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Peculiarities of natural regeneration in oak forests after different methods of regeneration fellings

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Abstract. An important task for Ukrainian foresters is to adapt forests to climate change and ensure sustainable forest management. One key measure for achieving this goal is the natural regeneration of tree species, which contributes to the biological resilience of forest stands. The purpose of this study is to assess the impact of different methods of main use fellings on the natural regeneration process of tree species in oak forests. The study was conducted within the territory of the Stradch Forestry Educational and Production Complex of the Ukrainian National Forestry University. Data on the quantity and height of oak seedlings and saplings, and other tree species, were collected through observation after various methods of main use fellings were applied in oak forests. An

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analytical method was applied to detect patterns and differences in quantitative and qualitative indicators of young trees of different species in sample plots. Statistical data analysis was employed to establish relationships and draw conclusions based on numerical data. Different success rates of natural regeneration of tree species were identified on plots subjected to various methods of main use fellings. Positive dynamics in the quantity of seedlings and saplings were observed due to first intervention of the uniform shelterwood felling, ranging from unsatisfactory to good levels. It is recognised that the distribution of seedlings and saplings of all tree species was uneven across the area. Hornbeam has the highest frequency of occurrence – 75.6%. Tree species like Scots pine, European birch, and goat willow exhibited occurrence frequencies ranging from 30.8% to 39.7%. In general, in all the studied areas, the undergrowth of tree species was dominated by a small fraction up to 20 cm of height. To ensure the prevalence of pedunculate oak in naturally formed young stands, silvicultural care for its saplings is necessary on all plots. The obtained results provide a basis for developing scientifically grounded forest management measures aimed at increasing the quantity and quality of valuable tree species' saplings, particularly pedunculate oak

Keywords: self-seeding; undergrowth; species composition; hight structure; frequency of occurrence; hornbeam-pine-oak forest on fresh relatively rich soils

Introduction

The natural regeneration of tree species in the forest-steppe region of Ukraine holds significant importance in terms of forest adaptation to climate change and the pursuit of sustainable forest management. The implementation of seed-based natural regeneration is a crucial step towards enhancing the quality of forest stands and ensuring the sustainable development of the forestry sector. However, to effectively utilise natural regeneration, comprehensive research and a scientifically grounded system of forestry measures are required to improve its efficacy.

Researchers pay attention to the problems that remained unresolved in previous studies. For example, M.G. Rumyantsev *et al.* (2016) and O.G. Krynytska (2019) concluded that by employing the uniform shelterwood felling with improved and progressive techniques, successful natural regeneration of pedunculate oak can be achieved. This contributes to the formation of natural oak forests, enhancing their resilience and ecological protection functions.

Numerous works in this field have been conducted in the Vinnytsia region. Specifically, O. Vasylevskyi *et al.* (2018; 2021) examined the impact of reconstructive cutting on forest regeneration under the canopy of middle-aged oak stands. They found that increased illumination of trees after cutting leads to better crown development. V.V. Levchenko (2019) established that release cutting should be performed in areas with dense natural oak seedling undergrowth, ensuring better illumination and preservation of the young oak generation.

The main forest-forming tree species of the Ukrainian Roztochya region, including the pedunculate oak, exhibit high reproductive potential. According to O.G. Krynytska (2019), under favorable conditions, they regenerate successfully both in clear-cuts and under the canopy of parent stands (with satisfactory and good regeneration rates at 80-100% occurrence frequency). However, O.B. Bondar *et al.* (2020) reflected on the question of unsatisfactory natural oak regeneration. The authors consider

the widespread implementation of selective and gradual clearcutting in operational forests, along with reforestation measures excluded from primary use, including actions to support natural oak regeneration, to be crucial. Overall, the success of natural seed-based regeneration of tree species is a complex process influenced by various factors. G.P. Ishchuk (2017) distinguished the following factors: the presence of seed sources, seed crop size, the regenerative maturity of the soil (with the condition of the forest floor being a criterion), and the conditions for the further development and growth of seedlings and saplings.

Results from M. Dillen *et al.* (2017) suggest a potentially significant positive impact of mixing certain tree species. Mixing species on an individual basis is recommended. Therewith, it is necessary to consider differences in the growth rate of young trees, as this variation can negatively affect pedunculate oak growth due to shading. Despite numerous studies on forest vegetation in general and oak stands in particular in the Ukrainian Roztochya, specifics of the natural regeneration of tree species in oak forests after different regeneration felling methods remain unexplored.

Studies on the natural regeneration of tree species remain relevant and vital for forest adaptation to climate change and sustainable forest management.

The purpose of the study is to assess the influence of different methods of regeneration in oak forests on natural regeneration of tree species.

