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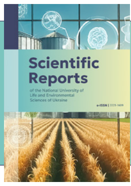

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Influence of shrub species on the natural regeneration of the main forest-forming tree species in Husiatyn forest district of the Chortkiv forestry

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Abstract. This article examined the characteristics of understorey formation in oak stands of the Chortkiv forestry and its influence on the growth, development, and survival of the principal tree species. The dominant shrub species recorded in the region's oak forests were common hazel, European spindle, warty spindle, common dogwood, wayfaring tree, Tatar maple, and field maple. Field investigations were carried out in Husiatyn Forest District on a series of experimental plots differing in shrub-layer composition. Particular attention was given to the effects of common hazel, Tatar maple, and Siberian peashrub on the growth of pedunculate oak and common ash. The most favourable results were obtained in plots with common hazel, where survival reached 92.8% for pedunculate oak and 95.7% for common ash. Trees in these plots also attained the greatest height, stem diameter, and crown size. The positive effect of common hazel appears to be associated with the creation of a more favourable microclimate, suppression of competing herbaceous vegetation, and reduced competition for soil

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moisture and nutrients. By comparison, plots containing Tatar maple or Siberian peashrub showed lower growth performance and a slight reduction in oak survival. Changes in understorey composition and density were also assessed across stands of different ages and stocking densities. It was found that Tatar maple predominates in young forest plantations, whereas European spindle and warty spindle dominate in middle-aged and mature stands. The obtained results confirm the important role of the understorey in creating a favourable microclimate, maintaining biodiversity, and ensuring the successful natural regeneration of oak forests

Keywords: pedunculate oak; common ash; understorey; forest stands; stocking density; stand density; light conditions

Introduction

Research into the impact of shrub species on the growth of common oak seedlings is of particular relevance given the need to enhance the effectiveness of natural regeneration and establish sustainable oak stands in the context of current climate change. In forest ecosystems, the undergrowth performs important ecological functions, creating a favourable microclimate and protecting the soil from overheating and drying out; however, it can also act as a competitor for light, moisture and nutrients, which directly affects the growth and development of oak seedlings. As of 2025, one of the priority tasks of Ukraine's forestry sector is the establishment of productive, biologically sustainable and climate-adapted oak stands, which requires scientifically sound regulation of the composition and density of the undergrowth. Identifying the specific effects of individual shrub species on oak development will enable the improvement of forestry management practices, in particular thinning and undergrowth regulation. The practical significance of such research lies in the development of recommendations for the conservation of beneficial undergrowth species and the control of those that inhibit oak growth, which will help to improve the success of forest regeneration, conserve biodiversity and ensure the ecological sustainability of forest ecosystems.

The role of shrubby plants in the natural regeneration of oak forests, their impact on the growth of young plants and the formation of stand structure is being actively investigated in scientific research. For example, M. Zadworny *et al.* (2021) investigated the effect of different methods of propagating common oak planting stock on root system development and the seedlings' resistance to water stress. In their study, the authors concluded that seedlings grown from acorns and in containers are characterised by a more developed root system and greater drought tolerance, which enhances their competitiveness in natural conditions. However, the researchers did not consider the influence of undergrowth and shrub species on the subsequent growth of young oaks after their emergence in forest stands. L. Demeter *et al.* (2021) investigated the causes of insufficient natural regeneration of common oak in European forests. In their study, the authors proposed the "powdery mildew hypothesis" and concluded that infection by the pathogen *Erysiphe alphitoides* significantly reduces the viability and competitiveness of oak seedlings beneath the forest canopy. At the same time, the authors emphasised that the success of natural regeneration is determined by the combined effects of pathogens, shading and competition from the undergrowth for light and resources. However, the quantitative impact of individual shrub species on the growth rate of oak seedlings has not been investigated.

M. Franzén *et al.* (2025) examined long-term successional changes in oak stands following the cessation of traditional forest management. They found that over an 87-year period the abundance of *Corylus avellana* L. increased substantially, whereas natural oak regeneration remained poor, accompanied by changes in stand structure and the dominance of common hazel in the understorey. These findings indicate that intensive development of the shrub layer can significantly affect the regeneration of oak stands. However, the spatial analysis used in the study did not allow the direct influence of common hazel on the growth of individual oak seedlings to be assessed. A. Lenk *et al.* (2025) investigated the effectiveness of different forest management measures for improving natural oak regeneration in floodplain forests. The authors concluded that the most favourable conditions for the growth of young oak trees are achieved through a combination of increased canopy openness and selective thinning of the understorey, whereas increasing light availability alone, without regulating competing vegetation, is insufficient. This indicates that understorey density is one of the key factors determining the successful regeneration of oak stands. Nevertheless, the study focused primarily on the effectiveness of forest management measures rather than on the specific effects of individual shrub species.

