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Structure and utilisation of forest resource potential of Scots Pine stands in the Volyn Polissya

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Abstract. The relevance of the research was driven by the necessity for the rational use of the forest resource potential of Scots pine stands in the Volyn Polissya, one of the most forested regions of Ukraine with significant ecological, economic, and social importance. The aim of the study was to examine the stand structure and analyse the utilisation of Scots pine stands in the Volyn Polissya, as well as to explore ways to optimise forest management processes in the region. A comprehensive analysis of the spatial and age structure, as well as the productivity of Scots pine stands in the Volyn Polissya region, was carried out, with an assessment of timber stock utilisation by type of felling. It was found that approximately 64% of forested areas in the study region were covered by Scots pine stands. Artificial pine stands prevailed in terms of area, accounting for over 52%. The most widespread were middle-aged stands, which could be explained by active post-war forest regeneration. The majority of pine stands grew in fresh and moist subor forests, which were optimal for the species' development. The average annual volume of Scots pine timber harvested by forest enterprises in the region amounted to 1.9 million m^3, with the majority obtained through principal fellings and sanitary cuttings. Among thinnings, a significant share of timber harvesting came from commercial thinning (age of 41-70). The proportion of other types of felling, both related and unrelated to forest management, ranged from 1 to 2%. The average volume of harvested Scots pine

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timber per hectare ranged from 2 m^3 ha^{-1} for pre-commercial thinning (age of 11-20) to 173 m^3 ha^{-1} for principal fellings. The results of the study may be used to improve forest management practices and to formulate a strategy for the sustainable development of forestry in the Volyn Polissya

Keywords: forest inventory indicators; age structure; forest cover; standing volume; timber harvesting

Introduction

Effective forest resource management, which should ensure ecological balance and economic stability in the forestry sector, required thorough planning of forestry operations. This, in turn, was impossible without up-to-date and reliable information on forest resource availability and the extent of its utilisation. Given the current challenges related to climate change, anthropogenic pressure, and the adaptation of national forest policy to pan-European standards, there was a need for a detailed understanding of the structural characteristics, dynamics, and utilisation of the forest resource potential of forest stands.

The territory of Ukraine was divided into four natural zones – Polissya, Forest-Steppe, Northern and Southern Steppe, two mountain regions – the Ukrainian Carpathians and the Crimean Mountains. In their study, I. Ivaniuk *et al*. (2020) noted that Polissya, as one of the largest natural zones in terms of area, was also among the most forested regions. It hosted the largest forest area in the country – 42.2% – and thus the stands of the region had a significant influence not only on Ukraine's climate but also on that of the whole of Eastern Europe. The researchers also established the phytomass density and carbon sequestration capacity of the region's forests, as well as analysed their bioproductivity. V. Myroniuk *et al*. (2024) conducted a comprehensive assessment of Ukraine's forests, combining field data collection on inventory plots with statistical evaluation, remote sensing, and modelling. It was found that among forest vegetation zones, Polissya ranked second in terms of forest cover, behind only the Carpathians – about 40% and over 50% respectively. The state of forest ecosystems in Western Polissya and the impact of climate change on forest growth and development were analysed by V. Yanitskyi (2024). It was noted that rising average air temperatures, an increase in the number of warm months per year, and moisture deficits were disrupting the ecological balance in forest ecosystems, increasing damage from pests and diseases, as well as raising the number of forest fires. Based on its physical and geographical characteristics, Ukrainian Polissya was divided into several regions, one of which was the Volyn Polissya. This natural region of Polissya was located between the Western Bug and Sluch rivers and occupied most of the Volyn Region, as well as the north-western part of the Rivne Region. The area lay within the western slope of the Ukrainian Shield and the Volyn-Podillia Monocline. It was characterised by the wide presence of glacial and karst landforms, valley landscapes, wetlands, and a considerable number of lakes (more than 200) (Netrobchuk *et al.*, 2021).

The Volyn Polissya belonged to the physical-geographical regions with one of the highest forest cover percentages in Ukraine. Therefore, forests in this area played extremely important roles. The total area of forest lands in the Volyn Polissya zone exceeded 1.4 million hectares, of which around 73% were classified as commercial forests. Forested areas covered

over 1.2 million hectares (approximately 85% of total forest land area). The study region was part of the mixed forest zone, where various coniferous and deciduous species grew. However, the dominant species over most of the area was Scots pine (Fesiuk, 2024). A.M. Zhezhkun (2022) noted that the formation of existing pine stands in the Polissya territory was connected to silvicultural practices, particularly principal felling methods. The study analysed the formation patterns of pine stands, their structure, and overall sanitary condition. In research on pine forests, scholars rarely distinguished the Volyn Polissya as a separate region, which confirmed the relevance of the selected research topic. At the same time, the peculiarities of distribution and problems associated with the cultivation of Scots pine (*Pinus sylvestris*) had received significant scientific attention due to the predominance of pine among forest stands across Ukraine. S.B. Kovalevskii *et al*. (2022) assessed the growth dynamics and productivity of Scots pine stands growing on soils with outcrops of crystalline parent rocks in Central Polissya. They confirmed the feasibility of establishing such stands on plots with varying depths of crystalline bedrock. In their study, V. Lavnyy *et al*. (2022) examined different methods for regenerating pine stands in Western Polissya. In particular, they analysed the effectiveness of natural regeneration of Scots pine through the application of various silvicultural measures, including thinning and principal felling. It was stated that proper planning of reforestation efforts significantly influenced the quality and resilience of the stands, as well as the productivity of forest stands in the region.

Research on forest protection and conservation had become increasingly relevant under global climate change conditions, accompanied by rising pest populations and the spread of forest diseases. In her study, V. Meshkova (2021) analysed factors contributing to the decline of Scots pine forests due to bark beetle infestation. In addition, an algorithm was developed for forecasting bark beetle outbreak centres, which could help improve pest management measures. Apart from the traditional timber-oriented perception of forest resource potential, the role of ecosystem services generated by forest stands, as part of the bioproductive process, was also important. The study by R. Vasylyshyn *et al*. (2023) on the primary productivity of forests in the Kyiv Region highlighted the region's significant potential for organic matter production and the performance of ecosystem functions. Particularly high levels of net primary productivity were recorded in hornbeam-oak forest types, indicating a close link between productivity, species composition, and age structure of forests.

