Received: 01.02.2024; Revised: 19.04.2024; Accepted: 29.05.2024

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 15(2)

UDC 630
DOI: 10.31548/forest/2.2024.118

Ecological and cenotic features of natural regeneration of forests in the Left-Bank Polissya of Ukraine

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Suggested Citation:
Tokarieva, O., Kushnir, A., Sendonin, S., Yavnyi, M., & Kurylo, O. (2024). Monumental trees of Ukraine and public awareness of them. *Ukrainian Journal of Forest and Wood Science*, 15(2), 118-134. doi: 10.31548/forest/2.2024.118

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Abstract. The research relevance of the complex, multi-stage process of natural regeneration of forest communities, as well as interactions and transformations, is determined by the rapidly growing challenges posed by climate change, deforestation and biodiversity loss. The study aims to assess the state and to identify the ecological and coenotic specificity of natural seed regeneration of the leading forest-forming species of the Left-Bank Polissya of Ukraine. The study was carried out using a set of methods, primarily geobotanical, population and mathematical and statistical. The process of natural recovery was studied in communities that are typical for the region and belong to 42 syntaxa in the rank of associations and 24 syntaxa in the rank of association groups. The study revealed the specifics of such forest-forming species as *Pinus sylvestris* L., *Quercus robur* L., *Acer platanoides* L., *Betula pendula* Roth., *Populus tremula* L., *and Tilia cordata* Mill. The study established that the representation of the undergrowth of the main forest-forming species in the forest plant communities of the Left-Bank Polissya of Ukraine varies quite significantly. The study described the determinants of the species composition of restoration, including the peculiarities of seed (fruit) dispersion and the adaptive potential of plants. The study determined that the condition of the understory and its population density are determined by the level of soil moisture (the highest values of understory density in most species were recorded in forests with soils moistened at the level of fresh and wet hygro-tops), and this process may intensify against the background of climate change. The results of the study can be used to develop effective strategies for forest management, biodiversity conservation and sustainable forest management in the Left Bank Polissia region, which will help improve the environmental situation and create favourable conditions for the restoration of forest ecosystems

Keywords: undergrowth; population density; seed dispersal; biodiversity; *Pinus sylvestris* L.; *Quercus robur* L.

Introduction

Forests play a key role in the planet's vegetation cover, covering large areas and performing important functions. Natural regeneration is one of the key processes for the existence of forest communities. This is a complex, long and multi-stage process, during which individuals of a new generation of forest-forming species undergo qualitative and quantitative changes that allow them to gradually move from one forest layer to the next until they reach the standing stage. The interactions and transformations that occur at each stage of regeneration, as well as the formation of a continuous flow of generations of forest-forming species that ensure the sustainable existence and functioning of forest phytocoenoses, are still not fully described. The study of these processes is an urgent scientific issue of great theoretical and practical importance for the conservation and sustainable use of forest resources.

Therefore, it is no coincidence that the issue of studying the reforestation process is constantly the focus of attention of both global and Ukrainian scientists. The study by K.R. Talakh & V.P. Krasnov (2023) provides valuable information on the peculiarities of pine forest restoration in the Zhytomyr region, which can be used to develop effective methods of reforestation in this region. It highlights the impact of various environmental and management factors on the success of the natural regeneration of pine forests. The methodological approaches of V.V. Batrin & V.P. Kichura (2020) to assessing the effectiveness of various methods of beech plantation restoration in the State Enterprise "Dovzhanske Forestry and Hunting Range" can be a useful tool for managing forest resources in regions with a predominance of beech forests. Their study revealed the advantages and disadvantages of different reforestation methods for beech forests. The analysis of changes in forest cover in the Skole Beskydy National Nature Park by O.H. Chaskovskyy & H.H. Hrynyk (2020) highlights the impact of logging on the highland forests of the Ukrainian Carpathians and can help to develop conservation measures. It also provides information on the dynamics of natural forest regeneration after logging in the region. V. Fesyuk *et al*. (2023) emphasise the importance of forest monitoring, remote sensing and natural regeneration for the rational use and protection of forests in the Volyn region. Their approach identified areas that require special attention and reforestation measures. Conclusions of Y.A. Kovalenko & T.M. Ivanyuk (2022) on the degradation of pine stands in Irshanske forestry can be used to develop strategies for restoring and increasing the resilience of pine forest stands in this region. Their research highlights the main factors leading to the degradation of pine forests. Research by M.G. Rumyantsev (2022) studied a relevant aspect of the regeneration of oak plantations naturally in fresh oak forests in the forest-steppe part of Sumy region, which can contribute to the conservation and restoration of valuable oak forests. Its results describe the conditions necessary for successful natural regeneration of oak forests in this region.