D. Dluhosch *et al.* (2025) investigated the role of mature oak trees in supplying water to understorey vegetation through hydraulic redistribution under drought conditions. The authors found that approximately 29% of the daily water consumption of oak seedlings during dry periods was supplied through this mechanism, highlighting the important role of mature trees in supporting natural regeneration. However, the influence of understorey shrub species on the utilisation of these water resources and their competitive interactions with oak seedlings was not examined.

Thus, a review of recent studies indicates that considerable attention has been devoted to the investigation of natural regeneration in oak stands, including the effects of light availability, water regime, successional processes, and forest management practices. However, the quantitative assessment of the influence of individual understorey shrub species, particularly common hazel, common dogwood, spindle species, and others, on the growth, development, and competitive interactions of oak seedlings remains insufficiently studied. This knowledge gap determines the relevance of the present research.

The aim of this study was to investigate the level of biotic diversity in oak stands and the relationship between natural regeneration and the species composition and age of the parent stand, as well as to assess the influence of the understorey on the growth and development of pedunculate oak regeneration. To achieve this aim, the following objectives were established:

- to determine the species composition of tree and shrub species, enabling the distribution of each species to be assessed and its percentage cover to be determined;
- to assess the intensity of natural regeneration of tree species in order to improve understanding of natural regeneration processes in the study region;
- to identify the characteristics of understorey development in pedunculate oak plantations, providing a basis for optimising silvicultural management practices.

Literature Review

The understorey plays an important role in the formation of the forest litter layer, which is relatively sparse in pure oak stands but considerably more abundant in mixed oak forests. Numerous researchers have investigated the characteristics of natural oak regeneration and the influence of shrub vegetation under different environmental conditions and in different regions. M. Rumiantsev *et al.* (2018) examined the main challenges of natural regeneration of oak forests in Ukraine. The authors analysed the causes of the decline in oak forest area, including inappropriate forest management practices, the influence of shrub vegetation, climate change, and insufficient regeneration of young trees. V. Zaika & Y. Kalenuk (2019) investigated the natural regeneration of oak stands with an admixture of small-leaved lime in

Western Podillia. The authors analysed how stand age, clear-cut conditions, and stand composition influence the establishment and development of young oak regeneration and associated tree species. V. Tkach *et al.* (2019) investigated the characteristics of natural regeneration in oak forests under fresh hornbeam-oak conditions in Podillia. The authors assessed the abundance and condition of common oak saplings, as well as the influence of light conditions, stand composition and forest growth conditions on the success of regeneration. The study concluded that effective natural regeneration of oak requires optimal light conditions and appropriate silvicultural management. An article by F.S. Gilliam (2007) demonstrates the role of the herbaceous layer (together with the undergrowth) in the functioning of temperate forest ecosystems. The author demonstrates that this layer significantly influences nutrient cycling, the formation of forest litter and tree regeneration, often acting as a competitor or filter for seedling germination. It is also emphasised that changes in the undergrowth, caused by human activities or natural factors, can significantly alter the structure and stability of forest ecosystems.

The study by V.J. Lieffers *et al.* (1999) examined the impact of light conditions and shading beneath the forest canopy on the growth and morphology of young trees. The authors demonstrate that limited light under the canopy and in the undergrowth (particularly due to shrubs) significantly alters the physiology of seedlings, reducing their growth and survival capacity. The study emphasises that light conditions are one of the key factors determining the success of natural forest regeneration. The work of G. Kunstler *et al.* (2012) examined the influence of biotic interactions on the formation of plant communities and forest regeneration. It demonstrates that the undergrowth and herbaceous cover can either restrict or promote the growth of tree species, depending on environmental conditions and the intensity of interactions. The authors emphasise that these processes are key to understanding ecosystem structure and predicting changes in biodiversity. The article by S. Hättenschwiler *et al.* (2005) demonstrated the influence of plant biodiversity on litter decomposition processes in terrestrial ecosystems. It demonstrates that plant species composition (including understorey shrubs) determines the rate of litter decomposition through the chemical properties of leaves and interactions with soil organisms. The authors emphasise that plant diversity enhances nutrient cycling and influences the functioning of forest ecosystems.

