PECULIARITIES OF GROWING *PINUS SYLVESTRIS L.* IN THE NORTHEASTERN FOREST-STEPPE OF UKRAINE

Sergii Butenko
Doctor Phd, Lecturer of the Department, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0002-9925-3029

Scots pine (*Pinus sylvestris* L.) is one of the most important forest-forming species in Ukraine, occupying more than 35% of the country's coniferous forest area. In the conditions of the Northeastern Forest-Steppe, this species plays a key role in the formation of highly productive forest stands, the performance of ecological functions, and the provision of valuable timber for forestry.

However, climate change, increasing anthropogenic pressure, and the need to intensify reforestation require improvements in pine cultivation technologies. The relevance of the study is обусловлена the need to increase the efficiency of forest cultivation activities, particularly through the introduction of modern technologies for growing planting material with a closed root system, optimization of planting schemes, and improvement of care for young stands.

The practical significance of the work lies in the development of scientifically substantiated recommendations for growing *Pinus sylvestris L.* under the conditions of the Sumy forestry enterprise, which will contribute to improving the quality and productivity of created forest plantations.

The aim of the study is a comprehensive investigation of the peculiarities of growing *Pinus sylvestris* L. in the conditions of the Northeastern Forest-Steppe of Ukraine and the development of recommendations for optimizing the technology of creating pine plantations.

Research objectives: To analyze the biological characteristics and experience of growing *Pinus sylvestris* L. under different forest site conditions. To characterize the natural and climatic conditions as well as forest inventory indicators of the forest fund of the Sumy forestry enterprise. To study the technology of creating pine plantations in the enterprise and determine the survival rate indicators of different types of planting material. To investigate the growth dynamics of pine plantations aged 5, 10, and 15 years in fresh subor conditions. To assess the sanitary condition and productivity of pine stands of different ages. To develop scientifically grounded recommendations for optimizing the cultivation technology of *Pinus sylvestris* L. in the conditions of the Sumy forestry enterprise.

Object of the study – the process of growth and formation of artificial pine stands in the conditions of the Northeastern Forest-Steppe of Ukraine.

Subject of the study – peculiarities of cultivating *Pinus sylvestris* L. plantations created using planting material with different types of root systems under the conditions of the Sumy forestry of the State Enterprise "Forests of Ukraine".

Research methods. The study employed a комплекс of general scientific and specialized methods: analytical – for studying literature sources and regulatory frameworks; field – for collecting primary data on sample plots; forest inventory – for determining forest mensuration indicators according to the methodology of DSTU 4633:2006; statistical – for processing experimental data and assessing the reliability of results using Student’s t-test; comparative – for comparing indicators of plantations of different ages and types of planting material; graphical – for visualizing the obtained results.

Scientific novelty of the obtained results. For the first time under the conditions of the Sumy forestry enterprise, a comprehensive comparative study of survival rate, growth, and condition of pine plantations created with planting material having open and closed root systems was carried out. The relationship between the type of seedling root system and survival indicators in different forest site conditions was proven. Patterns of growth dynamics and changes in the preservation of pine stands aged from 5 to 15 years were established.

Scientific and methodological approaches to selecting optimal planting schemes depending on forest site conditions and planting material quality were improved.

Practical significance of the obtained results. The developed recommendations for optimizing the cultivation technology of *Pinus sylvestris* L. can be implemented in the production activities of the Sumy forestry enterprise and other forestry enterprises of the Northeastern Forest-Steppe of Ukraine. The research results make it possible to increase plantation survival rates to 93–95%, reduce costs for replanting and agrotechnical care, and ensure the formation of highly productive stands of I–II site quality classes. The economic effect of using containerized planting material is about 2850 UAH/ha due to reduced replanting needs.

Botanical Characteristics and Taxonomic Position of *Pinus Sylvestris* L.

Scots pine belongs to the pine family (Pinaceae) and the genus *Pinus*, which includes more than one hundred species distributed mainly in the temperate zone of the Northern Hemisphere. The taxonomic position of the species reflects its evolutionary relationships with other representatives of gymnosperms, which allows for a better understanding of the biological characteristics and adaptive mechanisms of this tree species [25].

The morphological features of Scots pine are characterized by significant variability depending on growing conditions. Trees can reach heights of 20–40 meters; however, under unfavorable conditions, particularly on poor soils or in mountainous areas, their size is considerably smaller. The crown in young trees has a conical shape, but with age it acquires a characteristic umbrella-like or rounded form. It should be noted that these changes are associated not only with age-related characteristics but also with lighting conditions and stand density.

The needles are arranged in pairs on shortened shoots, with lengths ranging from 4 to 7 cm. Their color varies from bluish-green to dark green depending on age, climatic conditions, and mineral nutrition. Needles remain on the tree for 2–3 years, after which they are naturally replaced. The bark also shows age-related variability: in young trees it is thin and grayish-red, while in older trees it becomes thick, deeply fissured, with a characteristic reddish-brown color [16].

The generative organs of Scots pine have a structure typical of gymnosperms. Male cones are located at the base of young shoots, while female cones develop at the tips of current-year shoots. Pollination occurs in May–June, but seeds mature only in the second year after pollination. Cones are elongated-ovoid, 3–7 cm long, and at maturity acquire a grayish-brown or reddish-brown color. The seeds are small, with well-developed wings that enable effective wind dispersal over considerable distances, sometimes up to several hundred meters from the parent tree [4].

The root system of Scots pine is characterized by high plasticity, allowing it to grow successfully on soils with different mechanical compositions and moisture conditions. On deep, well-drained soils, a strong taproot develops, which can penetrate to depths exceeding 5–6 meters. In cases of shallow groundwater or dense underlying layers, the root system becomes more superficial, with well-developed lateral roots. This assumption is supported by numerous studies of pine growth under various forest site conditions, although precise data on root penetration depth in each specific case remain insufficient [29].

Natural Distribution Range and Ecological Characteristics of The Species

The natural range of Scots pine covers a vast territory from Scotland in the west to the Sea of Okhotsk in the east, from the Arctic Circle in the north to the mountainous regions of Spain, Italy and the Balkan Peninsula in the south. Such a wide range indicates the high ecological plasticity of the species and its ability to adapt to various climatic conditions. In Ukraine, Scots pine is found mainly in the Polissya zone, where it forms both pure and mixed stands, as well as in the Carpathians, where it grows at an altitude from the foothills to the upper border of the forest belt. The ecological amplitude of the species with respect to climatic factors is extremely wide. Scots pine can withstand winter temperatures down to –40 to –45°C, making it one of the most frost-resistant tree species. At the same time, it is capable of growing under the arid conditions of the steppe zone, although its growth slows and productivity decreases under such conditions. Optimal conditions for pine growth are areas with an annual precipitation of 500–700 mm and an average annual temperature of 5–8°C [2].

Light requirements are among the most characteristic ecological features of the species. Scots pine is a light-demanding species, which determines its competitive ability in different forest communities. At a young age, seedlings and natural regeneration can tolerate some shading; however, for normal growth and development, they require full or at least sufficient light. This explains why, in mixed stands, pine is often outcompeted by more shade-tolerant species such as spruce or beech if appropriate silvicultural measures are not applied.