Although research on natural forest regeneration is now widespread and covers various geographical regions, the study of this process remains extremely important for areas where forests play a key role in the formation of natural complexes and have significant ecological, environmental and economic importance. In Ukraine, one of these key areas is the Left Bank Polissia, where forests are a crucial component of the environment, ensuring environmental stability and performing important functions for biodiversity conservation and forestry.

Given the above, this publication aimed to assess the state and find out the ecological and cenotic features of natural seed regeneration of the leading forest-forming species of the Left-Bank Polissya of Ukraine.

Materials and Methods

A detailed in-depth study of the natural regeneration of the leading forest-forming species of the Left-Bank Polissia of Ukraine, namely *Pinus sylvestris* L., *Quercus robur* L., *Acer platanoides* L., *Betula pendula* Roth., *Populus tremula* L., *Tilia cordata* Mill, has been carried out for more than 10 years.

The study addresses the specifics of communities that are typical for the region and belong to 42 syntaxa in the rank of associations and 24 syntaxa in the rank of association groups. Their phytocoenotic affiliation and place in the system of the classification scheme of forest vegetation are given below.

During the study of ecological and cenotic features of natural forest regeneration in the Left-Bank Polissia of Ukraine, the ethical standards set out in the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973), which regulate the conservation of biodiversity, sustainable development and protection of rare species of animals and plants in the course of scientific research, was upheld.

To determine the state and structure of forest plant communities under the canopy of which the natural regeneration of the leading forest-forming species of the Left-Bank Polissya of Ukraine takes place, common geobotanical methods were used. To ensure the representativeness of the data in the studied forest communities, several 20 m×20 m plots were set up, where a detailed geobotanical description was carried out following standard methods (Yakubenko *et al.*, 2017). Based on the geobotanical descriptions and the dominant classification, the phytocoenotic affiliation of the studied communities and their correspondence to certain forest types were determined. To obtain the most complete information on the layer structure of forest phytocoenoses, the condition of trees was assessed using forest stand indicators (Pasternak & Nazarenko, 2019).

The success of natural regeneration is determined by the quantitative and qualitative indicators of the young generation (sub-generation) of forest-forming species. In this regard, three groups (cohorts) of the sub-adolescents were identified, which were respectively covered by this study and differentiated according to various characteristics:

1. Small undergrowth is plants up to 50-70 cm tall that are entirely located in the herbaceous layer. Their root system is superficial, their age is from 3-5 to tens of years, and they are mostly juvenile, immature or quasi-senile individuals.

2. The middle undergrowth is a 0.5-2.5 m high plant that "emerges" from the herbaceous and shrub layer into the undergrowth. These are mostly immature and virgin plants with fast growth.

3. Large undergrowth – individuals 2.5-8.0 m high, located in the undergrowth. Their root system is in the deeper layers of the soil.

During the surveys, the species composition of natural regeneration was determined, and the total number of young plants of forest-forming species was counted on 20×20 m plots, separately for each cohort. For small undergrowth, additional 0.25 m^2 plots of at least 50 units within the main plot were employed. The results were calculated per 1 ha of phytocoenosis. The null hypothesis was that there is no difference in the affiliation of the undergrowth of different forest-forming species to certain groups of forest communities (associations).

Specialised statistical packages STATISTICA and PAST were used to process the research results. The statistical reliability of the quantitative data obtained, and their generalisation were assessed using analysis of variance and the chi-square (χ^2) criterion. This ensured the proper level of reliability of the study's findings and to analyse the data correctly.

Results

Based on the results of the study, the representation of the undergrowth of the main forest-forming species in forest plant communities varies significantly. Stable recovery of *P. sylvestris* was recorded in 41.7% of the surveyed association groups, *Q. robur* – 70.8%, *A. platanoides* – 50%, *B. pendula* – 75%, *P. tremula* – 41.7%, *T. cordata* – 8.3% (Table 1).

Table 1. Species composition of sustainable natural regeneration of leading forest-forming species by main groups of associations of the Left-Bank Polissya of Ukraine

Type	Groups of associations																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Pinus sylvestris	+	+	+				+	+		+	+					+					+		+	
Quercus robur	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+				+		+	
Acer platanoides	+			+				+				+			+	+	+	+	+	+		+	+	

Table 1, Continued

Type	Groups of associations																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Betula pendula	+	+	+	+	+		+	+	+	+	+		+	+		+		+			+	+	+	+
Tilia cordata											+									+				
Populus tremula	+				+		+		+	+			+			+				+			+	+