Given the heavy dependence of the national economy on imported energy resources, forest stands had gained strategic importance for ensuring local energy security, serving as a vital source of renewable energy raw materials. The study by R. Vasylyshyn *et al*. (2022) analysed the annual biomass potential by major components (stemwood, logging and processing residues), considering the age structure of stands. This allowed for substantiating forest resource use directions within the context of transitioning to a low-carbon economy. At the same time, during the full-scale war launched by the Russian Federation against Ukraine, forest ecosystems had suffered significant disruptions, which greatly impacted the formation of their resource potential and their ability to perform ecosystem functions. A.D. Kuzyk & V.I. Tovarianskyi (2023) outlined the main factors of this impact and identified priority directions for post-war forest restoration, including demining, inventory, sanitary cuttings, and reforestation. Justifying the volume of forest use in line with the principles of sustainable forest management required analysis of many

indicators, including the structure of forest stands. Therefore, the aim of this study was to assess the distribution of pine stands according to key inventory and silvicultural indicators and to analyse the volume of timber harvested from these stands through various types of felling.

Materials and Methods

The study adopted an analytical approach and was based on digital processing of statistical data on Scots pine stands linked to a specific territory – namely, the Polissya natural zone within the Volyn and Rivne regions. The spatial boundaries of the analysis covered the northern part of these regions, which, from a geobotanical perspective, corresponded to the mixed forest zone of Ukrainian Polissya. The research area included the following districts: Verkhnoprypiatskyi, Nyzhnostyrskyi, Liuboml-Kovel, Manevychi-Volodymyrets, Kolky-Sarny, Turiisk-Rozhyshche, Kivertsi-Tsuman, and Kostopil-Berezne.

The main sources of information were: 1) the relational database "Forest Inventory Characteristics" (RDB "FIC") (Ukrainian State Forest Management Planning Association, n.d.); 2) the Unified State Electronic Timber Accounting System (Timber Accounting System) (State Forest Resources Agency of Ukraine, n.d.b). Analytical reports were generated from the RDB "FIC" containing data on stand area and growing stock by the following silvicultural and mensurational indicators: age groups, site index classes, stocking density, and forest site types. Particular attention was given to the distribution of Scots pine stands by age groups (young, middle-aged, maturing, mature, and overmature stands). For this purpose, relevant data were extracted from the RDB "FIC", considering the area and growing stock for each group. Data filtering was performed based on the administrative affiliation of the forest compartments to the Volyn and Rivne regions, the Polissya natural zone, and the species composition of the main tree species – Scots pine. The data were structured as summary tables and further analysed graphically in Microsoft Excel.

To analyse the utilisation of the Scots pine resource potential, statistical data on timber harvesting volumes from the Timber Accounting System for the years 2023-2024 were used. These data included information on timber harvested by permanent forest users and owners of forests of various ownership forms and subordination, who conducted forestry activities within the Polissya natural zone of the above-mentioned regions. The following forest enterprises were included in the dataset: Volyn Military Forestry Enterprise; State Forestry Enterprise "Syaivo"; Agricultural and Water Management Cooperative "Selyanskyi Lis"; Agricultural Forestry Cooperative "Agrolis"; Agricultural Forestry Cooperative "Selyanskyi Lis"; Agricultural Forestry Joint Stock Company "Tur"; Agricultural Consumer Production Cooperative "Dibrova"; Agricultural Consumer Production Cooperative "Selyanskyi Lis"; Agricultural Consumer Service Cooperative "Kuzmivskyi"; Farm "Amila"; State Enterprise (SE) "Forests of Ukraine" (Berezne Forestry Branch, Vysotsk Forestry Branch, Volodymyr-Volynskyi Forest Hunting Branch, Horodok Forestry Branch, Dubno Forestry Branch, Kamin-Kashyrskyi Forestry Branch, Kivertsi Forestry Branch, Klesiv Forestry Branch, Kovel Forestry Branch, Kolky Forestry Branch, Kostopil Forestry Branch, Liubeshiv Forest Hunting Branch, Liuboml Forestry Branch, Manevychi Forestry Branch, Ratne Forest Hunting Branch, Rafalivka Forestry Branch, Rokytne Forestry Branch, Sarny Forestry Branch, Sosnivka Forestry Branch); and Shatsk National Nature Park (NNP). Additional filtering by species was performed to allow for the selection and analysis of data

relating exclusively to Scots pine timber harvesting. The data were retrieved from the extended reporting module, applying filters for:

- types of felling: principal felling (clear-cutting), sanitary felling (clear and selective sanitary fellings), tending felling (pre-commercial and commercial thinning), and other types of felling (clearing for power lines, protective zone clearance, border strip felling, etc.);
- types and classes of timber quality: commercial timber (Class A, B, C, D), fuelwood for industrial use (IU), fuelwood for non-industrial use (NIU), and long-length logs.

The analytical processing of the data involved methods of comparative analysis, data structuring and normalisation, and calculation of specific indicators (e.g., average growing stock per hectare). All reports were harmonised in terms of measurement units and brought into a unified structure to enable accurate comparison.

Results and Discussion

According to the analysis of the database of the Ukrainian State Forest Management Planning Association (n.d.), it was established that artificially regenerated Scots pine stands predominated in the study region, comprising 52% of all Scots pine stands by area. Overall, Scots pine grew on 64% of forest-covered land areas. It should be noted that despite the prevalence of artificial forest regeneration methods in recent decades, naturally regenerated Scots pine stands accounted for approximately 48%, which was considered a positive factor in the context of climate change. Natural forests are known to demonstrate greater adaptability to environmental changes and higher resistance to pests and pathogens (Maurer & Kaidyk, 2016; Guegan *et al*., 2023).

At the same time, it was important to consider that the higher area of artificially regenerated pine stands compared to naturally regenerated ones was due to several factors, including the relative simplicity of reforestation methods and the higher productivity of artificial stands. Other tree species that covered significant areas in the Volyn Polissya included: alder (15%), birch (13%), and oak (6%).

Scots pine was recognised for its ecological adaptability to various site conditions and was present in almost all edaphic types, while exhibiting different growth vigour and productivity depending on those conditions. The distribution of Scots pine stands in the study region by soil nutrient conditions was as follows:

- bory (A) – 27%;
- subory (B) – 64%;
- sugrudy (C) – 9%;
- grudy (D) – less than 0.1%.

