

УДК 630

**Засновник:**

Національний університет біоресурсів і природокористування України,  
ТОВ «Наукові журнали»

**Рік заснування: 2010**

Періодичність випуску: 4 рази на рік

*Рекомендовано до друку та поширення  
через мережу Інтернет Вченою радою*

*Національного університету біоресурсів і природокористування України  
(протокол № 12 від 29 травня 2024 р.)*

**Державна реєстрація:**

**Ідентифікатор медіа R30-02293.**

Рішення Національної Ради України  
з питань телебачення і радіомовлення  
№ 1795, протокол № 31 від 21.12.2023 р.

**Журнал входить до переліку фахових видань України**

Категорія «А». Галузь наук – сільськогосподарські, технічні, біологічні,  
спеціальність – 206 «Садово-паркове господарство»,  
205 «Лісове господарство», 187 «Деревообробні і меблеві технології»,  
101 «Екологія», 091 «Біологія»

(наказ Міністерства освіти і науки України № 1543 від 20 грудня 2023 року)

**Журнал представлено у міжнародних наукометричних базах даних,  
репозитаріях та пошукових системах:**

Index Copernicus International, Scopus, Google Scholar, Національна бібліотека України імені  
В. І. Вернадського, MIAR, BASE, CABI, AGRIS, GEOBASE, Polska Bibliografia Naukowa (PBN),  
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ASCI, Zenty, OUCI (Open Ukrainian Citation Index), Worldcat, Scilit

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<https://forestscience.com.ua/uk>

UDC 630

**Founder:**

National University of Life and Environmental Sciences of Ukraine,  
LLC "Scientific Journals"

**Year of foundation: 2010**

Frequency of issue: Four times per year

*Recommended for printing and distribution  
via the Internet by the Academic Council  
of National University of Life and Environmental Sciences of Ukraine  
(Minutes No. 12 of May 29, 2024)*

**State Registration:**

**Media identifier R30-02293.**

Decision of the National Council  
of Television and Radio Broadcasting of Ukraine  
No. 1795, Minutes No. 31, dated 21.12.2023.

**The journal is included in the list of professional publications of Ukraine**

Category "A". Agricultural, technical, biological, specialty – 206 "Horticulture", 205 "Forestry", 187  
"Woodworking and Furniture Technologies", 101 "Ecology", 091 "Biology"  
(Order of the Ministry of Education and Science of Ukraine  
No. 1543, dated December 20, 2023).

**The journal is presented international scientometric databases,  
repositories and scientific systems:**

Index Copernicus International, Scopus, Google Scholar, Vernadsky National Library  
of Ukraine, MIAR, BASE, CABI, AGRIS, GEOBASE, Polska Bibliografia Naukowa (PBN), Scientific  
Indexing Services (SIS), UCSB Library, Ulrichsweb Global Serials Directory, EBSCO, Dimensions,  
University of Oslo Library, University of Hull Library, SOLO – Search Oxford Libraries Online,  
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Zendy, OUCI (Open Ukrainian Citation Index), Worldcat, Scilit

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UDC 57.04

DOI: 10.31548/forest/2.2024.08

## Impact of electric power facilities on natural phytocenotic diversity

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**Abstract.** The relevance of studying the impact of electric power facilities on natural phytocenotic diversity lies in the necessity to preserve ecosystems due to the increasing number and size of electrical facilities, which potentially can affect the functioning of natural environments. The research aims to investigate the impact of electric power facilities on species diversity. The research

### **Suggested Citation:**

Glibovytska, N., Rashevskva, H., Arkhypova, L., Adamenko, Ya., & Orfanova, M. (2024). Impact of electric power facilities on natural phytocenotic diversity. *Ukrainian Journal of Forest and Wood Science*, 15(2), 8-22. doi: 10.31548/forest/2.2024.08.

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is carried out at 46 monitoring sites in the immediate vicinity of the source of electromagnetic and noise pollution within the influence of the Burshtyn thermal power plant, the Bohorodchany solar power plant, the Shevchenkove wind power plant, the Tereble-Rytska hydroelectric power plant, under regional and cross-border power transmission lines. The representation of plant species at the monitoring sites is analysed. In general, 196 plant species are identified. Herbaceous plants dominate (from 74 to 100% of all plant life forms) at all monitoring sites, except for one site. Shrubs are present in 11 monitoring sites (from 5 to 25% of all plant life forms). The trees are represented in 20 monitoring sites (from 4 to 75% of all plant life forms). 179 species belong to the first class of constancy, 12 species belong to the second class and 5 species belong to the third class of constancy (91, 6.5 and 2.5%, respectively). The last plants have been identified as indicators of the influence of power plants. The most common plant families that exist under the influence of electrical installations are established. The largest number of species is represented by the *Asteraceae*, *Rosaceae* and *Poaceae* families – 37, 19 and 15 species, respectively. The species of the third constancy class have the highest representativeness. *Daucus carota* L., *Achillea millefolium*, and *Trifolium pratense* L. are the dominant plant species in the areas impacted by electric power facilities. 180 species belong to the first constancy class. They cannot be suitable as phytoindicators of the ecological state in the areas affected by power plants. The results can be used to develop environmental protection strategies and measures to reduce the negative impact of power generation facilities on flora

**Keywords:** biodiversity; constancy class; electrical power; pollution; environment

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## Introduction

Expanding on the relevance of studying the impact of electric power facilities on natural phytocenotic diversity is imperative due to the necessity of ecosystem preservation. Understanding these dynamics is crucial for formulating strategies to mitigate potential adverse effects on biodiversity, ensuring ecosystem preservation for current and future generations. Additionally, such research aids in fostering sustainable development practices that harmonize human activities with the natural world, promoting ecological resilience and stability.

R. Kravchynskyi *et al.* (2021) studied that plants are the primary recipients of technogenic influence, and they reflect the level of anthropogenic environmental transformation. M. Korchemlyuk & L. Arkhypova (2016) noted that the bioindicative role of plants allows timely monitoring of the smallest changes in

the ecological state and, if necessary, reacting to them. Y.A. Farghaly *et al.* (2019) considered that phytocenotic wealth is the main criterion for the stability and balance of any ecosystem. The decrease in plant diversity is a sign of bioenergy resources depletion of this territory. The research conducted by L. Simkiv *et al.* (2021) underscores the significance of analysing the phytocenotic diversity of plant communities as a pivotal indicator of ecosystem ecological health. Their study delves into the dynamic interplay of structural processes within these ecosystems, offering valuable insights into fostering sustainable development practices. By elucidating these dynamics, their analysis contributes to the formulation of informed strategies aimed at safeguarding biodiversity and promoting ecological resilience in the face of contemporary environmental challenges.

The electric power industry is a source of noise, vibration, and electromagnetic environmental pollution. Understanding the impact of these pollutants on natural ecosystems is essential for assessing the overall ecological health of affected areas. U. Andrusiv *et al.* (2021) described the optimization of balance components of fuel and energy resources for organizational and economic support of energy efficiency in Ukraine. Integrating the findings of the research of V. Kopei *et al.* (2022) enriched understanding of the multifaceted interactions between industrial activities and ecological systems, aiding in the development of holistic strategies for sustainable development and environmental conservation.

Electromagnetic radiation contributes to mutation emergence caused by single-strand breaks in DNA and leads to cell division and protein synthesis disruption, especially in tissues that are actively dividing. DNA synthesis and repair processes inhibition is observed under the impact of electromagnetic fields with a frequency of 50-100 Hz (Liu *et al.*, 2020). Changes in the diffusion rate through membranes, structures of organic compounds, denaturation of proteins owing to the absorption of thermal energy by the cell, and generation of free radicals occur under the impact of electromagnetic radiation. Free radicals are one of the ageing causes. The negative impact of noise and vibrations on the functioning of the cardiovascular, endocrine, nervous system and sensory organs of humans and animals has been defined by A. Aaron *et al.* (2019).

The functional state of plant communities under the influence of electric power facilities has not been studied. The literature sources provide data on changes in the size and shape of vegetative and generative plants' organs, and the violation of leaf asymmetry under the impact of radiation (Deruelle, 2020).

P. Bandara & D. Carpenter (2018) studied the noise influence on plants. They established that different frequencies of sound unequally influence the plants' growth. Vibration pollution affects the physiological qualities of plant seeds, which leads to their germination decrease. Optimal plant growth is observed when plants are exposed to pure tones, in which the wavelength coincides with the average main leaf sizes. The research on the phytomelioration role of woody plants under the electromagnetic radiation impact testifies about the higher plants' resistance with a large area and leaf plates' mass. The issue of the electric power industry facilities impact on natural biocenoses has not yet been studied and requires the attention of ecologists (Arkhypova *et al.*, 2021). A comprehensive study of electric power facilities' impact on plants and their cenosis within the transboundary Carpathian region of Ukraine has not been carried out.

The establishment of dominant plant species in the phytocenosis will allow informational phytoindication of the environmental state under the influence of electric power facilities. The purpose of our research is the analysis of the plant communities' species diversity under the electric power facilities influence in the Carpathian region of Ukraine. The main tasks of this article are:

- ◆ to analyse the probable impact of the electric power facilities on plants;
- ◆ to investigate the species composition of phytocenoses;
- ◆ to study the dominant plant species in the areas affected by power plants.

## Materials and Methods

The methods of biological monitoring of the environmental state were used in the work: observation, surveys, and field research, which provide the description, and study of plant groups as ecosystem components in natural

conditions, and research of their functioning, structure, and development (Kravchynskiy *et al.*, 2021). Field research (photo of different species), chamber work (identification of species), and analytical analysis of the results (determine constancy class) were carried out.

The research was conducted in 2021-2022 years as part of the implementation of the HUSKROUA international project on the Carpathian region territory of Ukraine in the monitoring areas under the influence of electric power facilities – transformer substations, power lines, and power plants. The monitoring network included 46 sites near the impact source. The influence zone of electromagnetic field objects can be more than 100 m (Ropyak *et al.*, 2023). The power lines create the main electromagnetic field of industrial frequency (Kusyi *et al.*, 2021). The sanitary protection zone for an overhead power line with a voltage of 1150 kV is 55 m and for an overhead power line with a voltage of 300 kV – 20 m (Ropyak *et al.*, 2023). Therefore, the research was carried out at a distance of 50 m from the source of the electromagnetic field. The level of electromagnetic and noise pollution was measured.

An analysis of the species diversity of phytocenoses within each monitoring point is carried out. Plants were photographed on a test plot with an area of 25 m<sup>2</sup>. The Plant Snap program and plant reference books were used to identify each plant species. When the phytocenosis has the form of a narrow strip (ruderal vegetation along the fence), the transects 2-2 m wide were laid. If the vegetation groups at the monitoring point were of small size (for example on wastelands), the entire vegetation centre was described. The taxonomic characteristics of each species and life form were determined according to the generally accepted method (Swadde *et al.*, 2015). The research complied with the ethical norms specified in the Convention on Biological Diversity (1992), the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973).

The phytocenotic diversity is determined as a percentage at each monitoring site. The plant diversity in the monitoring area with the largest number of plant species is taken as 100%. The coefficient and constancy class of each plant species are determined according to the following classification (Table 1).

**Table 1.** The characterization of the species constancy in the phytocenosis

Coefficient of constancy	Persistence class	Representativeness of the species
81-100	V	High
61-80	IV	
41-60	III	Middle
21-40	II	
<20	I	Low

**Source:** J. Dengler *et al.* (2009)

The research was conducted on the territory of the Ivano-Frankivsk and Zakarpattia oblasts in the observation areas under the influence of electric power facilities – transformer substations, power transmission lines and power plants. The impact of the activity of such

electric power facilities as the Burshtyn thermal power plant, the Shevchenkove wind power plant, the Bohorodchany solar power plant, and the Tereble-Rytska hydroelectric power plant was studied. Research was also conducted on the influence of overhead power lines and

transformer substations of various capacities. The influence of cellular communication stations was studied within the population centres. In total, the monitoring network includes more than 250 points in the immediate vicinity of the source of influence.

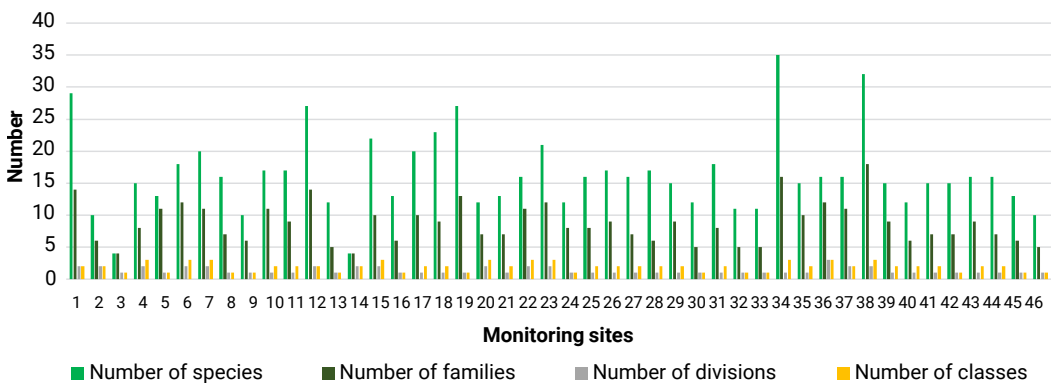
### Results and Discussion

The results of phytocoenotic diversity studies under power plants' impact demonstrate the following: the largest number of plant species is represented on the wind power plant territory in Shevchenkove village – 34 species (site 34) and the experimental area of Bohorodchany – 32 species (site 38). The smallest number of plant species (4 species) is represented on one of the experimental sites in Yaremche city (site 3) and the private sector territory in Tyachiv village (site 14) (Fig. 1).

The first experimental site in Yaremche city, the experimental site in Dilove village and also in Nizhnya Tisa village is characterized by high phytocoenotic diversity (more than 75%). In the areas affected by electrical installations ten

of the 47 identified families are the most common: *Asteraceae* – present at 45 sites, *Fabaceae* – 39 sites, *Rosaceae* – 26 sites, *Apiaceae* – 33 sites, *Poaceae* – 26 sites, *Lamiaceae* – 25 sites, *Ranunculaceae* – 24 sites, *Urticaceae* – 16 sites, *Plantaginaceae* – 23 sites, *Polygonaceae* – 17 sites. All other families are marked by a low representation in the system of biological monitoring of electric power facilities' impact – they are present in several 1 to 7 monitoring sites. The largest number of species is represented by *Asteraceae*, *Rosaceae* and *Poaceae* families – 37, 19, and 15 species, respectively (Fig. 2).

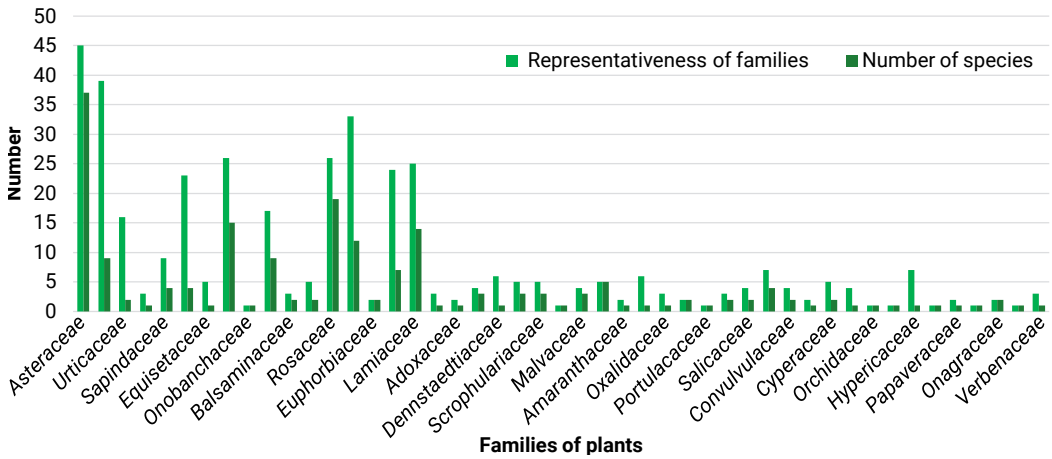
In the areas impacted by electrical installations *Lamiaceae* family is represented by 14 plant species, *Apiaceae* – 12 species, *Fabaceae* and *Polygonaceae* – 9 species, *Ranunculaceae* – 7 species. Other plant families are represented by from 1 to 5 species. Among 196 identified plant species at all monitoring sites, 179 species belong to the first constancy class, 12 species to the second and 5 species to the third constancy class, which in percentages is 91, 6.5 and 2.5%, respectively (Fig. 3).



**Figure 1.** Taxonomic characteristics of plants at monitoring sites of electrical installations' impact on the environment

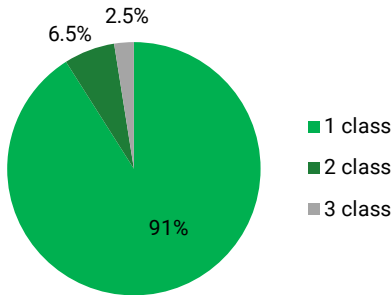
**Note:** site 1-5 – Yaremche, 6 – Yasinya, 7-11 – Rakhiv, 12 – Dilove, 13-16 – Tyachiv, 17-18 – Teresva, 19 – Nizhnya Apsha, 20-26 – Solotvyno, 27 – Sokyrnytsia, 28-29 – Khust, 30 – Lipcha, 31 – Nizhny Bystry, 32 – hydroelectric power station on the Tereblya River, 33 – Vyshkiv, 34-36 – Shevchenkove, 37-39 – Stari Bohorodchany, 40-46 – Burshtyn

**Source:** developed by the authors



**Figure 2.** Representativeness of plant families at monitoring sites of electrical installations impact on the environment

Source: developed by the authors



**Figure 3.** The percentage ratio of plant species by constancy classes at monitoring sites under electrical installations impact

Source: developed by the authors



**Figure 4.** *Achillea millefolium* L.

Source: photo by the authors



**Figure 5.** *Daucus carota* L.

Source: photo by the authors

Among 196 identified plant species, species belonging to the third constancy class have the highest representativeness – *Achillea millefolium* L. and *Bellis perennis* L. from the Asteraceae family, *Trifolium repens* L. and *Trifolium pratense* L. from Fabaceae family, *Daucus carota* L. from Apiaceae family. *Achillea millefolium*, *Trifolium repens* and *Daucus carota* are the dominant plant species in the areas affected by power plants, which are represented in 46, 48, and 50% of the experimental areas, respectively (Fig. 4-6).