The soil requirements of Scots pine are relatively low, allowing it to colonize areas with poor sandy or rocky soils where other tree species cannot grow successfully. Based on comparative analysis, the most favorable conditions are fresh and moist sandy loam and loamy soils with a well-developed humus horizon. However, pine is capable of growing even on dune sands and peatlands, although its productivity is significantly lower under such extreme conditions [8].

The species also demonstrates a wide tolerance to soil moisture. Scots pine can grow both on dry and excessively moist soils, including raised bogs. However, it grows best on fresh, well-drained soils, where an optimal balance of water and air is maintained. Under such conditions, trees develop a strong root system, show high productivity, and exhibit resistance to adverse factors. On waterlogged soils, pine develops a superficial root system, which reduces wind resistance and makes it more susceptible to windthrow.

Soil acidity has some, though not critical, importance for pine growth. The best growth performance is observed on slightly acidic to acidic soils with a pH of 4.5–6.5. On alkaline soils, pine grows хуже, and needle chlorosis is often observed due to impaired iron nutrition. This assumption requires further confirmation regarding the specific mechanisms of the influence of acidity on physiological processes; however, practical forestry experience confirms better results on acidic soils [5].

Silvicultural and Biological Properties of Scots Pine

The growth rate of Scots pine depends on the age of the trees and site conditions, making this species attractive for artificial forest cultivation. At a young age, approximately up to 10–15 years, height increment is relatively low and amounts to 20–30 cm per year. After this period, a phase of intensive growth begins, during which annual increments can reach 50–70 cm. Maximum growth intensity is observed at the age of 20–40 years, after which it gradually decreases. The total lifespan of Scots pine can reach 300–400 years; however, in forestry practice, the rotation period usually ranges from 80 to 120 years depending on the purpose of the stands.

Scots pine begins to bear cones relatively early: in open stands, the first cones may appear at the age of 15–20 years, whereas in dense stands, the onset of seed production occurs later, at 25–35 years. Abundant seed crops do not occur annually but with a periodicity of 3–5 years, which is related to weather conditions and biological rhythms of the species. In intermediate years, some cones are also formed, but in significantly smaller quantities. Pine seeds are characterized by high viability and germination capacity, which, under proper storage conditions, can be maintained for several years [17].

The regenerative capacity of Scots pine is realized mainly through seed regeneration, as this species lacks the ability to regenerate vegetatively. Natural regeneration occurs most successfully on mineralized soils, where seeds can directly contact the mineral layer. On sites with a thick litter layer or dense grass cover, natural regeneration is hindered, requiring specific silvicultural measures. It should be noted that young pine seedlings are particularly sensitive to competition from herbaceous vegetation during the first years of life [9].

Resistance to pests and diseases is one of the criteria determining the economic value of a tree species. Scots pine is relatively resistant to most pests and pathogens; however, under certain conditions, it may be affected by various organisms. Among the most dangerous pests is the pine sawfly, which during outbreak years can completely defoliate large areas. Among diseases, fungi causing needle cast (especially in young stands and forest nurseries) pose the greatest threat [37].

The fire hazard of pine stands requires special attention in forest management. Scots pine belongs to species with relatively low fire resistance, especially to surface fires that damage the thin bark in the lower part of the stem and the root system. Needle litter and dry herbaceous vegetation create highly flammable materials that contribute to the rapid spread of fire. However, mature trees with thick bark in the upper part of the stem can withstand low-intensity surface fires without significant damage.

The economic importance of Scots pine is determined by the high quality of its wood and its wide range of applications. Pine wood is characterized by straight grain, sufficient strength, ease of processing, and durability, making it a valuable material for construction, furniture production, and other industries. In addition to timber, pine is a source of resin, from which rosin and turpentine are produced. Pine-dominated forests also have recreational value due to the favorable microclimate created by the release of phytoncides [44].

Experience in The Establishment and Cultivation of Pine Plantations

The history of artificial cultivation of Scots pine in Ukraine spans more than a century, during which considerable experience has been accumulated in the establishment and management of pine plantations. The first large-scale plantings of pine on sandy soils of Polissya began in the late 19th century with the aim of stabilizing mobile sands and restoring forest cover. Since then, technologies for establishing forest plantations have been continuously improved, taking into account both positive experiences and past shortcomings.

The choice of planting material type has a significant impact on the success of pine plantation establishment and their subsequent development. Traditionally, bare-root seedlings aged 2–3 years, grown in open-ground forest nurseries, were used. In recent decades, the use of containerized seedlings with a closed root system, grown in specialized containers, has become increasingly widespread. Based on comparative analysis, it can be concluded that containerized seedlings demonstrate higher survival rates and initiate active growth earlier after planting [22].

Studies on the growth and condition of pine plantations established with different types of planting material, conducted in the Southeastern Forest-Steppe of Ukraine, have revealed certain patterns. Plantations established with containerized seedlings were characterized by higher plant survival, especially in the first years after planting. At the same time, growth rates during the first 3–5 years were approximately similar regardless of the type of planting material. This assumption requires further confirmation over longer observation periods; however, the available data allow recommending the use of containerized seedlings on sites difficult for afforestation [12].

Soil preparation prior to the establishment of forest plantations includes a комплекс of measures aimed at improving conditions for seedling survival and growth. On former agricultural lands, full plowing or disking is usually carried out to eliminate herbaceous vegetation and improve soil physical properties. On recent clear-cuts, both full and partial soil preparation methods may be applied, including the creation of furrows or planting spots. The choice of method depends on many factors, including soil texture, moisture conditions, site clutter, and the technical capabilities of the enterprise.

Planting schemes are determined by the intended purpose of the future stands and site conditions. For the establishment of highly productive stands, schemes of 2.5 × 0.7 m or 3 × 1 m are most commonly used, providing an initial density of 4,000–5,000 plants per hectare. Under difficult site conditions or when establishing protective plantations, higher planting densities may be applied. It should be noted that excessively dense plantations require early thinning, while overly sparse planting may lead to stem defects due to insufficient competition among trees [38].

Maintenance of pine plantations in the first years after establishment includes both agrotechnical and silvicultural treatments. Agrotechnical measures are aimed at controlling herbaceous vegetation that competes with the plantations for water and nutrients. Depending on the intensity of grass development, 2–3 treatments are carried out annually for 3–5 years until crown closure. Silvicultural treatments begin when the plantations reach a height of 2–3 meters and involve the removal of undesirable tree species and the formation of optimal stand density [11].

Modern Reforestation Technologies and Regulatory Framework

The technological process of growing pine planting material in modern forest nurseries is based on the application of scientific achievements in forest seed production and seedling cultivation techniques. A key stage is obtaining high-quality seeds from selectively chosen stands, which makes it possible to improve the hereditary traits of future plantations. Seeds are collected from a permanent forest seed base, which includes plus stands, plus trees, and seed orchards [13].

Pre-sowing seed preparation includes several operations aimed at improving germination and seed vigor. Pine seeds undergo stratification—keeping them in a moist state at low temperatures for 1–2 months. This method accelerates and synchronizes germination. Studies have shown that seeds of different colors may have different germination capacities; therefore, color sorting allows the selection of the highest-quality seeds for sowing [4].

Containerized seedling cultivation is becoming increasingly widespread due to its advantages over traditional methods. The use of special trays with cells filled with peat-based substrates creates optimal conditions for root system development. Seedlings can be grown in greenhouses with controlled conditions, allowing standard planting material to be obtained within a single growing season. It should be noted that container technologies require significant initial investment; however, they ensure higher quality and ease of use of planting material [21].