Materials and Methods

The examination of natural regeneration of pedunculate oak and other tree species was conducted within the territory of the Stradch Forestry Educational and Production Complex (SFEPC) of the Ukrainian National Forestry University, which falls within the geographical region of the Ukrainian Roztochya.

The Ukrainian Roztochya is a physiogeographical region situated between the basins of the Dniester, Syan, and Western Bug rivers, starting from the outskirts of Lviv and extending approximately 70 km northwestward to the border with Poland.

The investigation of the natural regeneration of tree species was conducted both in forest plots under the canopy of oak stands after uniform shelterwood felling and in continuous clearcut areas. To determine the quantity of tree seedlings and saplings, monitoring plots of 2 m^2 or 4 m^2 were established on each plot, and the number of tree plants was counted. The number of these plots ranged from 26 to 50 on each site. In addition, measurements of the height of seedlings and saplings were taken, and then they were categorised by height groups: less than 20 cm, 21-50 cm, 51-130 cm, and over 130 cm. The assessment of tree seedlings and saplings was conducted three times: at the beginning of the vegetation period in 2020, at the end of the vegetation period in 2020, and at the end of the vegetation period in 2021.

The examination of the natural regeneration of tree species after the first intervention of the uniform shelterwood felling was conducted in a 138-year-old hornbeam-pine-oak forest on fresh, relatively rich soils within the Lelekhivka Forest District of the SFEPC (Lviv Region) in section 17, compartment 5. The stand composition is 88% pedunculate oak, 9% common hornbeam, 2% Scots pine, and 1% silver birch. Pedunculate oak in the stand is represented by two generations, old and middle-aged trees. The first intervention in this section was performed in February-March 2020 over an area of 1.0 ha with an intensity of 31.7% (103 m^3 removed).

In the same forest type, to compare the success of natural regeneration of tree species, the assessment of tree seedlings and saplings was also performed in two clearcut areas in the

compartments 8 and 9 of the Lelekhivka Forest District of the SFEPC. The stand composition was 69% pedunculate oak, 10% Scots pine, 18% common hornbeam, and 3% silver birch, and the age was also 138 years. In compartment 8.1, the average diameter of oak trees was 40 cm, and in compartment 9.1 it was 36 cm. Clearcutting of the entire stand area was conducted in both compartments in February-March 2020 over an area of 1.0 ha.

Correlation analysis was used in the study to establish the relationship between the quantity of saplings and their occurrence frequency in the oak stand of the Lelekhivka Forest District after the regeneration fellings.

Results and Discussion

The obtained data indicate successful natural regeneration of tree species in all investigated areas within the conditions of a hornbeam-pine-oak forest on fresh relatively rich soils. After the the first intervention of the uniform shelterwood felling, the total quantity of tree seedlings and saplings changes from unsatisfactory at the beginning of the 2020 growing season (10,480 trees per hectare) to good at the end of the same period (41,825 trees per hectare). A year later, at the end of the 2021 growing season, the quantity of tree seedlings and saplings slightly increased and reached 42,693 trees per hectare (Table 1).

Table 1. Species composition and quantity of tree seedlings and saplings per experimental area after the first intervention of the uniform shelterwood felling, categorised by height groups, units per hectare

Tree species	Height groups, cm	Accounting period		
		spring 2020	autumn 2020	autumn 2021
Common hornbeam	⩽ 20	8173	11635	5577
	21-50	1442	1538	7212
	51-130	481	481	5000
	> 130			1346
Scots pine	⩽ 20		2019	5385
	21-50			96
	51-130			
	> 130			
Silver birch	⩽ 20		4423	1827
	21-50		96	3077
	51-130			2500
	> 130			
Pedunculate oak	⩽ 20	192	288	385
	21-50		192	385
	51-130		96	
	> 130			
Red oak	⩽ 20			
	21-50			96
	51-130			
	> 130			
Goat willow	⩽ 20		6154	192
	21-50		10192	4712
	51-130		4327	3558
	> 130			

Table 1, Continued

Tree species	Height groups, cm	Accounting period		
		spring 2020	autumn 2020	autumn 2021
White willow	⩽ 20			
	21-50			96
	51-130			
	> 130			
Sycamore maple	⩽ 20	192	96	
	21-50		96	673
	51-130			192
	> 130			
Rowan	⩽ 20			
	21-50		192	96
	51-130			96
	> 130			192
Total growth per 1 ha		10480	41825	42693

Source: compiled by the authors

The findings indicate an increase in the quantity of pedunculate oak seedlings and saplings under the canopy of the mother oak stand after the first intervention of the uniform shelterwood felling. During the 2020 growing season, its quantity increased from 192 trees per hectare to 576 trees per hectare, and a year later (in autumn 2021) it increased to 770 units per hectare, even though specific support for natural regeneration of pedunculate oak was not conducted on the site.