Materials and Methods

The object of the study was the understorey of oak stands in Husiatyn forest district, Chortkiv forestry. The subject of the study was the development of the understorey in pedunculate oak plantations, its influence on stand growth and development, and its effect on the natural regeneration of oak seedlings, which provides the basis for the establishment of naturally regenerated oak stands. The condition of natural regeneration beneath the forest canopy was assessed according to the methodology of A.I. Shvidenko & B.F. Ostapenko (2001) during the period from June to September. Ten experimental plots were established to determine the species composition of regeneration, its origin, spatial distribution, vitality, mean height, and density. On each sampling plot, the tree species, abundance of regeneration by age (or age group), height class, and vitality class were recorded. The abundance and condition of naturally regenerated seedlings and newly emerged tree seedlings were also assessed separately. The understorey was investigated according to the methodology of P.S. Pogrebnyak (1993). For the understorey, canopy cover, species composition, vertical stratification, and spatial distribution were determined. For each shrub species, abundance, mean height, and regeneration status (absent, weak, moderate, or abundant) were assessed. The following understorey characteristics were recorded: species composition, canopy cover, density (thousand plants ha^{-1}), height, and spatial distribution. Understorey assessments were carried out on ten sample plots, each containing ten sampling quadrats measuring

2 × 2 m. Within these sample plots, where the composition of the principal tree species was identical but the shrub component differed, a differentiated assessment of plant survival by species was conducted. Understorey height was calculated as the mean height of three to five representative individuals of different size classes. Heights were measured using a measuring tape or a measuring ruler. Three understorey layers were distinguished: Layer I – height greater than 1.5 m; Layer II – 0.5-1.5 m; and Layer III – up to 0.5 m (Tutin *et al.*, 1964).

The reliability of the obtained data was evaluated using Microsoft Excel. Statistical analysis of the experimental data was performed using descriptive statistics and sample comparison methods. The coefficient of variation was calculated to assess the uniformity of the replicates. The statistical significance of differences between treatments was determined using one-way analysis of variance (ANOVA), while the non-parametric Kruskal-Wallis test was applied when the assumptions of ANOVA were not satisfied. Differences were considered statistically significant at $p < 0.05$.

Results and Discussion

The understorey in oak forests is the lower layer of shrubs and small trees that plays an important ecological role. It protects the soil from drying out, prevents sodding (grass overgrowth that hinders oak regeneration), and promotes the formation of knot-free oak stems. The principal understorey species identified in the oak forests of Chortkiv forestry include common hazel, which is the most widespread and characteristic woody species and often forms dense thickets; European spindle and warty spindle, which are typical understorey species in oak forests; common dogwood, which is consistently found in the understorey of oak stands; wayfaring tree, which is almost always present in the shrub layer; black elder, a woody species common in the more humid site conditions of oak forests; alder buckthorn, which occurs in open oak stands; and Tatar maple and field maple, which mostly grow in the second storey or in the understorey.

Experimental plots were established in Husiatyn forest district to compare the effects of different shrub species on the growth and development of pedunculate oak and common ash. Common hazel, Tatar maple, and Siberian peashrub were used as components of the shrub layer and were planted in separate rows without being mixed. The summarised results of the study are presented in Table 1.

Table 1. *Survival of planted seedlings established with different shrub species*

No.of trial plots	Type of species mixture	Number of planting spots	Surviving plants	Plant survival (%)
1	Pedunculate oak	70	65	92.8
	Common ash	70	67	95.7
	Common hazel	90	85	94.4
2	Pedunculate oak	50	45	90.0
	Common ash	50	44	88.0
	Tatar maple	95	87	91.5
3	Pedunculate oak	46	30	65.2
	Common ash	42	36	85.7
	Siberian peashrub	85	79	92.9
Total		598	538	90.0

Source: the authors' research

The obtained results (Table 1) indicate a high survival rate of the principal tree species. The survival rates of pedunculate oak and common ash in stands with common hazel were 92.8% and 95.7%, respectively, while the survival rate of the common hazel understorey was 94.4%. In contrast, in the treatments with Tatar maple and Siberian peashrub, where the survival rates of these shrub species were 91.5% and 92.9%, respectively, a significant reduction in the survival of the principal tree species was recorded. The greatest losses of pedunculate oak were observed in plantations containing Siberian peashrub. However, the absence of data on the initial establishment success of the seedlings does not allow these losses to be attributed solely to the influence of this species. It should also be noted that the survival rates of the shrub species themselves differed: losses of Siberian peashrub amounted to only 7.1%, whereas the corresponding losses for Tatar maple and common hazel were 8.5% and 5.6%, respectively (Table 2).