The use of biological preparations in the cultivation of planting material is aimed at increasing plant resistance to adverse factors and stimulating growth. Studies on the effects of bio-organic compositions on pine seedlings have shown positive results. In particular, preparations based on basidiomycetes and nanoparticles contributed to improved development of both root systems and aboveground parts of plants. This assumption requires further confirmation regarding the economic feasibility of large-scale application of such preparations [35].

The regulatory framework for forest cultivation activities in Ukraine is represented by a комплекс of legislative acts and normative documents regulating forest regeneration processes. The main legislative document is the Forest Code of Ukraine, which defines the legal, economic, ecological, and organizational principles of sustainable forest management. The Code establishes principles for sustainable forestry development, biodiversity conservation, and ensuring ecological functions of forests [23].

The Instruction on the design, technical acceptance, accounting, and quality assessment of forest cultivation objects regulates technological processes for establishing forest plantations and requirements for their quality. The document defines evaluation indicators for forest cultivation activities at different stages, including the selection of plantation type, soil preparation, planting of seedlings, and maintenance. According to the instruction, forest plantations are considered successfully established if the survival rate of the main species is at least 85%, and the condition of plants is assessed as satisfactory or better [31].

The State Forest Management Strategy of Ukraine until 2035 defines long-term priorities for the development of forestry in the context of modern challenges. The strategy предусматриває the implementation of European forestry standards, strengthening forest protection, conserving biodiversity, and adapting to climate change. A separate focus is placed on the modernization of forest nurseries and the introduction of modern technologies for growing planting material. Based on comparative analysis, it can be concluded that the implementation of the strategy will contribute to increasing the efficiency of reforestation and improving the quality of established plantations [32].

General Characteristics of The Sumy Forest District of SE "Ukraine's Forests"

The state enterprise "Ukraine's Forests" operates as one of the largest state forestry companies in Europe, responsible for the protection, management, afforestation, reforestation, and timber harvesting across extensive areas of the country. The enterprise was established in 2022 through the reorganization of existing state forestry structures, which allowed for the optimization of forest fund management and increased efficiency in the use of forest resources. SE "Ukraine's Forests" includes numerous branches located in different regions, among which the "Northern Forest Office" branch unites the forests of the Sumy and Chernihiv regions [4-1].

The Sumy Forest District was created on the basis of the former state enterprise "Sumy Forestry," whose history dates back to 1936. Over nearly nine decades, the enterprise has undergone a complex development path influenced by changing economic conditions and approaches to forest management. The initial period was characterized by a predominance of exploitative functions, typical for the Soviet era. However, after Ukraine gained independence in 1991, priorities gradually shifted—emphasizing the balanced use of forest resources, biodiversity conservation, and ensuring the ecological functions of forests.

The organizational structure of the Sumy Forest District includes four forest units: Mohrytske, Nyzivske, Pishchanske, and Sumy, each performing specific functions in managing the allocated forest territories. The enterprise also includes production units: a timber processing workshop conducting primary processing of harvested raw materials; a souvenir workshop producing wooden goods for retail; a primary forest nursery supplying planting material for reforestation; a fire-chemical station responsible for forest fire prevention and suppression; and a machine-tractor fleet providing the necessary equipment for forestry operations [38-1].

The total area of forest fund lands permanently allocated to the Sumy Forest District is 26,687.4 hectares, of which 24,434.8 hectares are covered by forest vegetation, corresponding to a forest cover rate of approximately 91.6%. The distribution of forests by functional purpose reflects current priorities of multi-purpose forest use. Forests designated for conservation, scientific, and historical-cultural purposes occupy 4,058.0 hectares, or 15.2% of the total area. The largest share—21,109.4 hectares, or 79.1%—consists of recreational and wellness forests, mainly located in the suburban areas of the city of Sumy and other settlements. Protective forests cover 1,520.0 hectares, or 5.7%, performing anti-erosion and water protection functions along rivers and on slopes [27-1].

The main activities of the Sumy Forest District cover the entire range of forestry operations. Reforestation is carried out both artificially, through the planting of seedlings and saplings, and naturally, by preserving undergrowth and creating conditions for natural seeding. Logging activities include thinning, sanitary felling, and final harvest within the approved calculated cutting areas. Forest fire protection is ensured through preventive measures, patrolling, and rapid response to fire outbreaks. Protection against pests and diseases is carried out using biological methods and, if necessary, chemical treatments. In addition to production functions, the forest district actively cooperates with local communities and educational institutions, organizing school excursions, educational programs, and activities aimed at raising public ecological awareness.

Natural and Climatic Conditions of The North-Eastern Forest-Steppe of Ukraine

Sumy Oblast is located in the north-eastern part of Ukraine and occupies an area of 23.8 thousand square kilometers, which accounts for approximately 3.9% of the country's territory. The region's geographical position determines its unique natural conditions, encompassing parts of two physico-geographical zones: Polissya in the north and the Forest-Steppe in the south. This transitional position creates favorable conditions for forest vegetation development and allows for the cultivation of a wide range of tree species. The oblast borders Kharkiv and Poltava Oblasts to the south, Chernihiv Oblast to the west, and Kursk, Belgorod, and Bryansk regions of the Russian Federation to the east and north [14-1].

The climate of the region is classified as moderately continental with elements of moderate humidity, characterized by relatively mild winters and warm summers. The average annual air temperature ranges from 6.6 to 6.8 °C; however, over the past century, a trend of increasing temperature has been observed—rising by approximately 1.5 °C, consistent with global climate change. The winter period is characterized by average monthly temperatures from −5 to −8 °C in the coldest month (February), although more severe frosts down to −25 to −30 °C may occur during Arctic intrusions. Summer temperatures average 20–25 °C, with a maximum of around 25.8 °C in July, creating favorable conditions for active growth of woody plants [17-1].

Precipitation patterns exhibit marked seasonal variability, with a predominance of summer rainfall. The average annual precipitation ranges from 550 to 675 mm, of which about 64% falls during the warm period from April to October. The highest rainfall occurs in July (up to 80–90 mm), while the lowest occurs in February (around 30–35 mm). In recent decades, precipitation regimes have shown significant variability due to climate change. For example, the winter of 2019–2020 was characterized by anomalously low precipitation—only 50–70% of the long-term average. The growing season, with temperatures above 10 °C, lasts 200–210 days, sufficient for the successful growth of both coniferous and deciduous tree species [22-1].

The relief of the territory was shaped by ancient geological processes and consists of three main geomorphological units. Most of the oblast, including the territory of the Sumy Forest District, lies within the Dnipro Lowland, characterized by relatively flat and slightly undulating terrain. The northernmost part of the oblast belongs to the Polissya Lowland, with its poorly drained plains and sandy river terraces. To the east and northeast lie the spurs of the Central Russian Upland, featuring more dissected terrain with elevations up to 240 meters. The territory of the Sumy Forest District ranges from 130 to 180 meters above sea level and is characterized by gently undulating relief dissected by river valleys, gullies, and ravines 20–30 meters deep [19-1].

The hydrographic network belongs to the Dnipro basin and is represented by its left tributaries. The forest district lies mainly within the Psel River basin, which flows through the eastern part of the oblast and has a well-developed valley 9–12 km wide, including a floodplain and three terraces above the floodplain. In addition to the Psel, the district is crossed by its tributaries – small rivers and streams with unstable water regimes. The rivers exhibit typical forest-steppe hydrological patterns, with pronounced spring floods, rain-fed flow in summer and autumn with flash floods after heavy rains, and stable low water levels in winter [20-1].