**Figure 6.** *Trifolium pratense* L.

**Source:** photo by the authors

These plants have formed stable populations in various living conditions and are most adapted to heterogeneous habitats. Therefore, they are recommended to be used in the biological monitoring of anthropogenic influence, including the influence of electromagnetic and noise pollution, on the biotic environment (Gagliano *et al.*, 2017; Mesfin *et al.*, 2018).

The second class of permanence includes the following plants' species – *Taraxacum officinale* Wigg., *Centaurea jacea* L., *Plantago lanceolata* L., *Sonchus arvensis* L., *Calamagrostis epigejos* (L.) Roth., *Dactylis glomerata* L., *Ranunculus acris* L., *Mentha longifolia* L., *Tanacetum vulgare* L., *Artemisia vulgaris* L., *Urtica dioica* L. These species are represented in the amount of 20-40% of experimental points and can be used in ecomonitoring studies of electric power facilities' environmental impact (Slabbekoorn & Ripmeester, 2008).

All other species (*Urtica urens* L., *Juglans regia* L., *Acer platanoides* L., *Equisetum arvense* L., *Vicia villosa* Routh., *Molinia caerulea* L., *Aegopodium podagraria* L., *Rumex acetosella* L., *Impatiens parviflora* DC., *Festuca arundinacea* Schreb., *Rumex crispus* L., *Galium besseri* L., *Prunus domestica* L., *Lathyrus pratensis* L., *Phléum pratense* L., *Lactuca serriola* L., *Arc-tium minus* (Hill.) Bernh., *Triticum aestivum* L., *Euphorbia helioscopia* L., *Thuja occidentalis* L., *Iva annua* L., *Galinsoga parviflora* Cav., *Erigeron*

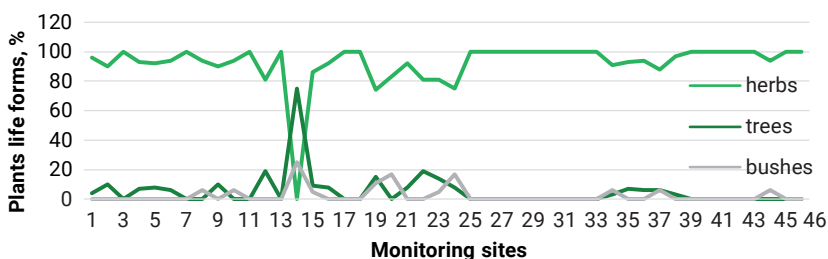
*annuus* (L.) Desf., *Aesculus hippocastanum* L., *Cardamine pratensis* L., *Filipendula ulmaria* (L.) Maxim., *Angelica archangelica* L., *Fraxinus excelsior* L., *Eupatorium cannabinum* L., *Stachys palustris* L., *Pteridium aquilinum* (L.) Kuhn., *Salvia glutinosa* L., *Rúbus idáeus* L., *Corylus avellana* L., *Stachys sylvatica* L., *Scrophularia nodosa* L., *Ulmus alata* Miehx., *Solidago virgaurea* L., *Tilia cordata* Mill., *Plantago major* L., *Actaea spicata* L., *Torilis arvensis* L., *Verbascum thapsus* L., *Phléum pratense* L., *Bidens tripartita* L., *Anuncus dioicus* (Walter.) Fernald., *Cirsium arvense* L., *Angelica sylvestris* L., *Anemone blanda* L., *Petasites albus* (L.) Gaertn., *Rumex acetosella* L., *Capsella bursa-pastoris* L., *Persicaria lapathifolia* L., *Origanum vulgare* L., *Erigeron canadensis* L., *Rosa rubiginosa* L., *Amaranthus retroflexus* L., *Lamium album* L., *Reynoutria sachalinensis* (F. Schmidt.), *Alliaria petiolate* (M. Bieb.) Cavara, *Reynoutria japonica* Houtt., *Rumex crispus* L., *Lamium maculatum* L., *Rúbus idáeus* L., *Agrimonia eupatoria* L., *Rorippa sylvestris* L., *Polygonum aviculare* L., *Polygonum hydropiper* L., *Symphoricarpos albus* (L.) S.F. Blake, *Oxalis dillenii* Java., *Impatiens glandulifera* Royle., *Hypochaeris radicata* L., *Rosa pendulina* L., *Acer campestre* L., *Lolium perenne* L., *Solidago canadensis* L., *Tilia platyphyllos* Scop., *Pastinaca sativa* L., *Salvia verticillata* L., *Echium vulgare* L., *Alnus glutinosa* (L.) Gaerth., *Robinia pseudoacacia* L., *Portulaca oleracea* L., *Digitaria sanguinalis* (L.) Scop., *Picea abies* (L.) H.Karst., *Prunus cerasifera* L., *Cichorium intybus* L., *Melilotus officinalis* (L.) Pall., *Ambrosia artemisiifolia* L., *Clematis vitalba* L., *Hibiscus syriacus* L., *Salix caprea* L., *Crepis capillaris* (L.) Wallr., *Bidens tripartita* L., *Raphanus raphanistrum* L., *Gypsophila muralis* L., *Panicum virgatum* L., *Convolvulus sepium* L., *Prunus domestica* L., *Cynodon dactylon* (L.) Pers., *Tordylium apulum* L., *Medicago sativa* L., *Prunella vulgaris* L., *Dipsacus fullonum* L., *Acer platanoides* L., *Rosa multiflora* Thunb., *Lamium purpureum* L., *Anthemis arvensis* L., *Fraxinus ornus* L., *Prunus cerasus* L.,

*Rubus ulmifolius* Schott., *Jacobaea erratica* (Ber-  
tol.) Fourr., *Fructus Rubi idaei*, *Lythrum salicar-  
ia* L., *Carex flacca* L., *Poa pratensis* L., *Hieracium  
canadense* L., *Heracleum sosnowskyi* Manden.,  
*Carpinus betulus* L., *Helianthus tuberosus* L.,  
*Ranunculus repens* L., *Sambucus ebulus* L.,  
*Galeopsis speciosa* L., *Rubus caesius* L., *Lysi-  
machia vulgaris* L., *Stellaria holostea* L., *Stachys  
palustris* L., *Anthemis cotula* L., *Rosa canina* L.,  
*Fraxinus ornus* L., *Heracleum sphondylium* L.,  
*Jacobaea vulgaris* Gaertn., *Matricaria chamo-  
milla* L., *Myrrhis odorata* (L.) Scop., *Salix pur-  
purea* L., *Ononis spinosa* L., *Campanula glomer-  
ata* L., *Hypericum perforatum* L., *Argentina  
anserina* (L.) Rydb., *Tussilago farfara* L., *Silene  
latifolia* Poir., *Malus sylvestris* Mill., *Symphytum  
officinale* L., *Stellaria graminea* L., *Prunus pa-  
dus* L., *Abies alba* Mill., *Agrostis capillaris* L., *Gal-  
ium sylvaticum* L., *Astrantia major* L., *Chaero-  
phyllum temulum* L., *Ranunculus lanuginosus* L.,  
*Matteuccia struthiopteris* (L.) Tod., *Rumex ob-  
tusifolius* L., *Hypochaeris radicata* L., *Melampy-  
rum pratense* L., *Pyrus communis* L., *Veronica  
anagallis-aquatica* L., *Persicaria hydropiper* (L.)  
Spac.) belong to the first constancy class and  
are present in less than 20% of experimental  
points. This makes it impossible to use them as  
environmental quality biological indicators.

The insignificant presence of most species  
on the experimental sites indicates their

inadequacy to resist technogenic impact and  
the strict adherence of these plants to environ-  
mental conditions (in particular, the need for  
humidity, soil type, mechanical composition  
and amount of nutrients of the specific growth  
areas' soils). Interpopulation interactions of  
phytocoenotic communities affect the surviv-  
al of plant populations. Therefore, a stronger  
plant population displaces weaker plants from  
the territory of existence. The insignificant  
presence of certain plant species in the exper-  
imental points is a sign of accidental spread by  
seed reproduction and wind, insects, and ani-  
mals transfer to certain distances. However, this  
indicates the low vitality of such species.

Each plant species is limited to growth in  
certain specific natural and climatic conditions.  
Environmental factors complex (biotic, abiotic  
and anthropogenic) affect plants spread in nat-  
ural and anthropogenically altered ecosystems.  
The herbaceous plants dominate in all investi-  
gated sites (except for the Tyachiv village edge  
site) and they make up from 74 to 100% of all  
life plants' forms. This is explained by the high  
level of herbaceous forms survival due to the  
structure, physiology, and individual develop-  
ment peculiarities. Shrubs are represented in  
11 out of 46 monitoring sites, and they make up  
from 5 to 25% of all life forms, trees – in 20 sites  
and make up from 4 to 75% (Fig. 7).



**Figure 7.** The percentage ratio of plants' life forms  
at monitoring sites under electrical installations impact

**Note:** site 1-5 – Yaremche, 6 – Yasinya, 7-11 – Rakhiv, 12 – Dilove, 13-16 – Tyachiv, 17-18 – Teresva, 19 – Nizhnya Apsha, 20-26 – Solotvyno, 27 – Sokyrnytsia, 28-29 – Khust, 30 – Lipcha, 31 – Nizhny Bystry, 32 – hydroelectric power station on the Tereblya River, 33 – Vyshkiv, 34-36 – Shevchenkove, 37-39 – Stari Bohorodchany, 40-46 – Burshtyn

**Source:** developed by the authors

In general, the average percentage value of plants' life forms in the research area is 94.33% for grasses, 12.25% for trees and 10% for shrubs.

Power generation and transmission facilities have a variety of negative effects on natural objects and biodiversity, which is associated not only with atmospheric emissions and waste generation but also with electromagnetic fields of power lines and noise impact, changes in albedo and thermal regime environment. Thus, researchers (Kopei *et al.*, 2023) conclude that the high intensity of electromagnetic fields (the experimental process is carried out at a voltage of about 1000 V and a current density of more than 500 A/m<sup>2</sup>) causes the need to take mandatory measures to protect against harmful effects.

The destructive effect of noise on terrestrial animals is manifested at noise intensity up to 40 dB. It changes the behaviour and physiological reactions of animals. As a result, there is a decrease in reproductive potential, an increase in mortality and increased migration among animals, noted M. Havas (2017). Birds, reptiles, and amphibians are especially sensitive to noise pollution. Their range is narrowing as a result of increased technogenic activity (Garcés *et al.*, 2020). Electromagnetic radiation has a similar effect on living organisms. It also has a powerful mutagenic and carcinogenic effect. Electromagnetic radiation is considered the cause of "chronic fatigue syndrome", which was diagnosed in people at the end of the 80s of the 20th century (Malovanyy *et al.*, 2022). Scientific studies of A. Wdowiak *et al.* (2017), A. Elgayar *et al.* (2019) have established several destructive processes in the human body and some animals under the influence of electromagnetic and noise pollution.

A paper by S.M. Grodsky *et al.* (2023) found that ants can serve as useful bioindicators of the severity of anthropogenic disturbances from solar energy development in deserts, and an analysis of indicators suggests that

solar energy infrastructure may adversely affect some species of high ecological value (e.g., ants-reapers). The negative impacts of solar energy development on ants can have significant consequences for the functioning and integrity of a desert ecosystem, but environmentally friendly design and construction of solar installations can avoid the bottom-up environmental consequences of increasing solar energy production during the transition to renewable energy sources.

The selection of plant bioindicators of the areas affected by power plants should be carried out, taking into account climatic zoning and their phytodiversity. It is necessary to systematically conduct research and modelling (Arkhypova *et al.*, 2021).

When studying the effect of low-intensity electromagnetic radiation on insects, teratogenic effects were observed, which were inherited. In their fundamental work, G. Redlarski *et al.* (2015) have established that electromagnetic radiation leads to the delay and termination of the reproduction processes of bacteria and viruses and reduces their infectious activity. Under the influence of electromagnetic radiation in the range of 50-55 GHz, the growth of unicellular eukaryotes – yeast *Saccharomyces cerevisiae* is stimulated.

L.V. Kucherenko & V.S. Kalinichenko (2013) concluded that some plants, notably corn and unicellular green algae, react to definite levels of radiation by increasing growth processes. For example, the pre-sowing treatment of corn seeds by the electromagnetic field with a frequency of 3-30 MHz increases the germination energy and the laboratory similarity of the treated material. This makes it possible to reduce the growing season and increase the crop yield. At insignificant values of the electromagnetic radiation energy, a slight increase in *Chlorella* microalgae cells is observed. Radiation intensity increases causes the following

irreversible processes of microalgae: enzymes, nucleic acids, proteins' denaturation, and destruction of cells through the appearance of the membrane pores. Electromagnetic radiation with energies above 3 kJ has a detrimental effect on *Chlorella* growth (Deruelle, 2020).

Researchers I.B. Korduba & Zh.I. Patlashenko (2023) has established that the unification of plant communities is observed under conditions of constant man-made influence, as a result of "ecological stress". The work of V.É. Molnár *et al.* (2020) evaluates the usefulness of the Air Pollution Resistance Index (APTI) as a composite index of the environmental condition in the city of Debrecen (Hungary). The amount of fine and coarse dust and elemental concentrations of *Celtis occidentalis* and *Tilia × europaea* were measured in June and September at three sampling sites (urban, industrial and rural) to evaluate the utility of APTI. Tree leaf APTI has been found to be a particularly useful proxy measure of air pollution as well as environmental health.

In the work of A. Cakaj *et al.* (2023), plants-bioindicators were studied for determining pollution by heavy metals in the urban and non-urban areas of Poznań. The authors conducted a study of such bioindicators as weeds: *Trifolium pratense* (*Trifolium pratense* L.), *Rumex acetosa* L., *Amaranth retroflexus* L., lanceolate plantain (*Plantago lanceolata* L.), ornamental *Alcea* species pink (*Alcea rosea* L.), *Lolium multiflora* L. var. Ponto. All species were found to have heavy metal accumulation potential, especially *A. rosea*, *P. lanceolata* and *L. multiflorum* for Zn (BCF=6.62; 5.17; 4.70) and *A. rosea*, *P. lanceolata* for Cd (BCF=8.51; 6.94). The translocation of Cu and Zn was most efficient in *T. pratense* (TF Cu = 2.55; TF Zn = 2.67) and *A. retroflexus* (TF Cu = 1.50; TF Zn = 2.23). It was established that the studied weeds are good bioindicators of heavy metal pollution, and their joint use makes it possible to comprehensively detect environmental threats.

The main energy facility on the territory of the Ivano-Frankivsk region is the Burshtyn TPP, which is also one of the largest sources of atmospheric air pollution. Research by H.V. Krechkivska (2022) found that within a radius of up to 500 m around the TPP there are 8 types of shrub-tree plants, deformation of shoots is observed in 75% of trees and bushes and leaf plates in 100%. This article is the closest to the research we have done. But it refers to tree-shrub vegetation, not grass.

Most plants have a high level of adaptation. At a distance of up to 1 km<sup>2</sup> from the Burshtynskaya TPP, there are already twenty species of shrub-tree vegetation, in which the deformation of shoots is much less and is observed in 35% of trees and bushes, but the deformation of leaf plates remains at 100%. Isolating the effects of the electromagnetic field and atmospheric air pollution on the intensity of deformation of shoots and leaf plates requires further detailed observations.

Conducted studies by S. Kaur *et al.* (2021) of physiological, biochemical and molecular changes in plant development showed that an electromagnetic field leads to a change in fermentation activity. This results in changes in plant cells and retardation of their growth. Thus, the effects of electromagnetic radiation will be integrated into the models of plant development. Therefore, the degree of soil cover by various types of plants and the degree of their overgrowth can be considered the main indicators of man-made influence. Impact zones should be characterized by an appropriate level of species and taxonomic diversity. When determining the level of pollution, it is possible to use phytoindicative scales of plant groups. At the same time, in some cases, they have a slight differentiation of values. Therefore, they are not always effective.

Therefore, the study conducted by the authors on the impact of electricity generation facilities on plant communities to use them as

indicators of impact within the Carpathian region of Ukraine is original and important from the point of view of the development of ecological knowledge.

### Conclusions

It has been established that under the impact of electrical installations the following plants families are the most common – *Asteraceae*, *Fabaceae*, *Rosaceae*, *Apiaceae*, *Poaceae*, *Lamiaceae*, *Ranunculaceae*, *Urticaceae*, *Plantaginaceae*, *Polygonaceae*, *Asteraceae*, *Rosaceae* and *Poaceae* families are represented by the largest number of species – 37, 19 and 15 species, respectively. 196 plant species are detected at 46 monitoring sites. 179 species belong to the first constancy class, 12 species to the second and 5 species to the third constancy class, which in percentages is 91, 6.5 and 2.5%, respectively. In all research sites, except for one site, herbaceous plants dominate, which make up from 74 to 100% of all life plant forms. This is explained by the high level of herbaceous forms survival due to the structure, physiology, and individual development peculiarities. Shrubs are represented in 11 monitoring sites out of 46. They make up from 5 to 25% of all life forms, and trees are represented in 20 sites and make up from 4 to 75%. The species that belong to the third constancy class have the highest representativeness. There are *Achillea millefolium* and *Bellis perennis* from the

*Asteraceae* family, *Trifolium repens* and *Trifolium pratense* from the *Fabaceae* family, *Daucus carota* from *Apiaceae* family. *Daucus carota*, *Achillea millefolium*, *Trifolium repens* are the dominant plant species in the areas impacted by the electric power facilities. They are represented by 46, 48 and 50% in the experimental sites, respectively. *Taraxacum officinale*, *Centaurea jacea*, *Plantago lanceolata*, *Sonchus arvensis*, *Calamagrostis epigejos*, *Dactylis glomerata*, *Ranunculus acris*, *Mentha longifolia*, *Tanacetum vulgare*, *Artemisia vulgaris*, *Urtica dioica* belong to the second constancy class. The remaining 180 species belong to the first constancy class. They cannot be suitable as phytoindicators of the environmental condition in the areas under the electric power facilities impact.