By soil moisture conditions, the distribution of Scots pine stand areas was:

- dry and very dry (0-1) – 5%;
- fresh (2) – 44%;
- moist (3) – 37%;
- wet (4) – 10%;
- waterlogged (5) – 4%.

The largest areas among all forest lands covered with forest vegetation were occupied by pine stands growing in moist subory (Fig. 1). A significant share was also occupied by fresh subory, which accounted for nearly one quarter of the total area of Scots pine stands. Fresh and moist subory created favourable conditions for the development of Scots pine, as they contributed both to its intensive growth and natural regeneration, while also ensuring the formation of high-quality timber suitable for commercial use. Over 26% of Scots pine stands grew under bory conditions, and up to 1% in grudy conditions. In sugrudy conditions, where up to 9% of pine stands were located, in productive years and in the absence of significant grass cover, it was considered appropriate to prioritise natural regeneration of pine following felling in January-February as the primary method of reforestation.

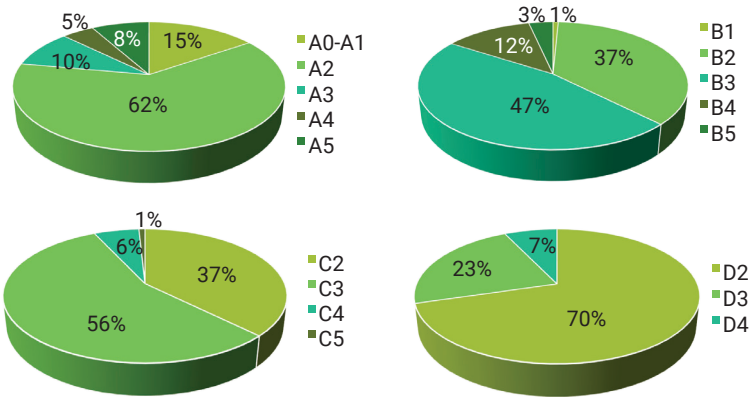

Figure 1. Distribution of Scots pine stand area by forest site type

Note: A0-A1 – very dry and dry bory, A2 – fresh bory, A3 – moist bory, A4 – wet bory, A5 – waterlogged bory, B1 – dry subory, B2 – fresh subory, B3 – moist subory, B4 – wet subory, B5 – waterlogged subory, C2 – fresh sugrudy, C3 – moist sugrudy, C4 – wet sugrudy, C5 – waterlogged sugrudy, D2 – fresh grudy, D3 – moist grudy, D4 – wet grudy

Source: compiled by the authors based on data from the Ukrainian State Forest Management Planning Association (n.d.)

In wet and waterlogged site conditions, Scots pine did not demonstrate intensive growth or high timber quality. Nevertheless, pine-dominated stands in such conditions accounted for 14% of the total forested land area. This indicated the need to reconsider the appropriateness of growing pine in these conditions and to explore opportunities for replacing such stands with more hygrophilous species such as alder. In these site conditions, alder as a dominant species ensured not only greater productivity and biological resilience of the stands but also enhanced forest ecosystem services (Lakyda *et al.*, 2019; Borsukevych, 2024).

According to Ukrainian State Forest Management Planning Association (n.d.), over 47% of the total pine stand area and more than 54% of the total growing stock within the Volyn Polissya region fell within the middle-aged group (Fig. 2). Other age groups were less represented in terms of both area and volume.

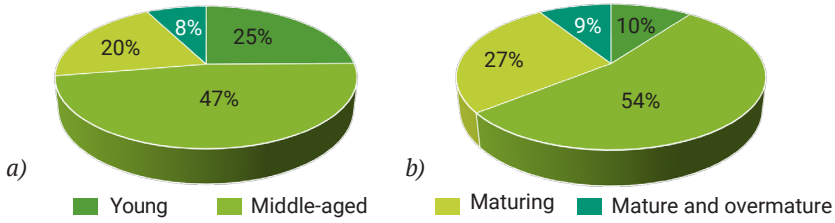

Figure 2. Distribution of pine stands by age group

Note: a) area distribution, b) growing stock

Source: compiled by the authors based on data from Ukrainian State Forest Management Planning Association (n.d.)

The predominance of middle-aged stands could be attributed to the widespread establishment of artificial Scots pine stands in the post-war period across Ukraine, including in the Volyn Polissya region, which provided particularly favourable conditions for Scots pine

growth. Analysis of the data from Ukrainian State Forest Management Planning Association (n.d.) revealed that the average age of Scots pine stands was 53 years. The age structure distribution (Fig. 2) indicated an imbalance in stand composition by age group, which could lead to various complications in forest management due to the long production cycle. Additionally, disparities in the dynamics of average growing stock per hectare across different age groups were observed. The average growing stock in mature stands was 261 m^3 ha^{-1}, in overmature stands – 188 m^3 ha^{-1}, and in maturing stands – 292 m^3 ha^{-1}. The average stock for middle-aged stands, which occupied the largest area, was 250 m^3 ha^{-1}, while young stands had 90 m^3 ha^{-1}. The overall average growing stock of Scots pine stands in Volyn Polissya was 219 m^3 ha^{-1}. The average stocking density of Scots pine stands in the region was 0.73. The largest area was covered by stands with stocking densities of 0.7-0.8, making up around 70% of the total forested land. The diversity of pine stands across different site types resulted in varying productivity. Pine stands in the study region were classified into a range of site index classes, from I^d to V^a (Fig. 3).

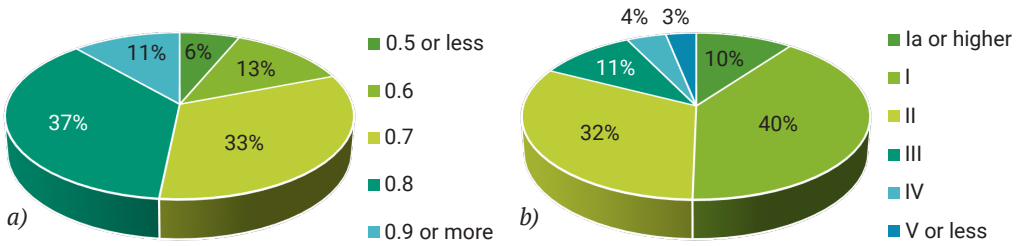

Figure 3. Area distribution of Scots pine stands
Note: a) by stocking density, b) by site index class
Source: compiled by the authors based on data from Ukrainian State Forest Management Planning Association (n.d.)