Table 2. *Descriptive statistics of plant survival*

No. of trial plots	Type of species mixture	M ± SD	CV,%	p-value
1	Pedunculate oak	92.80 ± 3.85	4.15	p > 0.05
	Common ash	95.70 ± 2.80	2.93	
	Common hazel	94.40 ± 4.45	4.72	
2	Pedunculate oak	90.00 ± 1.35	1.50	p > 0.05
	Common ash	88.00 ± 4.09	4.65	
	Tatar maple	91.50 ± 4.12	4.51	
3	Pedunculate oak	65.20 ± 2.82	4.33	p < 0.05
	Common ash	85.70 ± 3.43	4.01	
	Siberian peashrub	92.90 ± 3.61	3.88	

Source: the authors' research

According to the data presented in the table, the mean survival rate of plants in the first trial plot ranged from 92.8% to 95.7%, while in the second trial plot it ranged from 88.0% to 91.5%. Considerably greater variability was observed in the third trial plot, where survival ranged from 65.2% to 92.9%. The coefficient of variation did not exceed 5% for most treatments, indicating a satisfactory level of uniformity among the replicates. Comparison of the treatments using ANOVA or the Kruskal-Wallis test showed no statistically significant differences between the treatments in the first and second trial plots ($p > 0.05$). In the third trial plot, statistically significant differences were found between the treatments ($p < 0.05$), with the treatment containing Siberian peashrub showing the highest survival rate, while the lowest survival was recorded for pedunculate oak.

To determine the influence of shrub species on the growth of pedunculate oak and common ash, a complete inventory was carried out on the experimental plots. Plant height, stem diameter (measured at 25 cm above the root collar), and two mutually perpendicular crown diameters (measured along and across the planting rows) were recorded. The measurement results are presented in Table.

Table 3. *Effect of different shrub species on the growth of pedunculate oak and common ash*

<table>
<tr><th rowspan="3">Trial plot No.</th><th rowspan="3">Shrub species</th><th colspan="9">Mean values (cm)</th><th rowspan="3">p-value</th></tr>
<tr><th colspan="3">Height</th><th colspan="3">Stem diameter</th><th colspan="3">Crown diameter</th></tr>
<tr><th>Oak</th><th>Ash</th><th>CV, %</th><th>Oak</th><th>Ash</th><th>CV, %</th><th>Oak</th><th>Ash</th><th>CV, %</th></tr>
<tr><td>1</td><td>Common hazel</td><td>194 ± 2.18</td><td>187 ± 5.35</td><td>2.86</td><td>3.58 ± 0.04</td><td>2.18 ± 0.04</td><td>1.82</td><td>144 ± 5.34</td><td>43 ± 0.60</td><td>1.40</td><td>p > 0.05</td></tr>
<tr><td>2</td><td>Tatar maple</td><td>150 ± 3.05</td><td>129 ± 4.01</td><td>3.11</td><td>2.07 ± 0.03</td><td>1.70 ± 0.01</td><td>1.68</td><td>101 ± 2.25</td><td>38 ± 1.93</td><td>5.08</td><td>p > 0.05</td></tr>
</table>

Table 3. *Continued*

Trial plot No.	Shrub species	Mean values (cm)									p-value
		Height			Stem diameter			Crown diameter			
		Oak	Ash	CV, %	Oak	Ash	CV, %	Oak	Ash	CV, %	
3	Siberian peashrub	160 ± 1.91	125 ± 5.90	4.72	2.24 ± 0.04	1.5 ± 0.07	1.74	97 ± 4.52	40 ± 0.91	2.29	p > 0.05