Future research should focus on developing strategies and technologies to minimize the negative impacts of electricity facilities on natural plant diversity. This may include the development of environmentally friendly construction and operation technologies, as well as measures to restore and compensate for biodiversity losses.

### Acknowledgements

None.

### Conflict of Interest

None.

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## **Вплив електромагнітного забруднення на фітоценотичне різноманіття**

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**Анотація.** Актуальність вивчення впливу об'єктів електроенергетики на природне фітоценотичне різноманіття полягає в необхідності збереження екосистем через збільшення кількості та розмірів об'єктів електроенергетики, які потенційно можуть впливати на функціонування природного середовища. Мета дослідження – дослідити вплив об'єктів

електроенергетики на видове різноманіття. Дослідження проводились на 46 пунктах моніторингу в безпосередній близькості від джерела електромагнітного та шумового забруднення в межах впливу Бурштинської ТЕС, Богородчанської сонячної електростанції, Шевченківської ВЕС, Теребле-Рицької ГЕС, під регіональними та транскордонними лініями електропередачі. Загалом виявлено 196 видів рослин. Трав'янисті рослини домінують (від 74 до 100 % усіх життєвих форм рослин) на всіх ділянках моніторингу, крім однієї ділянки. Чагарники представлені на 11 ділянках моніторингу (від 5 до 25 % усіх життєвих форм рослин). Дерева представлені на 20 ділянках моніторингу (від 4 до 75 % усіх життєвих форм рослин). До першого класу константності відносяться 179 видів, до другого – 12 видів, до третього – 5 видів. Останні рослини були визначені як індикатори впливу електроенергетики. Встановлено найпоширеніші родини рослин, які існують під впливом електроустановок. Найбільшу кількість видів представлено родинами складноцвітими, розоцвітими та злаковоцвітими – 37, 19 та 15 видів відповідно. Найбільшу репрезентативність мають види третього класу константності. *Daucus carota* L., *Achillea millefolium*, *Trifolium pratense* L. є домінуючими видами рослин на територіях впливу об'єктів електроенергетики. *Taraxacum officinale* Wigg., *Centaurea jacea* L., *Plantago lanceolata* L., *Sonchus arvensis* L., *Calamagrostis epigejos* (L.) Roth., *Dactylis glomerata* L., *Ranunculus acris* L., *Mentha longifolia* L., *Tanacetum vulgare* L., *Artemisia vulgaris* L., *Urtica dioica* L. – рослини другого класу константності. Решта 180 видів належать до першого класу константності. Вони не можуть бути придатними як фітоіндикатори екологічного стану в зонах ураження електростанціями. Отримані результати можуть бути використані для розробки природоохоронної стратегії та заходів щодо зменшення негативного впливу об'єктів електроенергетики на рослинний світ

**Ключові слова:** біорізноманіття; клас константності; електроустановки; навколишнє середовище

UDC 528.9:332.362:630\*43:711.434

DOI: 10.31548/forest/2.2024.23

## Mapping Wildland-urban interfaces to support wildfire management over fire-prone forest outskirts of the Zhytomyr region

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### **Suggested Citation:**

Soshenskyi, O., Myroniuk, V., Zibtsev, S., Gumeniuk, V., de Miguel Díez, F., & Vasylyshyn, R. (2024). Mapping Wildland-urban interfaces to support wildfire management over fire-prone forest outskirts of the Zhytomyr region. *Ukrainian Journal of Forest and Wood Science*, 15(2), 23-40. doi: 10.31548/forest/2.2024.23.

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**Abstract.** Recent wildfire events in Ukraine caused considerable economic and human losses, drawing the attention of public opinion in Ukraine to further research the issue related to the management of the risks of forest fires, specially, in the current context of climate change and due to the growing frequency of critical fire weather conditions. Current approaches to fighting wildfires in Ukraine are focused on fire extinction, currently omitting the management of vegetation fuels and their effect on wildfire behaviour to facilitate its mitigation. Due to current wildfire risks to the population and forests, and insufficient research on this issue in Ukraine, it is needed to further develop and test new approaches to reduce wildfire risk. For that purpose, it is required a deep understanding of the fire resilience of vegetation as well as the factors that make the communities vulnerable. In this manuscript, a method for assessing and mapping the Wildland-urban interface with a focus on fire risks for part of the Ukrainian Polissya is suggested. Wildland-urban interface zones were delineated for settlements in the study area and used to identify areas for wildfire risk remediation and silvicultural practices to increase forest resilience to fire. A biodiversity analysis of the main tree species, undergrowth, and understory of the study region, produced a list of local deciduous species that could be used to reduce fire intensity by increasing their proportion in pure pine forests. The volume of silvicultural efforts to increase forest resilience to fire and reduce wildfire risks to human settlements was assessed for one of the most forested regions of Ukraine. Moreover, the first comprehensive assessment of wildlands, which can potentially contribute to wildfire impacts on communities, was provided, making recommendations to reduce wildfire risks for the settlements. In this study, feasible and effective methods to assess Wildland-Urban-Interfaces, and reduce fire risks are suggested, suggesting a methodology concerning wildfire risks for a heavily forested region of Ukraine. Moreover, the suggested approaches that could be used in Ukrainian Forest Management to mitigate wildfire risks in the context of climate change, urbanization, and low resistance of pure pine stands to fires as well as pests and diseases

**Keywords:** climate change; Forest Fire Resilience Edges; Pine stands; Ukrainian Polissya

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## Introduction

Growing the frequency and intensity of forest fires, especially in the context of climate change, poses a threat to ecosystems and settlements. Studying and mapping these interfaces allows for the development of effective strategies and measures to manage risks and prevent the spread of fires in regions where the interaction between nature and populated areas becomes particularly vulnerable. The development and implementation of new wildfire management strategies aimed at preserving ecosystems and protecting the population in the face of growing natural disaster risks are crucial.

An increasing tendency of the frequency of large fires with catastrophic consequences is observable in Ukraine (Soshenskyi *et al.*, 2021). The problem of forest fires in the WUI (Wildland Urban Interface) is a growing issue in the entire world (Ager *et al.*, 2019b; Bar-Massada *et al.*, 2023). Current dynamics of fires in the world show a growing trend in the number and frequency of large wildfires with catastrophic consequences (Dowdy *et al.*, 2019; Goldammer, 2021).

There are several differently developed approaches to identify and map WUI (Radeloff *et*

*al.*, 2005). Considering all developed methods, two WUI mapping methods must be highlighted: 1) the point-based approach and 2) the zonal approach, which are detailed in the study conducted by A. Bar-Massada (2021).

The main factors that determine the risk of wildfires and their exposure are the characteristics of vegetation fuels, weather conditions, and the source of ignition (Ager *et al.*, 2019a). The majority of wildfires in Europe (95% of all wildfires) are directly or indirectly caused by human behaviour and activities (San-Miguel-Ayán *et al.*, 2021; European Union, 2023). Such a situation is also typical in Ukraine where the main reason for wildfires is human activity, including negligence and arson as noted by O. Soshenskyi *et al.* (2021).

Vegetation has one of the main impacts on fire behaviour during wildfires. E.L. Loudermilk *et al.* (2022) indicated that long-term ecosystem management by altering vegetation structure as a fuel management practice can change fire distribution and intensity. Vegetation types can behave quite differently as fuel. Tree species affect flammability and are characterized by different resistance to fires (Stevens *et al.*, 2020; Chuvieco *et al.*, 2023). The overall ability of trees to resist fire is one of the indicators of forest resistance to increased fire activity under climate change conditions (Day *et al.*, 2023). Hence, forest structure, the species composition of forests and the adaptation of forest landscapes to fire are key elements in the formation of fire resistance in forests.

While conducting this research study, no publications for Ukraine could be found that had been focused on fuel management, in particular, increasing the proportion of deciduous species in the pure pine stands of Ukraine. Moreover, the research issue of the wildfire occurrence in the WUI zones in Ukraine has not yet been studied. The wildfire occurrence in 2020, when seven settlements were affected

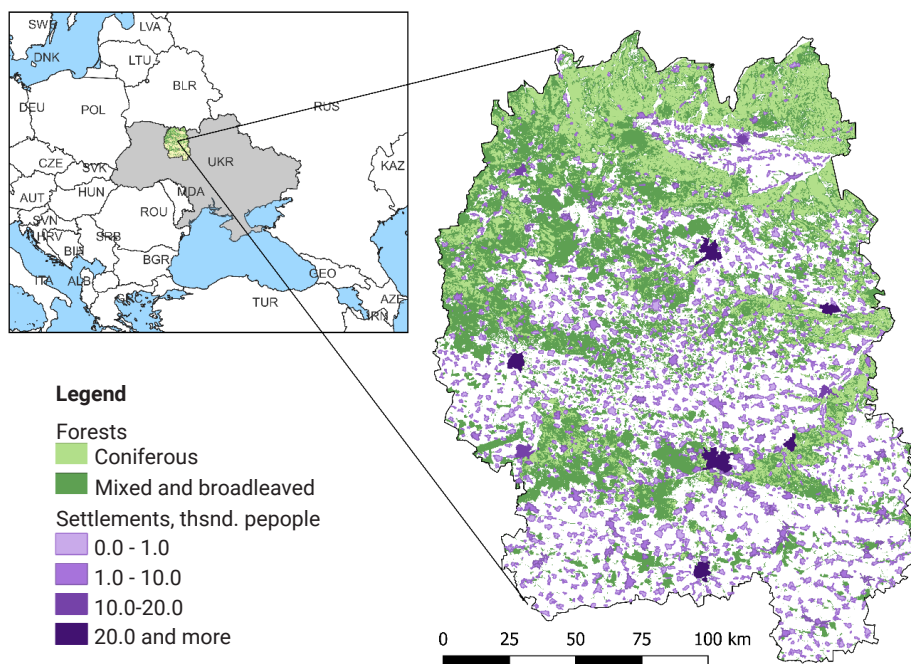
in the Zhytomyr region, in which 82 households were destroyed and damaged (Emergency Service of Ukraine, 2021) demanded researching of this issue.

This research study aimed to highlight regional-scale aspects of the wildfire problems within the WUI in Ukraine. The study provides the first comprehensive assessment of where wildlands can potentially contribute to wildfire impacts on communities as well as recommendations to reduce wildfire risks for the settlements through forest management to increase the resilience of pine stands in the context of climate change for the Polissya region.

## Materials and Methods

### Study area

The study was conducted in the region of Zhytomyr (29,827 km<sup>2</sup>) which is located in northern Ukraine (Fig. 1). The forests cover a surface of 1,123,000 ha, being primarily (59.1%) composed of Scots pine (*Pinus sylvestris* L.). The total forest cover of the Zhytomyr region is 34.1% and ranges in different administrative regions from 6.2% (in the south) to 69.8% (in the north) (Zhytomyr Regional State Administration, 2021). The population density of this region is 40 inhabitants per square km. The study area is characterized by a large fragmentation of settlements on the territory of the region. The northern part of the region is the most forested with the dominance of pure pine stands and the location of small settlements directly in the forests (Humanitarian Data Exchange, n.d.; Buchhorn *et al.*, 2020). According to the official sources, as of January 1, 2021, there are 12 cities and 1600 rural-type settlements with 1,195,500 people (59.5% are urban, and 40.5% – rural population) in this territory (Zhytomyr Regional State Administration, 2021). Study regions with spatial patterns of forest and density of settlements are shown in Figure 1.



**Figure 1.** Study area and settlement distribution by people density

**Source:** Humanitarian Data Exchange (n.d); M. Buchhorn *et al.* (2020)

The climate within the Zhytomyr region is moderately continental, characterized by mild winters and wet summers. The average annual temperature is 10°C, ranging from 4°C in January to 20°C in July. The average annual precipitation is 570-600 mm. According to climatic and soil conditions, the territory is dominated by pine stands, being the representation of stands of other tree species: oak forests (19.1%), birch

(14.7%), alder (4.7%), aspen (0.9%) and others (1.5%) (Zhytomyr Regional State Administration, 2021).

**Data**

*Land cover*

The “Land Cover 100 m data” (Buchhorn *et al.*, 2020) was used to characterize the land cover. The original land cover was reclassified as displayed in Table 1.

**Table 1.** Land cover classification

Original land cover classes (Buchhorn <i>et al.</i> , 2020)		Recoded classes
Class code	Class description	
111	“Closed Forest, evergreen needle leaf”	Coniferous forests
112	“Closed Forest, evergreen, broad leaf”	Broadleaved and mixed forests
113	“Closed Forest, deciduous needle leaf”	Broadleaved and mixed forests
114	“Closed Forest, deciduous broad leaf”	Broadleaved and mixed forests
115	“Closed Forest, mixed”	Broadleaved and mixed forests
116	“Closed Forest, unknown”	Broadleaved and mixed forests
20	“Shrubs”	Other natural landscapes

Table 1, Continued

Original land cover classes (Buchhorn <i>et al.</i> , 2020)		Recorded classes
Class code	Class description	
30	“Herbaceous vegetation”	Other natural landscapes
60	“Bare / sparse vegetation”	Other natural landscapes
90	“Herbaceous wetland”	Other natural landscapes
40	“Cultivated and managed vegetation/ agriculture (cropland)”	Croplands
50	“Urban / built up”	Settlements

Source: M. Buchhorn *et al.* (2020)

To analyse the species diversity of trees and shrubs that can be used to transform pure pine stands into more fire-resilient mixed stands, information about the forest stands from the Ukrainian State Forest Management

Planning Association (n.d.) was used. A list of species that form various structural elements of the forest; main tree species, understorey, and undergrowth was prepared (Table 2-Table 4).

**Table 2.** Distribution of the forest area by main tree species in the Zhytomyr region

Main tree species	Area, thousand ha	Share of area, %
<i>Pinus sylvestris</i> L.	3549.4	56.1
<i>Betula pendula</i> Roth.	1050.7	16.6
<i>Quercus robur</i> L.	957.3	15.1
<i>Alnus glutinosa</i> (L.) Gaerth.	427.9	6.8
<i>Picea abies</i> L.	88.0	1.4
<i>Pinus sylvestris</i> L.	83.2	1.3
<i>Populus tremula</i> L.	69.9	1.1
Other (44 species)	95.4	1.5
Total	6321.8	100

Source: developed by the authors using the data of the Ukrainian State Forest Management Planning Association (n.d.)

The species composition of the forests of the Zhytomyr region is very limited. The presence of deciduous species such as birch (*Betula pendula* Roth.) and oak (*Quercus robur* L.) is observed. These tree species can grow in those conditions where Scots pine also does. Although oak presents a lower commercial quality where this tree species is located in the conditions where pine grows, a mixed stand composed of these two species can have a positive effect on the resistance of pine trees to climate changes and fires, improving in this way their resilience.

Information about the species that can be found in the undergrowth and understorey makes it possible to choose local species to compose pine forest stands with a greater proportion of deciduous tree species (Table 3 and Table 4). The presence of *Quercus robur* L. and *Betula pendula* Roth. in the undergrowth of nature indicates the possibility of the formation of the under-canopy crops from these species. The diversity of shrubs is very high, being the most common in the regional stands: 1) *Frangula alnus* Mill., 2) *Corylus avellana* L., 3) *Rhododendron luteum*.

**Table 3.** Distribution of the forest area with understory of Zhytomyr region

Species	Area (ha)	Share of area, (%)
<i>Quercus robur</i> L.	395,300	42.4
<i>Carpinus betulus</i> L.	225,100	24.2
<i>Pinus sylvestris</i> L.	131,000	14.1
<i>Betula verrucosa</i> Ehrh.	108,000	11.6
<i>Acer platanoides</i> L.	16,300	1.7
<i>Picea abies</i> L.	10,300	1.1
Other (33 species)	45,500	4.9

**Source:** developed by the authors using the data of the Ukrainian State Forest Management Planning Association (n.d.)

**Table 4.** Distribution of the forest area with undergrowth of Zhytomyr region

Species	Area (ha)	Share of area (%)
<i>Frangula alnus</i> Mill.	1554,500	58.8
<i>Corylus avellana</i> L.	467,300	17.7
<i>Rhododendron luteum</i> , Sweet	241,500	9.1
<i>Sorbus aucuparia</i> L.	118,100	4.5
<i>Salix caprea</i> L.	53,500	2.0
<i>Salix pentandra</i> L.	50,800	1.9
<i>Salix aurita</i> L.	30,500	1.2
<i>Sambucus nigra</i> L.	27,500	1.0
Other (59 species)	100,200	3.8
Total	2,643,900	100

**Source:** developed by the authors using the data of the Ukrainian State Forest Management Planning Association (n.d.)

According to the type of forest vegetation conditions, which determine the potential species diversity of forests, an important part of the territory is occupied by poor soils that are fresh (soil moisture index – 2) in terms of moisture. 33% of the forests of the studied region grow on poor soils corresponding to the type of forest vegetation conditions  $A_2$ , 34% on  $B_2$  soils and 10% in poor, dry conditions  $A_1$  where site conditions A, B, C, D stand for soil fertility (from poor to fertile) and 0, 1, 2, 3, 4, 5 – soil moisture (from very dry to very wet) (Pogrebnyak, 1955).