Note: "+" – presence of individuals of a certain species; numbering of association groups: 1. *Pineta (sylvestris) hylocomiosa*; 2. *Pineta (sylvestris) calamagrostidosa (epigeioris)*; 3. *Pineta (sylvestris) nardosa (strictae)*; 4. *Pineta (sylvestris) coryloso (avellanae) – vacciniosa (myrtilli)*; 5. *Pineta (sylvestris) asarosa (europaei)*; 6. *Pineta (sylvestris) pteridiosa (aquilini)*; 7. *Pineta (sylvestris) franguloso (alni) – vacciniosa (myrtilli)*; 8. *Pineta (sylvestris) vacciniosa (myrtilli)*; 9. *Pineta (sylvestris) moliniosa (caeruleae)*; 10. *Pineta (sylvestris) sphagnosa*; 11. *Querceto (roboris) – Pineta (sylvestris) vacciniosa (myrtilli)*; 12. *Querceto (roboris) – Pineta (sylvestris) corylosa (avellanae) sparsi herbosa*; 13. *Betuleto (pendulae) – Pineta (sylvestris) vacciniosa (myrtilli)*; 14. *Querceta (roboris) majanthemosa (bifolii)*; 15. *Querceta (roboris) aegopodiosa (podagrariae)*; 16. *Querceta (roboris) convallariosa (majalis)*; 17. *Querceta (roboris) coryloso (avellanae) – convallariosa (majalis)*; 18. *Acereto (platanoiditis) – Querceta (roboris) coryloso (avellanae) – aegopodiosa (podagrariae)*; 19. *Acereto (platanoiditis) – Querceta (roboris) stellariosa (holosteae)*; 20. *Tilieto (cordatae) – Querceta (roboris) stellariosa (holosteae)*; 21. *Betuleta (pendulae) vacciniosa (myrtilli)*; 22. *Betuleta (pendulae) caricosa (pilosae)*; 23. *Betuleta (pendulae) stellariosa (holosteae)*; 24. *Populeta (tremulae) stellariosa (holosteae)*
Source: compiled based on V. Skliar *et al*. (2020)

The χ_2 criterion was used to determine the species composition of natural recovery to certain groups of associations. The null hypothesis is rejected if $\chi^2 > 3$ (Table 2). The data show that the undergrowth of four species: *P. sylvestris, P tremula, A. platanoides, and T. cordata,* statistically significantly gravitate towards certain groups of associations. At the same time, for the subspecies *B. pendula* and *Q.* are not linked to specific forest community types.

Table 2. Values of the χ^2 criterion for the understory of the main forest-forming species

	Types					
	Pinus sylvestris	*Betula pendula*	*Populus tremula*	*Quercus robur*	*Acer platanoides*	*Tilia cordata*
X^2 value	8.17*	1.5	8.17*	2.04	6*	20.17*

Note: * – cases for which the null hypothesis is rejected are noted
Source: compiled based on V.G. Skliar (2022)

The distribution of *Q. robur* subspecies in various types of forest communities is explained by the absence of a clearly defined narrow ecological restriction of this species. Mature oak trees are present in most plant communities of the study area. Despite the periodicity of fruiting, their seeds are dispersed by animals in large quantities to various forest habitats (Levchenko & Ganzhalyuk, 2022). In addition, acorns can retain their germination capacity for a long time, which contributes to the successful germination and development of seedlings.

A similar situation is observed with *B. pendula* – the growth of this species also does not show a clear association with certain groups of associations. The widespread occurrence of hanging birch, at least in the form of single specimens, in many forest communities, as well as the annual production of a significant amount of easily spread seeds, led to the widespread distribution of its understory (Sklyar, 2022).

In contrast to *Q. robur* and *B. pendula*, the lower representation of *P. sylvestris* subspecies in the phytocoenoses of the Left Bank Polissia is a consequence of the high requirements of this species to light and frequency of fruiting. The restriction of *P. tremula, A. platanoides* and *T. cordata* to certain groups of associations is largely due to the lower presence of their mothers in forest communities compared to the above species due to their demanding lighting conditions *(P. tremula*) and soil fertility *(A. platanoides*, *T. cordata*), which leads to the formation of their stands and young generation only in specific habitats.

In addition to the six species described above *(P. sylvestris*, *B. pendula*, *P. tremula*, *Q. robur*, *A. platanoides*, *T. cordata*), the tree layer in some forest phytocoenoses of the Left-Bank Polissia of Ukraine contains fragmentary, single trees of *Pyrus communis* L.*, Malus sylvestris* Mill. and *Ulmus laevis* Pall. and their undergrowth. However, the frequency of occurrence of subyearlings of these species by association groups is insignificant (4.2-12.5%), and the χ^2 values of 18.38-22.04 indicate a statistically significant attraction of their younger generation to certain association groups.

As already noted, the success of natural regeneration and the sustainable functioning and existence of forests significantly depend on the population density (number of individuals per unit area) of the sub-growth represented in forest phytocoenoses. If plants of all three cohorts (small, medium, and large) were present in certain phytocoenoses, the structure of the understory was assessed as complete, if any of them were absent, it was assessed as incomplete.