Source: the authors' research

Analysis of the biometric characteristics of pedunculate oak and common ash under different understorey species showed that the most intensive growth of the principal tree species was observed in the treatment with common hazel. The mean height of pedunculate oak in this treatment was 194 ± 2.18 cm, exceeding the corresponding value in stands with Tatar maple by 44 cm (29.3%) and in stands with Siberian peashrub by 34 cm (21.3%). A similar trend was observed for common ash, with a mean height of 187 ± 5.35 cm, compared with 129 ± 4.01 cm and 125 ± 5.90 cm in the treatments with Tatar maple and Siberian peashrub, respectively. The stem diameter measurements also demonstrated the superiority of the treatment with common hazel. The mean stem diameter of pedunculate oak reached 3.58 ± 0.04 cm, which was almost 1.7 times greater than that recorded in the Tatar maple treatment (2.07 ± 0.03 cm) and 59.8% greater than in the Siberian peashrub treatment (2.24 ± 0.04 cm). For common ash, the largest mean stem diameter was likewise recorded in the common hazel treatment (2.18 ± 0.04 cm), whereas in the Tatar maple and Siberian peashrub treatments it was 1.70 ± 0.01 cm and 1.50 ± 0.07 cm, respectively.

A similar pattern was observed for crown diameter. In the common hazel treatment, the mean crown diameter of pedunculate oak reached 144 ± 5.34 cm, whereas it was 101 ± 2.25 cm in the Tatar maple treatment and 97 ± 4.52 cm in the Siberian peashrub treatment. For common ash, the largest mean crown diameter was also recorded in the common hazel treatment (43 ± 0.60 cm), followed by the Siberian peashrub treatment (40 ± 0.91 cm), while the smallest value was observed in the Tatar maple treatment (38 ± 1.93 cm). The coefficient of variation (CV) for all measured parameters ranged from 1.40% to 5.08%, indicating a low level of variability. This demonstrates the satisfactory uniformity of the experimental treatments and the high reproducibility of the obtained results. The lowest variability was recorded for the crown diameter of common ash in the common hazel treatment (CV = 1.40%), whereas the highest was observed for crown diameter in the Tatar maple treatment (CV = 5.08%), which still falls within the range of low variability. Nevertheless, the statistical analysis showed that the differences between treatments were not statistically significant (p > 0.05). This indicates that, given the number of replicates, the observed differences may be attributable to random variation. However, a clear trend towards better growth of pedunculate oak and common ash was observed in the treatment with common hazel, whereas the use of Tatar maple and Siberian peashrub was associated with lower values of height, stem diameter, and crown diameter.

The improved growth and development of the principal tree species in the common hazel treatment can be explained by the soil-protective properties of this shrub. As a low-growing shrub with a dense crown that limits the penetration of direct sunlight, common hazel suppresses the development of weed vegetation. Furthermore, its shallow root system reduces competition with oak for moisture and nutrients, thereby creating favourable conditions for the growth of the principal tree species.

The formation of the understorey in oak forests depends on stand age, stand stocking density, and the forest management practices applied. At a stocking density of 0.8-1.0, a sparse understorey develops; at 0.7-0.8, the understorey is of medium density; whereas the most developed understorey is characteristic of stands with a stocking density of 0.5-0.7. The obtained results indicate that, under hornbeam-oak forest conditions, shade-tolerant shrub species predominate in terms of frequency of occurrence. These include Tatar maple (*Acer tataricum* L.), common fly honeysuckle (*Lonicera xylosteum* L.), warty spindle (*Euonymus verrucosus* Scop.), European spindle (*Euonymus europaeus* L.), wayfaring tree (*Viburnum lantana* L.), common hazel (*Corylus avellana* L.), common dogwood (*Swida sanguinea* (L.) Opiz), as well as edge species such as common buckthorn (*Rhamnus cathartica* L.), dog rose (*Rosa canina* L.), and blackthorn (*Prunus spinosa* L.).