#### *Classification of wooded areas according to wild-fire hazard*

To assess fire hazard, broadleaved and mixed forests were combined in two groups: 1) mixed

forests that included land cover classes with class codes 112, 113, 115, 116 and 2) deciduous forests – land cover class with class code 114. Accordingly, three levels of fire risk were assigned: 1) high (pine forest), 2) medium (mixed forest), and 3) low (deciduous forest). Such classification facilitates the selection of effective fuel treatment scenarios aimed at creating more fire-resistant forests in transition zones between natural forested landscapes and settlements (WUI).

#### *Settlements*

Boundaries of the settlements within the Zhytomyr region and their total population data were extracted from the Humanitarian Data Exchange (HDE) service (Humanitarian Data

Exchange, n.d.). According to that reference, 1,539 (92.8%) settlements in the Zhytomyr region are small, limiting their population to 1,000 inhabitants. Most of these settlements are located near the forests and are therefore vulnerable to forest wildfires. The methodology for assessing the area of fuel treatment that should be done to transform pure pine forests into more fire-resistant ones requires spatial information about settlements and forests to determine the WUI. Official data from the State Statistics Service of Ukraine, the Main Department of Statistics in the Zhytomyr region for the period from 1990 to 2021 were then used to estimate the dynamics of the population (State Statistics Service of Ukraine, 2022).

Within the Zhytomyr region, a decreasing trend in both urban and rural populations was observed. Over the last three decades, the population has decreased by 22.2%. The number of the rural population has decreased more intensively than the urban population (compared to 1990, the number of the urban population has decreased by 13.9%, and the rural population by 31.9%) (State Statistics Service of Ukraine, 2022). Generally, the population has decreased in small villages located far from large urban agglomerations, predominantly in the north of the region. This situation reduced wildfire risks due to the reduction of ignition sources but must be weighed against the increased wildfire hazard for settlements and individual houses located next to the forests due to the accumulation of fuels (growth of biomass) (Maillé & Espinasse, 2006; Maillé & Espinasse, 2012).

#### *Mapping WUI*

The term Wildland Urban Interface (WUI) is used to define those areas where buildings meet or encounter wild vegetation (Butler, 1974; Radeloff *et al.*, 2005). V.C. Radeloff *et al.* (2005) classified WUI into two types: 1) an intermix WUI (the area where houses and wildland vegetation

directly intermingle), and 2) an interface WUI (where settled areas abut wildland vegetation).

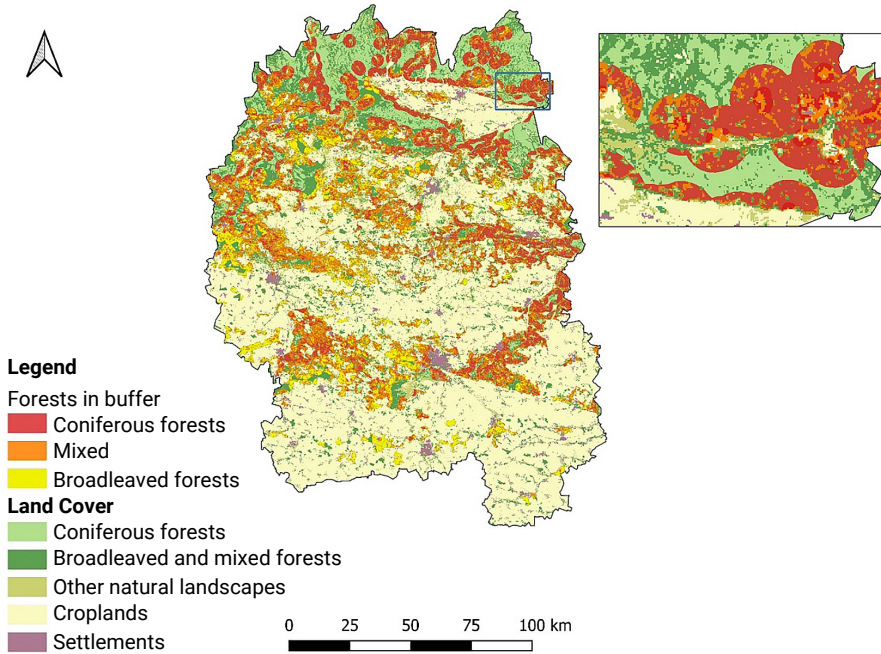
There are several ranges to determine the buffer distance from the forest area to settlements (houses). According to studies by W.G. Page *et al.* (2018), the maximum distance over which fires can spread is 2.7 km, and the distance within which they spread is 94% of all fire points within 500 m. California Fire Alliance (2001) recommended a distance of 2.4 km as an average distance in which a firebrand can fly ahead of a firefront. Although fuel types affect the potential spotting distance in the absence of data for Ukrainian conditions, we used a distance of 2.4 km to identify and map WUI in the method of V.C. Radeloff *et al.* (2005).

Due to the availability of data, the WUI point-based approach for mapping the WUI with some modifications was used. Instead of using houses, outlines of settlements were used. Implementing WUI approaches, the settlements located in the WUI zone were determined. A density threshold of 6.17 buildings per km<sup>2</sup> (i.e., 1 building per 16 hectares) was considered, where within 2.4 km of an area that is heavily vegetated (0.75% wildland vegetation) and larger than 5 km<sup>2</sup> (Radeloff *et al.*, 2005). Settlements located within a radius of 2.4 km from a forest with an area of more than 5 km<sup>2</sup> were identified. In addition, based on the research of W.G. Page *et al.* (2018), according to which 94% of all fire ignitions occur within 500 m, forest parts that are located in the buffer of 500 m from settlements were also identified. Thus, two arrays of data were defined: 1) zones of forest fire danger for settlements within the WUI (within a radius of 2.4 km) and 2) zones of extreme forest fire danger for settlements within the WUI (within a radius of 500 m). A distance of 2.4 km, which is recommended by the California Fire Alliance (2001) as an average distance that a firebrand can fly ahead of a firefront, was considered.

### Results and Discussion

One of the ways to reduce fire risks is to manage combustible materials, especially in the WUI zone. Two buffer zones in radiuses of 2, 4 and 0.5 km around settlements were

determined based on land cover information (Buchhorn *et al.*, 2020). Buffer zones within the WUI were mapped and classified into three wildfire risk classes defined above, and the forest zones around settlements (Fig. 2).



**Figure 2.** WUI over the Zhytomyr region:

fire-prone forested areas are shown within buffers of 2.4 km apart from settlements

**Source:** developed by the authors based on M. Buchhorn *et al.* (2020)

Figure 2 highlighted numerous zones that were classified as a high fire-risk area (pure pine forests – coniferous forests). Settlements in high fire-risk areas of the WUI zone, mainly located in the northern part of the region have a risk of negative consequences of forest fire.

Furthermore, the forest cover over both buffer zones (2.4 km and 0.5 km) was calculated. In doing so, the share of forests in the buffer zone with gradation by 25 per cent and the number of settlements in each gradation was calculated for each buffer (Table 5).

**Table 5.** Forest cover in the fire risk buffer zone of settlements in the Zhytomyr region

	Percentage of forests cover in the buffer zone (%)					Total
	<0.1	0.1-25.0	25.1-50.0	50.1-75.0	75.1-100	
<b>Buffer zone 2,400 m</b>						
<b>Forest cover</b>						
Forest area (ha)	43,125	406,893	136,043	51,131	6,327	643,519
Percentage	6.7	63.2	21.2	7.9	1.2	100

Table 1, Continued

	Percentage of forests cover in the buffer zone (%)					Total
	<0.1	0.1-25.0	25.1-50.0	50.1-75.0	75.1-100	
<b>Buffer zone 2,400 m</b>						
Number of settlements	357	583	347	252	119	1,658
Percentage	21.5	35.2	20.9	15.2	7.2	100.0
<b>Pine forest cover</b>						
Pine forest area, ha	41,584	94,230	82,915	39,676	6,002	264,408
Percentage	0.0	42.3	37.2	17.8	2.7	100.0
Number of settlements	612	838	152	50	6	1,658
Percentage	36.9	50.5	9.2	3.0	0.4	100.0
<b>Buffer zone 500 m</b>						
<b>Forest cover</b>						
Forest area, ha	4,751	20,713	5,575	1,357	53,496	85,893
Percentage	14.6	63.8	17.2	4.2	0.2	100.0
Number of settlements	640	494	242	157	125	1658
Percentage	38.6	29.8	14.6	9.5	7.5	100.0
<b>Pine forest cover</b>						
Pine forest area, ha	1,420	3,053	1,895	616	28,410	35,394
Percentage	0.0	54.6	33.9	11.0	0.5	100.0
Number of settlements	987	559	89	22	1	1,658
Percentage	59.5	33.7	5.4	1.3	0.1	100.0

**Note:** numerator – absolute value, denominator – percentage

**Source:** developed by the authors

The categories of forest highlighted in the map (Fig. 2) that characterize WUI made it possible to assess the scale of the possible impact of forest fires on the population. The total area of forests located in buffer zones with distribution by fire danger classes around settlements is presented in Table 6. This spatial information identified the

forest fire hazard for settlements in different zones of the Zhytomyr region and enabled effective fire management planning in these areas. Structural analysis of forests in these high fire-risk forests in WUI zones enables planning to develop a diverse fire-resistant forest structure based on species of diversity (Tables 2-4).

**Table 6.** Distribution of the total forest cover area within settlements buffer zones by the fire risk classes in the Zhytomyr region

Forest fire risk (land cover type)	Forest area within 2.4 km buffer		Forest area within 0.5 km buffer	
	ha	%	ha	%
High (pine forests)	264,408	41.1	35,394	41.2
Medium (mixed forests)	275,976	42.9	43,526	50.7
Low (broadleaved forests)	103,135	16.0	6,973	8.1
Total	643,519	100.0	85,893	100.0

**Source:** developed by the authors

The positive effect of introducing deciduous species into pine forests (Van Wilgen *et al.*, 1990; Parkins *et al.*, 2018) to increase forest fire safety justifies the planning to introduce

deciduous tree species into pine stands of Zhytomyr oblast. Considering the species composition of main tree species, undergrowth and understory species, given in Tables 2-4, local

deciduous species should be introduced in the pine forests of the study region: main shelter of a canopy – *Betula pendula* Roth., *Quercus robur* L.; undergrowth – *Frangula alnus* Mill., *Corylus avellana* L., *Rhododendron luteum*, *Sorbus aucuparia* L., *Salix caprea* L., *Salix pentandra* L., *Salix aurita* L., *Sambucus nigra* L.; understory – *Quercus robur* L., *Carpinus betulus* L., *Betula verrucosa* Ehrh. *Acer platanoides* L.

Considering the increased occurrence of severe wildfires over natural landscapes in Ukraine, as well as in Europe (FAO, 2015; San-Miguel-Ayanz *et al.*, 2020; European Environment Agency, 2021), it is necessary to comprehensively investigate the issue of landscape fire management in order to make further recommendations to reduce the risks of such fires. Climate change increases the potential for catastrophic wildfires that introduce a significant threat to settlements. Settlements and intense human activity next to forests in Ukraine increase the risk of human-caused ignition. Thus, there is an urgent need to promote the development of effective solutions to reduce the risks of forest fires in the WUI zone.

A survey conducted by a multidisciplinary team (composed of technicians of the fire management system as well as scientists) in 2020 at the national level regarding the forest fire and fire management system in Ukraine showed that the main cause of forest fires was the human activity (98%) (Soshenskyi *et al.*, 2021). O. Soshenskyi *et al.* (2021) found out that there was a relationship between the number of wildfires within pine forests and the population, which confirmed the fact that forest fires in Ukraine are mainly caused by activities related to forest visitors. Population growth leads to increased ignition probability, i.e., the fire occurrence, but simultaneously reduces wildfire burn probability due to reduced biomass (e.g., thinning forests for construction) (Maillé & Espinasse, 2006; 2012).

Thus, settlements with a few people located within fire-prone pine forests characterized, create low risks of fire ignition, but are high burning risks. Such situations' develop hazardous wildfires that can threaten settlements.

The problem of fire risks over WUI is influenced by the expansion of communities and the construction of new houses which does not account for the risk of forest fires, and forest policies that do not promote the reduction of the risk of forest fires for settlements. Currently, forest policy is limited to fire prevention measures rather than fuel treatments. A decrease in the number of rural populations leads to a reduction in the number of firefighting units in those regions, which reduces the effectiveness of reacting to fires.

In the Zhytomyr region, settlements are characterized by great fragmentation and are often located either close to or within the forests. The present study is the first research quantification effort devoted to the vulnerability of natural and anthropogenic landscapes to forest fire risk in the WUI zone in Ukraine.

Pure pine stands, which are inherent in the study region, correspond to the paradigm of forest policies in Ukraine of the last century, which promoted to plant of monospecific pine stands for production purposes. Under current circumstances of climate change and increases in the number of communities near the forests, such forests have risks of forest fires traversing settlements. Such a situation requires the development of guidelines to increase the resistance of pine forests to wildfires as well as to pests and diseases by transforming pure pine forests into mixed, complex coniferous-deciduous stands.

The composition of a mixed structure of stands instead of pure pine stands occasionally does not meet the central aim of forest management, e.g., it can lead to a decrease in the total volume of high-quality commercial wood.

However, the gained effect in terms of wildfire risk reduction transcends commercial revenue from timber. Increasing tree species diversity in forests through the creation of more mixed stands is a common aim of forest policies in different parts of the world, both as a means of increasing the delivery of ecosystem services from forests and as a way of increasing resilience to climate change as noted by W.L. Mason *et al.* (2018). One of the responsibilities of forest fire management is the execution of an analysis of how boundary and density of settlements as well as structural characteristics of forest change.

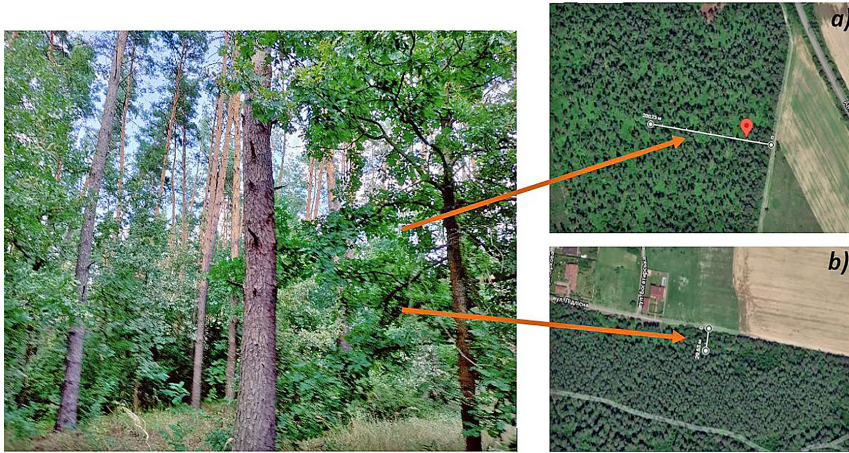
Two main approaches to reducing forest fire risks for settlements in the study region through forest management in the WUI zone are suggested in this study: 1) increasing the proportion of deciduous species in pine forests and forming complex multi-component forest edges; and 2) reducing the supply of combustible materials' through thinning of pine stands to the point where the forest fire cannot spread through the crowns of trees. The first approach requires measures to create forests artificially or naturally, providing a proportion of deciduous species in the upper tier, understory, and undergrowth. The second approach requires regulation through controlled burning of the amount of combustible materials from grasses, which are formed with increased access of light to the soil surface. Considering the features of buffer zones, climatic anomalies in recent years and the economic features of the region, the most optimal way to increase the fire resistance of forests and the safety of settlements from fires is the regulation of combustible materials through the formation of more fire-resistant stands in forest edges and buffer zones of buildings during forest management. The use of the method of controlled burning is also an option to reduce the risks of wildfires. However, this method has

not yet been tested, described, and regulated by legislation in Ukraine.

Since forest edges commonly overlap with WUI zones, it is important to mention that D. Armenteras *et al.* (2013) demonstrated that a vast majority of wildfires (98%) occurred within 1000 m of the edge, while only two per cent of fires occurred at greater distances. Authors D. Armenteras *et al.* (2013) also revealed that the most intense wildfires (exceeding 500 MW) occurred close to the edge, i.e., the first 2 km inside or outside the edge.

The classification of forest edges plays an important role in forest management in the WUI zone. In Ukraine, A.D. Kuzyk (2011) was engaged in the classification of forest edges according to their fire value, which distinguishes three types of forest edges, according to the width of the forest strip from the edge, which differs from the forest in the middle in microclimate, tree taxonomic indicators, biodiversity. According to this classification, false (Fig. 4), elementary (Fig. 3b) and multi-component (Fig. 3a) forests are distinguished. Multicomponent forest edges are formed naturally over a long period in the absence of human activity. Furthermore, it is possible to speed up the process of formation of such edges by forestry measures. In areas with a high risk of wildfires occurring and spreading from populated areas to forest areas, or vice versa, it is advisable to ensure the formation of such forest edges with a width of 100-200 m (Fig. 3).

Most forest edges in pine forests on the border with populated areas are false forest edges (Fig. 4) or elementary forest edges (Fig. 3). Such woodlands are characterized either by the absence of undergrowth, understory, and shrubs, or by an insignificant diversity of trees, shrubs, and herbaceous plants, which is observed in a strip with a width smaller than the average height of the stand.



**Figure 3.** An example of multi-component (a) and elementary (b) forest edges

Source: authors' photos



**Figure 4.** An example of a false forest edge

Source: authors' photo

A separate example of fire-resistant edges in pine forests to reduce risks for settlements is the formation of sparse stands because continuity of surface fuels is important for the spread of fire, according to K. Parkins *et al.* (2018). Such forests play a recreational or protective function and thus, the loss of technical qualities of wood in such forests can be justified. The main advantage of such forest edges is the reduction of the amount of combustible materials in the path of a possible crown forest fire since such

a structure does not support crown forest fire, and it is easier to stop ground fires in such places. The disadvantage of such forest edges is a large amount of sunlight, which contributes to the appearance of dense grass cover, which creates high fire risks in dry conditions (autumn and spring). Therefore, in such forest edges, it is necessary to implement the practice of using controlled burnings – safe and controlled burning of ground combustible materials. Examples of such edges are shown in Figure 5.



