the region formed part of Austria-Hungary and Poland. A similar pattern was identified by T.V. Yuskevych *et al.* (2011), who summarised data on the distribution of

black pine and Crimean pine in the forests of western Ukraine. The researchers also noted that the actual area of black pine stands may have been underestimated because some stands were incorrectly classified as Scots pine in forest inventory records.

The distribution of stand area by forest site conditions confirms the pronounced ecological differentiation of the studied taxa (Table 2). In Crimean pine stands, 84.8% of the total area occurs under very dry and dry forest site conditions. The largest areas are concentrated in dry fairly fertile site types (C_1) and dry poor site types (A_1), which together account for more than two-thirds of the total area occupied by this taxon. This distribution characterises Crimean pine as a taxon that has been widely used under conditions of moisture deficiency and low to moderate soil fertility.

Table 2. Distribution of black pine stand area by forest site conditions

Forest-site types	Austrian pine, ha	Crimean pine, ha
A_0	-	2,340.9
A_1	18.0	30,959.3
A_2	9.6	6952.6
A_3	-	59.9
B_0	-	3,058.4
B_1	2.4	10,450.1
B_2	12.8	3,780.2
B_3	2.7	88.0
C_0	-	4,532.8
C_1	26.7	57,793.2
C_2	100.8	7,473.4
C_3	24.9	132.6
D_0	-	254.2
D_1	26.0	4,003.3
D_2	63.6	1,867.9
D_3	0.4	26.3
Total	287.9	133,773.1

Note: A_0 – very dry, poor; A_1 – dry, poor; A_2 – fresh, poor; A_3 – moist, poor; A_4 – wet, poor; A_5 – very wet, poor; B_0 – very dry, fairly poor; B_1 – dry, fairly poor; B_2 – fresh, fairly poor; B_3 – moist, fairly poor; B_4 – wet, fairly poor; B_5 – very wet, fairly poor; C_0 – very dry, fairly rich; C_1 – dry, fairly rich; C_2 – fresh, fairly rich; C_3 – moist, fairly rich; C_4 – wet, fairly rich; C_5 – very wet, fairly rich; D_0 – very dry, rich; D_1 – dry, rich; D_2 – fresh, rich; D_3 – moist, rich

Source: developed by the authors

The forest-site spectrum of Austrian pine is shifted towards fresh and moist conditions, which account for 74.6% of its total stand area. Its stands are most widely represented in fresh fairly fertile site types and fresh fertile site types. Thus, the differences between the two taxa concern not only the extent of their distribution but also their predominant ecological niches: Crimean pine is associated mainly with drier sites, whereas Austrian pine occurs more frequently on better-moistened and more fertile sites. However, a large stand area within a particular forest site type is not a direct indicator of its optimality for species growth. The predominance of Crimean pine in C_1 and A_1 largely reflects the scale of artificial afforestation undertaken

on dry lands. A study by S. Gülsoy & T. Çınar (2019) in Anatolian black pine stands showed that site quality is determined by the combined effects of elevation, slope position, aspect, soil characteristics, and water availability. As summer drought intensified, productivity declined even within the natural range of the subspecies *pallasiana*.

The physiological capacity of Crimean pine to respond to different levels of moisture availability was confirmed by V. Bessonova & S. Yakovlieva-Nosar (2022). In erosion-control plantations in Dnipropetrovsk Oblast, the authors identified seasonal changes in the concentrations of soluble sugars and starch in needles depending on forest site conditions. These

responses characterise mechanisms of adaptation to water deficit but do not imply uniformly high productivity throughout the entire xerophytic range of the species. The obtained results provide grounds for distinguishing between the ecological resilience and productive efficiency of the species. The ability of Crimean pine to form stands under very dry and dry conditions determines its protective and phytomeliorative importance. Nevertheless, its growth potential can be most fully realised on sites offering a more favourable combination of moisture availability and soil fertility.

The age structure of the stands reflects differences in the history of their establishment and subsequent management (Fig. 1). In Crimean pine, most of the stand area is occupied by second-age-class young stands and middle-aged stands (Fig. 1a). This structure resulted from the large-scale artificial afforestation of the southern and eastern regions of Ukraine during the second half of the twentieth century. The relatively small proportion of mature and overmature stands indicates the limited representation of older age cohorts in the present-day forest estate.

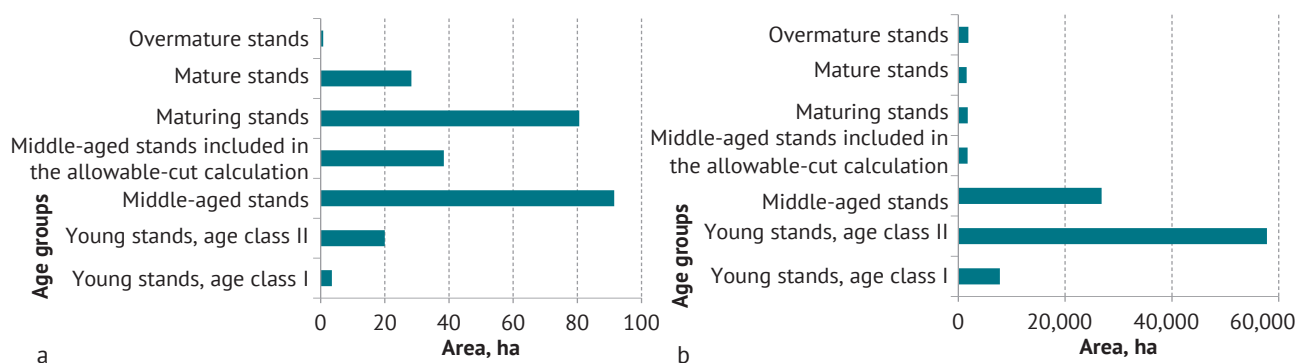


Figure 1. Age structure of black pine stands by taxon

Note: a – Austrian pine; b – Crimean pine

Source: developed by the authors

Austrian pine stands are dominated by middle-aged and maturing age groups (Fig. 1b). This pattern corresponds to the localised nature of the taxon's introduction and the survival of plantations established during different historical periods. Differences in age structure should be taken into account when comparing mean height, mean diameter, growing