The native forest stands are dominated by Site Class I pedunculate oak, while the second storey is formed by common hornbeam. Norway maple, sycamore maple, wild pear, and wych elm occur as associated species. Secondary stands are represented mainly by hornbeam forests. In unclosed pedunculate oak plantations up to three years old, the density, height, canopy cover, and frequency of occurrence of the understorey tend to increase. During this period, shrub density ranges from 3.5 to 8.5 thousand plants ha^{-1} at canopy closure values of 0.5-1.0. In addition to shade-tolerant species, light-demanding shrubs such as common buckthorn, wayfaring tree, common dogwood, dog rose, common hazel, and blackthorn actively develop on clear-cut sites up to six years old. Edge species form the first layer of the understorey, while the remaining species occupy the second and third layers. Overall, the understorey is distributed irregularly or semi-uniformly, with a frequency of occurrence ranging from 10% to 60%. In plantations aged 1-6 years, the understorey is dominated by Tatar maple, European spindle, common dogwood, and dog rose, while common hazel occurs only occasionally. Tatar maple is characterised by rapid leaf decomposition and the active return of mineral nutrients to the soil, thereby enriching the upper soil horizons. According to the study results, young oak plantations protected by shrubs, particularly common hazel, grow two to three times more vigorously than those established in open areas owing to the reduced impact of adverse temperature conditions.

In plantations aged 7-10 years, the composition, density, canopy cover, and height of the understorey are determined by stand stocking density, canopy closure, and the forest management practices applied. During this stage, European spindle, warty spindle, and Tatar maple are the dominant species, while edge species such as common buckthorn, common dogwood, and common hazel are also present. Understorey density ranges from 3.7 to 6.5 thousand plants ha^{-1} at canopy closure values of 0.5-1.0. The understorey forms the first and second layers, with heights of 70-250 cm, and is distributed irregularly. The frequency of occurrence of most species ranges from 15% to 50%, whereas that of Tatar maple may reach 70%.

In stands aged 10-20 years, shrub species form a well-developed understorey, the characteristics of which depend on stand stocking density. Shade-tolerant species predominate, particularly European spindle, warty spindle, and common dogwood. Understorey density ranges from 3.9 to 9.4 thousand plants ha^{-1}. In 16-year-old stands, understorey height varies between 50 and 170 cm, corresponding to the first and second layers, whereas in 30-year-old stands the understorey is mainly confined to the third layer, with heights decreasing to 20-30 cm. As stand age increases, the understorey tends to become lower, less branched, and more prostrate.

In pole-stage stands (21-40 years old), stand stocking density ranges from 0.72 to 0.96, accompanied by a decrease in understorey density to 2.4-3.7 thousand plants ha^{-1} at canopy closure values of 0.2-0.7. Shade-tolerant species predominate, particularly warty spindle and common hawthorn. Common dogwood, wayfaring tree, and common hazel occur only occasionally. The understorey is mainly confined to the third layer (up to 0.5 m), whereas common hazel and common hawthorn occupy the second layer. Its spatial distribution is patchy, with a frequency of occurrence ranging from 20% to 80%. In middle-aged and older stands, understorey density varies between 2.4 and 5.7 thousand plants ha^{-1}. The understorey is represented mainly by the second and third layers: maple, common hawthorn, and common dogwood form the second layer (0.7-1.3 m), whereas warty spindle and European spindle exhibit a prostrate growth form (up to 0.5 m). Warty spindle dominates the understorey, accounting for up to 72% of its composition, while Tatar maple represents 40-60%. Other species, including wayfaring tree, common dogwood, and European spindle, occur as associated species. The spatial distribution remains predominantly irregular, with a frequency of occurrence ranging from 10% to 80%. The study showed that on non-forested clear-cut sites, Tatar maple is the dominant understorey species, accounting for 40-70% of the understorey in plantations aged 1-3 and 6-9 years (Fig. 1).