An analysis of the species composition of the saplings revealed that common hornbeam and goat willow dominate among the tree species, accounting for 57.9% and 23.1% of the total quantity, respectively. Pedunculate oak accounts for only 1.7% of the total amount of undergrowth (Table 1). There is also natural regeneration of species such as Scots pine (5.9%), silver birch (9.4%), sycamore maple (1.4%), and others, the proportion of which in the sapling composition does not exceed 0.5% (Table 1, Fig. 1).

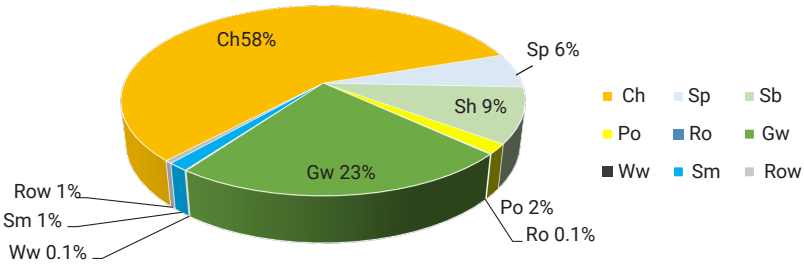


Figure 1. Proportion of tree species in the composition of seedlings and saplings under the canopy of the oak stand after the first intervention of the uniform shelterwood felling

Note: Ch – common hornbeam, Sp – Scots pine, Sb – silver birch, Po – pedunculate oak, Ro – red oak, Gw – goat willow, Ww – white willow, Sm – sycamore maple, Row – rowan

Source: compiled by the authors

An analysis of the height structure of the saplings revealed that after the first intervention of the uniform shelterwood felling within the oak stand, small (≤20 cm) and medium (21-50 cm) size fractions dominate in the pedunculate oak seedlings. Seedlings and one-year-old saplings constitute the major part of the regeneration, whereas large saplings taller than 130 cm are mainly observed among common hornbeam and common rowan (Table 1, Fig. 2).

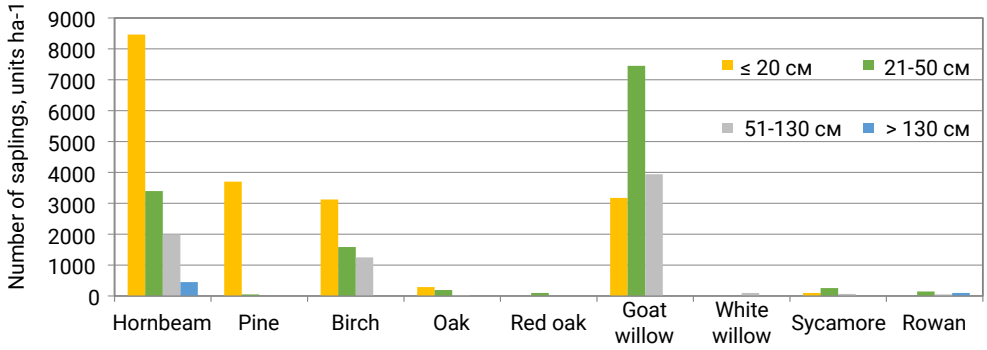


Figure 2. Distribution of understory by height groups under the canopy of an oak stand after the first intervention of the uniform shelterwood felling

Source: compiled by the authors

The spatial distribution of understory within the plot represents the frequency of occurrence, expressed as a percentage ratio of the number of sample plots with presence of certain tree seedlings and saplings to the total number of established sample plots within the plot area. Under the canopy of the oak stand, the natural regeneration of all tree species is characterised by an uneven distribution across the area. The highest frequency of occurrence is observed in common hornbeam – 75.6 %. Other species such as Scots pine, silver birch, and goat willow have occurrence frequencies ranging from 30.8% to 39.7%. All other tree species, including pedunculate oak, are encountered much less frequently (from 1.3% to 12.8%) (Fig. 3).

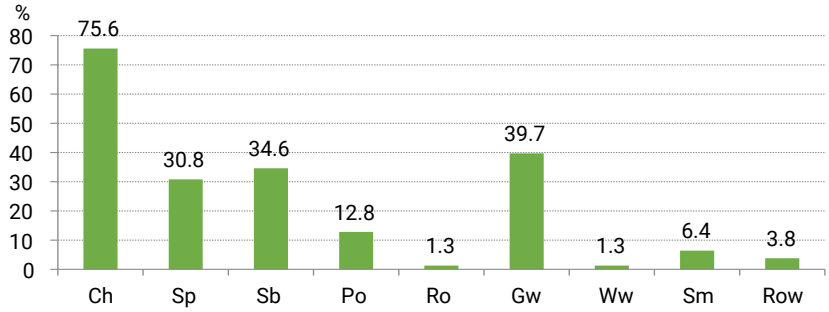


Figure 3. Occurrence frequency of tree seedlings and saplings (%) under the canopy of the oak stand