stock, and timber merchantability, since a higher mean value for one taxon may result not only from its biological characteristics but also from the greater representation of a particular age group. The analysis of stand origin in the four principal dry forest site types revealed the predominance of artificially established stands (Table 3).

Table 3. Distribution of black pine stand area by taxon and origin in dry edatopes

Forest site type	Austrian pine, ha		Crimean pine, ha	
	Artificial	Natural	Artificial	Natural
A ₁	18.0	–	20,400.2	45.8
B ₁	2.4	–	7,458.9	1,027.7
C ₁	26.7	–	38,922.0	5,440.3
D ₁	23.6	1.1	3,138.8	16.0
Total	70.7	1.1	69,919.9	6,529.8

Source: developed by the authors

Artificially established stands account for 91.5% of the analysed Crimean pine area and 98.5% of the Austrian pine area. Natural Crimean pine stands are most widely represented in B₁ and C₁, where their share exceeds 12%. Under the edaphically contrasting conditions of A₁ and D₁, the proportion of naturally originated stands is minimal. This structure suggests that the natural regeneration of Crimean pine is most successful not under the poorest pine-site conditions, but in dry relatively poor and fairly fertile site types, where moisture deficiency is combined with a more adequate level of soil

nutrient availability. In their study of Crimean pine forests, Y.V. Pluhatar *et al.* (2010) also identified substantial differences between natural and artificially established stands in species composition, age structure, relative density, site-quality class, growing stock, and the proportion of merchantable timber. The authors emphasised the need for a differentiated assessment of the realised and potential productivity of stands of different origins.

Pure stands predominate within A₁, B₁, C₁, and D₁, accounting for approximately 74% of the area for both taxa (Table 4). However, the internal structure of this

proportion differs between them. Crimean pine has the highest proportion of pure stands in dry poor site types, whereas the contribution of mixed stands increases

with increasing site trophicity. This pattern indicates a broader range of associated tree species under more fertile site conditions.

Table 4. Distribution of black pine stand area by taxon and species composition in dry edatopes

Forest site type	Austrian pine, ha		Crimean pine, ha	
	Pure	Mixed	Pure	Mixed
A ₁	5.5	12.5	17,525.4	2,742.9
B ₁	–	2.4	6,035.3	2,451.0
C ₁	26.2	0.5	30,571.2	13,560.6
D ₁	21.6	3.1	2,299.7	854.7
Total	53.3	18.5	56,431.6	19,609.2

Source: developed by the authors

For Austrian pine, the ratio between pure and mixed stands varies considerably among forest site types. In A₁ and B₁, the taxon occurs predominantly as a component of mixed stands, whereas pure plantations prevail in C₁ and D₁. However, the limited total area occupied by Austrian pine restricts the extent to which this pattern can be generalised across all regions of Ukraine. The predominance of even-aged, artificially established, and pure stands distinguishes most Ukrainian plantations from natural old-growth black pine forests. T.A. Nagel & M. Cerioni (2023) found that natural black pine stands in South-Eastern Europe generally exhibit uneven-aged structures and include broadleaved and shade-tolerant associated species. The contribution of such species increases on more productive sites, whereas black pine maintains long-term dominance primarily on steep, rocky slopes. The prevalence of pure plantations has practical implications for their long-term stability. G.M. Tudoran *et al.* (2023), studying black pine outside its natural range in the Romanian Carpathians, documented a deterioration in the condition of dense monodominant stands caused by defoliation, insufficient spring–summer precipitation, and competition for soil moisture. The authors considered the development of stable mixed stands involving locally adapted

tree species more promising than the maintenance of extensive monocultures.

The composition of associated tree species changes consistently with increasing trophicity of forest site conditions (Table 5). In dry poor pine-site types, Scots pine predominates among the associated species in Crimean pine stands, while Dnieper birch also makes a substantial contribution. These species are adapted to the ecological constraints of sandy soils and limited moisture availability. The contribution of other associated species in A₁ is comparatively low. In dry relatively poor site types, species diversity increases through the inclusion of sessile oak, downy oak, and Stankewicz's pine. In dry fairly fertile site types, the principal associated species are downy oak and sessile oak, with black locust, Scots pine, and wild cherry also present. This composition reflects the greater nutrient availability of the soils and the potential for the formation of stands with more complex species structures. In dry fertile site types, the areas occupied by individual associated species are smaller, although their species composition is the most diverse. Alongside Scots pine and black locust, pedunculate oak, field elm, and Norway maple also occur. The increasing contribution of broadleaved species under more fertile conditions is consistent with the natural successional trajectory of these sites.