**Figure 5.** An example of a sparse forest edge in a pine stand on the border with settlements  
**Source:** authors' photo

This study assessed two critical WUI zones in the Zhytomyr region that can be used to reduce wildfire risks through forest management. The first zone is pure pine forests in a buffer zone of 500 m around populated areas are the primary volume of forestry measures for the formation of fire-resistant forests, which is 38.4 thousand hectares (3.4% of all forests in the region). The second zone is pure pine forests in a buffer zone of 2,400 m around settlements, which requires a strategic plan for the transformation of pure pine forests over a long period – 275.3 thousand hectares (24.5% of the forests of the region). Forest management in this zone should take into account the economic functions of these forests but still follow the principles of formation of pine forests resilient to fires, pests, and diseases.

Within the framework of the “RESILPINE – Transformation of pine forests to a close-to-nature forest management in Ukraine and with special consideration of resilience to fire” (Global Fire Monitoring Center, 2021) project, eight permanent plots were established to test methods of transforming pure pines to increase their resistance to fires, pests, and diseases, and now have the first positive results of growth

and adaptation. Experimental sites were laid out in different regions of the Polissya natural zone, which includes the Zhytomyr region. Various methods were tested in experimental plots – an increase of deciduous tree/shrub species in pure pine stands, planting of fire-resistant forest edges, fire-resistant forest edge, under canopy culture with common oak in pure pine stands. Proven options for creating understory crops or increasing the proportion of hardwoods in pure pine stands to reduce wildfire risk can be used to reduce wildfire risks in the WUI area described in this study.

## Conclusions

Concluding this study, a method to assess and map WUI with a focus on fire risks for one of the regions of Ukraine is suggested. In the involved regions, pure pine forests are common and have forest fire risks for settlements. Assessment of the WUI zone in Zhytomyr region (oblast) showed 35.4 thousand ha of pine forests in the 0.5-km buffer zone (3.4% of the total forests of Zhytomyr oblast) and 264.4 thousand ha of pine forests in the 2.4-km buffer zone (25.3% of the total forest area of Zhytomyr oblast). Such pure pine forests with other

species of single trees are characterized by a high risk of forest fires and require transformation into more resilient mixed stands to reduce the vulnerability of settlements near such forests. Based on the analysis of the species diversity of the main tree species, undergrowth and understory, a list of local species that can be used to increase the proportion of deciduous species in pure pine forests was suggested. The approaches, which are described in this study, can be used to estimate the areas of forests within the WUI zone in which it is necessary to reduce the risks of forest fires in other regions of Ukraine. Approaches to forest management in the WUI zone can be used to reduce the risks of forest fires both in the study region and in other regions of the Ukrainian Polissia. The WUI zone assessment method described in this study is a tool for defining forest management policies in these zones in order to reduce forest fire risks in the context of ongoing climate change, urbanization, and reduced resistance of pure pine stands to pests, diseases, and fires.

Future research could focus on refining and optimizing the methodology employed in

mapping WUI zones. This could involve incorporating additional spatial and environmental variables, advanced remote sensing techniques, and data from emerging technologies such as satellite imagery, drones, or geographic information systems (GIS).

### Acknowledgements

This study was undertaken within the framework of the “RESILPINE” project, which was financially supported by the Federal Ministry of Food and Agriculture (BMEL) (Grant number: 28I-034-01).

The authors are grateful to Richard J. Lasko for improving the text and providing very helpful comments. We thank our colleagues Director of the Global Fire Monitoring Center (GFMC) Dr. Prof. Johann Georg Goldammer and Dr. Prof. Peter Spatthelf from the Eberswalde University for Sustainable Development who provided insight and expertise that greatly assisted the research.

### Conflict of Interest

None

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## **Картування зон взаємодії між природними ландшафтами та населеними пунктами Житомирської області для зниження ризиків лісових пожеж**

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**Анотація.** Лісові пожежі, які трапилися на території України в останнє десятиліття і мали масштабні негативні наслідки підтвердили актуальність досліджень управління ризиками лісових пожеж в умовах зміни клімату та зростання частоти критичних пожежонебезпечних погодних умов. Поточна система управління лісовими пожежами, яка передусім орієнтована

на гасіння, потребує розробки нових стратегій для зниження ризиків лісових пожеж, що включає управління лісовими горючими матеріалами. Зважаючи на існуючі ризики лісових пожеж для населення та лісів, а також недостатню дослідженість цього питання в Україні, необхідно продовжувати розробляти та тестувати нові підходи до зниження ризиків лісових пожеж. Мета дослідження полягала в розробці та застосуванні методу для оцінки та картографування інтерфейсу «дика природа – населений пункт» з акцентом на пожежну небезпеку для частини Українського Полісся. Зони інтерфейсу «дика природа – населений пункт» були виділені для населених пунктів на досліджуваній території та використані для визначення територій, на яких необхідно відновити лісові насадження, а також лісогосподарських практик, спрямованих на підвищення стійкості лісів до пожеж. Аналіз біорізноманіття основних деревних порід, підліску та підросту досліджуваного регіону дозволив скласти список місцевих листяних порід, які можуть бути використані для зменшення інтенсивності пожеж шляхом збільшення їх частки в чистих соснових лісах. Для одного з найбільш лісистих регіонів України було оцінено обсяг лісогосподарських заходів, спрямованих на підвищення стійкості лісів до пожеж та зменшення ризиків пожеж для населених пунктів. Була проведена перша комплексна оцінка диких земель, які потенційно можуть сприяти впливу лісових пожеж на населені пункти, та надані рекомендації щодо зниження ризиків лісових пожеж для населених пунктів. Запропоновано методи оцінки взаємодії між природними ландшафтами та містом, а також зниження ризиків виникнення пожеж для частини Поліської природної зони України. Представлені підходи можуть бути використані в українському лісовому господарстві для зменшення ризиків лісових пожеж в умовах зміни клімату, урбанізації та низької стійкості чистих соснових деревостанів до пожеж, а також шкідників і хвороб

**Ключові слова:** зміна клімату; лісові протипожежні смуги; соснові насадження; Українське Полісся

UDC 630\*4:632.4:633.877(477.86)

DOI: 10.31548/forest/2.2024.41

## **Systematic and structural analysis of forest mycobiota with the participation of *Abies alba* Mill. in the Pokutsko-Bukovyna Carpathians**

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**Abstract.** The value and uniqueness of forest ecosystems are determined by their species diversity and biotic resistance to negative environmental impacts. The aim of the study is to determine the species composition, systematic position, trophic specialization, as well as the occurrence and abundance of forest mycobiota with *Abies alba* in the Pokutsko-Bukovyna Carpathians. The study was conducted in 2019-2023 within the forests of the branches “Kutske Forestry”, “Ivano-Frankivsk Forestry” and “Beregomet Forestry” of the State Specialized Enterprise “Forests of Ukraine”, as well as the forests of the National Nature Park “Vyzhnytskyi” and the National Nature Park “Hutsulshchyna”. Classical mycological identification methods were used in the study. Information from the interactive databases Index Fungorum, MycoBank, and World of Fungi of Ukraine was used to clarify the current systematic position and current names of taxa. It was found that the consortial relationships of the fungal biota of the Pokutsko-Bukovyna Carpathians forests are most closely related to the woody plants *Picea abies*, *Abies alba*, and *Fagus sylvatica*. During the mycological expedition, 54 species of representatives of the kingdom *Fungi* were identified, 81.5% of which belong to the order *Basidiomycota* and 18.5% to the order *Ascomycota*. It was found that the most numerous is the order *Polyporales*, and the least numerous are the orders *Corticiales*, *Gomphales*, *Phallales*, *Pucciniales* and *Tremellales*. It is shown that, according to trophic specialization, representatives of the studied mycobiota of the Pokutsko-Bukovyna Carpathians belong to the following groups: xylotrophic facultative saprotroph, xylotrophic facultative pathogen, xylotrophic obligate saprotroph, obligate pathogen and aboveground saprotroph. It is noted that the most widely represented are saproxyliotrophs, which generally develop on dead and fallen wood. Thus, the systemic and structural analysis of the fungal biota of the Pokutsko-Bukovyna Carpathians

### **Suggested Citation:**

Kulbanska, I. (2024). Systematic and structural analysis of forest mycobiota with the participation of *Abies alba* Mill. in the Pokutsko-Bukovyna Carpathians. *Ukrainian Journal of Forest and Wood Science*, 15(2), 41-58. doi: 10.31548/forest/2.2024.41.

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forests allows for assessing the biocenotic value of fungi as bioindicators of the current state of stands, as well as identifying reference and valuable areas characterized by high biodiversity

**Keywords:** white fir; mycocenosis; systematic position; species composition; trophic specialization

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## Introduction

One of the most important components of forest biocenosis is mycotic communities of different trophic affiliation, which, like other heterotrophs, determine its depth, systematically interact with woody plants at different stages of their ontogeny – from endophytism to biodegradation, and are valuable food and medicinal resources for humans. Fungi are directly involved in the functioning of the forest biocenosis as a biological system. The structure and relationships of species (communities) of mycocoenoses with other living organisms are of particular importance for the development of forest ecosystems. Most of them are xylobionts (from the Greek ξύλον – “felled tree” and βίωv (βίοντος) – “living”) and are present at all stages of wood xylolysis – from the moment of damage to living woody plants to complete utilization of the remains at the final stages of decomposition. A significant number of species grow on the soil and forest floor, some representatives of this group are mycorrhizal formers, while others are poorly lichenicolous. Being part of a consortium where the substrate or partner in life is higher, in this case, woody plant species, fungi can enter into indifferent, negative and antagonistic relations with the latter.

The fungal communities of the Ukrainian Carpathian forests have been studied to a certain extent (some literature sources have almost a century of history), which allows for a comparative analysis of previous results, despite some fragmentation of these studies. The taxonomic composition of the xylo-trophic ascomycobiota of forest ecosystems of protected areas of the Ukrainian Carpathians, which

were considered in the work of Y.Yu. Bublyk & O.S. Klymyshyn (2023), is represented by 406 taxa belonging to 190 genera, 66 families, 26 orders, 10 suborders, 6 classes of the subdivision *Pezizomycotina* of the division *Ascomycota*. It is noted that the distribution or specialization of wood-destroying ascomycetous fungi to woody substrates depends on the life forms and species diversity of trees.

Several works have been devoted to the study of the species diversity of mycorrhizal fungi of the Hutsulshchyna National Nature Park (including new rare species). The study by S.I. Fokshei (2022) involved a comprehensive study of the diversity and ecological role of *Ascomycota* fungi in the park's ecosystem. The study analysed the various *Ascomycota* species present in the region to reveal their distribution, ecological significance, and possible contribution to the overall biodiversity of the park. The results contributed to the formulation of conservation strategies and a deeper understanding of the ecological dynamics of Hutsulshchyna Park.

The results of the study by S.I. Fokshei & L.M. Derzypilskyi (2021) not only expand the understanding of the mycological component of the ecosystem of this park, but also identify new species of high rarity. This may have a significant impact on the conservation and management strategies of this unique natural area. In addition, the new species of mycetes discovered in the Hutsulshchyna National Park provide new information about biodiversity and ecological relationships in this unique natural environment (Bohoslavets & Prydiuk, 2023).

In total, as of 1 January 2022, more than 1000 species of fungi and fungi-like organisms were identified in the forest communities of the Hutsulshchyna NNP, 23 of which are listed in the Red Data Book of Ukraine (Pasayliuk, 2022).

Ectomycorrhizal fungi in the forest ecosystems of the Western Carpathians are discussed in the work by E. Luptáková & I. Mihál (2020). The authors identified 51 species of ectomycorrhizal mycorrhizal fungi, the dominant species being *Ramaria formosa*, *Hygrophorus pustulatus*, *Lactarius aurantiacus*, *Lactarius rufus*, *Paxillus involutus*, etc. It is noted that these species play an important role in the process of succession, in particular, in the reforestation of former agricultural lands. Also, M. Senila *et al.* (2024) presented the results of a study of toxic metals in some wild edible mushrooms (*Cantharellus cibarius*, *Boletus edulis*, and *Amanita rubescens*) growing in the mountainous region of the Western Carpathians. This study aims to investigate in detail the levels of toxic metals in these mushrooms, providing important information for determining the safety of their consumption and assessing the possible impacts of mining activities on their nutritional value. I. Sopushynskiy *et al.* (2021) focus on the peculiarities of biological damage to the stem wood of white fir *Phellinus Hartigii* in the Ukrainian Carpathians. The study aims to determine the mechanisms and features of the interaction between white spruce and Hartig's tinder fungus, taking into account the impact on the physiological and structural aspects of wood. Given the importance of white spruce as an important forest vegetation species in the Ukrainian Carpathians, understanding these features is important for developing strategies for managing and protecting forests from the parasitic impact of Hartig's tinder fungus.

Thus, even though the species composition of fungi and fungi-like organisms in the Carpathian region is to some extent outlined,

some issues, in particular, regarding phytopathogenic species, as well as their ecological and nutritional specialization, remain unresolved. Therefore, the present study is aimed at determining the species composition (with an assessment of biocenotic significance), systematic and structural analysis, and trophic groups of the mycobiota of forests with *Abies alba* Mill. in the Pokutsko-Bukovyna Carpathians.

## Materials and Methods

Analysis of the system-structural analysis of representatives of the mycobiota of forest ecosystems with the participation of *Abies alba* Mill. in the Pokutsko-Bukovyna Carpathians is based on the processing of own herbarium collections of mycetes from the forests of the Kutske Forestry Branch, Ivano-Frankivsk Forestry Branch and Beregommet Forestry Branch of the State Specialized Economic Enterprise (SSE) "Forests of Ukraine", forests of the National Nature Park (NNP) "Vyzhnytskyi" and NNP "Hutsulshchyna", which fully represent the typical conditions of the study area, during 2019-2023. Some information was obtained from the data established during the processing of herbarium specimens stored in the collection of the Department of Forestry of the National University of Life and Environmental Sciences of Ukraine, the interactive database The world of mushrooms in Ukraine (n.d.).

The distribution of the trophic chain of the identified mycobiota representatives is based on the generally accepted trophic specialization (nutritional characteristics of heterotrophic organisms). Currently, they are divided into two large groups: parasites (using nutrients for their development from living cells throughout their lives) and saprotrophs (using nutrients for their development from dead cells). This is usually characteristic of the most extreme representatives of the trophic chain of the kingdom Fungi. Among the fungi found on the

experimental woody plants, we identified *obligate pathogens* – OPs (the ecological niche of this group of fungi is living plant tissue, and they are not capable of saprotrophic nutrition under natural conditions, the term “biotrophs” is synonymous with them); *optional (optional) pathogens* – OPs (spend most of their development on a dead substrate but are able to continue feeding on a living substrate, the term “necrotrophs” is synonymous with them). *Facultative (optional) saprotrophs* – FS (spend most of their development on a living substrate, but are able to continue feeding on a dead substrate); *obligate saprotrophs* – OS (live exclusively on a dead substrate); *Mycorrhizal fungi* – MF (symbiotrophic species that coexist with the roots of woody plants and are obligate exo-, endo- and exo-endogenous mycorrhizal fungi). Based on the fact that all the identified fungi are xylotrophs, i.e., they use wood (trunks, roots, shoots) for their nutrition, the authors added the word “xylotroph” to this taxonomy to distinguish facultative saprotrophs and pathogens from other substrates on which they develop. In addition, the terms “obligate pathogen” and “facultative pathogen” were used to distinguish between the studied fungal species of different specializations (instead of the previously used “obligate parasite” and “facultative parasite”). This approach is based on a literal understanding of the term “pathogen” (from the Greek παθογένεια – “one that causes suffering”), i.e. organisms (usually myco- and microorganisms) that can cause infectious pathology. As for the term “parasite” (from the Greek Παράσιτο – “freeloader”), it is appropriate to refer to factors of living nature that cause damage that is not related to infection (pathological process). This approach allows for distinguishing between different types of impact on the plant (infectious and non-infectious). In any case, it is inappropriate to combine processes that are different in nature under one name.

Distribution by micro-horizons: 1 – root; 2 – above-ground (including dead wood, fallen trees, dead branches); 3 – coma; 4 – trunk; 5 – crown; “-” – not detected. The species occurrence was assessed on a conditional point scale: + – very rarely; 1 – rarely; 2 – not rarely; 3 – often; 4 – very often. The scale is based on the calculation of the average proportions of species (with fruiting bodies) in the community during the observation period (taking into account the long-term annual repetition of observations).

Species abundance (as the number of individuals per unit of inhabited space) was estimated on a point scale: + – very rare; 1 – rare and scattered; 2 – not abundant; 3 – abundant; 4 – very abundant. Latin names of higher plant species are given by: World Flora Online (n.d.), mycobiota – according to Index Fungorum (n.d.). The research was conducted in compliance with the standards specified in the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973). Modern names of fungi and their systematic affiliation are consistent with the nomenclature database MycoBank (n.d.) and the International Code of Nomenclature for algae, fungi, and plants (2019).

## Results and Discussion

The total number of recorded and identified species of forest mycobiota with *Abies alba* Mill. in the Pokutsko-Bukovyna Carpathians is 54 species, including 13 species of European spruce (*Picea abies* L.), 6 species of white fir (*Abies alba* L.), and 35 species of European beech (*Fagus sylvatica* L.).