Note: Ch – common hornbeam, Sp – Scots pine, Sb – silver birch, Po – pedunculate oak, Ro – red oak, Gw – goat willow, Ww – white willow, Sm – sycamore maple, Row – rowan

Source: compiled by the authors

A strong correlation was found between the number of tree seedlings and saplings and their occurrence frequency in the oak forest of Lelekhivka Forest District after the first intervention of the uniform shelterwood felling ($R^2 = 0.9$):

$$N = 0.881 \cdot Z^2 + 133.82 \cdot Z - 494.65, \qquad (1)$$

where N – number of undergrowth, units; Z – occurrence rate, %.

The prediction of the future participation of tree species in the forest structure can be performed based on the occurrence frequency of the respective species in the understory. The quantity and species composition of the understory are largely influenced by the development of the ground cover and undergrowth, the presence of forest fauna, crown closure of the mother trees, and other factors. Suppression by herbaceous vegetation is one of the main reasons for the mortality of the understory. The indices of the projective cover of the herbaceous layer on the sample plots varied greatly (from 1% to 100%), and its height ranged from 3 cm to 120 cm. Optimal natural regeneration of tree species was observed in places with low closure of the herbaceous cover, and in situations where low-growing plants predominated in its structure.

The composition of the ground cover on the sample plots was quite uniform. It was dominated by European dewberry (*Rubus caesius* L.), reed bent grass (*Calamagrostis epigejos* (L.) Roth), and brown sedge (*Carex brizoides* L.), while white bedstraw (*Galium album* Mill.) and male fern (*Dryopteris filix-mas* (L.) Schott) were less common. The thickness of the forest litter averaged 2 cm.

In contrast to the plot subjected to the first intervention of the uniform shelterwood felling, the two areas that underwent clearcut logging of a mature 138-year-old oak stand exhibited a notably higher abundance of young tree seedlings and saplings. The collective count of understory vegetation on these clear-cut areas ranged from 175.6 to 275.3 thousand specimens per hectare at the commencement of the 2020 growing season, rising to 299.4 thousand specimens per hectare by the conclusion of the same growing season, and further increasing to 461.2 thousand specimens per hectare during the autumn of 2021 (Table 2). It should be noted that the predominant proportion of tree seedlings and saplings on these clear-cut areas comprises youthful common hornbeam entities, forming dense clusters across certain sample plots.

Table 2. Species composition and quantity of tree seedlings and saplings on clear-cut areas by height groups, units per hectare

Tree species	Height groups, cm	Lelekhivka Forest District, compartment 25, subcompartment 8.1			Lelekhivka Forest District, compartment 25, subcompartment 8.1		
		Accounting period			Accounting period		
		VI 2020	X 2020	X 2021	VI 2020	X 2020	X 2021
Common hornbeam	⩽ 20	239500	226400	154900	164861	178750	53472
	21-50	100	1700	147700	278	1806	211250
	51-130	100	200	11100	139	139	25556
	> 130					278	
Scots pine	⩽ 20		4600	3200		4861	2500
	21-50	300		1600			1389
	51-130						

Table 2, Continued

Tree species	Height groups, cm	Lelekhivka Forest District, compartment 25, subcompartment 8.1			Lelekhivka Forest District, compartment 25, subcompartment 8.1		
		Accounting period			Accounting period		
		VI 2020	X 2020	X 2021	VI 2020	X 2020	X 2021
Silver birch	⩽ 20		19100	7600		5417	1250
	21-50		4300	36500		1389	9444
	51-130			28800			10833
	> 130			1100			
Pedunculate oak	⩽ 20	30700	35700	19000	5417	4861	2639
	21-50	1800	3200	19400		972	4444
	51-130			100			139
	> 130						
Small-leaved linden	⩽ 20		1800	1800			139
	21-50		800	5700			139
	51-130			2100			278
Goat willow	⩽ 20			1300			694
	21-50			8700			6389
	51-130			5900			3194
	> 130			100			
White willow	⩽ 20			800			
	21-50			200			
	51-130						278
	21-50			200			
	51-130						139
Norway maple	⩽ 20	1900	1100	900	1528	694	556
	21-50	600	400	300	139	556	556
	51-130	100	100	200			
Common beech	⩽ 20				139		139
	21-50				278	278	139
	51-130			100	2361	2361	2917
	> 130				417	278	139
Scots elm	⩽ 20	200					
	21-50			300			
	51-130			200			
	21-50			1200			139
	51-130			200			556
Total growth per 1 ha		275300	299400	461200	175557	202640	339307