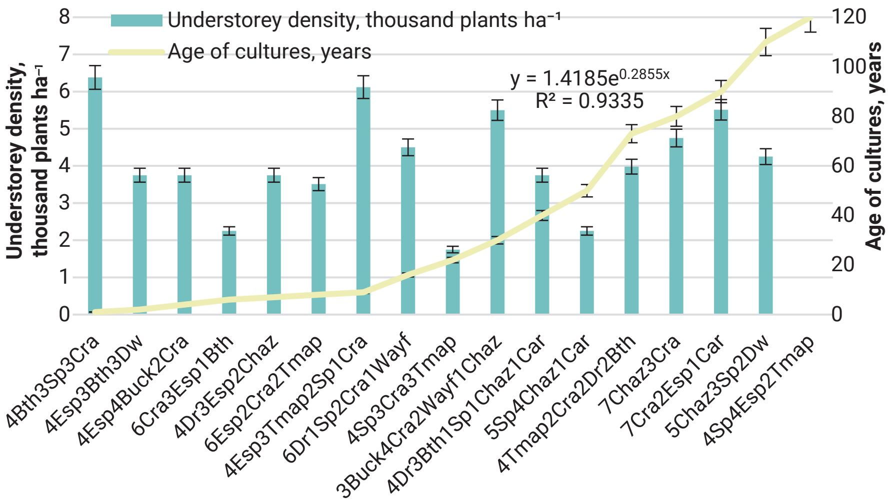

***Figure 1.** Composition of the understorey on clear-cut sites and beneath the canopy of pedunculate oak plantations*

Note: Car – Caragana, Sp – Spindle, Esp – European spindle, Cra – Crataegus oxyacantha, Wayf – Wayfaring tree, Buck – European buckthorn, Tmap – Tatarian maple, Chaz – Common hazel, Dw – Dogwoods, Bth – Blackthorn, Dr – Dog rose

Source: the authors' research

In older stands beneath the forest canopy, the dominant position gradually shifts to European spindle and warty spindle. European spindle predominates in stands aged 9, 10, 15, and 35 years, whereas in maturing and mature stands (90-120 years), warty spindle becomes the principal component of the understorey, accounting for up to 70% of its composition. It has been established that the total number of undergrowth plants varies significantly depending on the age of the stand; however, no clear trend towards a steady increase or decrease has been identified. A similar pattern is also characteristic of species composition: it remains relatively stable, whilst the abundance of individual species may fluctuate depending on the age stage of the stand and environmental conditions.

The studies conducted have shown that the species composition and biometric characteristics of the undergrowth significantly influence the formation and development of young oak-ash stands. Based on the results from the experimental stands, a high survival rate of the main tree species was observed in all treatments; however, the best growth indicators for common oak and common ash were recorded in the treatment with common hazel, where the highest values for height, stem diameter and crown size were noted. The results indicate that common hazel creates the most favourable conditions for the growth of tree species due to its soil-protecting properties, reduced development of herbaceous vegetation, and less competition for moisture and nutrients. Consequently, establishing an optimal species composition of the undergrowth is a key element of forest management, as it provides favourable conditions for the growth and conservation of the main forest-forming species, enhances the biological resilience of young stands and contributes to the formation of productive oak stands.

The article by T. Lustiuk (2015) investigates the influence of light levels beneath the forest canopy on the quantity and quality of natural regeneration of common oak in the moist sub-oaks of Western Polissya. The author establishes that as stand density decreases, more light penetrates the canopy, which contributes to an increase in the number of young oak saplings. This study also confirmed that stand structure and the presence of undergrowth significantly influence the amount of sunlight reaching the forest floor and the success of natural forest regeneration. The study by W. Cornwell *et al*. (2008) demonstrates how the functional properties of plants determine the rate of litter decomposition in various ecosystems around the world. As in this study, it is emphasised that species composition (including shrubs) directly influences the formation of forest litter and the nutrient cycle. The article by D. Wardle *et al*. (2004) demonstrates the interrelationships between aboveground vegetation and soil organisms in ecosystems. It shows that the composition of the undergrowth determines the properties of the litter and soil, thereby influencing microorganisms and decomposition processes. The authors emphasise that these interactions form feedback loops that determine the productivity and stability of ecosystems. The article by S. Hart (2008) is devoted to the influence of the undergrowth and shrub layer on the natural regeneration of trees in forest ecosystems. It shows that dense undergrowth can significantly limit the emergence and growth of seedlings due to competition for light, moisture and nutrients, but at the same time, under certain conditions, it can perform a protective function. The authors emphasise that the balance of these effects determines the success of future stand formation, which is also confirmed by the results presented above. The article by A. Royo & W. Carson (2006) examines the impact of light conditions and competition in the undergrowth on the growth and survival of tree seedlings in forest ecosystems. The study shows that shading under the forest canopy and the presence of undergrowth significantly limit photosynthesis and the growth of young plants, altering their morphological adaptations. The authors emphasise that light conditions and undergrowth structure are key factors in successful natural forest regeneration, which is consistent with the data obtained. The article by F.E. Putz *et al.* (2024) highlighted current changes in the undergrowth of forest ecosystems and their impact on tree regeneration and biodiversity. Their analysis demonstrated that the composition of shrub and herbaceous vegetation influences seed germination, seedling survival, and growth through competition for resources and changes in the microclimate. Similar relationships were observed in the present study. Consequently, based on the work carried out, the following scientific novelty and practical significance of the research results can be formulated.