Table 5. Distribution of mixed Crimean pine stand area in dry edatopes by subdominant tree specie

Forest site type	Subdominant tree species	Area, ha
A ₁	Black locust (<i>Robinia pseudoacacia</i> L.)	698.2
	Dnieper birch (<i>Betula borysthena</i> Klokov)	1,989.2
	Silver birch (<i>Betula pendula</i> Roth)	89.1
	Scots pine (<i>Pinus sylvestris</i> L.)	5,919.8
	Black poplar (<i>Populus nigra</i> L.)	815.0
B ₁	Black locust (<i>Robinia pseudoacacia</i> L.)	584.8
	Downy oak (<i>Quercus pubescens</i> Willd.)	311.9
	Sessile oak (<i>Quercus petraea</i> (Matt.) Liebl.)	877.4
	Scots pine (<i>Pinus sylvestris</i> L.)	2,182.5
	Stankewicz's pine (<i>Pinus stankewiczii</i> (Sukaczew) Fomin)	279.1
C ₁	Black locust (<i>Robinia pseudoacacia</i> L.)	1,918.6
	Downy oak (<i>Quercus pubescens</i> Willd.)	5,248.5
	Sessile oak (<i>Quercus petraea</i> (Matt.) Liebl.)	5,111.2

Table 5. Continued

Forest site type	Subdominant tree species	Area, ha
C ₁	Scots pine (<i>Pinus sylvestris</i> L.)	1,626.6
	Wild cherry (<i>Prunus avium</i> (L.) L.)	1,080.9
	Black locust (<i>Robinia pseudoacacia</i> L.)	192.7
D ₁	Field elm (<i>Ulmus minor</i> Mill.)	132.3
	Pedunculate oak (<i>Quercus robur</i> L.)	201.9
	Norway maple (<i>Acer platanoides</i> L.)	164.6
	Scots pine (<i>Pinus sylvestris</i> L.)	158.5

Source: developed by the authors

In Austrian pine stands within A₁ and B₁ forest site types, Scots pine is the predominant associated tree species (Table 6). In C₁ and D₁, the species spectrum expands to include Norway maple, European ash, honey locust, northern white cedar, and American sycamore. However, owing to the limited area occupied by Austrian pine, these species combinations are predominantly local and partly reflect the specific characteristics of individual forest plantation sites. The observed increase in the contribution of broadleaved species under more fertile site conditions is consistent with the findings of T.A. Nagel & M. Cerioni (2023), who documented the development of shade-tolerant and late-successional species beneath the canopy of black pine on productive sites. The principal difference is that the natural old-growth forests examined by these authors had a more complex uneven-aged structure, whereas artificially established even-aged stands predominate in

Ukraine. A common pattern is the increasing role of broadleaved species with rising site productivity. From a silvicultural perspective, the admixture of oak species, maple, elm, ash, and other locally adapted tree species may promote the development of a more complex vertical stand structure, enhance biological stability, and improve the differentiation of soil resource use. At the same time, the proportion of associated species should be regulated according to the intended function of the stand, because on productive sites they may gradually displace the light-demanding black pine. The distribution of mean site-quality classes confirms that the productivity of both taxa depends on site trophicity and moisture conditions. Austrian pine achieves its highest productivity in fresh fertile, fresh fairly fertile, and moist fairly fertile site types. In dry poor, dry fairly fertile, and certain moist site types, its stands are predominantly assigned to site-quality classes III-IV (Fig. 2).

Table 6. Distribution of mixed Austrian pine stand area in dry edatopes by subdominant tree species

Forest site type	Subdominant tree species	Area, ha
A ₁	Scots pine (<i>Pinus sylvestris</i> L.)	18.0
B ₁	Scots pine (<i>Pinus sylvestris</i> L.)	2.4
	Black locust (<i>Robinia pseudoacacia</i> L.)	2.0
	Norway maple (<i>Acer platanoides</i> L.)	1.2
	Scots pine (<i>Pinus sylvestris</i> L.)	0.6
C ₁	Northern white cedar (<i>Thuja occidentalis</i> L.)	3.2
	European ash (<i>Fraxinus excelsior</i> L.)	0.1
	Honey locust (<i>Gleditsia triacanthos</i> L.)	3.1
	Norway maple (<i>Acer platanoides</i> L.)	2.3
	American sycamore (<i>Platanus occidentalis</i> L.)	0.1
D ₁	Scots pine (<i>Pinus sylvestris</i> L.)	5.2
	European ash (<i>Fraxinus excelsior</i> L.)	3.5

Source: developed by the authors

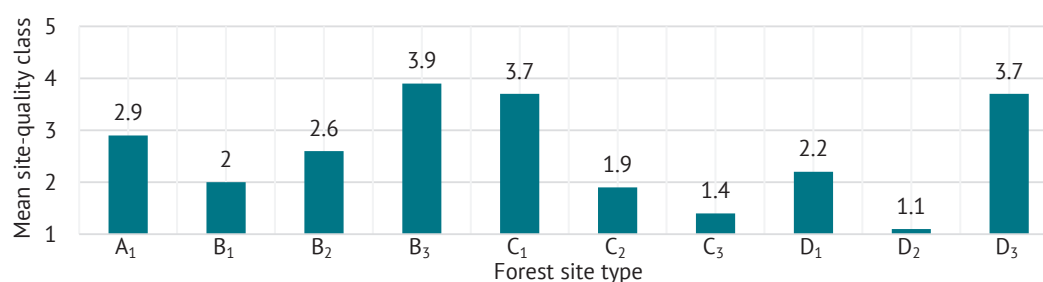


Figure 2. Mean productivity of Austrian pine stands in relation to forest site conditions

Source: developed by the authors

Crimean pine occurs across a considerably broader range of forest site conditions; however, its high-site-quality stands are likewise concentrated mainly in fresh and moist fertile site types and in moist fairly fertile site types. Productivity declines in very dry poor,

relatively poor, fairly fertile, and fertile site types. The area-dominant C_1 site type does not provide the highest mean site quality, confirming the distinction between the extent of species distribution and the optimality of site conditions for realising its growth potential (Fig. 3).