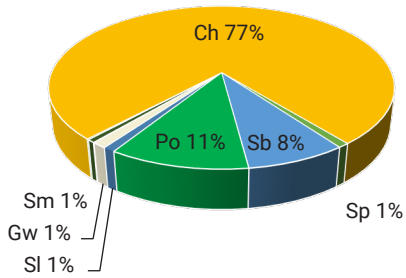
Source: compiled by the authors

Unlike the abundant presence of common hornbeam saplings on the clear-cut areas, the number of pedunculate oak saplings was significantly lower and remained relatively consistent throughout the study period. For instance, in compartment 25, subcompartment 8.1

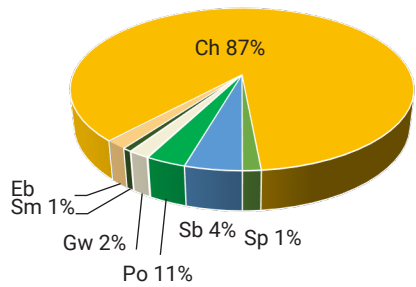
of the Lelekhivka Forest District, the number of pedunculate oak saplings was 32,500 units per hectare in the spring of 2020, 38,900 units per hectare at the end of the 2020 growing season, and slightly decreased over the following year to reach 38,500 units per hectare in the fall of 2021.

Due to the recent implementation of clearcut logging, it is logical that both clear-cut areas predominantly feature a small fraction of young tree seedlings and saplings. The growth of species such as beech, birch, and various types of maple with a height of 51 cm and above is primarily attributed to their vegetative regeneration.

To gain a more comprehensive understanding of the natural regeneration process on the clear-cut areas within the context of the hornbeam-pine-oak forest on fresh relatively rich soils, the collected data has been summarized in Figure 4.



a) Lelekhivka Forest District, compartment 25, subcompartment 8.1



b) Lelekhivka Forest District, compartment 25, subcompartment 9.1

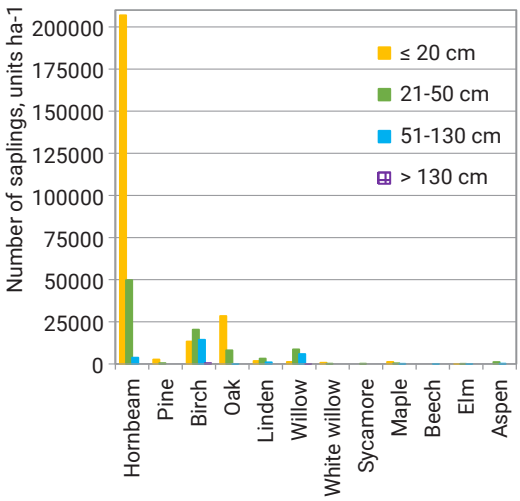
Figure 4. Distribution of tree species in the composition of tree seedlings and saplings on clear-cut areas

Note: Ch – common hornbeam, Sp – Scots pine, Sb – silver birch, Po – pedunculate oak, Gw – goat willow, Sb – silver birch, Eb – European beech, Sm – sycamore maple, Sl – small-leaved linden

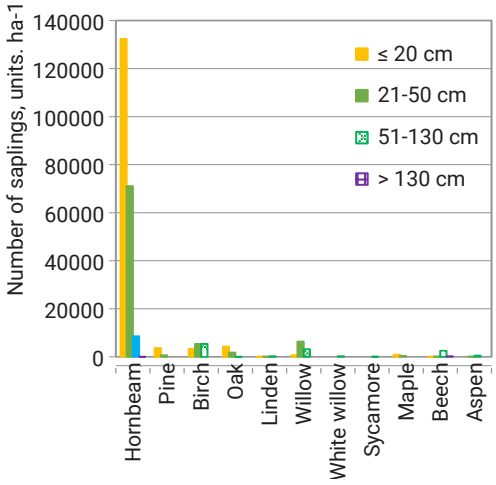
Source: compiled by the authors

The analysis of the sapling composition on the investigated clear-cut areas indicates the dominance of common hornbeam among other tree species. The average proportion of common hornbeam, based on three counts, ranges from 77% to 87% of the total number of young individuals, while the proportion of pedunculate oak accounts for only 3% to 11%. Occasional occurrences of other accompanying species like Scots pine, silver birch, goat willow, white willow, sycamore maple, Norway maple, small-leaved linden, common rowan, European beech, rough-leaved elm, red oak, and European aspen are observed (Table 2, Fig. 4). Thus, natural regeneration of all representative tree species is present on the clear-cut areas, allowing forest management methods to establish a stable stand of native trees.