On over 92% of forested land, Scots pine stands belonged to site index classes I^a-III. Lower site index classes (IV and below) accounted for up to 8% of the area. The average site index class was I,7. Notably, over 98% of the total pine stand area was composed of high- and medium-density stands, which were nearly equally represented (48% and 50%, respectively). A significant portion of the total growing stock belonged to stands of site index classes I-III. The highest average growing stock per hectare was observed in stands of site class I^b – 340 m^3 ha^{-1}. The average growing stock for site classes I, II, and III was 241, 188, and 136 m^3 ha^{-1}, respectively.

Within the overall forest production accounting system, electronic timber tracking played an important role by enabling continuous monitoring of timber flows and preventing illegal logging (Mulyk *et al.*, 2024). Electronic timber accounting begins with the registration of timber directly at the logging sites (Order of the Ministry of Environmental Protection and Natural Resources of Ukraine No. 621, 2021). Analysis of data from the Unified State System of Electronic Timber Accounting (hereinafter – ETAS) for 2023-2024 revealed that approximately 1.9 million m^3 of Scots pine timber were harvested annually in the forests of Volyn Polissya. Nearly 80% of this volume, from both forest enterprises and other forest owners operating in the region, originated from sanitary fellings and principal fellings. Specifically, 1.45 million m^3 came from principal fellings and 1.51 million m^3 from sanitary fellings during the specified period (State Forest Resources Agency of Ukraine, n.d.b) (Fig. 4).

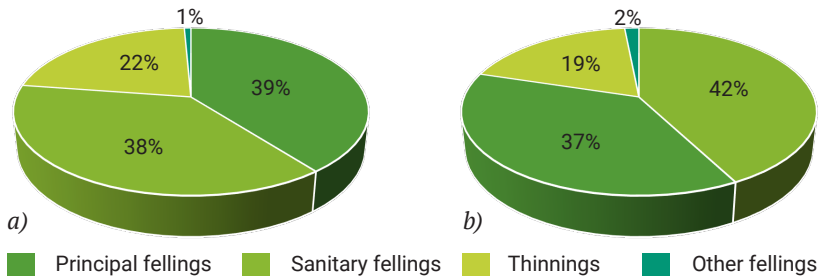

Figure 4. Distribution of pine timber harvesting volumes by felling type
Note: a) 2023 felling, b) 2024 felling
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

The significant share of sanitary fellings (38% in 2023 and 42% in 2024) indicated an unsatisfactory sanitary condition of pine stands in the region. In this context, the importance of natural regeneration and mixed stand formation was growing. Other types of fellings accounted for only 1-2% of total pine timber harvesting. These included maintenance of protected and infrastructure zones, forest road construction, and other silvicultural and forest health activities.

An analysis of average Scots pine timber harvested per hectare showed an overall increase in felling intensity in 2024 compared to 2023. On average, 33 m^3 ha^{-1} of Scots pine timber were harvested in 2023, increasing to 37 m^3 ha^{-1} in 2024. The highest average yield was recorded for principal fellings (clear-cut), which increased from 170 m^3 ha^{-1} to 173 m^3 ha^{-1}. Moreover, the total volume and average intensity of clear sanitary fellings also increased: from 136 m^3 ha^{-1} in 2023 to 161 m^3 ha^{-1} in 2024 (Fig. 5).

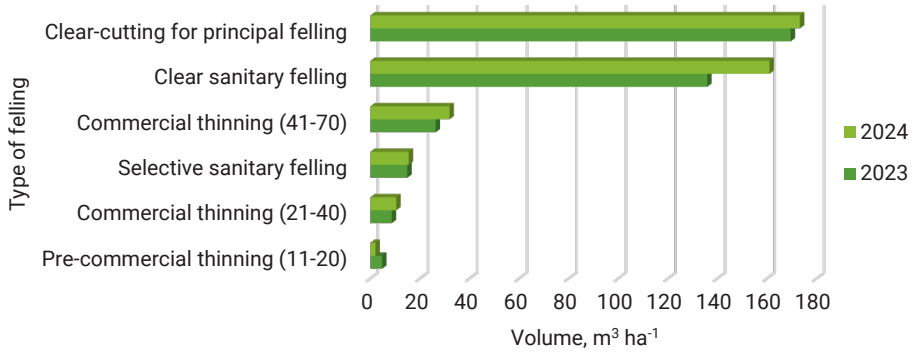

Figure 5. Average volume of Scots pine timber harvested by felling type
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

Among thinning operations, commercial thinning (age of 41-70) accounted for the largest share of harvested timber volume: 91% in 2023 and 88% in 2024 (Fig. 6). This confirms their key role in the harvesting of merchantable timber among thinning in Scots pine stands of the region, which is primarily determined by the age of the stands where they are conducted. However, there was a downward trend in harvested volumes from

commercial thinning (age of 41-70) – a decrease of 55 thousand m³ in 2024 compared to 2023. At the same time, the volume of commercial thinning (age of 21-40) increased by 10 thousand m³, possibly reflecting a shift in silvicultural focus or resulting from the uneven age structure of pine stands. A decrease of over 3 thousand m³ from pre-commercial thinning (age of 11-20) might indicate a lack of merchantable timber. Furthermore, the absence of data on pre-commercial thinning (age of up 10) in ETAS could suggest that the resulting timber was non-marketable and therefore not recorded in official statistics.

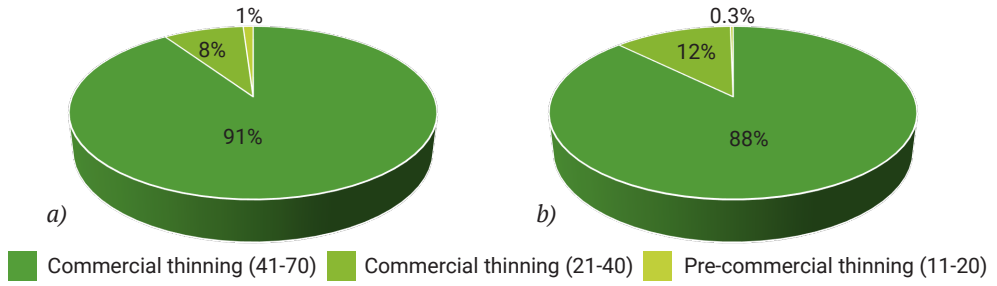

Figure 6. Distribution of Scots pine timber harvested from thinning operations
Note: a) 2023, b) 2024
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

Sanitary fellings represented one of the main sources of timber harvesting in Scots pine stands within the study area. In 2023, over 445 thousand m³ of Scots pine timber were harvested from selective sanitary fellings, compared to over 470 thousand m³ in 2024. A similar trend was observed for clear sanitary fellings: in 2024, their total volume reached 340.3 thousand m³ – an increase of 84.5 thousand m³ compared to 255.8 thousand m³ in 2023 (Fig. 7).