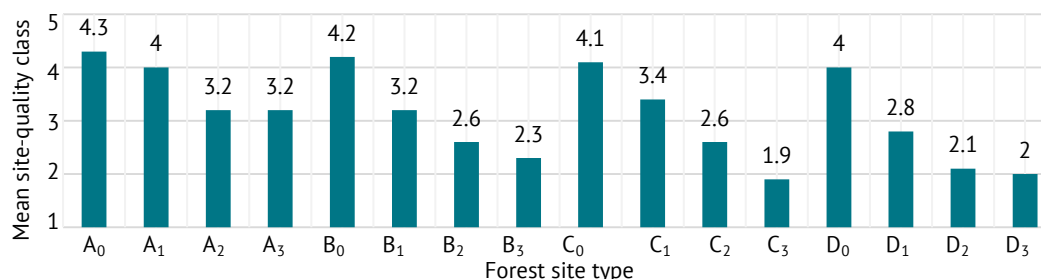


Figure 3. Mean productivity of Crimean pine stands in relation to forest site conditions

Source: developed by the authors

Similar patterns were identified by L.I. Tereshchenko *et al.* (2019) in their survey of Austrian pine stands in Kirovohrad, Kharkiv, and Sumy oblasts. The species was generally inferior to Scots pine in height, but in certain stands it exceeded Scots pine in diameter and was characterised by better stem quality and vitality. The authors confirmed the potential of Austrian pine for protective afforestation on eroded lands, while also recording substantial variability in performance among individual study sites. Thus, the site-quality structure does not confirm the universal superiority of either taxon. Crimean pine is characterised by a broader ecological range and an ability to persist under arid conditions, whereas Austrian pine attains higher productivity mainly in fresh and

relatively fertile site types. For forest management planning, this indicates the need to assess the protective effectiveness and timber productivity of the stands separately.

The dynamics of mean growing stock in Crimean pine stands are generally characterised by an increase from young stands to middle-aged, maturing, and mature stands (Fig. 4). At the same time, the rate of growing-stock accumulation varies substantially depending on forest site conditions. In dry poor site types, growing stock remains lower than in dry fairly fertile and fertile site types, particularly in older age classes. This confirms that limited soil nutrient availability in A_1 constrains the realisation of productive potential even over a prolonged growth period.

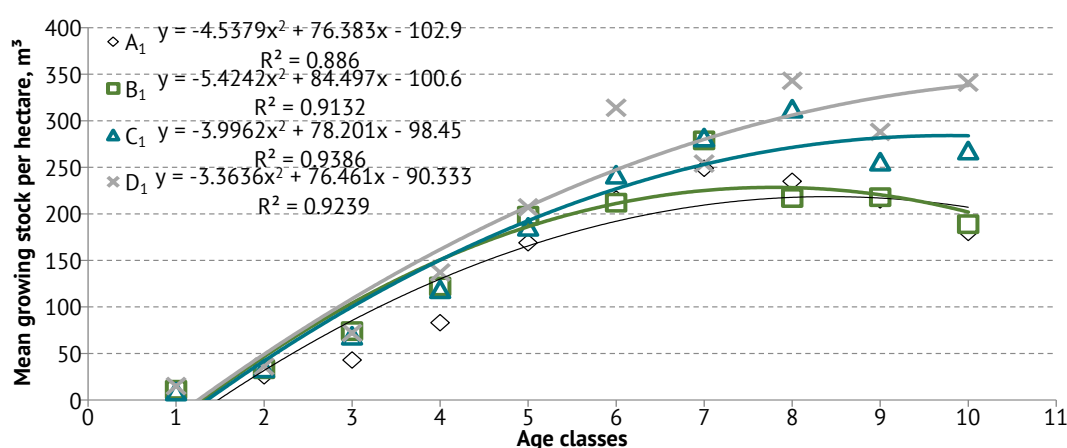


Figure 4. Dynamics of mean growing stock in Crimean pine stands under dry edaphic conditions

Source: developed by the authors

The highest mean growing stocks of Crimean pine were recorded in D_1 and C_1 . In the older age classes, individual values exceed $300 \text{ m}^3 \cdot \text{ha}^{-1}$. Growing stock fluctuates among the older age classes and does not form a completely monotonic sequence. These variations

cannot be attributed solely to the biological ageing of the stands. Growing stock is influenced by relative density, species composition, the intensity of thinning and sanitary interventions, natural mortality, management history, and the number of forest inventory

compartments represented within each age group. Because the data comprise aggregated indicators from different stands, the resulting series characterises the age gradient of the stand population rather than the continuous developmental trajectory of a single stand.