An analysis of the height structure of the saplings on the clear-cut areas reveals that the dominance of small sapling fractions (up to 20 cm in height) is prevalent for both pedunculate oak and other tree species (Fig. 5). However, a substantial portion of these saplings later succumbs to damage caused by forest animals, lack of light, intense competition from the forest floor vegetation, and other unfavourable factors.



a) Lelekhivka Forest District, comp. 25, subcomp. 8.1

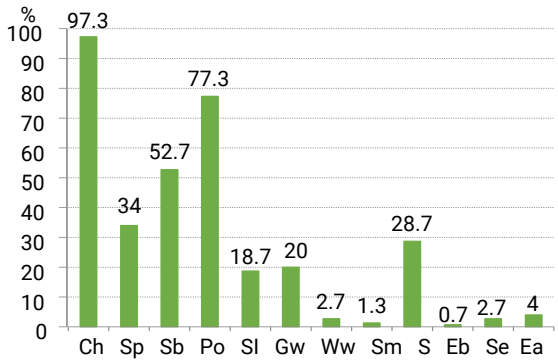


b) Lelekhivka Forest District, comp. 25, subcomp. 9.1

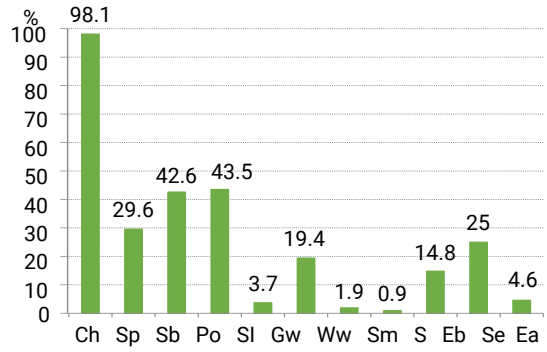
Figure 5. Distribution of tree saplings on clear-cut areas by height groups

Source: compiled by the authors

The distribution pattern of saplings across the area indicates that the natural regeneration of all tree species is characterised by uneven spread on the clear-cut areas. The highest frequency is observed for common hornbeam, ranging from 97.3% to 98.1%. Less frequent occurrences include pedunculate oak (43.5% to 77.3%), silver birch (42.6% to 52.7%), and Scots pine (29.6% to 34.0%). Other tree species such as small-leaved linden, willow, white willow, sycamore maple, sycamore, European beech, rough-leaved elm, and European aspen account for 0.7% to 20% (Fig. 6).



a) Lelekhivka Forest District, comp. 25, subcomp. 8.1



b) Lelekhivka Forest District, comp. 25, subcomp. 9.1

Figure 6. Frequency of tree sapling occurrence (%) on clear-cut areas

Note: Ch – common hornbeam, Sp – Scots pine, Sb – silver birch, Po – pedunculate oak, Sl – small-leaved linden, Gw – goat willow, Ww – white willow, Sm – sycamore maple, S – sycamore, Eb – European beech, Se – Scots elm, Ea – European aspen

Source: compiled by the authors

Very close correlations were established between the number of undergrowth in the test areas and the frequency of its occurrence:

$$N = 39{,}712 \cdot Z^2 - 1719{,}5 \cdot Z + 10643$$
$$(R^2 = 0.9)\ (25\ \text{comp., subcomp. } 8.1); \quad (2)$$

$$N = 24{,}574 \cdot Z^2 - 787{,}67 \cdot Z + 4556{,}1$$
$$(R^2 = 1{,}0)\ (25\ \text{comp., subcomp. } 9.1), \quad (3)$$

where N – number of undergrowth, units; Z – frequency of occurrence, %.

The extent of the projected ground cover of the herbaceous layer on the clear-cut areas varied from 10% at the beginning of the 2020 growing season (the first year after clearcut logging) to over 70% by the end of the 2021 growing season. The average height of this herbaceous layer was 6 cm and 70 cm, respectively. The most successful natural regeneration process occurred in areas with low plants and a sparse herbaceous cover. The herbaceous layer composition on the clear-cut areas was dominated by wood anemone (*Anemone*

sylvestris L.), common reed (*Calamagrostis epigejos* (L.) Roth.), tawny sedge (*Carex brizoides* L.), wood spurge (*Euphorbia amygdaloides* L.), lily of the valley (*Convallaria majalis* L.), lungwort (*Pulmonaria officinalis* L.) and greater stitchwort (*Stellaria holostea* L.). The average thickness of the forest litter was 1.0 cm.