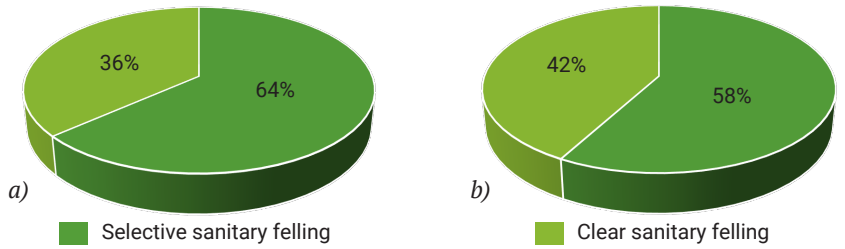

Figure 7. Distribution of Scots pine timber volumes from sanitary fellings
Note: a) 2023, b) 2024
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

Annual volume of principal fellings in the administrative territories of Volyn and Rivne regions exceeded 1.5 million m³. The distribution of the felling volume by forest types was as follows: coniferous – 64%, softwood deciduous – 28%, and hardwood deciduous – 8%. The actual volumes of timber harvesting within the Volyn Polissya during 2023-2024 indicated that over 1.1 million m³ of timber were harvested annually from principal fellings, with approximately 65% of this amount accounted for by Scots pine.

A notable fact was that only clear-cutting operations were conducted in the studied region during this period, with felling area widths ranging from 51 to 100 metres (Order of the State Committee of Forestry of Ukraine No. 364, 2009). Naturally, in flatland areas such as Volyn Polissya, this method remained predominant due to its organisational simplicity. However, considering the impacts of climate change, which posed significant challenges for forestry, it became necessary to integrate principles of ecologically oriented forestry into the forest management activities of enterprises. One of the core directions of this approach was the transition towards selective systems of harvesting (Yavorovskyi *et al*., 2019). Thus, the implementation of new, more environmentally sound approaches to principal fellings appeared to be justified. Figures 8 and 9 present the total volume of pine timber harvested in the study region in 2023 and 2024, grouped by wood types (merchantable timber, fuelwood, long-length logs) and disaggregated by felling types. Analysis of these data demonstrated that the type of felling directly affected the quality composition of harvested timber. During the studied period, the average share of merchantable timber amounted to 60%. Over 3% of the harvested timber was recorded as long-length logs. To obtain a more detailed understanding of the utilisation of forest resources in the region, it was necessary to perform an additional analysis of all operations recorded in the ETAS related to this timber, particularly the bucking of long-length logs.