The soil cover of the territory is highly variable due to the transitional position between the Polissya and Forest-Steppe zones. On elevated terrain, gray forest soils dominate, with varying degrees of podsolization – from light gray to dark gray. Dark gray podzolized soils occupy the largest areas and are characterized by 3–4% humus content, a humus horizon thickness of 30–40 cm, and a medium loamy texture. In lower areas and on river terraces, sod-podzolic sandy and loamy soils prevail, with lower humus content (1.5–2.5%). In some locations, podzolized chernozems and meadow soils occur. The agrochemical assessment of soils in the oblast averages 51 points, one of the highest scores in Ukraine, indicating high natural fertility [15-1, 21-1].

Forestry and Taxation Characteristics of The Forest Fund

The forest fund of the Sumy Forest District is characterized by a predominance of coniferous and hardwood stands, typical for the Forest-Steppe zone of Ukraine. The total area of forest fund lands is 26,687.4 hectares, of which 24,434.8 hectares, or 91.6%, are directly covered with forest vegetation. The remaining area consists of lands not covered by forest, including clearings, glades, nurseries, firebreaks, mineralized strips, and other land categories with auxiliary functions for forestry operations. The forest cover index of the district exceeds the average for Sumy Oblast, which is 17.9%, since the district predominantly includes large continuous forest tracts [27-1].

Table 1. Distribution of the Sumy Forest District Fund by Dominant Tree Species

Species	Area, ha	Share, %	Stock, thousand m³	Average Stock per ha, m³
Scots pine (*Pinus sylvestris*)	9,680	39.6	2,904	300
Pedunculate oak (*Quercus robur*)	9,420	38.6	2,826	300
Silver birch (*Betula pendula*)	1,340	5.5	268	200
Common ash (*Fraxinus excelsior*)	1,245	5.1	374	300
Black alder (*Alnus glutinosa*)	1,075	4.4	215	200
Aspen (*Populus tremula*)	490	2.0	98	200
Small-leaved lime (*Tilia cordata*)	390	1.6	117	300
Other species	795	3.2	159	200
Total	24,435	100	6,961	285

The species composition of the forests reflects both the natural conditions of the region and the historical characteristics of stand formation. The main species is Scots pine (*Pinus sylvestris* L.), occupying 9,680 hectares, or 39.6% of the forested land. The second most common species is pedunculate oak (*Quercus robur* L.), covering 9,420 hectares, or 38.6%. Among other species, significant areas are occupied by silver birch (*Betula pendula*) – 1,340 hectares (5.5%), common ash (*Fraxinus excelsior*) – 1,245 hectares (5.1%), black alder (*Alnus glutinosa*) – 1,075 hectares (4.4%), aspen (*Populus tremula*) – 490 hectares (2.0%), and small-leaved lime (*Tilia cordata*) – 390 hectares (1.6%). Other species, including Norway spruce (*Picea abies*), sycamore maple (*Acer platanoides*), elm (*Ulmus*), poplar (*Populus*), and fruit trees, together occupy approximately 795 hectares, or 3.2% of the forested area [33-1].

Analyzing the data from Table 2 it can be noted that two main species—Scots pine and pedunculate oak—dominate, together accounting for over 78 percent of the forest fund. Coniferous stands are represented almost exclusively by Scots pine, as European spruce occupies only minor areas on waterlogged sites.

Among the broadleaf species, oak predominates, along with ash and small-leaved lime, together covering approximately 45 percent of the area. Soft-leaved species—birch, aspen, and black alder—occupy about 12 percent and are mostly found as admixtures in mixed stands or form pure stands on waterlogged and disturbed sites.

The age structure of the stands has certain characteristics shaped by historical events of the past century. The average age of all stands is 65 years, indicating the predominance of middle-aged and maturing forests. For Scots pine, the average age is 58 years, and for oak, 72 years, which is associated with different growth rates and the timing of maturity of these species. Young stands up to 20 years old cover about 3,950 hectares, or 16.2 percent of the area; middle-aged stands (21–60 years) occupy 9,774 hectares, or 40.0 percent; maturing stands (61–80 years) cover 6,353 hectares, or 26.0 percent; and mature and overmature stands occupy 4,358 hectares, or 17.8 percent.

Table 2. Distribution of Stands in the Sumy Forest District by Age Groups

Age Group	Area, ha	Share, %	Average Age, years
Young stands (1–20 years)	3,950	16.2	12
Middle-aged (21–60 years)	9,774	40.0	42
Maturing (61–80 years)	6,353	26.0	70
Mature and overmature (>80 years)	4,358	17.8	105
Total	24,435	100	65

This age structure developed as a result of intensive forest restoration during the post-war period of 1945–1960 and the large-scale establishment of new forests in 1960–1980. The share of mature and overmature stands is gradually increasing, creating conditions for higher volumes of final felling in the coming decades.

The productivity of the stands is high. The total timber stock amounts to 6,961 thousand cubic meters, corresponding to an average of 285 cubic meters per hectare. The annual increment of timber is approximately 102.6 thousand cubic meters, or 4.2 cubic meters per hectare, which exceeds the average indicators for the region.

Forestry and Cultivation Activities of The Enterprise

The technologies for establishing forest plantations in the Sumy Overforestry Unit are based on many years of practical experience and modern advances in forestry science. Site preparation for forest cultivation is differentiated depending on land category and forest-growing conditions. On fresh clear-cut areas, after final felling, partial soil preparation is carried out by creating furrows using the combined forest plow PKL-70. This approach preserves the natural soil structure, undergrowth, and existing regeneration of valuable species. The furrows are 50–70 centimeters wide, 20–25 centimeters deep, and spaced according to the planned planting scheme, typically 2.5–3.0 meters apart. Former agricultural lands designated for afforestation undergo complete plowing to a depth of 25–30 centimeters, followed by harrowing to level the surface and control weeds.

The choice of species for plantations is determined by the type of forest-growing conditions according to Pogrebnyak's edaphic grid and the intended purpose of the future forest. In fresh pine forests (A_2) and subpine forests (B_2), Scots pine (*Pinus sylvestris*) is the main species for forest restoration, planted in a 1.5×1.5 meter scheme (initial density 4,444 seedlings per hectare) or 2.0×0.7 meters (7,143 seedlings per hectare), depending on the quality of the planting material and available funding. In fresh oak forests (D_2) and fresh oak-birch forests (C_2), oak plantations are established with a 2.5×2.5 meter or 3.0×1.0 meter scheme (1,600–3,333 seedlings per hectare). Oak plantations often include companion species—common ash, Norway maple, and small-leaved linden—in 10–20% of the total planting density, which enhances the biological stability of the stands.

Seedling production is carried out at the main forest nursery covering 8.5 hectares, located in the Nizivske Forest District. The nursery includes a sowing section of 3.2 hectares for seedlings, a seedbed section of 2.8 hectares for saplings, and auxiliary plots. The annual production of standard planting material is approximately 800–900 thousand units, of which about 60% is Scots pine, 25% is common oak, and the remainder includes ash, linden, maple, and other species. Scots pine seedlings are grown using two technologies: the traditional open-root system, where seedlings are grown in the sowing section for 2–3 years to standard size (height at least 12 cm, root collar diameter at least 2 mm), and container technology.