The results of the study of the population density of the undergrowth in forest phytocoenoses of the *Pineta sylvestris* formation showed that in several association groups, in particular, *Pineta (sylvestris) coryloso (avellanae) – vacciniosa (myrtilli*), Pineta (sylvestris) *asarosa (europaei*), *Pineta (sylvestris) pteridiosa (aquilini*), there is no natural recovery of the main forest-forming species – *P. Sylvestris* (Table 3). The recovery of *Q. robur*, a species involved in the formation of the second tier of stands, is more constant. In the forests of this formation, the density of small *P. sylvestris* can reach almost 4500 individuals per 1 ha, medium – 3800 pcs/ha, and large – 1600 pcs/ha. Similar indicators for *Q. robur*, respectively, are about 4100 pcs/ha, 2800 pcs/ha and 2200 pcs/ha, and for *B. rendula* 3200 pcs/ha, 2900 pcs/ha, 1800 pcs/ha. The *Pineta sylvestris* forests also contain different cohorts of *P. tremula*subspecies. The density of their individuals within the population fields is less than 1750 individuals/ha. The regeneration of *A. platanoides* is represented by small and much less frequently by medium-sized subgrowth, the density of individuals of which usually does not exceed 2500 pcs/ha.

Table 3. Average population density of the undergrowth (individuals/ha) of the leading forest-forming species of the Left-Bank Polissya of Ukraine in different forest phytocoenoses

	Groups of associations	***Pinus sylvesrtis***			***Quercus robur***			***Acer platanoides***		
		Small	Medium	Big	Small	Medium	Big	Small	Medium	Big
1	*Pineta (sylvestris) hylocomiosa*	4456.3	321 3.1	1606.6	4081	2763.7	913.2	2218.1	1625.8	-
2	*Pineta (sylvestris) calamagrostidosa (epigeioris)*	719.1	812.9	-	594.3	481.9	-	-	-	-

Table 3, Continued

	Groups of associations	*Pinus sylvesrtis*			*Quercus robur*			*Acer platanoides*		
		Small	Medium	Big	Small	Medium	Big	Small	Medium	Big
3	*Pineta (sylvestris) nardosa (strictae)*	506.8	900.5	-	-	-	-	-	-	-
4	*Pineta (sylvestris) coryloso (avellanae) – vacciniosa (myrtilli)*	-	-	-	413.1	-	119.1	2419.1	-	-
5	*Pineta (sylvestris) asarosa (europaei)*	-	-	-	1056.9	1175.2	-	-	-	-
6	*Pineta (sylvestris) pteridiosa (aquilini)*	-	-	-	2281	-	-	-	-	-
7	*Pineta (sylvestris) franguloso (alni) – vacciniosa (myrtilli)*	2875.2	3494.2	1287.3	1650.3	586.1	313.7	-	-	-
8	*Pineta (sylvestris) vacciniosa (myrtilli)*	2243.4	3831.7	-	2700.5		2169.1	1681.2	-	-
9	*Pineta (sylvestris) moliniosa (caeruleae)*	-	-	-	1713.8	2456.1	-	-	-	-
10	*Pineta (sylvestris) sphagnosa*	2600.3	2600.2	1813.1	1656.7	-	1581.8	-	-	-
11	*Querceto (roboris) – Pineta (sylvestris) vacciniosa (myrtilli)*	2938.1	1763.7	-	1706.1	1707.4	1813.2	-	-	-
12	*Querceto (roboris) – Pineta (sylvestris) corylosa (avellanae) sparsi herbosa*	-	-	-	-	-	413.1	5569.5	1668.3	-
13	*Betuleto (pendulae) – Pineta (sylvestris) vacciniosa (myrtilli)*	-	-	-	1288.2	2189.3	1619.5	-	-	-
14	*Querceta (roboris) majanthemosa (bifolii)*	-	-	-	4194.5	1906.8	-	-	-	-
15	*Querceta (roboris) aegopodiosa (podagrariae)*	-	-	-	-	-	-	11781	3338.1	-
16	*Querceta (roboris) convallariosa (majalis)*	1775	-	-	1844.1	1712.9	1713.4	2275.4	1869.5	-
17	*Querceta (roboris) coryloso (avellanae) – convallariosa (majalis)*	-	-	-	3769.7	1338.7	-	-	1375	-
18	*Acereto (platanoiditis) – Querceta (roboris) coryloso (avellanae) – aegopodiosa (podagrariae)*	-	-	-	-	-	-	5863.7	15119.2	3456.1