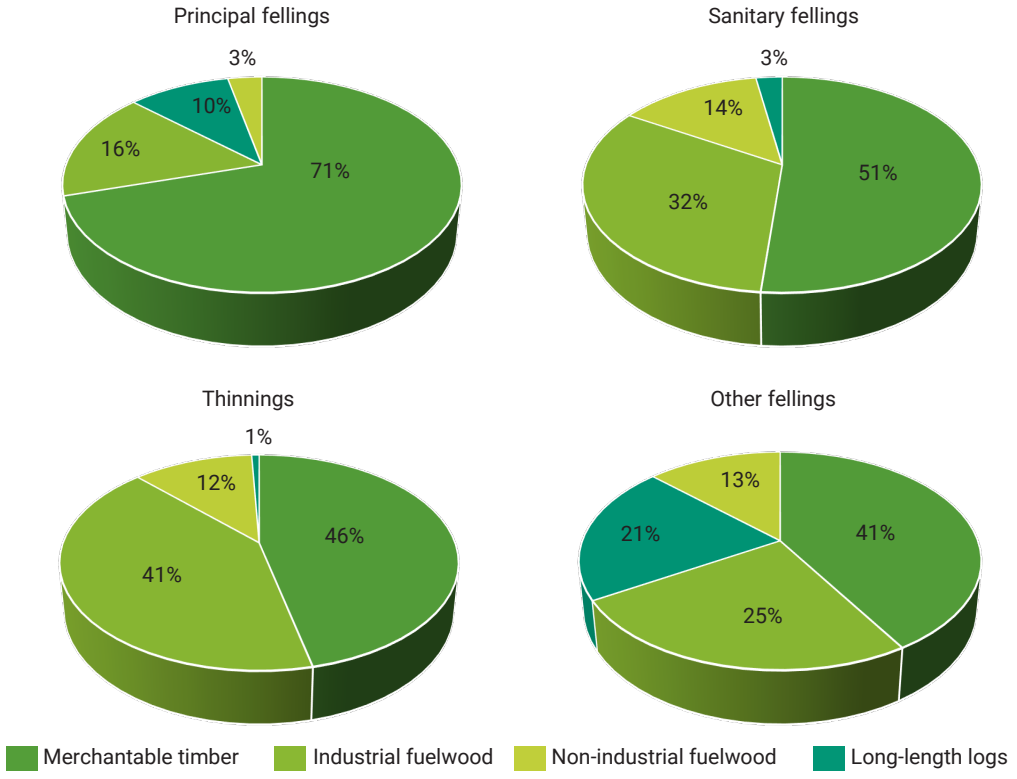

Figure 8. Distribution of pine timber volume by wood type, 2023

Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

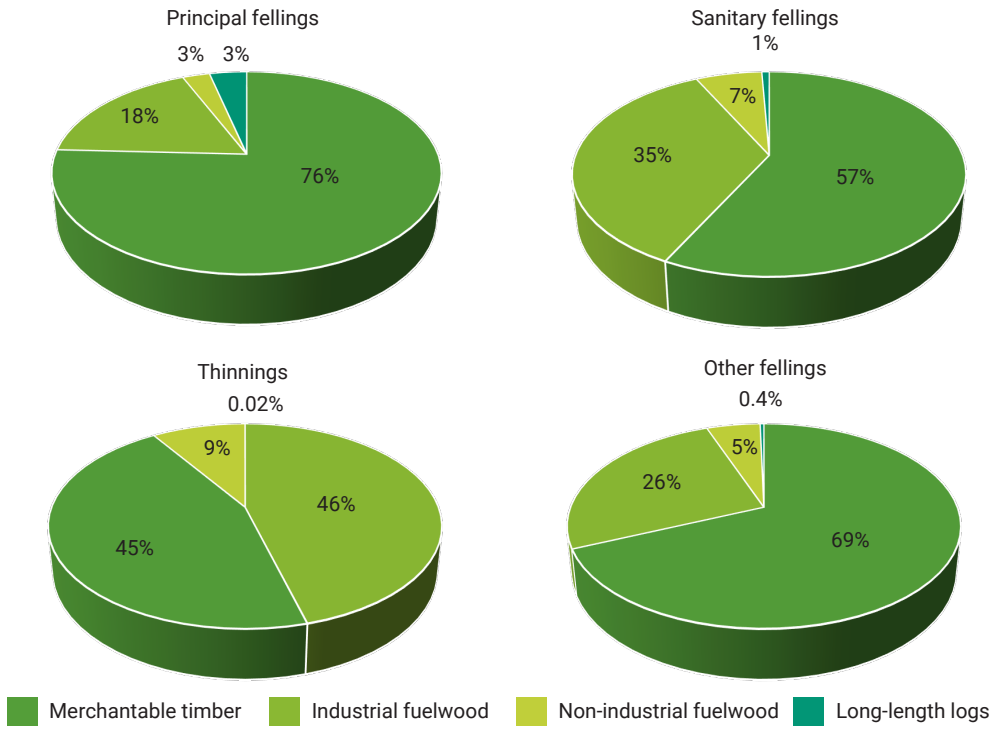

Figure 9. Distribution of pine timber volume by wood type, 2024
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

The largest proportion of merchantable timber was obtained from principal fellings, amounting to 71% in 2023 and 76% in 2024. This indicated that principal fellings remained the main source of harvested merchantable timber. Sanitary fellings also contributed a significant amount of timber. Although the wood type distribution within these fellings was less optimal for commercial use, the share of merchantable timber remained considerable even in these operations, which were aimed at removing diseased and damaged trees. Specifically, in 2023 and 2024, the share of merchantable timber obtained from sanitary fellings was 51% and 57% respectively. As for thinning, they yielded the lowest amount of merchantable timber. Most of the timber from thinnings belonged to the fuelwood category, particularly for industrial use. Nonetheless, the share of merchantable timber during thinning remained notable – 46% in 2023 and 45% in 2024. This could be explained by the trends discussed above, especially the significant volumes of timber harvested from commercial thinning (age of 41-70), where the stands approached the age of technical maturity, making it possible to obtain merchantable timber even during care cuttings.

Figures 10 and 11 illustrate the distribution of pine merchantable timber by quality class in 2023 and 2024, taking into account the types of felling. As in the previous analysis by wood type, the quality of merchantable timber largely depended on the type of felling. Over the study period, the majority of pine merchantable timber belonged to quality class C, which averaged 60%.

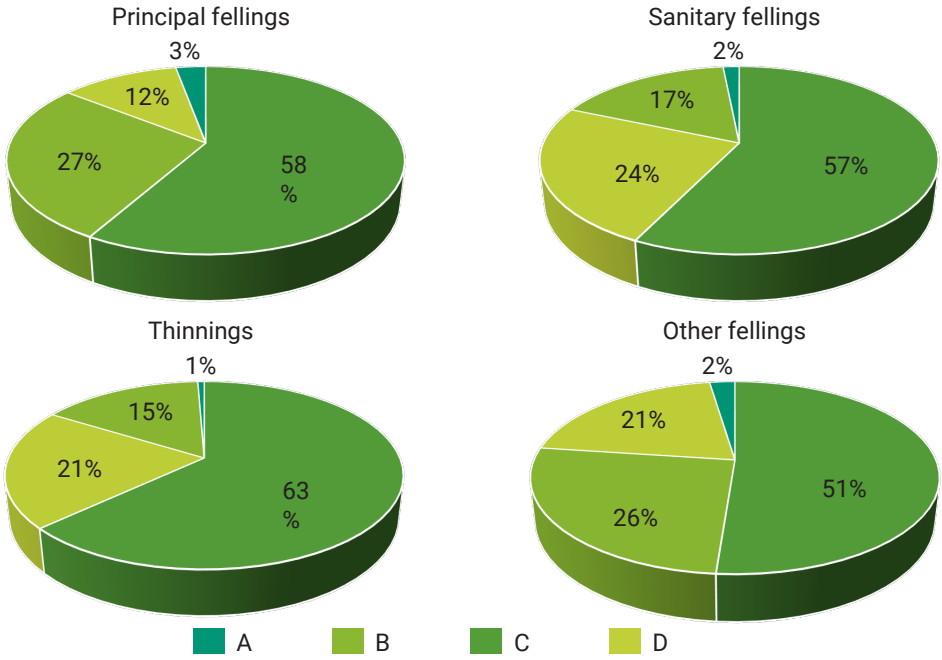

Figure 10. Distribution of pine merchantable timber by quality class, 2023
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

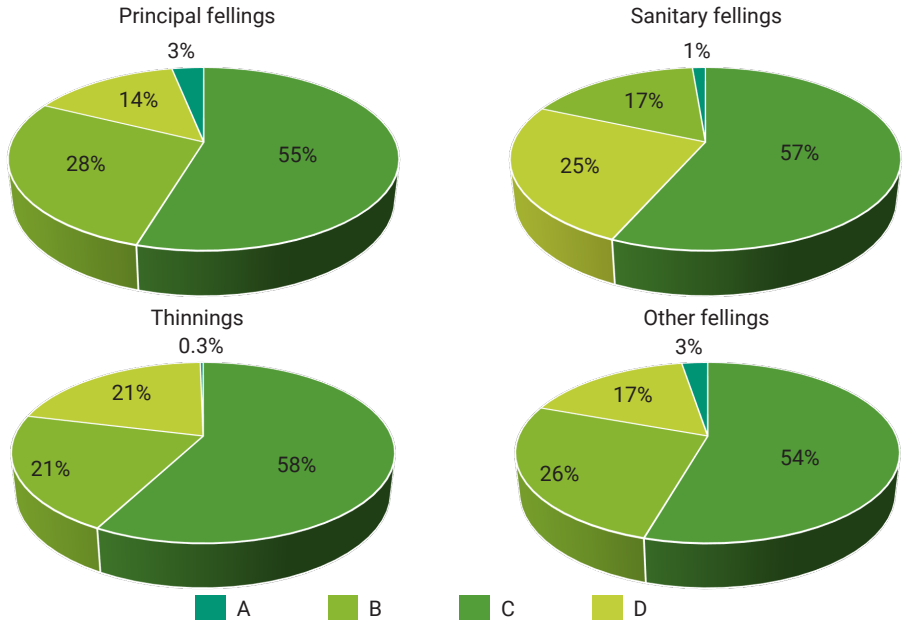

Figure 11. Distribution of pine merchantable timber by quality class, 2024
Source: compiled by the authors based on data from State Forest Resources Agency of Ukraine (n.d.b)