Container cultivation has been implemented in the enterprise since 2018, using special "Planta" trays with 90 cm^3 cells. The substrate consists of 70% sphagnum peat, 20% sand, and 10% perlite with added slow-release mineral fertilizers. Cultivation occurs in greenhouses with controlled temperature and humidity, allowing standard planting material 15–20 cm tall to be produced in a single growing season. Survival rates for container-grown seedlings reach 92–95%, compared to 85–88% for open-root seedlings, though container seedlings are approximately 1.8 times more expensive.

Table 3. Afforestation Volumes in the Sumy Overforestry Unit, 2020–2024

Year	Artificial Regeneration, ha	Natural Regeneration, ha	Total, ha	Seedlings Planted, thousand pcs
2020	72	26	98	288
2021	75	29	104	300
2022	68	24	92	272
2023	77	28	105	308
2024	73	27	100	292
Average	73	27	100	292

Afforestation volumes in the Sumy Overforestry Unit have remained relatively stable in recent years. On average, 95–105 hectares of forest are restored annually, with 70–75 hectares through artificial planting of seedlings or sowing of seeds, and 20–30 hectares through natural regeneration under the canopy of parent stands or on clear-cuts with sufficient viable understory. Artificial regeneration is primarily carried out on areas affected by sanitary clear-cuts due to dieback from pests or diseases, as well as on final-felling clear-cuts in mature and overmature stands.

Analysis of the data in Table 2.3 shows that the volumes of forest regeneration have remained relatively stable, with minor fluctuations from year to year. The slight decrease in 2022 was due to objective circumstances caused by Russia's military aggression against Ukraine, which led to temporary reductions in funding and limited access to certain forest areas. The ratio between artificial and natural regeneration remains approximately 73 to 27 percent, which generally corresponds to the recommendations for the forest-steppe zone, although in the future it would be advisable to increase the share of natural regeneration as a more cost-effective and ecologically justified method.

Methodology of The Study

The objects of the study were Scots pine (*Pinus sylvestris* L.) plantations aged 5, 10, and 15 years, established in the Nyzivske Forestry of the Sumy Over-Forestry within fresh subor stands (forest site type B_2 according to the Pogrebnyak classification). These age categories were selected to track the dynamics of growth and development at critical stages: 5 years represents the results of survival and initial growth; 10 years corresponds to the period of active stem and crown formation after canopy closure; 15 years reflects plantations that have entered the pole stage. All studied plantations were established using container-grown seedlings from the forestry's nursery, with a uniform planting scheme of 2.0 × 0.7 m, corresponding to an initial density of 7,143 seedlings per hectare.

Sample plots were established following the requirements of DSTU 4633:2006 "Seeds of Trees and Shrubs. Methods for Determining Seed Quality" and the "Instructions for Designing, Technical Acceptance, Accounting, and Quality Assessment of Forest Plantation Objects," approved by the State Forestry Committee of Ukraine on 05.11.2010 No. 448. In each age category, three temporary rectangular plots of 0.25 ha (50 × 50 m) were laid out, providing sufficient representativeness for statistical analysis. Plots were randomly located within areas with homogeneous forest site conditions – fresh subor stands on dark gray podzolic loamy soils, flat relief, without waterlogging. Plot boundaries were determined using a Garmin GPSMAP 64 device with 3 m accuracy, and corners were marked with 80 cm wooden stakes labeled with the plot number.

On each plot, all trees were inventoried and assigned individual numbers, and a set of mensuration parameters was measured. Tree height was measured using a Blume-Leiss hypsometer with 0.1 m precision by sighting the terminal bud of the main shoot. Diameter at 1.3 m above ground (DBH) was measured using a caliper with 0.1 cm precision in two mutually perpendicular directions, then averaged. For 5-year-old plantations, most trees did not reach 1.3 m, so stem base diameter was measured with a Vernier caliper (ШЦ-I) to 0.1 mm accuracy. Each tree's condition category was visually determined according to sanitary rules in Ukrainian forests: I – healthy, II – weakened, III – severely weakened, IV – dying, V – fresh deadwood, VI – old deadwood.

Mensuration methodology included determining both individual tree parameters and average stand-level values. Plantation survival was calculated as the ratio of living trees (categories I-IV) at the time of measurement to the theoretical initial planting density of 7,143 seedlings/ha, expressed as a percentage. Mean height was calculated using the Lorrey method as the arithmetic mean of heights of trees closest to the stand's mean diameter. Mean diameter was computed as the quadratic mean of all tree diameters. Timber volume was determined according to standard mensuration tables for Scots pine juveniles developed by UkrNDILGA. To assess current growth intensity, annual height increment was measured on 10 model trees per age randomly selected from healthy trees (category I) as the length of the last year's shoot. Current diameter increment was measured using a Pressler increment borer by extracting two cores at 1.3 m in perpendicular directions.

Statistical analysis methods included calculation of basic statistical parameters for each mensuration variable: arithmetic mean, standard deviation, coefficient of variation, and standard error of the mean. Differences between age groups were tested using Student's t-test for independent samples at a significance level of $\alpha = 0.05$, commonly applied in forestry studies. Correlation analysis was used to determine the strength and nature of relationships between variables, e.g., between tree height and diameter, and between plantation age and survival. Data processing was performed using Microsoft Excel 2019 and specialized forestry mensuration software "Lisotaksator 3.0." Fieldwork was conducted from May to September 2024, with measurements taken twice per plot – at the start (May) and end (September) of the growing season – allowing assessment of seasonal growth dynamics.

Technology of Scots Pine Plantation Establishment in The Forestry

The technology of establishing Scots pine plantations in the Sumy Over-Forestry involves a set of sequential operations, starting with site preparation and ending with tending young stands until they are fully established. Soil preparation is differentiated depending on the land category and its previous use.

On fresh clear-cut areas after final felling, partial soil preparation is carried out by creating furrows with a combined forest plow PKL-70, mounted on a LHT-100 tractor. The plow forms furrows 60–70 cm wide and 20–25 cm deep, turning the topsoil along with the litter layer to one side. The distance between the centers of adjacent furrows is determined by the future planting scheme and usually ranges from 2.5 to 3.0 meters. The mineralized layer in the furrow provides favorable conditions for seedling survival, ensuring direct contact of the root system with mineral soil and reducing competition from herbaceous vegetation.

On former agricultural lands transferred for afforestation, soil preparation follows a different procedure. Initially, the stubble is harrowed using a BDT-3 disc harrow to a depth of 8–10 cm to stimulate weed seed germination. After 2–3 weeks, following mass emergence of weeds, a deep plowing is performed with a PLN-4-35 plow to a depth of 25–30 cm. In spring, before planting, the soil is cultivated and harrowed to level the surface and eliminate emerging weeds. This system significantly reduces weed infestation and creates optimal conditions for mechanized planting. On heavy loamy soils, additional subsoiling to 40–45 cm is performed to improve water permeability and aeration of the root-bearing layer.

Planting methods and spacing schemes are determined by the type of planting material, forest site conditions, and the intended purpose of the stand. Manual planting with a Kolesov spade is primarily used, which is the most common and reliable method for partially prepared soils. The Kolesov spade allows creating a furrow of the required depth, placing the seedling root system without bending, and firmly compacting the soil around the roots. For bare-root seedlings, planting depth is 15–18 cm; for container seedlings, it corresponds to the container height, usually 12–15 cm. The root collar is buried 1–2 cm below the soil surface to prevent drying of the upper root system.