Table 3, Continued

	Groups of associations	*Pinus sylvesrtis*			*Quercus robur*			*Acer platanoides*		
		Small	Medium	Big	Small	Medium	Big	Small	Medium	Big
19	*Acereto (platanoiditis) – Querceta (roboris) stellariosa (holosteae)*	-	-	-	-	-	-	3494.9	3294.3	3194.8
20	*Tilieto (cordatae) – Querceta (roboris) stellariosa (holosteae)*	-	-	-	-	-	-	5750.3	-	119.5
21	*Betuleta (pendulae) vacciniosa (myrtilli)*	3631.1	2550.8	1638.4	1856.5	-	-	-	-	-
22	*Betuleta (pendulae) caricosa (pilosae)*	-	-	-	-	-	-	1613.7	1763.9	-
23	*Betuleta (pendulae) stellariosa (holosteae)*	887.2	1619.1	-	1613.7	-	-	1294.2	1825.8	-
	p-level	0*	0*	0.0451*	0*	0*	0.009*	0*	0*	0*

Note: p-level calculated based on the results of analysis of variance; * – statistically significant differences
Source: ompiled based on V.G. Skliar (2022)

Among the association groups represented by the *Pineta sylvestris* formation, the forests of the *Pineta (sylvestris) hylocomiosa* association group have the most diverse species composition and the highest density of understory individuals, especially *P. sylvestris* and *Q. robur*. In the phytocoenoses of the *Pineta (sylvestris) calamagrostidosa (epigeioris*) and *Pineta (sylvestris) nardosa (strictae*) association groups, the undergrowth is neither species diversity nor high density: each cohort of a species per 1 ha of forest is represented by no more than 901 individuals.

Difficulty of natural regeneration of *P. sylvestris* is a common feature and a significant problem of forest phytocoenoses of the *Querceto (roboris) – Pineta (sylvestris*) subformation. The recovery of *Q. robur* is more constant here. The recovery of *A. platanoides*, *B. rendula* and *T. cordata*is not stable. In the communities of the *Querceto (roboris) – Pineta (sylvestris) vacciniosa (myrtilli*) association group, *Q. robur*is most successfully restored: all cohorts of undergrowth are present, and their average density reaches 1706.1-1813.2 units/ha. The recovery of *P. sylvestris* is represented by small and medium-sized subgrowth, *B. rendula* only by medium-sized, and *T. cordata* only by small. The density of these cohorts of undergrowth in *P. sylvestris* is 1763.7-2938.1 pcs/ha, *B. rendula* – 800.5-1694.1 pcs/ha, and *T. cordata* – 213.2 pcs/ha. In the phytocoenoses of the *Querceto (roboris) – Pineta (sylvestris) corylosa (avellanae) sparsi herbosa* association group, *A. platanoides*is the most successful in restoring. Here, up to 7300 individuals of this species grow on 1 hectare.

The communities of the *Betuleto (pendulae) – Pineta (sylvestris) vacciniosa (myrtilli*) association group (*Betuleto (pendulae) – Pineta (sylvestris*) subformation) are quite common in the study area. In these forests, there is an undergrowth of *B. pendula*, *Q. robur* and *P. tremula*. Of these species, *Q. robur* is distinguished by the presence of undergrowth in all three cohorts, with population densities mostly in the range of 1300-2100 individuals/ha. The regeneration of *B. rendula* and *P. tremula*is represented by medium and large subshrubs. In *B. pendula*, the average density of these cohorts varies from 1762.1-2875.3 units/ha, and in *P. tremula* – 894.6-1719.2 units/ha.

The results of studying the quantitative characteristics of the natural regeneration of forest phytocoenoses of the *Querceta roboris* formation indicate that in some of its communities (association group *Querceta (roboris) aegopodiosa (podagrariae)*, *Acereto (platanoiditis) – Querceta (roboris) coryloso (avellanae) – aegopodiosa (podagrariae)*, *Acereto (platanoiditis) – Querceta (roboris) stellariosa (holosteae)*, *Tilieto (cordatae) – Querceta (roboris) stellariosa (holosteae)*)) lack natural recovery of the dominant species – *Q. robur*. However, in some phytocoenoses, the density of *Q. robur* undergrowth can reach high levels: small – up to 4200 pcs/ha, medium – about 1906 pcs/ha, and large – 1700 pcs/ha. The natural regeneration of *A. platanoides* is usually represented by the youngest cohorts of the subshrub (small and medium).

The greatest diversity of restored species is characteristic of the *Querceta (roboris) convallariosa (majalis*) association group. In its communities, the undergrowth of the main forest-forming species has a high density and the most complete structure in terms of cohort representation. Aside from *Q. robur* and *A. latanoides*, *B. rendula*, *P. sylvestris*, P. *tremula*, *P. communis*, *M. sylvestris*, and *U. laevis*are being restored in these forests. The density of individuals of *B. pendula* and *P. sylvestris* reaches almost 2600 and 1800 pcs/ha, respectively, while in *P. tremula*, *P. communis*, *M. sylvestris*, *U. laevis* it varies from 90 to 320 pcs/ha.