The share of the highest-quality merchantable timber (classes A and B) throughout the study period amounted to approximately 25%. The greatest amount of such timber was obtained from principal fellings, where their proportion reached 30% in 2023 and 31% in 2024. A relatively high proportion of premium-grade merchantable timber was also obtained from other types of felling, where classes A and B together accounted for up to 30%. Thinnings in the region yielded a significant amount of class C merchantable timber. The share of class D merchantable timber exhibited minor variations across different felling types during 2023 and 2024. In particular, in 2024, the volume of class D merchantable timber in other fellings decreased by 4%, possibly indicating an improvement in the quality of harvested timber. Within the overall structure of merchantable timber by quality class, the highest shares of lower-quality timber originated from thinnings and sanitary fellings.

According to the State Forest Resources Agency of Ukraine (n.d.a), the majority of Ukraine's forests were located in the Polissya and Ukrainian Carpathian regions, with around 33% covered predominantly by Scots pine. It was also reported that approximately half of all forests in Ukraine were of artificial origin, which required intensive management. These findings corresponded with the results of this study: in particular, it was established that Volyn Polissya accounted for over 13% of the country's forest area, and the forest cover of this region significantly exceeded the national average. A similar pattern was observed with regard to forest origin – artificially established forests comprised a considerable portion of the region's structure, aligning with national trends. However, in Volyn Polissya, the majority of forests were suitable for economic use: around 73% of forest land belonged to the category of exploitable forests. For comparison, only about 50% of forests nationwide were subject to limited-use regimes.

According to the State Forest Resources Agency of Ukraine (2024), middle-aged stands prevailed in Ukraine's age structure (47.5%), while the share of mature and overmature stands amounted to 18.7%, and the average forest age exceeded 60 years. At the same time, this study established that the average age of pine stands in Volyn Polissya was 53 years – slightly below the national figure. The share of middle-aged pine stands in this region exceeded 47% by area and 54% by growing stock, which closely corresponded to the nationwide structure. Regarding timber stock, the national average was approximately 235 m^3 ha^{-1}, whereas in Volyn Polissya's pine stands it amounted to 219 m^3 ha^{-1}. These results indicated a general similarity in the age structure and forest inventory characteristics between the regional and national levels, albeit with slightly lower productivity in the studied region.

Ukraine's Polissya is one of the most forested natural-geographical regions of the country, characterised by diverse site conditions and a subdivision into smaller ecological units. Therefore, it was appropriate to compare the findings of this study with similar research conducted in other parts of the Ukrainian Polissya. In particular, Y.Yu. Siruk *et al*. (2015) reported that in Central Polissya, pine occupied 59% of forest-covered areas, which was 5% lower than in the current study. Large areas were also covered by softwood deciduous species – alder and birch – and the share of oak in Central Polissya (16%) significantly exceeded that in Volyn Polissya (6%). The productivity of pine stands in Central Polissya ranged from site index class V, 2 under wet pine forest conditions (A5) to site index class Ia,3 in fresh loamy soils (C2). The majority of forested areas were found on fresh and moist subory and sugrudy. This suggested that the forest soils in Central Polissya were generally more fertile, while pine stand productivity was comparable,

indicating favourable growing conditions for Scots pine in both regions.

The share of natural-origin pine forest plots in Eastern Polissya (which included Sumy and Chernihiv regions) amounted to approximately 20%, which was significantly lower than in Volyn Polissya (48%). In both regions, the largest pine areas were concentrated in moist subory, favouring high stand productivity – a significant share of forests grew under site index classes Ia-I (Lakyda & Matushevich, 2013). Notably, Volyn Polissya had a higher share of site index class II pine stands – around 32% compared to 12% in Eastern Polissya. High- and medium-density stands made up the vast majority of pine forests in both regions – exceeding 95%.

According to the State Statistics Service of Ukraine (n.d.), over 30 million cubic metres of timber were harvested in Ukraine during 2023-2024, of which 15.1 million cubic metres were Scots pine. Approximately 25% of this volume was attributed to the Volyn Polissya region. The share of merchantable timber in the total harvesting structure increased both in the research region and across Ukraine. At the same time, in Volyn Polissya this indicator significantly exceeded the national average: 58% compared to 44% in 2023, and 62% compared to 46% in 2024. The main sources of timber supply in Ukraine remained principal fellings and sanitary fellings. The proportion of principal fellings at the national level was higher than in Volyn Polissya: 43-44% versus 39-37% respectively in 2023-2024. Meanwhile, the share of sanitary fellings, accounting for about 40%, indicated issues with the sanitary condition of Ukraine's forests, particularly the Scots pine stands of the studied region.

According to the study by A.S. Torosov & I.N. Zhezhkun (2021), in 2019 among the administrative oblasts located within Ukrainian Polissya, the highest volumes of roundwood harvesting were recorded in Zhytomyr (17.4%), Kyiv (9.8%), Rivne (8.5%), and Volyn (7.3%) regions. Furthermore, in terms of sawn timber production, Rivne (8.8%) and Volyn (14.4%) regions were among the top four leaders nationwide. These figures demonstrated a substantial concentration of logging and primary wood processing in Volyn Polissya, confirming the high forest resource potential of the region and correlating with the identified high productivity of Scots pine stands.