D. Candel-Pérez *et al.* (2022) found that the growth of *P. nigra* along a latitudinal gradient depends on the combined effects of climate, age, tree diameter, and stand structure. The positive effect of spring precipitation varied according to stand density and tree-size differentiation; therefore, climatic responses cannot be

interpreted independently of mensurational structure. A comparison of northern and southern black pine populations conducted by Ş.C. İzmir *et al.* (2024) also revealed spatial heterogeneity in climate-driven growth. Southern populations of *P. nigra* subspecies *pallasiana* exhibited certain indications of greater drought resilience; however, their growth remained dependent on the seasonal distribution of precipitation and the duration of water deficit. The graphical representation of age-related changes in mean height and diameter confirms the patterns identified for growing stock (Fig. 5, 6).

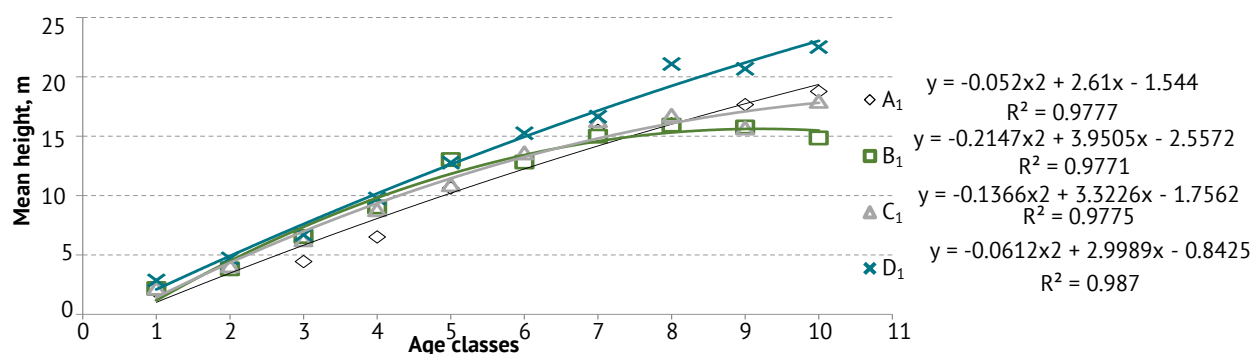


Figure 5. Dynamics of mean height in Crimean pine stands under dry edaphic conditions

Source: developed by the authors



Figure 6. Dynamics of mean diameter in Crimean pine stands under dry edaphic conditions

Source: developed by the authors

In poor site types, the dynamics of both characteristics proceed more slowly, whereas larger mean tree dimensions are attained in fairly fertile and fertile site types. In the older age groups, height increment gradually slows, while diameter continues to increase, although the mean values exhibit some fluctuations. For Crimean pine, the greatest heights and diameters are characteristic of D₁ and C₁. Under D₁ conditions, mean height reaches 23 m in age class X, while mean diameters in C₁ and D₁ exceed 32 cm. Thus, soil fertility substantially influences the dimensional structure of stands, whereas the drought tolerance of the species primarily ensures stand persistence under harsh conditions but does not eliminate constraints on growth. The proportion of merchant-

able timber generally increases with age, although the pattern of this change depends to some extent on forest site conditions (Table 7). In young stands, the yield of merchantable timber is low because small-diameter stems predominate. In middle-aged and maturing stands, increasing mean diameter and the natural pruning of lower branches contribute to improved merchantability. For Crimean pine, the most consistent increase in the proportion of merchantable timber is observed in C₁ and D₁. In older age classes, values exceeding 60-70% are attained in these site types. In dry poor and relatively poor site types, the pattern is less stable, which may be associated with greater branchiness, uneven relative density, and an unfavourable soil water regime.

Table 7. Dynamics of the mean proportion of merchantable timber under dry edaphic conditions, %

Age class	Forest site type			
	A ₁	B ₁	C ₁	D ₁
1	–	–	–	–
2	27	27	7	9
3	24	24	27	25
4	34	36	37	37
5	44	47	48	43
6	55	52	56	53
7	56	46	69	58
8	62	52	72	63
9	62	53	67	56
10	–	43	71	62

Source: developed by the authors

A. Zeidler *et al.* (2024) investigated the physical and mechanical properties of wood from introduced pine species growing on reclaimed lands in Central Europe. Black pine was characterised by high wood density and potential suitability for producing higher-value products. At the same time, the authors emphasised that wood quality depends on age, site conditions, and climate, and that the species should be introduced as a component of diverse stands rather than extensive pure plantations.

The results of the present study complement this work by characterising the merchantable structure of the growing stock. The proportion of merchantable timber reflects the silvicultural yield of timber assortments, whereas wood density and mechanical strength indicate its technological quality. An integrated assessment of these characteristics is necessary to determine the actual economic value of Crimean pine.

CONCLUSIONS

The two black pine taxa in Ukraine were found to exhibit clearly differentiated spatial and silvicultural structures, reflecting two distinct models of land use rather than two variants of the same productivity pattern. Of the 134.1 thousand ha of *Pinus nigra* stands, 99.8% were established to be represented by Crimean pine, with 73.7% of its area concentrated in Crimea and Kherson, Mykolaiv, and Odesa oblasts, whereas Austrian pine was shown to occur only locally, mainly in western Ukraine. Crimean pine was found to be strongly associated with xeric sites, with 84.8% of its area occurring under very dry and dry forest site conditions, while Austrian pine was concentrated mainly in fresh and moist, more fertile sites. This divergence was found to be consistent with the age structure of the two taxa – Crimean pine is dominated by second-age-class young and middle-aged stands, whereas Austrian pine is represented mainly by middle-aged and maturing stands – and with their origin and structure: in the principal dry site types, artificially established stands were shown to account for 91.5% of Crimean pine and 98.5% of Austrian pine stands, and pure stands were found to occupy approximately three-quarters of the area of both taxa.