The phytocoenoses of the association group *Acereto (platanoiditis) – Querceta (roboris) coryloso (avellanae) – aegopodiosa (podagrariae*) and *Acereto (platanoiditis) – Querceta (roboris) stellariosa (holosteae)* are distinguished by successful recovery of *A. platanoides*. In the communities of the first group of associations, the average density of small undergrowth of this species reaches 5863.7 units/ha, medium – 15119.2 units/ha, and large – 3456.1 units/ha. In the forests of the second group of associations, these cohorts have a lower density, which mostly ranges from 3194 to 3495 units/ha. The subspecies of one of the main unifiers and dominants of – *Q. robur,* is absent or rare in both groups of associations.

The phytocoenoses of the *Tilieto (cordatae) – Querceta (roboris) stellariosa (holosteae*) association group are also favourable for the formation of small subgrowth of *A. platanoides*: its average density here reaches 5750.3 units/ha. These forests also have an undergrowth of *T. cordata* (413.7 specimens/ha) and *P. tremula* (219.2 specimens/ha).

In the forests of the *Betuleta pendulae* formation, there is not only natural regeneration of *B. pendula* but also several other species: *P. sylvestris*, *Q. robur*, *A. platanoides*, and *P. tremula.* In the forests of this formation, the density of individuals in different cohorts of the substand varies around the following indicators: 1440 – 2600 pcs/ha in *B. pendula*, 880 – 3640 pcs/ha in *P. sylvestris*, 1610 – 1860 pcs/ha in *Q. robur*, 1300 – 1830 pcs/ha in *A. platanoides* – 1300 – 1830 pcs/ha, and 720 – 1300 pcs/ha in *P. tremula* – 720 – 1300 pcs/ha.

In the communities of the association group *Populeta (tremulae) stellariosa (holosteae*), the natural regeneration of *B. rendula* and *P. tremula* is represented by all three cohorts of the subshrub. Their density ranges from 1681 to 3869 units/ha.

To assess the population density of the undergrowth, the patterns of change (trend) of this indicator by cohorts of the undergrowth were studied: small, medium, and large. In general, the following trend options are possible:

1. The highest density is achieved at the level of small undergrowth.

2. The highest density is achieved at the level of the middle growth.

3. The highest density is achieved at the level of a large understory.

4. The density of undergrowth in all cohorts is the same.

Of the listed options, the first and second trends are most often implemented in wood species (Table 4). Forest-forming species also have species-specific features in terms of “sets” of trend options and the likelihood of their implementation. The greatest variety of trend variants was found in *B. rendula*. However, in general, this species has the highest density in the smallest cohorts of sub-adults (small and medium).

P. sylvestris, *Q. robur*, *A. platanoides*, *P. tremula* and *P. communis* each show three of the four trends. In *P. sylvestris*, *Q. robur*, *A. platanoides*, *and P. communis*, the highest density is often recorded at the level of small subshrubs. In *T. sordata* and *M. sylvestris*, two variants of trends were present: one and two. *U. laevis* has only one first.

Table 4. Representation of different variants of trends in the dynamics of population density of the understory in forest-forming species*

Type	Trend variants** and their representation (%)			
	1	2	3	4
Pinus sylvestris	58.3	33.3	-	8.4
Quercus robur	58.8	35.3	5.9	-
Acer platanoides	66.7	25	8.3	-
Betula pendula	40	46.6	6.7	6.7
Populus tremula	33.3	50	16.7	-
Tilia cordata	50	50	-	-

Note: * – data reflects the situation only for groups with sub-adults; ** – the numbering of trend options corresponds to the one given in the text
Source: based on the results of a study by V.G. Skliar (2022)

In the forest-forming species of the Left-Bank Polissya of Ukraine, both synchronous dynamics of the undergrowth density by its cohorts and species specificity in terms of the representation of certain trend variants were registered. The latter is manifested in the fact that each species within a particular forest phytocoenosis implements its variant of the trend, which does not coincide with the trends of other species.

Discussion

Natural regeneration is an important component of the complex of processes associated with the functioning of forest communities (Connel, 1989; Ward & Worthley, 2004). The final results of the study of the species and cohort composition of natural regeneration, as well as the population density of the undergrowth, indicate that the forests of the Left-Bank Polissya of Ukraine have difficulty in realising their ability to sustain themselves. The forests of the *Pineta sylvestris* formation hold a leading position in the structure of the region’s forest fund. In these forests, the natural regeneration of dominant (co-dominant) species is unstable, which is often manifested in the absence of the entire understory or its cohorts. This sign of difficulty in the process of self-sustaining phytocoenoses is also inherent in several forests of other formations. In general, the density of cohorts of forest-forming species in most forest phytocoenoses of the Left-Bank Polissia of Ukraine according to the scale of assessment of the success of natural seed regeneration mostly varies from insufficient to satisfactory (Yanitskyi, 2024). The existence of complexity in the cycle of forest generations is also evidenced by the peculiarities of the ontogenetic and vitality structure of the price populations of forest-forming species: a wide representation of incomplete ontogenetic spectra (Skliar *et al.*, 2020), populations of the "depressed" category with negative values of the index of vitality dynamics (IVD) by stages of natural recovery.