The analysis of the taxonomic structure of the identified mycobiota showed that the species belong to 45 genera, 31 families, 4 suborders, 13 orders, 6 subclasses, 5 classes, 3 subdivisions and two divisions, in particular 18.5% of species are representatives of the division *Ascomycota* Caval.Sm., 1998, and 81.5%, respectively,

of *Basidiomycota* Whittaker ex Moore, 1980 of the subkingdom *Dikarya* Hibbett, 2007 of the kingdom *Fungi* Bartling, 1830. The systematic distribution of the detected and identified mycobiota is presented in Table 1.

All species of the order *Ascomycota* are represented by representatives of the suborder *Pezizomycotina* O.E. Erikss. & Winka, 1997 of the class *Sordariomycetes* O.E. Erikss. & Winka, 1997, within which 2 subclasses (*Hypocreomycetidae* and *Xylariomycetidae*), 2 orders (*Hypocreales* and *Xylariales*), 5 families (*Diatrypaceae*, *Hypocreaceae*, *Melanconidaceae*, *Nectriaceae*, *Xylariaceae*), 7 genera (*Diatrype*, *Kretzschmaria*, *Melogramma*, *Nectria*, *Neonectria*, *Trichoderma*, *Xylaria*) and 10 species of mycetes.

*Basidiomycota* is represented by 2 suborders (*Agaricomycotina* and *Pucciniomycotina*), 4 classes (*Agaricomycetes*, *Dacrymycetes*, *Pucciniomycetes* and *Tremellomycetes*), 4 subclasses (*Agaricomycetidae*, *Phallomycetidae*, *Phallomycetidae*, *Tremellomycetidae*), 11 orders (*Agaricales*, *Corticiales*, *Dacrymycetales*, *Gloeophyllales*, *Gomphales*, *Hymenochaetales*, *Phallales*,

*Polyporales*, *Pucciniales*, *Russulales*, *Tremellales*), 4 suborders (*Marasmiineae*, *Melampso-rineae*, *Phyllotopsidineae* and *Pleurotineae*), 26 families (*Amylocorticiaceae*, *Bondarzewiaceae*, *Clathraceae*, *Climacocystaceae*, *Corticaceae*, *Dacrymycetaceae*, *Fomitopsidaceae*, *Ganodermataceae*, *Gloeophyllaceae*, *Gomphaceae*, *Hericiaceae*, *Hymenochaetaceae*, *Incrustoporiaceae*, *Irpicaceae*, *Laetiporaceae*, *Mycenaceae*, *Phanerochaetaceae*, *Physalacriaceae*, *Polyporaceae*, *Pucciniastraceae*, *Pycnoporellaceae*, *Radulomycetaceae*, *Schizophyllaceae*, *Stereaceae*, *Tremellaceae* and *Trichaptaceae*), 38 genera (*Amylocorticium*, *Armillaria*, *Bjerkandera*, *Calocera*, *Ceriporus*, *Chondrostereum*, *Clathrus*, *Climacocystis*, *Dacrymyces*, *Daedalea*, *Daedaleopsis*, *Dentipellis*, *Fomes*, *Fomitopsis*, *Ganoderma*, *Gloeophyllum*, *Henningsomyces*, *Hericium*, *Heterobasidion*, *Inonotus*, *Irpex*, *Laetiporus*, *Melampsorella*, *Panellus*, *Phellinus*, *Plicaturopsis*, *Pycnoporellus*, *Radulomyces*, *Ramaria*, *Rhodofomes*, *Schizophyllum*, *Skeletocutis*, *Stereum*, *Trametes*, *Trametopsis*, *Tremella*, *Trichaptum* and *Vuilleminia*) and 44 species of mycetes (Table 1).

**Table 1.** Systematic position of macromycetes of the consortium *Abies alba* L., *Picea abies* L., and *Fagus sylvatica* L. in the forests of the Pokutsko-Bukovyna Carpathians

Department	Class.	Order.	Family.	Reid	View
<i>Ascomycota</i>	<i>Sordariomycetes</i>	<i>Xylariales</i>	<i>Melanconidaceae</i>	<i>Melogramma</i>	<i>Melampsorella cerastii</i> (Pers.) J. Schröt. 1887
			<i>Diatrypaceae</i>	<i>Diatrype</i>	<i>Melogramma spiniferum</i> (Wallr.) De Not., 1863
			<i>Xylariaceae</i>	<i>Kretzschmaria</i>	<i>Diatrype disciformis</i> (Hoffm.) Fr., 1849
		<i>Xylaria</i>		<i>Kretzschmaria deusta</i> (Hoffm.) P.M.D. Martin, 1970	
		<i>Hypocreales</i>	<i>Nectriaceae</i>	<i>Nectria</i>	<i>Xylaria polymorpha</i> (Pers.) Grev., 1824
				<i>Neonectria</i>	<i>Nectria ditissima</i> Tul. & C. Tul. 1865
					<i>Nectria cinnabarina</i> (Tode) Fr. 1849
<i>Nectria galligena</i> Bres. 1901					
		<i>Hypocreaceae</i>	<i>Trichoderma</i>	<i>Neonectria coccinea</i> (Pers.) Rossman & Samuels, 1999	

Table 1, Continued

Department	Class.	Order.	Family.	Reid	View	
Basidiomycota	Agaricomycetes	Russulales	Bondarzewiaceae	Heterobasidion	<i>Heterobasidion parviporum</i> Niemelä & Korhonen 1988 <i>Heterobasidion abietinum</i> Niemelä & Korhonen, 1998	
			Stereaceae	Stereum	<i>Stereum hirsutum</i> (Willd.) Pers. 1800	
			Hericiaceae	Dentipellis	<i>Dentipellis fragilis</i> (Pers.) Donk, 1962	
				Hericium	<i>Hericium cirrhatum</i> (Pers.) Nikol., 1950 <i>Hericium coralloides</i> (Scop.: Fr.) Pers 1974	
			Polyporales	Climacocystaceae	Climacocystis	<i>Climacocystis borealis</i> (Fr.) Kotl. & Pouzar., 1958
				Fomitopsidaceae	Fomitopsis	<i>Fomitopsis pinicola</i> (Sw.) P. Karst. 1881
					Rhodofomes	<i>Rhodofomes roseus</i> (Alb. & Schwein.) Vlasák, 1990
					Daedalea	<i>Daedalea quercina</i> (L.) Pers. 1801
				Pycnoporellaceae	Pycnoporellus	<i>Pycnoporellus alboluteus</i> (Ellis & Everh.) Kotl. & Pouzar 1963
				Polyporaceae	Cerioporus Cerioporus	<i>Cerioporus varius</i> (Pers.) Zmitr. & Kovalenko, 2016 <i>Cerioporus mollis</i> (Sommerf.) Zmitr. & Kovalenko, 2016
		Fomes				<i>Fomes fomentarius</i> (L.) Fr. 1849
		Daedaleopsis			<i>Daedaleopsis confragosa</i> (Bolton) J. Schröt, 1888	
		Trametes			<i>Trametes versicolor</i> (L.) Lloyd, 1920	
		Laetiporaceae		Laetiporus	<i>Laetiporus sulphureus</i> (Bull.: Fr.) Murrill 1920	
		Incrustoporiaceae	Skeletocutis	<i>Skeletocutis amorphia</i> (Fr.) Kotl. & Pouzar, 1958		
		Irpicaceae	Trametopsis	<i>Trametopsis cervina</i> (Schwein.) Tomsovský, 2008		
			Irpex	<i>Irpex lacteus</i> (Fr.: Fr.) Fr. 1828		
		Ganodermataceae	Ganoderma	<i>Ganoderma applanatum</i> (Pers.: Wallr.) Pat. 1887 <i>Ganoderma resinaceum</i> Boud. 1889		
		Phanerochaetaceae	Bjerkandera	<i>Bjerkandera adusta</i> (Willd.) P. Karst., 1879		
		Agaricales	Amylocorticiaceae	Amylocorticium	<i>Amylocorticium subsulphureum</i> (P. Karst.) Pouzar 1959	
				Plicaturopsis	<i>Plicaturopsis crispa</i> (Pers.) D.A. Reid, 1964	
			Physalacriaceae	Armillaria	<i>Armillaria mellea</i> (Vahl) P. Kumm.	
			Mycenaceae	Panellus	<i>Panellus stipticus</i> (Bull.) P. Karst., 1879	

Table 1, Continued

Department	Class.	Order.	Family.	Reid	View		
			<i>Schizophyllaceae</i>	<i>Henningsomyces</i>	<i>Henningsomyces candidus</i> (Pers.) Kuntze 1898		
				<i>Schizophyllum</i>	<i>Schizophyllum commune</i> Fr. 1815		
				<i>Chondrostereum</i>	<i>Chondrostereum purpureum</i> (Fr.) Pouzar 1959		
				<i>Radulomycetaceae</i>	<i>Radulomyces</i>	<i>Radulomyces molaris</i> (Chaillat ex Fr.) M.P. Christ., 1960	
			<i>Gloeophyllales</i>	<i>Gloeophyllaceae</i>	<i>Gloeophyllum</i>	<i>Gloeophyllum abietinum</i> (Fr.) P. Karst. 1882 <i>Gloeophyllum odoratum</i> (Wulfen) Imazeki, 1943	
			<i>Phallales</i>	<i>Clathraceae</i>	<i>Clathrus</i>	<i>Clathrus archeri</i> (Berk.) Dring, 1980	
			<i>Hymenochaetales</i>	<i>Trichaptaceae</i>	<i>Trichaptum</i>	<i>Trichaptum fuscoviolaceum</i> (Ehrenb.) Ryvar den 1972	
		<i>Trichaptum abietinum</i> (Pers. ex J.F. Gmel.) Ryvar den, 1972					
				<i>Hymenochaetaceae</i>	<i>Phellinus</i>	<i>Phellinus hartigii</i> (Allesch. & Schnabl) Pat., 1903 <i>Phellinus igniarius</i> (L.) Quél. 1886	
					<i>Inonotus</i>	<i>Inonotus obliquus</i> (Pers.) Pilát 1942	
			<i>Corticiales</i>	<i>Corticaceae</i>	<i>Vuilleminia</i>	<i>Vuilleminia comedens</i> (Nees.: Fr.) Maire 1902	
			<i>Gomphales</i>	<i>Gomphaceae</i>	<i>Ramaria</i>	<i>Ramaria aurea</i> (Fr.) Quél. 1888	
			<i>Dacrymycetes</i>	<i>Dacrymycetales</i>	<i>Dacrymycetaceae</i>	<i>Calocera</i>	<i>Calocera cornea</i> (Batsch) Fr., 1827
						<i>Dacrymyces</i>	<i>Dacrymyces stillatus</i> Nees, 1817
			<i>Tremellomycetes</i>	<i>Tremellales</i>	<i>Tremellaceae</i>	<i>Tremella</i>	<i>Tremella mesenterica</i> (Schaeff.) Retz., 1769
	<i>Pucciniomycetes</i>	<i>Pucciniales</i>	<i>Pucciniastraceae</i>	<i>Melampsorella</i>	<i>Melampsorella cerastii</i> (Pers.) J. Schröt. 1887		

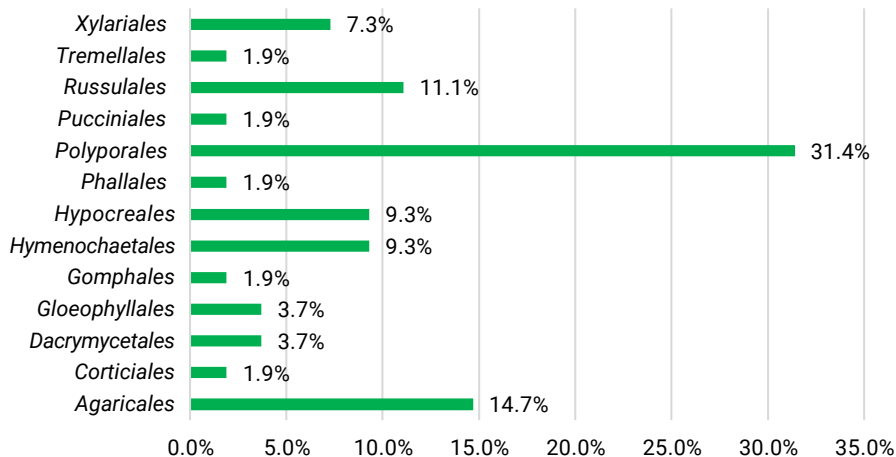
**Source:** developed by the authors based on MycoBank (n.d.)

The maximum number of identified mycetes in the forests of the Pokutsko-Bukovyna Carpathians belongs to the order *Polyporales* – 31.4%. Typical representatives of this order are xylobionts, i.e. wood biodestructors, and therefore occupy an extremely important place in forest ecology. The species composition of the order *Polyporales* includes 17 species of mycetes belonging to 9 families: *Climacocystaceae*, *Fomitopsidaceae*, *Ganodermataceae*, *Incrustoporiaceae*, *Irpicaceae*, *Laetiporaceae*, *Phanerochaetaceae*, *Polyporaceae* and *Pycnoporellaceae*.

The share of the order *Agaricales* is 14.7% of the total. The representatives of this order include destructive fungi, mycorrhizal fungi and soil saprotrophs. A typical characteristic of the order is that the fruiting bodies of agaric fungi are predominantly stalked and capped with a lamellar hymenophore. The order *Agaricales* in the studied forests is represented by 8 species of fungi belonging to 5 families: *Amylocorticaceae*, *Mycenaceae*, *Physalacriaceae*, *Radulomycetaceae* and *Schizophyllaceae*. Also, relatively numerous is the order *Russulales* (11.1%),

which is represented mainly by mycorrhizal fungi, saprotrophs, and phytopathogenic species. We managed to identify 6 species of this order belonging to 3 families: *Bondarzewiaceae*, *Hericiaceae* and *Stereaceae*. Other orders are

less numerous, in particular *Hypocreales* and *Hymenochaetales* (9.3% each), *Xylariales* – 7.3%, *Gloeophyllales* and *Dacrymycetales* (3.7% each), *Corticiales*, *Gomphales*, *Phallales*, *Pucciniales* and *Tremellales* (1.9% each) (Fig. 1).



**Figure 1.** Taxonomic structure of the species composition of forest mycobiota with *Abies alba* in the Pokutsko-Bukovyna Carpathians at the level of orders

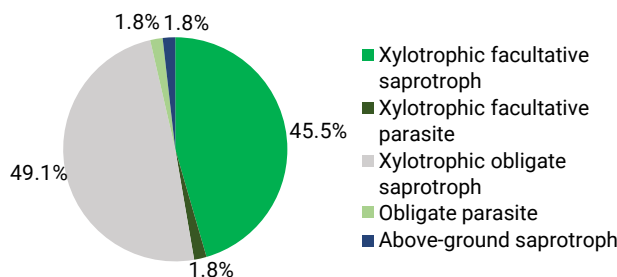
**Source:** developed by the authors

Analysing the distribution of mycobiota representatives of the forests of the study region by food specialization, it was found that most species are saprotrophs, whose vital activity is ensured by the decomposition of dead plant residues, carrying out ammonification (mineralization) of nitrogen, as well as releasing metabolic products ( $\text{CO}_2$ ,  $\text{H}_2\text{O}$ , urea, etc.), organic acids and siderophores, which affect the functionality of root cells and facilitate the release and supply of ferrous ions and other trace elements to the plant from insoluble compounds in the soil (Antonyak *et al.*, 2013). The most numerous is the group of obligate saprotrophs, their share is 49.1% of the total distribution. The share of obligate pathogens is 45.5%. Representatives of other trophic groups (xylotrophic facultative pathogen, obligate pathogen and aboveground saprotroph)

were not numerous, with their share in the total distribution reaching 1.8% (Fig. 2). The distribution of fungal taxa by nutritional regime may have elements of subjectivity, because, for some species of xylotrophic fungi, we have not found information on the presence of these fungi as normal mycobiota of healthy (or weakened) trees. If these fungi are present in such trees as endophytes, including vital obligates (i.e., fungi that are an integral component of living trees that use metabolites of living cells for their existence), they can be switched from obligate saprotrophs to facultative saprotrophs and vice versa. Thus, considering the consortial relations between fungi and consortium-edifying trees, we note that in indifferent consortial relations, representatives of mycobiota develop on no more than 10-20% of host plants, affecting (infecting) them to a relatively weak degree

and for a short period, without leading to noticeable deviations in growth and development compared to healthy specimens. A negative type of relationship should be considered when

fungi parasitize 50-80% of plants, causing severe damage to them, leading to general weakening, impaired assimilation capacity, and, often, loss of phytocoenosis.



**Figure 2.** Distribution of mycobiota representatives of forests with *Abies alba* by food specialization

**Source:** developed by the authors

Analysing the trophic specialization of mycobiota in the context of tree species, we note that *Picea abies* consortia are represented mainly by xylophilic-obligate saprotrophs, their share being 57.1%. Facultative saprotrophs, whose vital activity is confined mainly to living substrates, account for 35.7%. One fungal species is classified as a xylophilic facultative pathogen, *Armillaria mellea*, whose basidiomycetes and rhizomorphs are found both in dead or dying wood and on the trunks of living trees.

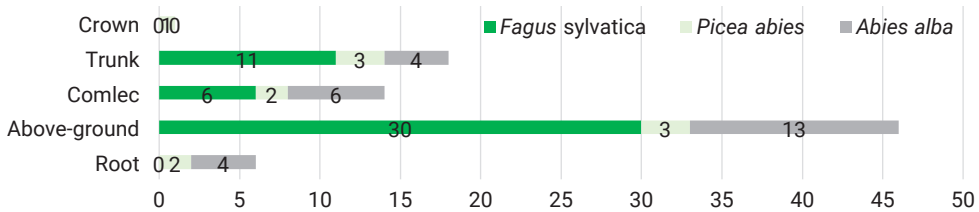
The *Abies alba* consortium is also formed by three trophic groups of mycetes: xylophilic-obligate saprotroph (50.0%), xylophilic-facultative saprotroph (33.3%) and obligate pathogen (16.7%). In general, most of the identified fungal species are associated with symbiotic or mutualistic relationships with fir and, developing on dead wood, are active participants in bioconversion in the forest.