It was established, however, that stand productivity is governed more strongly by site quality than by the extent of taxon distribution. The highest site-quality classes and the greatest mean tree dimensions and growing stocks were found to be associated with fairly fertile and fertile site types, whereas dry poor sites were shown to constrain the realisation of growth potential. For Crimean pine, the most favourable growth patterns were recorded in C₁ and D₁: in older age classes, mean growing stock was found to exceed 300 m³·ha⁻¹, mean height reached 23 m in D₁, mean diameter exceeded 32 cm in C₁ and D₁, and the proportion of merchantable timber generally reached more than 60-70%. Austrian pine likewise showed its highest productivity on fresh and relatively fertile sites. The same fertility-driven pattern was revealed to underlie the composition of associated tree species, which becomes progressively more diverse with increasing site trophicity: Scots pine was identified as the principal associated species on the poorest dry sites, whereas the contribution of oaks and other broadleaved species was found to increase in fairly fertile and fertile site types – in Crimean pine stands expressed particularly through the increasing importance of sessile and downy oak, followed by maple, elm, and other broadleaved species on richer sites. Austrian pine was shown to exhibit a similar tendency, although its associated-species combinations are more local because of the limited area occupied by this taxon. Taken together, these findings indicate that drought tolerance primarily enables stand persistence under adverse conditions, whereas high timber productivity – and the formation of more compositionally complex mixed stands – requires more favourable soil fertility and moisture availability.

These findings suggest that Crimean and Austrian pine should not be evaluated by a single productivity criterion: their management should account for differences in ecological niche, stand structure, and functional role, with greater emphasis on protective functions under poor xeric conditions and on combining protective and timber-production objectives on more fertile sites. It should be noted that the conclusions regarding

Austrian pine, whose area amounts to only 0.2% of the total, were derived from a substantially smaller dataset and should therefore be interpreted with corresponding caution. Further research should focus on developing regional models of stand growth and productivity, assessing the resistance of pure and mixed stands to drought, fire, pests, and diseases, and refining forest inventory data through field surveys and remote-sensing methods.