The results obtained from this study confirm the importance of issues related to the preservation and effective management of forest ecosystems, particularly within the unique natural complex of the Ukrainian Roztochya region, which holds significance as part of the Main European Watershed (Soroka, 2008). In general, the study of natural oak regeneration was conducted under diverse edaphoclimatic conditions and across multiple geographical regions of Ukraine: from Zakarpattska Oblast (Agiy *et al.*, 2016) to Sumy Oblast (Rumyantsev, 2016; Bondar *et al.*, 2020).

The findings share common features with the results of other researchers. Similar key factors for successful and high-quality oak forest regeneration in northwestern Germany were described by the German researchers A. Mölder *et al.* (2019). They recommend natural oak regeneration to be performed in close proximity to old oak stands or directly within them. Similar conclusions were drawn by English researchers. R. Harmer *et al.* (2005) asserted that in southern England, the number of oak seedlings is closely linked to the quantity and distance from parent trees, decreasing by 40-50% each year. Likewise, Dobrowolska (2006), who conducted studies in floodplain oak forests of Lower Silesia (Poland), arrived at similar conclusions.

M.M. Vedmid (2008), R. Crouzeilles *et al.* (2016), L.I. Kopiy *et al.* (2017) have found that naturally regenerated oak forest stands are more viable and advantageous compared to artificially established forests. These naturally regenerated stands grow faster, exhibit higher competitive ability against other tree species, and demonstrate greater resilience to negative natural influences. Harnessing the potential of natural oak regeneration not only reduces the costs of reforestation but also significantly shortens the time required for oak wood production and enhances the productivity of oak forest stands. This approach also contributes to the formation of more resilient oak-dominated stands that can better withstand adverse natural phenomena. These conclusions are supported by O. Vasylevskyi *et al.* (2018; 2021), who conducted extensive studies on natural oak forests in Vinnytsia. They assert that the main reason for the decline in the proportion of natural oak forests in Vinnytsia is the establishment of forest plantations and the low utilisation of natural oak regeneration.

Moreover, apart from the described and studied factors influencing the success of natural seedling regeneration of tree species, P. Annighöfer *et al.* (2015), J. Leonardsson *et al.* (2015), and M.V. Matusyak *et al.* (2019) indicate the following factors as relevant: the presence of seed sources, abundant fruiting, regenerative soil maturity, which is indicated by the state of forest litter, and the conditions for the further development and growth of seedlings and saplings. However, the most considerable factors in the natural regeneration of oak stands are illumination and competition of oak seedlings with associated tree species and herbaceous vegetation (Didenko & Polyankov, 2019; Mölder *et al.*, 2019). Polish researchers concluded that to achieve the best stem quality, it is necessary to ensure full canopy illumination for oak as soon as possible, but no later than 20 years from the start of pedunculate oak regeneration (Skrzyszewski & Pach, 2015).

T.P. Fedonyuk *et al.* (2017) demonstrated that five years is the ultimate deadline when oak can withstand inadequate illumination in coppice and understorey conditions. The vertical structure of the stand, understory, and

the undergrowth of older generations directly influence the solar radiation reaching the oak seedlings. Therefore, to ensure successful natural seed regeneration of oak on relatively rich soils and to ensure its participation in future stands, it is proposed to maintain a relative stand density of no more than 0.7. Similar views are also upheld by O.G. Krynytska (2019). For successful regeneration and formation of natural oak stands, she recommends implementing measures that promote natural regeneration and appropriate forest management to preserve oak seedlings and undergrowth. Among these, the main ones include thinning the parent stands to a relative density of 0.6-0.7, reducing competition from herbaceous cover and understory, and timely canopy openings.

In addition to illumination, the success of pedunculate oak regeneration also significantly depends on the acorn yield and the population size of wildlife. To mitigate the impact of ungulates, R. Solymos (1993) from Hungary and J. Leonardsson *et al.* (2015) from Sweden suggest establishing enclosures to protect oak seedlings or saplings.

Another important factor influencing the intensity and quality of natural regeneration of key forest-forming species, including pedunculate oak, is the development of competing understorey and herbaceous vegetation (Leonardsson *et al.*, 2015; Lavnyy, 2021). The research conducted by C.J. Schweitzer *et al.* (2016) pertains to factors affecting fruiting and survival of young oak trees. They identify two main factors for successful natural regeneration: ensuring previous oak regeneration under the canopy of advancing stands and subsequent promotion of its undergrowth by thinning the upper canopy of the stand and removing parts of trees from the second canopy layer.

Similar to this study, in the conditions of fresh oak-pine coppice in Volyn region, M. Shevchuk *et al.* (2021) found that the highest number of pine and oak saplings is present in areas with low to moderate herbaceous cover density. The optimal environment for the emergence and preservation of seedlings is in low-lying and plain microrelief areas, where the oak sapling density is highest. The modelling systems of German researchers A. Mölder *et al.* (2019) yielded similar results. Competition from secondary tree species and herbaceous vegetation is the most decisive factor in the success of pedunculate oak regeneration.