N.C. Reid *et al.* (2023), using examples of reforestation and forest rehabilitation in temperate regions, show that the effectiveness of forest restoration depends on various factors, such as local climatic conditions, available resources, level of community participation and economic opportunities. The results of the research presented in this publication also show that the density of undergrowth in the forests of the Left-Bank Polissia of Ukraine does vary significantly in different communities and is determined by the influence of a complex of ecological and cenotic factors. First and foremost, it is soil moisture, the closeness of the upper layers, light, and the composition of the living topsoil (Ivanova *et al.*, 2022). In the conditions of the study region, the highest values of understory density for most species were inherent in forests with soils with sufficient (at the level of fresh and wet hygrotopes – association groups *Pineta (sylvestris) hylocomiosa, Pineta (sylvestris) vacciniosa (myrtilli*), etc.), but not excessive moisture (Fernandes *et al.*, 2023). In *P. sylvestris* and *Q. robur*, the highest density of undergrowth was recorded in phytocoenoses with a stand crown closure of 0.4-0.5, and in *A. platanoides* – 0.6 and above. *P. sylvestris* demonstrated a tendency for an increase in the density of undergrowth in the stand windows. The amount of undergrowth is significantly reduced in phytocoenoses characterised by high soil sodification (*Pineta (sylvestris) calamagrostidosa (epigeioris*), *Pineta (sylvestris) nardosa (strictae*) association groups).

All other things being equal in terms of quantitative and qualitative indicators of seed productivity, the growth of species with a wider ecological amplitude will have a greater chance of being represented in forest communities. Such species have a higher probability of matching their potential ecological niches with the actual conditions of certain habitats, which contributes to the successful emergence, growth and development of the young generation of these species in forests. Compared to adult plants, the undergrowth often demonstrates higher shade tolerance, which expands the possibilities of its presence in various communities (Oliynyk & Viter, 2011; Gerasko *et al.*, 2024). However, the undergrowth is more vulnerable to adverse natural factors, such as droughts, frosts, etc., which often occur in the study area, which can significantly reduce its number and representation by habitat (Kovalenko, 2018; Litvinova *et al.*, 2023).

The presence in a significant number of forest communities in the Left-Bank Polissia of Ukraine of a sub-storey structure with incomplete representation of different cohorts, as well as the expression of different trends in the dynamics of sub-storey density (especially those when the maximum values are in the middle or large sub-storey) indicate that the process of natural regeneration is inherent in dynamism, in particular as a result of the manifestation of "waves of regeneration". In general, the growth of woody plants under the canopy of stands is one of the most unstable elements of the structural organisation of biogeocenosis (Shuvar & Korpita, 2023). Emerging continuously or in "outbreaks" and dying out in the same way, it is a stable reserve whose representatives gradually or in a short time replace the parental generations in the process of struggle for existence (Kovalenko, 2018). The important ecological and stabilising role of natural regeneration has been proven by research by M. Rosa *et al.* (2021), G. Davidson *et al.* (2024) which focused on assessing changes in native forest cover in the Atlantic Forest of Brazil. They determined that while indigenous forest cover remained constant between 1990 and 2017, there was a steady loss of old-growth indigenous forests, mostly in the lowlands, during this time. However, this loss was compensated by an increase in young indigenous forest cover.

The study of the population density of the undergrowth of the leading forest-forming species of the Left-Bank Polissya of Ukraine in forest phytocoenoses showed that, in addition to general trends, each tree species in each community has its specific features of natural regeneration (Bobos *et al*., 2019). They are manifested in the different survival rates of individuals, in the presence of differences in their transition from cohort to cohort. Given the above, the issue of developing forest restoration programmes is becoming increasingly significant for regions with forest cover. For instance, N.C. Reid *et al.* (2023) provided various reforestation programmes in New Zealand and Colorado. H. Qu *et al*. (2024) demonstrated the effectiveness of natural regeneration in restoring ecological functions in degraded natural forests. Accordingly, the issue of promoting natural regeneration should be given more attention when considering the sustainable functioning of the forests of the Left-Bank Polissya of Ukraine.

The success of natural recovery is shaped not only by local ecological and cenotic interactions but also by global ones (Evison & Wyse, 2023; Stephens *et al.*, 2023). In particular, the research of D. Pragya & P. Jaiswal (2022) shows that one of the main challenges to forest restoration has been insufficient attention to the impacts of climate change. Therefore, scientists proposed the implementation of such forest restoration strategies as rehabilitation, reconstruction, reclamation and replacement. The study of the impact of climate change on natural regeneration is also relevant for the Left Bank Polissia of Ukraine (Jiang *et al.*, 2022; Lee *et al.*, 2023). When considering various aspects of natural forest regeneration in different regions, it is advisable to use both classical and modern methods: remote sensing for monitoring, assessment and restoration of damaged forests, GIS tools, and modelling methods.