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REFERENCES

- [1] Adamenko, S., Shlapak, V., Kozachenko, I., & Parubok, M. (2018). Peculiarities of seasonal growth of *Pinus nigra* J.F. Arnold under the conditions of introduction in the Right-Bank Forest-Steppe of Ukraine. *Journal of Forest Science*, 64(8), 340-344. doi: [10.17221/63/2018-JFS](https://doi.org/10.17221/63/2018-JFS).
- [2] Ayan, S., Yücedağ, C., & Simovski, B. (2021). A major tool for afforestation of semi-arid and anthropogenic steppe areas in Turkey: *Pinus nigra* J.F. Arnold subsp. *pallasiana* (Lamb.) Holmboe. *Journal of Forest Science*, 67(10), 449-463. doi: [10.17221/74/2021-JFS](https://doi.org/10.17221/74/2021-JFS).
- [3] Bessonova, V., & Yakovlieva-Nosar, S. (2022). Dynamics of non-structural carbohydrates in *Pinus pallasiana* D. Don needles under different forest growth conditions of ravine anti-erosion plantations. *Folia Forestalia Polonica*, 64(1), 38-48. doi: [10.2478/ffp-2022-0004](https://doi.org/10.2478/ffp-2022-0004).
- [4] Bessonova, V., & Yusypiva, T. (2021). Physiological parameters of the state of *Pinus pallasiana* D. Don in different forest-growth conditions in Ravine Viyskovyi. *Ekológia (Bratislava)*, 40(2), 137-144. doi: [10.2478/eko-2021-0016](https://doi.org/10.2478/eko-2021-0016).
- [5] Bricca, A., Zerbe, S., Fellin, H., Alessi, N., Maccherini, S., & Bonari, G. (2025). Passive rewilding of old-established plantations into native forests. *Journal of Vegetation Science*, 36(6), article number e70085. doi: [10.1111/jvs.70085](https://doi.org/10.1111/jvs.70085).
- [6] Bulut, S., Günlü, A., & Şatır, O. (2023). Estimating net primary productivity of semi-arid Crimean pine stands using biogeochemical modelling, remote sensing, and machine learning. *Ecological Informatics*, 76, article number 102137. doi: [10.1016/j.ecoinf.2023.102137](https://doi.org/10.1016/j.ecoinf.2023.102137).
- [7] Candel-Pérez, D., Lucas-Borja, M.E., García-Cervigón, A.I., Tíscar, P.A., Andivia, E., Bose, A.K., Sánchez-Salguero, R., Camarero, J.J., & Linares, J.C. (2022). Forest structure drives the expected growth of *Pinus nigra* along its latitudinal gradient under warming climate. *Forest Ecology and Management*, 505, article number 119818. doi: [10.1016/j.foreco.2021.119818](https://doi.org/10.1016/j.foreco.2021.119818).
- [8] Collado, E., De Cáceres, M., de-Dios-García, J., Rubio-Gutiérrez, R., Rozenbergar, D., & Piqué, M. (2026). Forest management and drought interaction on tree growth in black pine forests across the Mediterranean Basin. *Dendrochronologia*, 96, article number 126497. doi: [10.1016/j.dendro.2026.126497](https://doi.org/10.1016/j.dendro.2026.126497).
- [9] Devi, N.M., Kukarskih, V.V., & Bubnov, M.O. (2023). Elevational changes in climate response of *Pinus nigra pallasiana* tree-rings on the Crimean Peninsula. *Dendrochronologia*, 79, article number 126092. doi: [10.1016/j.dendro.2023.126092](https://doi.org/10.1016/j.dendro.2023.126092).
- [10] Dias, A., Carvalho, A., Silva, M.E., Lima-Brito, J., Gaspar, M.J., Alves, A., Rodrigues, J. C., Pereira, F., Morais, J., & Lousada, J.L. (2020). Physical, chemical and mechanical wood properties of *Pinus nigra* growing in Portugal. *Annals of Forest Science*, 77, article number 72. doi: [10.1007/s13595-020-00984-8](https://doi.org/10.1007/s13595-020-00984-8).
- [11] Dias, A., Louzada, J., & Fonseca, T. (2022). Growth pattern of European black pine outside its current natural range: A case study in Portugal. *Land*, 11(6), article number 794. doi: [10.3390/land11060794](https://doi.org/10.3390/land11060794).
- [12] Giovannelli, G., Tallieu, C., Davi, H., Guibal, F., Scotti-Saintagne, C., & Fady, B. (2026). Adaptive effects of geographic origin on ring-width and radial growth-climate relationships in *Pinus nigra* Arnold, the European black pine. *Annals of Forest Science*, 83, article number 31. doi: [10.1186/s13595-026-01347-5](https://doi.org/10.1186/s13595-026-01347-5).
- [13] Gülsoy, S., & Çinar, T. (2019). The relationships between environmental factors and site index of Anatolian black pine (*Pinus nigra* Arn. subsp. *pallasiana* (Lamb.) Holmboe) stands in Demirci (Manisa) district, Turkey. *Applied Ecology and Environmental Research*, 17(1), 1235-1246. doi: [10.15666/aeer/1701_12351246](https://doi.org/10.15666/aeer/1701_12351246).
- [14] Information from the State Forest Cadastre. (2019). *State forest cadastre as of 1 January 2011: General data on the forest fund of Ukraine by administrative-territorial units*. Retrieved from <https://surl.li/yewvkc>.
- [15] Ivetić, V., Tsakaldimi, M., Ganatsas, P., Kerkez Janković, I., & Devetaković, J. (2021). Freezing and heating tolerance of *Pinus nigra* seedlings from three south to north Balkan provenances. *Sustainability*, 13(16), article number 9290. doi: [10.3390/su13169290](https://doi.org/10.3390/su13169290).
- [16] Izmir, Ş.C., Jevšenak, J., Krajnc, L., Hafner, P., & Köse, N. (2024). Distinct spatial patterns in climate-growth relationships, vegetation and resilience indices of black pine (*Pinus nigra* J. F. Arnold) from its northern and southern distribution range. *Dendrochronologia*, 88, article number 126236. doi: [10.1016/j.dendro.2024.126236](https://doi.org/10.1016/j.dendro.2024.126236).