Therefore, to increase the number of oak seedlings and undergrowth, V.V. Levchenko (2019), M. Shevchuk *et al.* (2021) recommend implementing forestry measures to promote natural regeneration. One of the most effective measures for increasing oak participation in the undergrowth is the proper selection of cutting methods (selective, gradual, transformation), which will improve oak tree fruiting and its quality natural regeneration.

Conclusions

The findings indicate that there is successful natural regeneration of tree species in the oak forests of the Stradch Educational and Production Forest Enterprise of the Ukrainian National Forestry University. This regeneration occurs both under the canopy of mature oak stands after the implementation of the first intervention of the uniform shelterwood felling and on clearcuts after the implementation of clearcutting in mature oak stands. Among the regenerating plants, common hornbeam was the most frequently observed species on the studied plots, comprising an average proportion ranging from 58% to 87% of the total regenerating population. The study showed that the proportion of pedunculate oak among the regenerating and undergrowth plants is relatively low: only 2% after the first intervention of the uniform shelterwood fellingg and 3-11% on clearcuts. This emphasises the necessity of implementing

silvicultural measures across all areas to support the natural regeneration of pedunculate oak, ensuring its dominance within the naturally formed young stand. It was established that the natural regeneration of tree species in the studied areas depends on a complex of abiotic, biotic, and anthropogenic factors. Key among them are climatic indicators, species composition, and density of the understory, forest fauna, organisation of forestry operations, and proper execution of clearcut site preparation.

Analysis of the height structure of the undergrowth on sample plots showed that the dominant fraction is the small one (up to 20 cm). The frequency of occurrence of young pedunculate oak plants on the sample plots varies, accounting for 12.8% after the first intervention of the uniform shelterwood felling and 43.5-77.3% on clearcuts. A very strong correlation was found between the amount of undergrowth on sample plots and its frequency, confirmed by the coefficient of determination R^2 ranging from 0.9 to 1.0.

Based on the obtained results and the aforementioned conclusions, an important area for further studies is a deeper understanding of the mechanisms of natural regeneration of oak forests and the impact of various factors on this process. Further studies may involve analysing a wider spectrum of abiotic, biotic, and anthropogenic factors, the dynamics of the height structure of the undergrowth, and establishing further relationships between its quantity and frequency. In addition, these studies can be extended to other forest ecosystems to obtain more generalised and representative data on the natural regeneration of tree species, which will contribute to sustainable forest management and the preservation of natural biodiversity.

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Conflict of Interest

The authors declare no conflict of interest.

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Особливості природного поновлення в дубових лісах після різних способів рубок головного користування

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Анотація. Важливим завданням лісівників України є адаптація лісів до змін клімату та забезпечення сталого лісового господарства. Одним із ключових заходів для цього є природне поновлення деревних видів, яке сприяє підвищенню біологічної стійкості деревостанів. Метою дослідження була оцінка впливу способів рубок головного користування у дубових лісах на процес природного поновлення деревних видів. Дослідження проводилося на території

Страдчівського навчально-виробничого лісокомбінату Національного лісотехнічного університету України. За допомогою методу спостереження було проведено збір даних щодо кількості та висоти самосіву і підросту дуба звичайного та інших деревних видів після різних способів рубок головного користування в дубових лісах. Метод аналізу був застосований для виявлення залежностей та відмінностей між кількісними та якісними показниками молодих особин різних деревних видів на пробних площах. За допомогою статистичної обробки даних було встановлено зв'язки та зроблені висновки на основі числових даних. На ділянках з різними способами рубок головного користування було виявлено різну успішність природного поновлення деревних видів. Внаслідок першого прийому рівномірно-поступової рубки спостерігалася позитивна динаміка кількості самосіву та підросту від незадовільного до доброго рівня. Встановлено, що самосів і підріст всіх деревних видів характеризувався нерівномірним поширенням на площі. Найбільшу частоту трапляння має граб звичайний – 75,6 %. Такі види як сосна звичайна, береза повисла та верба козяча мають частоту трапляння в межах від 30,8 % до 39,7 %. Загалом на всіх досліджених ділянках у складі підросту деревних видів переважала дрібна фракція висотою до 20 см. Для забезпечення переваги дуба звичайного в складі природно сформованого молодого деревостану на всіх ділянках потрібно провести лісівничий догляд за його підростом. Результати дослідження дають підстави для розробки науково обґрунтованих лісогосподарських заходів з метою підвищення кількості та якості підросту цінних деревних видів, зокрема дуба звичайного

Ключові слова: самосів; підріст; видовий склад; висотна структура; частота трапляння; свіжа грабово-соснова судіброва