The main planting scheme for Scots pine is 2.0 × 0.7 m, corresponding to an initial density of 7,143 seedlings per hectare. This density ensures formation of high-quality stands with straight, full-length stems through timely crown closure and natural branch self-pruning. On sites with better forest conditions, a sparser scheme of 2.5 × 0.8 m (5,000 seedlings per hectare) is applied to reduce planting material costs while maintaining stand quality. In fresh pine stands on poor sandy soils, a denser scheme of 1.5 × 0.7 m (9,524 seedlings per hectare) is used to compensate for expected losses and ensure sufficiently dense stands. Long-term experience supports these schemes, although precise optimization data for each case is limited.

The planting material used is critical for successful afforestation. In the Sumy Over-Forestry, Scots pine plantations are established using seedlings produced in the forestry's nursery, allowing quality control at all stages. Traditionally, two-year-old bare-root seedlings grown in the nursery were used, with the following standard characteristics: height 12–20 cm, root collar diameter ≥2.5 mm, root length 20–25 cm with well-developed lateral roots.

Since 2018, the forestry has introduced container-grown seedlings using "Planta 81F" containers (90 cm^3 volume). These seedlings are grown in a greenhouse during one growing season and reach 15–22 cm in height, with a root collar diameter of 2.8–3.5 mm. Compared to bare-root seedlings, container seedlings have significant advantages: higher survival rate, ability to plant at any time during the growing season, and better preservation of the root system during transport.

Thus, the technology of Scots pine plantation establishment in the Sumy Over-Forestry is characterized by a differentiated approach to soil preparation, predominance of manual planting with the Kolesov spade at a 2.0 × 0.7 m spacing, and gradual transition from traditional bare-root seedlings to container-grown seedlings, which increases the efficiency of forest cultivation operations.

Survival Rate of Scots Pine Plantations

Survival rate is one of the most important indicators of successful forest plantation establishment, as it determines the need for additional supplementary planting and, ultimately, the economic efficiency of afforestation.

The survival of Scots pine plantations was studied on plots established in 2020, 2021, 2022, and 2024, which allowed tracking the dynamics of this indicator over several years and identifying the factors that most significantly affect seedling survival.

Table 4. Survival of Scots Pine Plantations by Year of Establishment in the Nizivske Forestry of Sumy Forest District

Year of Establishment	Root System Type	Survey Area, ha	Planted, pcs/ha	Survived, pcs/ha	Survival Rate, %
2020	(DRS)	0.75	7143	6071	85.0
2020	(CGS)	0.75	7143	6643	93.0
2021	(DRS)	1.20	7143	6214	87.0
2021	(CGS)	1.20	7143	6714	94.0
2022	(DRS)	0.85	7143	5714	80.0
2022	(CGS)	0.85	7143	6500	91.0
2024	(DRS)	1.50	7143	6357	89.0
2024	(CGS)	1.50	7143	6786	95.0

Survival was recorded in the autumn of the planting year through a complete count of living seedlings on temporary monitoring plots of 0.25 hectares, established under typical conditions for each year of plantation establishment.

Analyzing the data from Table 3.1, it can be concluded that the survival rate of cultures created with container-grown seedlings consistently exceeds that of bare-root seedlings by 6–11 percent. The average survival rate over four years for container-grown seedlings is 93.3%, whereas for bare-root seedlings it is only 85.3%. The lowest survival rates were recorded for the 2022 plantings, which can be attributed to unfavorable weather conditions during the growing season – abnormally high temperatures in May–June and a deficit of precipitation. It is worth noting that even under such adverse conditions, the survival of container-grown seedlings remained relatively high.

The effect of root system type on seedling survival can be explained by several factors. Container-grown seedlings maintain an intact root system because their roots develop within the container and are not cut during extraction. This allows the plants to resume growth more quickly after planting and minimizes the stress adaptation period. In addition, the peat substrate surrounding the roots of container seedlings provides supplemental nutrients during the initial stage and maintains an optimal moisture level in the root zone. Bare-root seedlings, when dug up, lose a significant portion of their fine absorbing roots, which reduces their ability to take up water and minerals during the first weeks after planting.

The dependence of survival on site conditions is also quite clear. The highest survival rates are observed in fresh subor (B_2) stands on dark gray podzolized loamy soils, where survival for bare-root seedlings ranges from 87–90%, and for container-grown seedlings – 94–96%. In fresh pine stands on sod-podzolic sandy loam soils, survival is somewhat lower: 82–85% for bare-root seedlings and 90–92% for container-grown seedlings. This is due to the lower water-holding capacity of sandy soils and their tendency to dry out quickly during dry periods. Based on these comparisons, it can be concluded that the most critical factor for seedling survival is sufficient moisture during the first 2–3 weeks after planting, when the root system has not yet developed enough to effectively absorb water from deeper soil layers.

Table 5. Survival of Pine Plantations Depending on Forest-Growing Conditions

Forest-Growing Type	Soil Characteristics	Survival, Bare-Root Seedlings (%)	Survival, Container-Grown Seedlings (%)	Difference (%)
A_2 (fresh pine forest)	Sandy sod-podzolic	83	91	8
B_2 (fresh subor)	Dark gray podzolized loam	88	95	7
C_2 (fresh oak-pine mixed forest)	Gray forest light loam	86	93	7

The data in Table 5 show that container-grown seedlings have advantages across all types of forest-growing conditions, with the most pronounced effect observed in the poorest conditions of fresh pine forests, where the difference in survival reaches 8 percent. This assumption requires further confirmation on a larger number of plots, but the available data allow recommending the priority use of container-grown seedlings on poor sandy soils.

In addition to the type of forest-growing conditions, survival is influenced by the timing of planting—spring plantings (April) provide 3–5 percent higher survival compared to autumn plantings (October), due to more favorable moisture conditions and the absence of the risk of winter frost damage to weakened seedlings.

Thus, the survival rates of pine plantations in the Sumy Forest District are at a high level, especially when using container-grown seedlings, whose survival consistently exceeds 90 percent across all forest-growing conditions, indicating the effectiveness of the applied forest restoration technology.

The growth dynamics of Pinus sylvestris L. plantations of different ages were studied on nine sample plots established in 5-, 10-, and 15-year-old stands created in fresh subpine forests on dark gray podzolic loam soils. Three sample plots in each age category provided representative data on changes in key mensuration parameters with age and allowed assessment of the growth rates of Scots pine under the conditions of the Sumy Forest District. Measurements were conducted in August–September 2024 following the methodology described in Section 2, which ensured the possibility of accurate comparison of the obtained results.

Table 6. Height and Diameter Parameters of Scots Pine *(Pinus sylvestris* L.*)* Cultures of Different Ages

Age, years	Number of trees surveyed, pcs	Average height, m	Average diameter, cm	Survival rate, %	Health category
5	2680	1.8 ± 0.3	2.4 ± 0.4	93	I
10	2420	4.2 ± 0.6	5.8 ± 0.9	84	I
15	2150	7.5 ± 1.1	10.3 ± 1.6	75	I–II

Analyzing the data from Table 6, a clear pattern of increasing linear dimensions of the trees with age can be observed. Five-year-old cultures have an average height of 1.8 meters and an average diameter at 1.3 meters (or at the root collar for trees that have not reached this height) of 2.4 centimeters. By ten years of age, trees reach an average height of 4.2 meters, an increase of 2.3 times, while the diameter grows to 5.8 centimeters, an increase of 2.4 times. At fifteen years, the average height is 7.5 meters and the diameter is 10.3 centimeters.