- [17] Koval, I. (2013). [Climatic signal in earlywood, latewood and total ring width of Crimean pine \(*Pinus nigra* subsp. *pallasiana*\) from Crimean Mountains, Ukraine](#). *Baltic Forestry*, 19(2), 245-251.
- [18] Krasnov, V.P., Orlov, O.O., & Vedmid, M.M. (2009). [Atlas of indicator plants and forest site types of Ukrainian Polissia](#). Zvyagel: NOVOhrad.
- [19] Lucas-Borja, M.E., Jing, X., Candel-Perez, D., Parhizkar, M., Rocha, F., Heydari, M., Muñoz-Rojas, M., & Zema, D.A. (2022). Afforestation with *Pinus nigra* Arn ssp. *salzmannii* along an elevation gradient: Controlling factors and implications for climate change adaptation. *Trees*, 36, 93-102. [doi: 10.1007/s00468-021-02184-x](#).
- [20] Martín-Alcón, S., & Coll, L. (2016). Unraveling the relative importance of factors driving post-fire regeneration trajectories in non-serotinous *Pinus nigra* forests. *Forest Ecology and Management*, 361, 13-22. [doi: 10.1016/j.foreco.2015.11.006](#).
- [21] Nagel, T.A., & Cerioni, M. (2023). Structure and dynamics of old-growth *Pinus nigra* stands in Southeast Europe. *European Journal of Forest Research*, 142, 537-545. [doi: 10.1007/s10342-023-01540-5](#).
- [22] Olsson, S., Grivet, D., Cattonaro, F., Vendramin, V., Giovannelli, G., Scotti-Saintagne, C., Vendramin, G.G., & Fady, B. (2020). Evolutionary relevance of lineages in the European black pine (*Pinus nigra*) in the transcriptomic era. *Tree Genetics & Genomes*, 16, article number 30. [doi: 10.1007/s11295-020-1424-8](#).
- [23] Pluhatar, Y.V., Shvets, Y.P., Trofymenko, I.O., & Diahovets, O.O. (2010). [Crimean pine: Range, forest types, and productivity](#). *Scientific Bulletin of UNFU*, 20(6), 39-50.
- [24] Raptis, D.I., Kazana, V., Kazaklis, A., & Stamatiou, C. (2021). Mixed-effects height-diameter models for black pine (*Pinus nigra* Arn.) forest management. *Trees*, 35, 1167-1183. [doi: 10.1007/s00468-021-02106-x](#).
- [25] Seki, M., & Sakici, O.E. (2022). Ecoregional variation of Crimean pine (*Pinus nigra* subspecies *pallasiana* [Lamb.] Holmboe) stand growth. *Forest Science*, 68(5-6), 452-463. [doi: 10.1093/forsci/xfac030](#).
- [26] Skrobach, T.B. (2006). [Black pine \(*Pinus nigra* Arn.\) in forest stands of the Western region of Ukraine](#). (PhD dissertation, Ukrainian National Forestry University, Lviv, Ukraine).
- [27] Soroka, M., & Yuskevych, T. (2011). Phytosociological aspects of the naturalisation of black pine (*Pinus nigra* Arn.). [Proceedings of the Forestry Academy of Sciences of Ukraine](#), 9, 58-63.
- [28] Tereshchenko, L.I., Los, S.A., Petrenko, M.I., & Samoday, V.P. (2019). Productivity and condition of Austrian pine (*Pinus nigra* var. *austriaca* Asch. et Gr.) in central and north-eastern parts of Ukraine. *Forestry and Forest Melioration*, 135, 68-78. [doi: 10.33220/1026-3365.135.2019.68](#).
- [29] Tudoran, G.-M., Cicșa, A., Dobre, A.-C., Cicșa, M., Pascu, I.-S., & Leca, Ș. (2023). Health and growth of black pine outside its natural distribution range in the Romanian Carpathians. *Forests*, 14(5), article number 884. [doi: 10.3390/f14050884](#).
- [30] Ukrderzhlisproekt Production Association. (2006). *Instruction for forest management planning of the forest fund of Ukraine. Part 1. Field works*. Irpin: Ukrderzhlisproekt.
- [31] Ukrderzhlisproekt Production Association. (2012). *Directory on the forest fund of Ukraine based on the state forest inventory as of January 1, 2011*. Irpin: Ukrderzhlisproekt.
- [32] Vacek, Z., Cukor, J., Vacek, S., Gallo, J., Bažant, V., & Zeidler, A. (2023). Role of black pine (*Pinus nigra* J.F. Arnold) in European forests modified by climate change. *European Journal of Forest Research*, 142, 1239-1258. [doi: 10.1007/s10342-023-01605-5](#).
- [33] Versace, S., et al. (2022). New evidence for population-specific responses to drought events from tree ring chronologies of *Pinus nigra* ssp. *laricio* across the entire distribution range. *Agricultural and Forest Meteorology*, 323, article number 109076. [doi: 10.1016/j.agrformet.2022.109076](#).
- [34] Yuskevych, T.V., Skrobach, T.B., & Smikh, V.M. (2011). [Distribution of *Pinus nigra* Arn. and *Pinus pallasiana* D. Don in forest stands of the Western region of Ukraine](#). *Scientific Bulletin of UNFU*, 21(17), 74-76.
- [35] Zeidler, A., Borůvka, V., Tomczak, K., Vacek, Z., Cukor, J., Vacek, S., & Tomczak, A. (2024). The potential of non-native pines for timber production – a case study from afforested post-mining sites. *Forests*, 15(8), article number 1388. [doi: 10.3390/f15081388](#).

Лісівничо-таксаційна структура насаджень *Pinus nigra* в Україні за даними державного обліку лісів станом на 2011 рік

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Анотація. Метою дослідження було встановити територіальні, лісотипологічні та лісівничо-таксаційні закономірності формування насаджень сосни кримської та сосни австрійської в Україні. Аналіз виконано за повидільною базою даних державного обліку лісів станом на 2011 рік із застосуванням структурованих запитів у системі керування базами даних Microsoft SQL Server, розрахунку середньозважених показників і регресійного аналізу вікової динаміки таксаційних характеристик. Загальна площа досліджуваних насаджень становила 134,1 тисячі гектарів, з яких 99,8 % припадало на *P. nigra* subsp. *pallasiana* та 0,2 % – на *P. nigra* subsp. *austriaca*. Основний масив сосни кримської зосереджений у південних і східних регіонах, тоді як насадження сосни австрійської мають локальне поширення переважно у західній частині країни. У дуже сухих і сухих типах лісорослинних умов зосереджено 84,8 % площі сосни кримської, насамперед у сухих сугрудах і сухих борах. Сосна австрійська частіше траплялася у свіжих сугрудах і грудах. У структурі обох таксонів переважали штучні та чисті деревостани; у сухих умовах частка штучних насаджень становила 91,5 % для сосни кримської та 98,5 % для сосни австрійської. Найвищі класи бонітету, середні висоти, діаметри, запаси та частка ділової деревини формувалися переважно у сугрудах і грудах, тоді як у сухих борах лісорослинний потенціал обмежувався дефіцитом вологи та низькою родючістю ґрунтів. Видовий склад супутніх порід ускладнювався зі зростанням трофності місцезростань: у борах домінувала *P. sylvestris*, а в сугрудах і грудах збільшувалася участь твердолистяних порід.

Ключові слова: сосна кримська; сосна австрійська; типи лісорослинних умов; стовбуровий запас; продуктивність; ділова деревина; динаміка росту