A comparative analysis of the qualitative structure of harvested timber revealed significant differences between Volyn Polissya and the Slobozhanskyi region (Uvarov, 2024). In the study region, the share of merchantable timber was about 60%, which was significantly higher than in the Slobozhanskyi Forest Office of the SE "Forests of Ukraine" (37%). Additionally, Volyn Polissya showed a higher share of higher-quality timber: quality class A accounted for 2% (compared to 1%), class B – 23% (compared to 10%), while in the Slobozhanskyi region quality classes C and D dominated (together 89%). In Volyn Polissya, class C timber also prevailed (56%), but the share of the lowest class D was noticeably lower – around 20%.

The comparison of the study's findings with similar data from Zhytomyr region, which belongs to the same natural-geographical region of Polissya, enabled a broader understanding of the differences in forest resource structure and timber harvesting within the region. In Zhytomyr region, according to I.H. Patseva *et al*. (2023), the total forest fund area was 1.09 million hectares, of which 952.6 thousand hectares were covered with forest vegetation. Among tree species, Scots pine dominated (59.1% of the forest-covered area), which was also reflected in its predominance in total timber harvesting – 2,188.6 thousand cubic metres, exceeding 80% of all harvested timber. The share of merchantable timber was around 52%, which was lower than in Volyn Polissya (60%).

Scots pine stands in Volyn Polissya played a key role in shaping the region's forest resource potential, both in quantitative and qualitative terms. An in-depth analysis of forest inventory indicators revealed an uneven age structure and a high proportion of middle-aged stands, indicating the need to revise forest management planning strategies and implement adaptive long-term management measures. The assessment of pine distribution by site conditions revealed the dominance of productive trophic types (fresh and moist subory), which created an optimal environment for the development of high-quality stands suitable for targeted forestry use. The structure of fellings in the region indicated a significant dependence of timber harvesting on sanitary measures, which, along with the identified stand condition, signalled a need for systematic forest rehabilitation and a shift towards more nature-oriented reforestation methods. The high proportion of merchantable timber harvested during principal fellings confirmed the significant economic potential of the region's pine forests, while the qualitative composition of timber from sanitary fellings and thinnings pointed to room for improving resource efficiency. The electronic timber accounting system enabled the identification of annual changes and the clarification of productivity for different types of felling, providing a basis for informed forest management decisions. The results obtained confirmed the representativeness of the region for studying nationwide trends in the forestry sector, while also revealing specific features linked to the prevalence of production forests, high forest cover, and established approaches to forest utilisation.

Conclusions

The average forest inventory indicators of Scots pine stands in Volyn Polissya were as follows: average age – 53 years; average growing stock – 219 m^3 ha^{-1}; average stocking density – 0.73; average site index class – I,7. Scots pine stands in Volyn Polissya exhibited an uneven age structure, necessitating a set of long-term forestry measures to achieve optimality, including a revision of harvesting volumes. It was also necessary to reassess the appropriateness of continuing the cultivation of stands in site index classes V and lower, unless they fulfilled important ecological or other functions. In moist site conditions, it was deemed advisable to replace pine with more moisture-loving species to fully utilise the potential of such forest lands.

Low-density stands occupied less than 2% of the total area. Nevertheless, their presence indicated the need to implement forestry measures to prevent such plots from transitioning into the sparse forest category. These measures might include reconstruction, promoting natural regeneration, and establishing partial forest cultures. During 2023-2024, 1.45 million cubic metres of Scots pine were harvested in the forests of Volyn Polissya from principal fellings and 1.51 million cubic metres from sanitary fellings. The average volume harvested per hectare over 2023-2024 was 35 m^3, with the following distribution by main types of felling: principal felling – 171 m^3, clear sanitary felling – 149 m^3, commercial thinning (age of 41-70) – 29 m^3, selective sanitary felling – 15 m^3, commercial thinning (age of 21-40) – 10 m^3, pre-commercial thinning (age of 11-20) – 4 m^3.

The dimensional and qualitative structure of Scots pine timber harvested in Volyn Polissya varied significantly depending on the type of felling. Principal fellings yielded the largest volumes of merchantable timber, particularly of quality classes A and B, while sanitary fellings and thinnings typically yielded lower-quality timber. The research findings underscored the need to improve forestry practices to enhance the efficiency of forest resource use and the condition of forest stands in the region. Future research aims to update

the analysis based on up-to-date forest inventory materials, national inventory data, and the authors' own research findings. This will enable the evaluation of growth dynamics and structural changes in Scots pine stands in Volyn Polissya, and refine the directions for an in-depth analysis of the state and utilisation of forest resources in the region.

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Conflict of Interest

None.

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Структура та використання лісоресурсного потенціалу соснових насаджень Волинського Полісся

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Анотація. Актуальність дослідження зумовлена необхідністю раціонального використання лісоресурсного потенціалу соснових насаджень Волинського Полісся як одного з найбільш лісистих регіонів України з вагомим екологічним, економічним і соціальним значенням. Метою дослідження було вивчення таксаційної структури та аналіз використання соснових насаджень Волинського Полісся, пошук шляхів оптимізації процесу ведення лісового господарства в регіоні. Проведено комплексний аналіз просторової, вікової структури та продуктивності соснових насаджень Волинського Полісся з оцінкою використання їх запасів за видами рубок. Встановлено, що в регіоні дослідження близько 64 % площі лісових ділянок вкритих лісовою рослинністю зайняті сосновими насадженнями. Переважаючими за площею були штучні соснові насадження, які становили понад 52 %. Найбільш розповсюдженими були середньовікові насадження, що могло пояснюватися активним лісовідновленням у післявоєнні роки. Найбільше соснових насаджень зростало у свіжих і вологих суборах, які були оптимальними для росту цієї породи. Щорічний обсяг заготівлі деревини породи сосна лісогосподарськими підприємствами досліджуваного регіону в середньому становив 1,9 млн м^3, а більшість цієї деревини надходила від рубок головного користування та санітарних рубок. Серед рубок догляду значна частка заготівлі деревини припадала на прохідні рубки. Частка інших рубок, пов'язаних і не пов'язаних з веденням лісового господарства, становила 1-2 %. Середній обсяг заготівлі деревини породи сосна з 1 га перебував в межах від 2 м^3/га для рубок прочищення до 173 м^3/га для рубок головного користування. Результати дослідження можуть бути використані для вдосконалення лісогосподарських методів і формування стратегії сталого розвитку лісового господарства Волинського Полісся

Ключові слова: таксаційні показники; вікова структура; лісистість; запас; заготівля деревини