Conclusions

Based on the generalisation of materials on the state of natural regeneration in the forests of 24 groups of associations typical for the Left-Bank Polissya of Ukraine, the study determined that in the direction of decreasing representation of natural regeneration in the composition of forest phytocoenoses, the leading forest-forming species of the region form the following series: *Betula pendula – Quercus robur – Acer platanoides – Pinus sylvestris*, *Populus tremula – Tilia cordata*. The results of the study show that for most of the species studied, the growth is reliably confined to certain groups of forest associations. This indicates that ecological and phytocoenotic characteristics and interrelationships in forest communities, such as root competition, the influence of the herbaceous layer, and abiotic environmental factors, can significantly determine the presence and distribution of a particular tree species in phytocoenoses. The peculiarities of seed (fruit) dispersion and the adaptive potential of plants are also among the determining factors for the species composition of restoration.

The forest phytocoenoses of the region differ statistically significantly in terms of the population density of the undergrowth (small, medium, large), which at the level of these individual cohorts mostly varies from 500 to 4000 individuals/ha. At the same time, quantitative indicators of the undergrowth (population density) and qualitative indicators (species composition, completeness of recovery spectra, etc.) indicate the dynamism of forest regeneration, the existence of "recovery waves" and, in general, the difficulty of implementing the self-sustaining capacity of the forests of the Left-Bank Polissia of Ukraine.

Quite often, forests lack the regeneration of species that form the stand layer. This, along with low population densities of such species, creates preconditions for the phenomenon of "species change" in forests. Currently, the tendencies towards the implementation of this process are manifested in the forests of all studied formations in the groups of associations *Pineta (sylvestris) coryloso (avellanae) – vacciniosa (myrtilli)*, *Pineta (sylvestris) asarosa (europaei)*, *Pineta (sylvestris) pteridiosa (aquilini)*, *Querceta (roboris) aegopodiosa (podagrariae)*. Given that the condition of the understory and its population density is also determined by the level of soil moisture (the highest values of understory density in most species were recorded in forests with soils moistened at the level of fresh and wet hygro-tops), this process may intensify against the background of climate change. Accordingly, this fact is another argument in favour of the fact that an important area for further scientific research on forests should be the study of the impact of climate change on their natural regeneration.

Acknowledgements

None.

Conflict of Interest

None.

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Еколого-ценотичні особливості природного відновлення лісів Лівобережного Полісся України

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Анотація. Актуальність вивчення складного, багатоетапного процесу природного відновлення лісових угруповань, а також взаємодій і перетворень обумовлена стрімкими зростаючими викликами, пов'язаними зі зміною клімату, вирубкою лісів та зменшенням біорізноманіття. Мета роботи – оцінити стан і виокремити еколого-ценотичну специфіку природного насіннєвого відновлення провідних лісоутворювальних видів Лівобережного Полісся України. Дослідження проведене на основі використання комплексу методів, насамперед, геоботанічних, популяційних та математико-статистичних. Вивчення процесу природного відновлення було здійснене в угрупованнях, які є типовими для регіону та належать до 42 синтаксонів у ранзі асоціацій й 24 синтаксонів у ранзі груп асоціацій. В ході проведення дослідження було розкрито специфіку таких лісоутворюваних видів, як *Pinus sylvestris* L., *Quercus robur* L., *Acer platanoides* L., *Betula pendula* Roth., *Populus tremula* L., *Tilia cordata* Mill. Встановлено, що представленість підросту основних лісоутворювальних видів в складі лісових рослинних угруповань Лівобережного Полісся України досить суттєво різниться. В ході дослідження було описано визначальні чинники щодо видового складу відновлення, одними з яких є особливості дисперсії насіння (плодів) та адаптаційний потенціал рослин. В результаті проведеного дослідження було встановлено, що *стан підросту та показники його популяційної щільності визначаються рівнем вологості ґрунту (*найвищі значення щільності підросту у більшості видів були зареєстровані в лісах, ґрунти яких мають зволоженість на рівні свіжих та вологих гігротопів), *зазначений процес може активізуватись* на тлі кліматичних трансформацій. Здобуті в ході дослідження результати можуть бути використаними для розробки ефективних стратегій управління лісовими ресурсами, збереження біорізноманіття та сталого лісокористування в регіоні Лівобережного Полісся, що сприятиме покращенню екологічної ситуації та створенню сприятливих умов для відновлення лісових екосистем

Ключові слова: підріст; популяційна щільність; дисперсія насіння; біорізноманіттся; *Pinus sylvestris* L.; *Quercus robur* L.