It is noteworthy that the coefficient of variation in height and diameter increases with tree age: at 5 years, it ranges from 16–17%, while at 15 years it reaches 14–16%, indicating greater differentiation among trees due to competition for light, water, and mineral nutrients.

Annual growth shows uneven dynamics, associated with the biological characteristics of Scots pine growth. In the first 3–4 years after planting, growth is relatively slow – the average annual height increment is about 30–40 cm, and diameter growth is 0.4–0.5 cm. This period is characterized by intensive root system development and adaptation to site conditions. After crown closure, which occurs at 6–7 years of age, the phase of intensive height growth begins – the average annual increment increases to 50–60 cm, while diameter growth reaches 0.8–1.0 cm per year.

Based on this comparison, it can be concluded that the maximum growth rates in fresh subor conditions occur between 8–12 years of age, when trees have not yet experienced strong competition but have already developed a well-established root system.

The data in Table 7 clearly illustrate the pattern of increasing current annual increments with the age of the stands. While the average annual height growth during the first five years is 36 cm, it nearly doubles to 66 cm in the 11–15 year age period. Diameter growth shows a similar upward trend, rising from 0.48 cm/year in the first five years to 0.90 cm/year in the 11–15 year period. Although this observation requires further confirmation through long-term monitoring, the available data align well with the classical growth patterns of Scots pine stands in the forest-steppe zone.

Table 7. Presents the current annual increments of Scots pine cultures by age period

Age period, years	Average annual height increment, cm/year	Average annual diameter increment, cm/year
1–5	36	0.48
6–10	48	0.72
11–15	66	0.90

A comparative analysis of the sample plots revealed some variability in growth indicators even within the same type of forest-growing conditions. Among the three plots in the 15-year-old stands, the difference in average height ranged from 7.2 to 7.9 m, and in diameter – from 9.8 to 10.9 cm. This variability can be attributed to microclimatic differences between the plots, heterogeneity of the soil cover, and the quality of silvicultural operations performed during stand establishment. The best growth indicators were recorded on the plot located on the northern slope of a gentle hill, where trees were better supplied with moisture and protected from drying southern winds. The lowest growth was observed on a plot with a shallow clay subsoil (70–80 cm depth), which limited the development of the root system downward.

Thus, the growth dynamics of Scots pine stands in the Sumy Forestry Enterprise are characterized by a gradual increase in growth rates after the adaptation period, reaching maximum values at 10–15 years of age, indicating favorable conditions for Scots pine cultivation in the study region.

Condition and Productivity of Scots Pine Stands

The sanitary condition of the pine stands was assessed using the tree condition categories in accordance with the Sanitary Rules in the Forests of Ukraine. On each plot, all trees were classified into categories: I – healthy (no signs of weakening), II – weakened, III – strongly weakened, IV – dying, V – recently dead, VI – old dead. The inventory results showed that the overall sanitary condition of the studied stands is rated as good or satisfactory, depending on the age of the stands. In 5-year-old stands, the proportion of healthy trees (Category I) was 91 %, weakened (Category II) – 6 %, strongly weakened and dying (Categories III–IV) – 2 %, and no dead trees were recorded. This distribution indicates successful establishment and the absence of significant stress factors during the formation of young stands.

The stand volume of Scots pine plantations was calculated using volumetric tables for young pine stands developed by UkrNDILGA. For 10-year-old stands, the volume is 32 m³/ha, which corresponds to an average of 0.005 m³ (5 dm³) per tree. Fifteen-year-old stands have a volume of 122 m³/ha, with an average of 0.023 m³ per tree. The current annual volume increment, calculated as the difference in volumes divided by the number of years between measurements, is 3.2 m³/ha/year for the 5–10-year period and increases to 8.1 m³/ha/year for the 10–15-year period. These figures correspond to high-productivity stands and indicate the effectiveness of the applied silvicultural practices.

Thus, the sanitary condition of the Scots pine plantations in the Sumy Forestry Enterprise is assessed as good, tree survival meets regulatory requirements, and the indicators of site quality, stand density, and volume demonstrate high productivity and favorable growing conditions for Scots pine.

Based on the conducted research, it is recommended to further expand the use of planting material with a closed root system, which provides 6–11 % higher survival compared to traditional seedlings and allows for a broader range of optimal planting periods, including summer. It is also advisable to optimize the planting patterns depending on the forest-growing conditions: in fresh sub-boreal gray forest loamy soils, an initial density of 6,000–6,500 container-grown seedlings per hectare is sufficient, while in fresh pine stands on sandy soils, the traditional density should be maintained or slightly increased.

Regarding silvicultural techniques, it is recommended to improve soil preparation technology by using selective furrow creation instead of continuous plowing, and on former agricultural lands – pre-sowing of green manure crops. Critically important is the intensive care during the first 2–3 months after planting, including two soil treatments and weed control, with a subsequent reduction in care intensity to once per year during the second and third years, followed by standard forestry maintenance after crown closure at 6–7 years of age.

Conclusions

Analysis of the literature shows that *Pinus sylvestris* L. is characterized by high ecological plasticity, a wide natural range, and the ability to grow successfully on soils of varying fertility. In the conditions of the North-Eastern Forest-Steppe of Ukraine, Scots pine forms productive stands of site quality class I–II, but the effectiveness of forest regeneration largely depends on the correct choice of plantation technology and the quality of planting material.

The natural and climatic conditions of the Sumy Forestry Enterprise (moderately continental climate, mean annual temperature 6.6–6.8 °C, annual precipitation 550–675 mm, predominance of dark-gray podzolic loamy soils) are favorable for the cultivation of *Pinus sylvestris* L. The forest fund is dominated by pine (39.6%) and oak (38.6%) stands, with an average age of 65 years and a total volume of 6,961 thousand m³.

It has been established that the survival rate of Scots pine plantations created with container-grown seedlings (closed root system) consistently exceeds that of seedlings with an open root system by 6–11% across all forest-growing conditions. The average survival of container seedlings is 93.3%, compared to 85.3% for open-rooted seedlings. The highest survival rates (94–96%) were observed in fresh sub-boreal stands on dark-gray podzolic loamy soils.

Growth dynamics studies revealed a consistent increase in tree dimensions with age: 5-year-old plantations have an average height of 1.8 m and diameter 2.4 cm, 10-year-old – 4.2 m and 5.8 cm, 15-year-old – 7.5 m and 10.3 cm. Current annual height increment increases from 36 cm/year in the 1–5-year period to 66 cm/year in the 11–15-year period, while diameter increment rises from 0.48 cm/year to 0.90 cm/year. Maximum growth intensity occurs at 8–12 years, after the development of a strong root system.

The sanitary condition of the studied plantations is assessed as good: in 5-year-old stands, 91% of trees are healthy, while in 15-year-old stands – 78%. Stand survival naturally decreases from 93% at age 5 to 75% at age 15 due to natural mortality under competitive conditions. Productivity is high: the volume of 15-year-old stands is 122 m³/ha, with site quality class I–II and stand density 0.8.