Representatives of the mycobiota associated with *Fagus sylvatica* wood were grouped into three trophic groups, with the most numerous being facultative (51.4%) and obligate (45.7%) saprotrophs. One species, *Clathrus archeri*, was

also recorded, which turned out to be a typical above-ground saprotroph. It should be noted that this fungus is a unique and valuable find, as it is listed in the Red Book of Ukraine and has the status of “endangered”.

The studied forest mesocosms of the Pokutsko-Bukovyna Carpathians are characterized by specialization in substrate-forming tree species (so-called consortium-unitising trees). The largest number of species was found within the *Fagus sylvatica microhabitat* (35 species, 64.8% of the total number of finds), with a much smaller number in *Picea abies* (13 species, 24.0%) and *Abies alba* (6 species, 11.1%). The species composition of the consortium and the nature of consortial relationships between its components are variable at different stages of ontogeny of higher woody plants and in different biogeocoenoses, in particular, environmental conditions greatly influence them.

Analysing the overall distribution of the mycobiota of forests with *Abies alba* in the Pokutsko-Bukovyna Carpathians by microhierarchy, it was found that the largest number of species is confined to the subsoil horizon (Fig. 3).

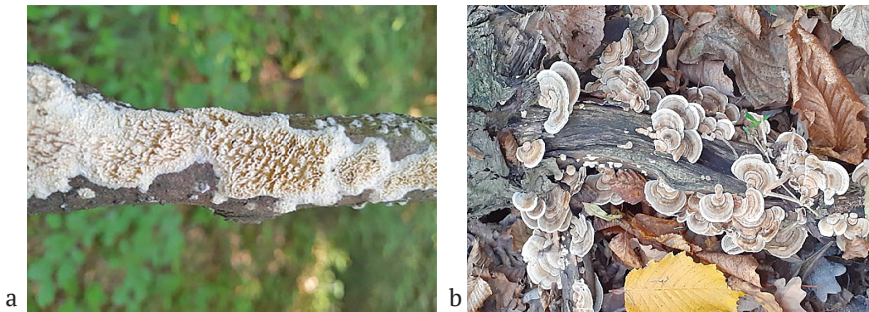


**Figure 3.** Distribution of forest mycobiota with *Abies alba* in the Pokutsko-Bukovyna Carpathians by microhierarchy

**Source:** developed by the authors

It is worth noting that some species (e.g. *Trichaptum abietinum* and *Fomitopsis pinicola*) were recorded simultaneously in microhabitats of different woody plant species. The following species were typical representatives of this group:

*Amylocortium subsulphureum*, *Vuilleminia comedens*, *Gloeophyllum abietinum*, *Irpex lacteus* (Fig. 4a), *Pycnoporellus alboluteus*, *Trichaptum fuscoviolaceum*, *Trichaptum abietinum*, *Chondrostereum purpureum*, *Cerioporus varius*, etc.



**Figure 4.** *Irpex lacteus* (a) and *Trametes versicolor* (b)

**Source:** photo by the authors

Representatives of pathogenic mycobiota of different levels of trophic nutrition are concentrated in the coma and root horizons, which, as a result of their vital activity, have a significant impact on the overall sanitary condition of the stand. For example, *Heterobasidion abietinum* basidiomata develop on the roots, lower parts of trunks, stumps, and trunks of living *Abies alba* trees (Fig. 5b), and *Heterobasidion parviporum* on *Picea abies*, which cause variegated core rot of wood and root system and are among the most dangerous pathogens of mycotic diseases that lead to massive drying of

coniferous forests. These macromycetes massively infect stands and lead to the loss of a significant amount of wood and a decrease in the protective properties of forests. They also lead to the gradual weakening and death of trees in plantations, which subsequently turn into sparse forests. In weakened trees, the pressure of the sapwood decreases, which mechanically and physiologically protects trees from damage by stem pests, whose breeding frequency occurs at irregular intervals, but is usually typical for weakened stands under physiological stress (Díaz-Yáñez *et al.*, 2019).



**Figure 5.** *Ramaria aurea* (a) and *Heterobasidion parviporum* (b)

**Source:** photo by the authors

A significant part of mycetes grows and develops within the stem microhabitat. These are mainly tinder fungi, which, settling on tree trunks, lead to the formation of various types of rot (core, sapwood or mixed), gradually weakening the plant. Among the most common species, we noted the following: *Gloeophyllum odoratum*, *Inonotus obliquus*, *Climacocystis borealis*, *Laetiporus sulphureus*, *Fomitopsis rosea*, *Phellinus hartigii*, *Phellinus igniarius*, *Fomitopsis pinicola*, *Fomes fomentarius*, etc. It was found that some species of macromycetes begin utilization of dead wood/substrate in xerophilic crown conditions and are grouped depending

on microclimatic and trophic preferences of individual species.

Basidiomata of *Ganoderma applanatum* and *Ganoderma resinaceum* were found in the basal part of the trunks of living trees, which cause light yellow root and basal rot of the corrosive-destructive type, making trees potentially dangerous to windbreaks. The fruiting bodies of an equally dangerous species of phytopathogenic fungus, *Armillaria mellea*, were also identified. It should be noted that the discovery of fruiting bodies of *Hericium coralloides*, which is a Red Data Book species for Ukraine and has a “vulnerable” status, was important (Fig. 6b).



**Figure 6.** *Clathrus archeri* (a) and *Hericium coralloides* (b)

**Source:** photo by the authors

The smallest number of species (1 species) were confined to the crown horizon. Thus, in the

crown of growing *Abies alba* trees, typical manifestations of infection with *Melampsorella*

*caryophyllacearum*, which is the causative agent of white fir ulcerative tumour disease and is currently spreading massively in the forests of the study region, were noted (Kulbanska *et al.*, 2024).

**Table 2.** Distribution of *Abies alba* forest mycobiota (by food specialization, microhabitats and other indicators)

Latin name	Trophic specialization	Micro-horizon	Encounter, point	Number, points
<b><i>Picea abies</i></b>				
<i>Heterobasidion parviporum</i> Niemelä & Korhonen 1988	K-FS	1,2,3	2	2
<i>Armillaria mellea</i> (Vahl) P. Kumm. 1871	K-FP	1,2,3	3	3
<i>Climacocystis borealis</i> (Fr.) Kotl. & Pouzar., 1958	K-OS	2,3,4	1	1
<i>Fomitopsis pinicola</i> (Sw.) P. Karst. 1881	K-FS	2,4	3	2
<i>Fomitopsis rosea</i> (Alb. & Schwein.) P. Karst. 1881	K-FS	2,3,4	1	1
<i>Trichaptum fuscoviolaceum</i> (Ehrenb.) Ryvarden 1972	K-OS	2	2	4
<i>Trichaptum abietinum</i> (Pers. ex J.F. Gmel.) Ryvarden, 1972	K-OS	2	2	3
<i>Amylocorticium subsulphureum</i> (P. Karst.) Pouzar 1959	K-OS	2	1	3
<i>Henningsomyces candidus</i> (Pers.) Kuntze 1898	K-OS	3	+	2
<i>Pycnoporellus alboluteus</i> (Ellis & Everh.) Kotl. & Pouzar 1963	K-OS	2	+	3
<i>Gloeophyllum abietinum</i> (Fr.) P. Karst. 1882	K-OS	2	1	+
<i>Gloeophyllum odoratum</i> (Wulfen) Imazeki, 1943	K-FS	4	1	+
<b><i>Abies alba</i></b>				
<i>Heterobasidion abietinum</i> Niemelä & Korhonen 1988	K-FS	3	2	2
<i>Trichaptum abietinum</i> (Dicks.: Fr.) Ryvarden 1972	K-OS	2	2	3
<i>Hericium coralloides</i> (Scop.: Fr.) Pers 1974	K-OS	2	+	3
<i>Melampsorella cerastii</i> (Pers.) J. Schröt. 1887	OP	4,5	2	1
<i>Phellinus hartigii</i> (Allesch. & Schnabl) Pat., 1903	K-FS	2,3,4	2	1
<i>Gloeophyllum abietinum</i> (Fr.) P. Karst. 1882	K-OS	2	1	+
<b><i>Fagus sylvatica</i></b>				
<i>Nectria ditissima</i> Tul. & C. Tul. 1865	K-FS	4	2	2
<i>Neonectria coccinea</i> (Pers.) Rossman & Samuels, 1999	K-FS	2	2	2
<i>Nectria cinnabarina</i> (Tode) Fr. 1849	K-FS	2	2	1
<i>Nectria galligena</i> Bres. 1901	K-FS	2	3	2
<i>Stereum hirsutum</i> (Willd.) Pers. 1800	K-FS	2,5	3	3
<i>Irpex lacteus</i> (Fr.: Fr.) Fr. 1828	K-OS	2	1	2
<i>Chondrostereum purpureum</i> (Fr.) Pouzar 1959	K-OS	2	2	3
<i>Vuilleminia comedens</i> (Nees.: Fr.) Maire 1902	K-OS	2	1	1
<i>Schizophyllum commune</i> Fr. 1815	K-FS	2	3	2
<i>Cerioporus varius</i> (Pers.) Zmitr. & Kovalenko, 2016	K-OS	2	1	1
<i>Laetiporus sulphureus</i> (Bull.: Fr.) Murrill 1920	K-FS	4	3	1
<i>Ganoderma applanatum</i> (Pers.: Wallr.) Pat. 1887	K-FS	3,4	1	1
<i>Ganoderma resinaceum</i> Boud. 1889	K-FS	2,4	1	1
<i>Ramaria aurea</i> (Fr.) Quél. 1888 (Fig. 5a)	K-OS	2	2	3
<i>Inonotus obliquus</i> (Pers.) Pilát 1942	K-FS	4	+	+
<i>Phellinus igniarius</i> (L.) Quél. 1886	K-FS	2,4	2	2
<i>Daedalea quercina</i> (L.) Pers. 1801	K-FS	2	2	2

Table 2, Continued

Latin name	Trophic specialization	Micro-horizon	Encounter, point	Number, points
<i>Fomes fomentarius</i> (L.) Fr. 1849	K-FS	2,4	4	2
<i>Fomitopsis pinicola</i> (Sw.) P. Karst. 1881	K-FS	4	3	3
<i>Melogramma spiniferum</i> (Wallr.) De Not., 1863	K-OS	2,5	1	1
<i>Trichoderma sulphureum</i> (Schwein.) Jaklitsch & Voglmayr, 2014	K-OS	2	1	1
<i>Diatrype disciformis</i> (Hoffm.) Fr., 1849	K-OS	2	1	1
<i>Kretzschmaria deusta</i> (Hoffm.) P.M.D. Martin, 1970	K-OS	2	1	1
<i>Xylaria polymorpha</i> (Pers.) Grev., 1824	K-OS	2,3	1	2
<i>Plicaturopsis crispa</i> (Pers.) D.A. Reid, 1964	K-OS	2	1	1
<i>Panellus stipticus</i> (Bull.) P. Karst., 1879	K-OS	2	1	1
<i>Radulomyces molaris</i> (Chaillat ex Fr.) M.P. Christ., 1960	K-OS	2	2	2
<i>Calocera cornea</i> (Batsch) Fr., 1827 (Fig. 7a)	K-OS	2,3	2	2
<i>Dacrymyces stillatus</i> Nees, 1817	K-OS	2,3	1	1
<i>Trametopsis cervina</i> (Schwein.) Tomsoský, 2008	K-FS	4	1	2
<i>Bjerkandera adusta</i> (Willd.) P. Karst., 1879	K-FS	2	1	2
<i>Daedaleopsis confragosa</i> (Bolton) J. Schröt, 1888	K-FS	4	1	1
<i>Cerioporus mollis</i> (Sommerf.) Zmitr. & Kovalenko, 2016	K-OS	2,4	1	1
<i>Trametes versicolor</i> (L.) Lloyd, 1920 (Fig. 4b)	K-FS	2,3	3	3
<i>Clathrus archeri</i> (Berk.) Dring, 1980 (Fig. 6a)	EMERGENCY	2	+	+

**Note:** K-FS – xylotrophic facultative saprotroph, K-PP – xylotrophic facultative parasite, K-OS – xylotrophic obligate saprotroph, OP – obligate parasite, NS – aboveground saprotroph

**Source:** developed by the authors

The occurrence and abundance of species are partially correlated. For example, the species *Armillaria mellea*, *Fomes fomentarius*, *Fomitopsis pinicola*, *Nectria galligena*, *Schizophyllum commune*, *Stereum hirsutum* (Fig. 7b), *Trichaptum fuscoviolaceum* are characterized by almost equally high (3-4 points) occurrence and abundance within the study areas.

A similar dependence can be observed for very rare species (+) and is characterized by low numbers of individuals per unit of habitat. These are *Inonotus obliquus* and *Clathrus archeri*. It should be noted that these indicators are conditional and vary depending on the year, weather conditions, stand, microclimate, substrate, etc.



**Figure 7.** *Calocera viscosa* (a) and *Stereum hirsutum* (b)

**Source:** photo by the authors

I. Dudka *et al.* (2019) noted that the problems of studying the species diversity of fungi of the Ukrainian Carpathians and protecting their gene pool are currently inseparable. Establishing the boundaries of the species' range and the degree of its endemism is essential not only for assessing the actual rarity of the species but also for determining the level of sensitivity of the phytocoenosis to anthropogenic changes in the landscape. Every year, reports of discoveries of rare fungal species in the forests of the Carpathian region become available. S. Fokshei & L. Derzypilskyi (2021) indicate the discovery and identification of 9 species of mycetes included in the Red Data Book of Ukraine (*Anthurus archeri* (Berk.) E. Fischer, *Boletus regius* Krombh, *Clavariadelphus pistillaris* (L.) Donk, *Hericium coralloides* (Scop.) Pers., *Leucagaricus nympharum* (Kalchbr.) Bon., *Mutinus caninus* (Huds.) Fr, *Polyporus umbellatus* (Pers.) Fr, *Russula turci* Bres., *Strobilomyces strobilaceus* (Scop.) Berk.), 6 species rare for Ukraine (*Ganoderma lucidum* (Curtis) P. Karst, *Gyromitra infula* (Schaeff.) Quél., *Hericium alpestre* Pers, *Hericium cirrhatum* (Pers.) Nikol., *Sarcosphaera coronaria* (Jacq.) J. Schröt., *Sparassis nemecii* Pilát & Veselý) and 2 species of macromycetes that are candidates for inclusion in the Red List of Fungi of the International Union for Conservation of Nature (*Asterophora lycoperdoides* (Bull.) Ditmar, *Craterellus cornucopioides* (L.) Pers.) Their studies emphasize the value and uniqueness of the Kamystychnyi tract of the Hutsulshchyna National Park as a place of concentration of rare representatives of fungal biota. M.O. Zghonnyk (2022) described the lichenicolous species *Multiclavula mucida* (Pers. ex Fr.) R.H. Petersen, which parasitizes green algae of the genus *Coccomyxa*. The species was found on the semi-decomposed wood of an unidentified woody plant in the Skole Beskydy mountain range. It is noted that *M. mucida* is an indicator of the biological value of old-growth forests.

During a mycological excursion by V.O. Grebenshchikov & U.V. Pakhar (2022), a population (60 individuals) of *Porpolomopsis calyptriformis* (Berk.) Bresinsky was found for the first time in the Ukrainian Carpathians on the edge of the Prochert pasture in Putyla village, Chernivtsi region. This finding confirmed that the forests of the Putyla region are promising for the expansion of existing and the formation of new objects of the nature reserve fund due to the significant diversity of mycobiota. O. Klymyshyn (2020), studying the representatives of xylophilic ascomycobiota in the forests of the Skole Beskydy, emphasizes its role and importance in the processes of dead wood destruction. Attention is focused on their key role and importance in the processes of dead wood degradation. This study contributes to our better understanding of the internal mechanisms of wood decomposition in montane forest ecosystems, which can have practical applications in the context of optimizing forest management and conservation of natural bioresources.

It should be remembered that in addition to valuable and useful species, the mycobiota of the Ukrainian Carpathian forests are also represented by species that act as dangerous phytopathogens, infesting living growing trees, slowly weakening them, and causing the formation of various types of rot. A thorough study of the species composition of beech destructors in the forests of the Hutsulshchyna NNP was conducted by M. Pasaylyuk (2018). In the process of beech wood destruction, 50 species of fungi and fungi-like organisms were found on beech wood. This study indicates a high level of biological activity in forest ecosystems. These results contribute to a deeper understanding of wood decay processes and their impact on the ecological functions of the forest environment. I. Sopushynskyi *et al.* (2021) investigated the wood science aspects of the quality of fir stem wood affected by *Phellinus Hartigii*

(Allesch et Schnadl) Bond. This study is of great forestry importance in the context of the dying of fir stands in the Carpathians and the rational use of forest wood resources. The study by I. Sopushynskiy *et al.* (2021) on the formation of the quality of fir stem wood affected by *Phellinus Hartigii* is an important contribution to the study of the impact of fungal infection on wood characteristics, which is important for the rational use of forest resources and planning of forestry activities in the Carpathian region. O. Bogoslavets (2022), studying wood-destroying fungi of the Gorgany Nature Reserve, identified 25 species of fungi inhabiting the wood substrate. Among the valuable finds were the following species: *Athelia decipiens* (Höhn. & Litsch.) J. Erikss., *Antrodia sinuosa* (Fr.) P. Karst, *Coniophora puteana* (Schumach.) P. Karst, *Ceriopora excelsa* (S. Lundell) Parmasto, *Dacrymyces chrysospermus* Berk. & M.A. Curtis, *Mucronella calva* (Alb. & Schwein.) Fr., *Hericium coralloides* (Scop.) Pers, *Pholiotia limonella* (Peck) Sacc., *Piloderma byssinum* (P. Karst.) Jülich, *Pholiotina brunnea* (Watling) Singer, *Postia caesia* (Schrad.) P. Karst, *Pluteus leoninus* (Schaeff.: Fr.) P. Kumm., *Rigidoporus sanguinolentus* (Alb. & Schwein.) Donk, *Skeletocutis amorpha* (Fr.) Kotl. & Pouzar.