Conclusions

It was established that increasing stand age and stocking density are accompanied by changes in the vertical structure of the understorey. In young plantations, shrubs predominantly form the first and second layers, reaching heights of

70-250 cm, whereas in stands older than 20 years most species occur in the second and third layers, and the height of the understorey gradually decreases to 20-30 cm. The spatial distribution of the understorey remains predominantly irregular or patchy, with species occurrence frequencies ranging from 10% to 80%. On clear-cut sites and in young plantations (1-9 years), Tatar maple predominates, accounting for 40-70% of the understorey, whereas in older stands the dominant species are European spindle and warty spindle. In maturing and mature stands, the proportion of warty spindle reaches 70%, indicating a gradual change in understorey structure as canopy closure increases. The experimental plantations demonstrated a high survival rate of the principal tree species regardless of the shrub species present in the understorey. The highest survival rates of pedunculate oak (92.8%) and common ash (95.7%) were recorded in the treatment with common hazel. In the treatment with Tatar maple, the corresponding values were 90.0% and 88.0%, while in the treatment with Siberian peashrub they were 65.2% and 85.7%, respectively. The survival rates of the shrub species themselves were also high, amounting to 94.4% for common hazel, 91.5% for Tatar maple, and 92.9% for Siberian peashrub. The best biometric growth characteristics of pedunculate oak and common ash were observed in the treatment with common hazel. The mean height of pedunculate oak was 194 cm and that of common ash was 187 cm, exceeding the corresponding values in the Tatar maple treatment by 29.3% and 45.0%, respectively, and those in the Siberian peashrub treatment by 21.3% and 49.6%. The mean stem diameter of pedunculate oak in the common hazel treatment reached 3.58 cm, while that of common ash was 2.18 cm. In the Tatar maple treatment, the corresponding values were 2.07 cm and 1.70 cm, whereas in the Siberian peashrub treatment they were 2.24 cm and 1.50 cm. The largest crown diameters were also recorded in the common hazel treatment, reaching 144 cm for pedunculate oak and 43 cm for common ash.

Further research will focus on investigating the long-term effects of the understorey on the productivity, stability, and natural regeneration of oak stands, as well as on the physicochemical properties of forest soils and the microclimate of forest ecosystems under changing climatic conditions.

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Conflict of Interest

None.

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Вплив чагарникових порід на природне поновлення основних лісоутворюючих порід в Гусятинському лісництві Чортківського надлісництва

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Анотація. У статті досліджено особливості формування підліску в дубових насадженнях Чортківського надлісництва та його вплив на ріст, розвиток і збереженість головних деревних порід. Визначено основні види чагарникової рослинності, характерні для дібров регіону, серед яких найбільш поширеними є ліщина звичайна, бруслина європейська, бруслина бородавчаста, свидина звичайна, калина-гордовина, клен татарський і клен польовий. Дослідження проводили у Гусятинському лісництві на дослідних ділянках із різними варіантами чагарникового ярусу, де вивчали вплив ліщини звичайної, клена татарського та акації жовтої на ріст дуба звичайного і ясена звичайного. У результаті досліджень встановлено, що найкращі показники збереженості та росту головних порід спостерігалися у варіантах із ліщиною звичайною. За її участі збереженість дуба звичайного становила 92,8 %, а ясена звичайного – 95,7 %, при цьому дерева характеризувалися найбільшою висотою, діаметром стовбурів і кронами. Встановлено, що ліщина звичайна створює сприятливий мікроклімат, пригнічує розвиток бур'янової рослинності та зменшує конкуренцію за вологу й поживні речовини. Водночас використання акації жовтої та клена татарського супроводжувалося нижчими показниками росту й частковим зниженням збереженості дуба. Проаналізовано динаміку складу і густоти підліску залежно від віку та повноти деревостану. Виявлено, що у молодих культурах переважає клен татарський, тоді як у середньовікових і стиглих насадженнях домінують бруслина європейська та бруслина бородавчаста. Отримані результати підтверджують важливу роль підліску у формуванні мікроклімату, підтриманні біорізноманіття та забезпеченні успішного природного поновлення дубових лісів

Ключові слова: дуб звичайний; ясен звичайний; підлісок; насадження; повнота; густота; освітлення