The economic efficiency of using container seedlings has been confirmed: despite the higher cost of container seedlings (8.5 UAH vs. 5.3 UAH), additional expenses are offset by savings on supplementary planting (about 2,850 UAH/ha) due to higher survival rates and elimination of the need for repeat planting.

A set of recommendations has been developed for optimizing the cultivation technology of *Pinus sylvestris* L. under the conditions of the Sumy Forestry Enterprise, including: increasing the share of container-grown seedlings to 70–80% of total production, applying optimized planting patterns (2.2×0.7 m in fresh sub-boreal stands, 1.8×0.7 m in fresh pine stands), improving soil preparation methods, and refining the system of silvicultural treatments.

REFERENCES

1. Agrotechnology of Scots pine (*Pinus sylvestris* L.) seedling cultivation. URL: http://um.co.ua/5/5-1/5-1343.html (accessed: 05.10.2025).
2. Andreeva V. V., Voityuk V. P., Kychyliuk O. V., Hetmanchuk A. I., Tereshchuk A. M. Forestry and selection assessment of Scots pine stands in Cheremskyi Nature Reserve. Nature of Western Polissya and adjacent territories: collection of scientific papers / ed. by F. V. Zuzuk. Lutsk: East European National University named after Lesya Ukrainka, 2019. № 16. P. 176–184.
3. Biotechnology in forestry. URL: https://www.brc.a-star.edu.sg (accessed: 05.10.2025).
4. Boiko H. O., Puzrina N. V. Germination capacity and vigor of Scots pine (*Pinus sylvestris* L.) seeds of different colors. Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine. Series «Forestry and Ornamental Gardening». 2015. Issue 219. P. 113–117.
5. Boiko T. O., Boiko P. M., Pluhatar Yu. V. Ecological forestry: textbook. 2nd ed., revised and supplemented. Kherson: Oldi Plus, 2019. 268 p.
6. Boiko T. O., Melnyk M. A., Melnychenko L. D. Problems and prospects of forest management development in Kherson region in the context of forest and hunting management reform. Tavriyskyi Scientific Bulletin. 2017. № 97. P. 189–195.
7. Boiko T. Practical training of forestry specialists in southern Ukraine – a guarantee of sustainable regional development. 2021.
8. Vakulyuk P. H., Samoplavskyi V. I. Forest restoration and afforestation in Ukraine. Kharkiv: Prabor, 2016. 384 p.
9. Hordienko M. I., Huz M. M., Debryniuk Yu. M., Maurer V. M. Forest cultures: textbook. Lviv: Kamula, 2015. 608 p.
10. Davydenko K., Baturkin D. Ophiostomatoid fungi associated with bark beetles and colonizing Pinus sylvestris in Sumy region (Ukraine). Scientific Works of the Forest Academy of Sciences of Ukraine. 2020. № 21. P. 118–128. DOI: https://doi.org/10.15421/412037.
11. Danylenko O. M., Mostepanyuk A. A., Hupal V. V. Economic efficiency of growing seedlings with closed root systems and forest cultures using them in SE «Kharkiv LNSD». V. M. Vynogradov Scientific Readings: materials of the first open regional scientific-practical Internet conference dedicated to the 5th anniversary of the Department of Forestry and Landscape Architecture of Kherson State Agrarian University, Kherson, May 23–24, 2019. Kherson, 2019. P. 62–64.
12. Danylenko O. M., Yushchyk V. S., Rumyantsev M. H., Mostepanyuk A. A. Growth and condition of Scots pine cultures created with different planting materials in the South-Eastern Forest-Steppe of Ukraine. Scientific Bulletin of NLTU of Ukraine. 2021. Vol. 31, № 1. P. 26–29. DOI: https://doi.org/10.36930/40310104.
13. Debryniuk Yu. M., Yavorsky M. V., Myakush I. I. Selection inventory of permanent seed base objects of SE «Busk Forestry» and ways to restore genetic resources of main forest-forming species. Lviv: Manuscript, 2021. 152 p.
14. State Target Program «Forests of Ukraine» for 2010–2015: Resolution of the Cabinet of Ministers of Ukraine dated 16.09.2009 № 977 (as of 20 Mar. 2018). URL: https://zakon.rada.gov.ua (accessed: 05.10.2025).
15. State Enterprise «Forests of Ukraine». URL: https://e-forest.gov.ua (accessed: 05.10.2025).
16. Dyshko V. A., Dyshko S. M. Morphological characteristics of generative organs of Scots pine in natural and artificial stands in Ukraine. Scientific Bulletin of NLTU of Ukraine. 2015. Issue 25.2. P. 58–63.
17. DSTU 8558:2015. Seeds of trees and shrubs. Methods for determining sowing qualities (germination, viability, quality). Effective from 2017-01-01. Kyiv: UkrNDNC, 2017. 87 p.
18. Krynytsky H. T., Zaika V. K. Morphophysiological basis for genetic-selection assessment of tree growth intensity in forest stands. Forestry Science: status, problems, development prospects (UkrNDILGA – 90 years): materials of international scientific-practical conference, Kharkiv, June 23–24, 2021. Kharkiv: Planeta-Print, 2021. P. 258–260.
19. Lozinska T. P., Zadorozhnyi A. I., Masalskyi V. P. Study of new technologies and innovations in forestry. Agrobiology. 2024. № 1. P. 43–48. DOI: 10.33245/2310-9270-2024-1-43-48.
20. Lozinska T. P., Yatsenko V. M. Introduction as a tool to increase forest cover and improve species composition and biodiversity of forest plantations. Study and conservation of biodiversity of ecosystems of Ukraine: materials of the All-Ukrainian scientific-practical conference of students and young scientists, Bila Tserkva, April 20–23, 2021. Bila Tserkva: BNAU, 2021. P. 26–28.
21. Lyalin O. I. Methodical recommendations for performing practical works on forest seed production from the course «Forest cultures». Kharkiv: KhNUMG named after O. M. Beketov, 2018. 38 p.
22. Lyalin O. I., Tarnopilska O. M., Tkach L. I., Musienko S. I., Bondarenko V. V. Germination, survivability, and condition of Scots pine (Pinus sylvestris L.) seedlings grown in containers. Scientific Bulletin of NLTU of Ukraine. 2020. Vol. 30, № 2. P. 44–48. DOI: https://doi.org/10.36930/40300208.
23. Forest Code of Ukraine: Law of Ukraine dated 21.01.1994 № 3852-XII (as of 17 Feb. 2000). URL: https://ips.ligazakon.net/document/view/t385200?an=ul-1&ed=2000_02_17 (accessed: 05.10.2025).
24. Mazhula O. S., Fuchylo Ya. D., Shiyanova T. P., Skorokhodov M. Yu., Ryabchun V. K. Long-term preservation of Scots pine (Pinus sylvestris L.) seeds as a basis for creating fast-growing energy plantations on marginal lands in Ukraine. Scientific Works of the Institute of Bioenergy Crops and Sugar Beets. 2018. Issue 26. P. 84–90. DOI: https://doi.org/10.47414/np.26.2018.211208.
25. Manilych M., Konechna R. Scots pine (Pinus sylvestris L.): an analytical literature review. Modern Medicine, Pharmacy and Mental Health. 2023. № 2 (11). P. 96–108. DOI: https://doi.org/10.32689/2663-0672-2023-2-14.