The fungal biota of the Earth is one of its most important components, which performs biodegradation, ensures and supports the functioning of higher plants, and is a valuable resource of food and medicinal raw materials. At the same time, the fungal biota, its participation in the functioning of the biosphere, the role of fungi in global energy processes in biomass utilization, the importance of fungi of different groups for the development of forest ecosystems, the structure, and relationships of species within mycocoenoses with other organisms, the properties of fungi and their use in human life, as well as many other aspects have been insufficiently studied and evaluated. Therefore, knowledge about species diversity,

population size, habitat conditions, ecological and trophic specialization makes it possible to assess the current state of the biocenosis, of which representatives of the kingdom Fungi are an integral part.

## Conclusions

Based on the systematic and structural analysis of the mycobiota of forests with *Abies alba* in the Pokutsko-Bukovyna Carpathians, 54 species of fungi were recorded and identified. Of these, 13 species form consortial relationships with *Picea abies*, 6 species with *Abies alba*, and 35 species with *Fagus sylvatica*.

The current state and peculiarities of the taxonomic structure of the identified species showed that during the mycological expedition, 18.5% of representatives of the *Ascomycota* and 81.5% of representatives of the *Basidiomycota* of the kingdom of Fungi were identified. The identified fungal biota belongs to 5 classes, 6 subclasses, 13 orders, 4 suborders, 31 families, 45 genera. The most numerous was the order *Polyporales*, which includes 31.4% of mycobiota species. The least numerous are the orders *Corticiales*, *Gomphales*, *Phallales*, *Pucciniales* and *Tremellales*, which include 1.9% of species for each order, respectively.

Among the representatives of the studied mycobiota of forests with *Abies alba* in the Pokutsko-Bukovyna Carpathians, the following ecological groups were identified: xylotrophic facultative saprotroph, xylotrophic pathogen, xylotrophic obligate saprotroph, obligate pathogen and aboveground saprotroph. According to the data obtained, saproxylotrophs are most widely represented in the studied mycoflora, which generally develop on dead and fallen wood. Obligate and facultative pathogens, as well as humus saprotrophs, are represented by a much smaller number of species.

In particular, a group of micromycetes as pathogens of infectious diseases of various

organs of forest woody plants and macromycetes – wood-destroying fungi (xylobiotrophs) that cause root and stem rot – were identified. These pathogens can have a significant impact on the formation and viability of forest stands at different stages of their ontogeny. By analysing the nature of the relationship in the system “plant-host-phytopathogen-environment”, it is possible to assess the role of phytopathogenic fungi in the forest consortium of a particular region and, accordingly, to predict measures aimed at reducing the harmful effects they cause.

It has been established that the occurrence and abundance of forest mycobiota species with *Abies alba* in the Pokutsko-Bukovyna Carpathians are mostly directly related. For example, some species (*Schizophyllum commune*, *Armillaria mellea*, *Stereum hirsutum*, *Fomes fomentarius*, *Nectria galligena*, *Fomitopsis pinicola*, *Trichaptum fuscoviolaceum*, etc.) within the study areas are characterized by relatively high rates of both occurrence and number of individuals per unit of inhabited space. A similar dependence was observed for species characterized by low occurrence and abundance (e.g. *Inonotus obliquus* and *Clathrus archeri*). It is important to understand that these indicators are rather conditional and correlate depending on the season, microclimate, meteorological conditions, state of the forest ecosystem,

substrate environment, etc. Thus, the accumulation of knowledge about the species diversity and functional purpose of mycobiota, the study of factors influencing the distribution and biology of fungi, the analysis of the systematic position, and the determination of trophic relationships with higher plants within the forest biocenosis makes it possible to establish certain systemic relationships in the secondary succession processes of the forests of the study region, as well as to form knowledge about the fungal biota as a significant bioindicator of forest condition.

A promising area for further research is to assess the degree of transformation of forest ecosystems, in addition to the known silvicultural and sanitary changes in the stand, signs of forest floor and soil degradation, based on qualitative and quantitative changes in xylomycorrhizal indicators (species composition, distribution along microhumidifiers, the stage of wood destruction by xylotrophs, an increase in the proportion of stenotrophs and biotrophic facultative species, etc.)

### Acknowledgements

None.

### Conflict of Interest

None.

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## Системно-структурний аналіз мікобіоти лісів за участю *Abies alba* Mill. у Покутсько-Буковинських Карпатах

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**Анотація.** Цінність та унікальність лісових екосистем визначаються їх видовим різноманіттям та біотичною стійкістю до негативного впливу навколишнього середовища. Метою дослідження є визначення видового складу, систематичного положення, трофічної спеціалізації, а також показників зустрічності та чисельності представників мікобіоти лісів за участю *Abies alba* у Покутсько-Буковинських Карпатах. Дослідження проводили впродовж 2019-2023 років у межах лісових масивів філій «Кутське лісове господарство», «Івано-Франківське лісове господарство» та «Берегометське лісомисливське господарство» Державного спеціалізованого господарського підприємства «Ліси України», а також лісів Національного природного парку «Вижницький» та Національного природного парку «Гуцульщина». У роботі використано класичні мікологічні методи ідентифікації. Для уточнення сучасного систематичного положення та актуальної назви таксонів використано інформацію із інтерактивних баз даних «Index Fungorum», «Mycobank» та «Світ грибів України». Досліджено, що консортивні зв'язки грибної біоти лісів Покутсько-Буковинських Карпат найбільш тісно пов'язані із деревними рослинами *Picea abies*, *Abies alba* та *Fagus sylvatica*. У ході мікологічної експедиції ідентифіковано 54 види представників царства *Fungi*, які на 81,5 % належать до відділу *Basidiomycota* та на 18,5 % – до відділу *Ascomycota*. Встановлено, що найбільш чисельним є порядок *Polyporales*, а найменш чисельно представлені порядки *Corticiales*, *Gomphales*, *Phallales*, *Pucciniales* та *Tremellales*. Показано, що згідно трофічної спеціалізації представники досліджуваної мікобіоти лісів Покутсько-Буковинських Карпат належать до наступних груп: ксилотроф-факультативний сапротроф, ксилотроф-факультативний патоген, ксилотроф-облігатний сапротроф, облігатний патоген та надгрунтовий сапротроф. Зазначається, що найширше представлені сапроксилотрофи, що загалом розвиваються на сухостійній та опалій деревині. Таким чином, системно-структурний аналіз грибної біоти лісів Покутсько-Буковинських Карпат дозволяє провести оцінку біоценотичного значення грибів як біоіндикаторів сучасного стану деревостанів, а також виокремити еталонні та цінні території, які характеризуються високими показниками біорізноманіття

**Ключові слова:** ялиця біла; мікоценоз; систематичне положення; видовий склад; трофічна спеціалізація

UDC 630.155.32:630.131.6

DOI: 10.31548/forest/2.2024.59

## Prevention and management of forest fires in an immersive environment

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**Abstract.** The global trend of innovative development of society positions virtual reality (VR) technologies as an integral tool in the management process. The study aims to analyse the potential of using immersive technologies in the system of forest fire prevention and management. The research was conducted using special scientific methods – experimentation and statistical methods descriptive and inferential statistics. The study determined that immersive technologies are now rapidly developing from the position of innovation to a practical range of tools. The study established that their implementation in the paradigm of environmental management policy is positioned as a prospective necessity and a factor in intensifying the quality of preventive environmental protection. The essence of the phenomenon of immersive technologies is specified, and their components, in particular, objective, virtual and augmented reality, are described. The potential of immersive technologies in the concept of expanding the toolkit of a modern industry specialist is investigated. The study proved that the use of VR applications has a significant potential for a positive impact on reducing the number of forest fires and improving the state of forest ecosystems. The specifics of the use of immersive technologies in the concept

### **Suggested Citation:**

Ye, S.H., Onpium, P., & Ying, F. (2024). Prevention and management of forest fires in an immersive environment. *Ukrainian Journal of Forest and Wood Science*, 15(2), 59-78. doi: 10.31548/forest/2.2024.59.

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of forest fire prevention and management were analysed in the study. An example of the use of virtual reality technologies in the process of modelling the situation of fire prevention in a certain forest area using a VR application in the educational environment is presented. In the process of studying the features of virtual reality technologies in environmental modelling, the advantages and risks of their integration are highlighted. The results of the study can be effectively used in the practical process of implementing the concept of ensuring a sustainable environment in terms of forest fire prevention

**Keywords:** virtual reality; augmented reality; application; modelling; preventive protection

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## Introduction

Global climate change and anthropogenic pressure are causing a significant increase in the frequency and intensity of forest fires in most regions of the world. Wildfires cause significant potential economic losses due to the destruction of forest resources, and infrastructure, and impacts on the tourism industry and biodiversity, which makes it imperative to develop effective strategies for preventing and controlling wildfires. Addressing these issues requires a comprehensive approach that synergises planning, risk management, research and active public engagement. Innovative digitalisation capabilities and immersive technologies should be given a priority role in the modern forest fire prevention system. The concept of using immersive technologies to prevent and manage forest fires is based on the potential of virtual reality technologies to simulate situational variations, which can be successfully implemented in training and educational programmes. The key aspect of the topic under study is the study of the preventive impact of immersive technologies in the educational environment on the prevention of forest fires, the overall reduction of their number and destructive power.

The issues of implementing virtual reality technologies in the environmental sector, as well as developing measures to optimise sectoral programmes in the context of sustainable development, are reflected in the works of

modern researchers (Buil *et al.*, 2016). D. Hamilton *et al.* (2021) argue that it is advisable to use the method of immersion in virtual reality as a universal analytical tool. The researchers conducted a systematic review of studies on quantitative learning outcomes and experimental design, demonstrating the significant potential of the technologies under study. M.A. Kuhail *et al.* (2022) implemented analytics of practical experience of immersive learning. The researchers believe that a modern environmental management system should be based on the synergy of traditional and immersive preventive methods of environmental protection. The authors demonstrate the effectiveness of such synergies by highlighting the recent achievements of certain experimental studies and pilot projects. Some scientists, in particular, G. Makransky & G.B. Petersen (2021), argue that the effectiveness of the cognitive-affective model of immersive learning is a prerequisite for the successful development of educational programmes, including for the prevention and management of undesirable and threatening environmental phenomena.

C. Chen (2022) analysed the practical experience of optimising the paradigm of managerial innovation in terms of convergence of the main traditional principles and the latest tools of immersive technologies. Scientists address the need to study the potential of the

latter in the concept of the actual problem of conservation of biological resources for sustainable development of regions. Scientists such as V.W. Lee *et al.* (2020) investigated the concepts of optimising the environmental management process using immersive virtual reality and non-immersive virtual reality in the educational environment. Scientists point out that virtual reality has significant prospects for development, so its progressive advancement in the educational and managerial spheres will lead to their obvious qualitative growth and effective functioning. Scientists are convinced that the improvement of virtual reality technologies contributes to modernisation in the field of management, which is related to the intensification of scientific and technological achievements.

Related risks and challenges were explored by R. Liu *et al.* (2022) by analysing basic solutions in the context of the concept under study. The authors emphasize the problematic issues of disclosing the relationship between immersive technologies academic achievements, and scientific motivation, thus providing insights into the integration of immersive tools into the existing system of social progress. The work of contemporary scholars, in particular, S. Aguayo & C. Eames (2023) position monitoring as an important element in the implementation of optimal measures for the implementation of immersive technologies. Scientists have conducted several studies on the use of immersive learning in mixed reality to improve environmental education. The results of the study of S. Aguayo & C. Eames (2023) show that the possibilities of innovative immersive technologies can significantly improve the understanding of environmental science, facilitating knowledge of environmental literacy, and attitudinal and behavioural change. The implications include rethinking the tools of the management environment with self-educational mobile learning,

as well as the priority of tactile and sensory capabilities of virtual reality for the environmental preventive direction of management policy.

Furthermore, T. Chandler *et al.* (2021) addressed the possibilities of modelling ecosystem reference conditions in virtual reality. Their study aimed to prove that virtual reality can be used to recreate virtual landscapes as an immersive, visceral experience and convey ecosystem dynamics to users effectively and engagingly. Scientists have proved the significant potential of virtual reality in terms of the outlined issues, but at the same time, they have identified the need for further research on related risks and challenges to improve the use of this tactic in a secure concept. The basis for research in this area is the work of J.C. Sneed *et al.* (2021), which provides the basics of immersion technology, which, according to the authors, can be a way to more thoroughly study the structure of the relationship between humans and nature, with the levelling of certain obstacles to personal access to nature.

The results of the research of these scientists characterise the problems, achievements and current state of the system of implementation of virtual reality technologies in environmental protection strategies. Despite their significant significance, the priority of promising areas for optimising the management system in the chosen direction has not been fully determined, and the issues of transforming approaches to ensuring the safety of the process of using virtual reality technologies remain poorly understood. The study aims to investigate the potential of immersive technologies for forest fire prevention and management.

### **Materials and Methods**

The study was carried out using special scientific methods, such as experimentation and statistical methods. The methodological and theoretical basis of the study was a systematic

approach, as well as the accepted concepts of complexity and dialectic. The systemic concept has created the preconditions for an effective analysis of the phenomenon under study as a systemic phenomenon in the entirety of inter-relationships.

An experimental method was used in the study, which involved the use of virtual reality technologies in the educational school environment. A certain area of the forest was designated, where a fire prevention situation was modelled using the FLAIM Systems VR software. A specific forest area was explored using VR, focusing on the preconditions, factors and consequences of forest fires. FLAIM Trainer was used to recreate the stress and uncertainty of real-life situations, conveying not only visuals but also tactile sensations. The complex simulates behaviour by heating the user with a thermal vest, recreating the experience of acting in scenarios with different locations of flame sources.

The experiment with VR technologies was conducted at school. The experiment was carried out at the Guangzhou Academy of Fine Arts (China). The sample for this study consisted of 277 students with different levels of experience and knowledge of the subject. The sample was selected on the principle of random sampling, as students were selected from one educational institution that had access to the necessary technologies and resources. The sample was divided into two groups: one that used a meta-environment (138 students) and another that used a traditional virtual environment (139 students). Students were randomly assigned to each group. The study was conducted in compliance with all the standards set out in the Helsinki Declaration (1975).

The meta-environment included virtual and real elements such as physical objects and real-time feedback. The traditional virtual environment was a purely digital environment that did not include any real-world elements.

The students in both groups completed a series of tasks and assessments designed to measure their level of learning, engagement and satisfaction with the learning process.

Inferential statistics were used to test hypotheses and draw conclusions about the general population based on the samples. A paired-sample t-test was conducted to determine whether there was a statistically significant difference between the pre-training and post-training knowledge scores, indicating whether the training programme was effective in improving the knowledge of the participants.

Descriptive statistics were used to summarise and describe the characteristics of the data, such as mean, median, mode, standard deviation and range. This identified patterns and trends in the data. In addition, inferential statistics were used to conclude the larger population from the sample data.

## Results

The number of forest fires is growing globally and regionally. Understanding fire drivers and assessing where fires are likely to occur are critical factors in developing more effective plans to mitigate wildfire initiation and identify risk areas. The fact that fires do not occur by chance, but are caused by people or natural processes, and are significantly dependent on permanent and variable environmental factors, should be recognised. Assessing the occurrence of a fire requires a comprehensive temporal and spatial analysis. As the experience of foreign countries shows, large forest fires can last for months, and even technologically advanced countries sometimes cannot effectively counteract this element. In countries with extremely dry and hot summers (the Mediterranean, the southern United States, some countries of Central and Latin America, and Western Europe), the number of simultaneously active forest fires sometimes reaches tens or even hundreds.

Forest fires are uncontrolled ignition and burning of vegetation that spreads spontaneously within the forest area. The main root causes of forest fires are human activity, as well as lightning discharges, spontaneous combustion of peat crumbs and agricultural arson during the fire-hazardous season. The latter includes the period from the moment the snow cover melts in the forest until the emergence of a full green cover or the onset of stable rainy autumn weather. Forest fires have a devastating effect on trees and shrubs, as well as on timber harvested in the forest. As a result of their spread, water conservation, protection and other practical functions of the forest are significantly reduced, flora and fauna, auxiliary structures are destroyed, biodiversity is threatened, and in some places, settlements are threatened. In addition, wildfires pose a serious threat to adjacent agricultural land, animals and people. Depending on the nature of the fire and the composition of the forest, forest fires are divided into grassland, upland and ground fires (peatland burning). According to the level of intensity, forest fires can be weak (burning depth does not exceed 25 cm), medium (25-50 cm) and strong (more than 50 cm). It is worth noting that the intensity of combustion depends on the condition and level of combustible materials, wind strength, terrain slope, time of day and several other factors. Fires differ in the speed of fire spread. For a strong bottom fire, this value does not exceed 1 m/min, for a strong fire – more than 3 m/min, and for a weak top fire. At the same time, a strong grass fire can reach speeds of up to 100 m/min.

The identification of a forest fire is due to the activities of ground-based observation posts. In addition, ground and aerial patrols of forests are common. The process of directly extinguishing a large fire is conditionally differentiated into certain stages, including fire reconnaissance, localisation (eliminating the

variability of new fire spread), and firefighting, i.e., extinguishing the fire, and patrolling the burned areas. Localising a fire is the most difficult and time-consuming task. The procedure for localising a forest fire is implemented in two stages. Initially, the fire contour is directly impacted, followed by the construction of barrier ditches and strips, and the treatment of peripheral fire areas using specialised methods to prevent the potential for renewed fire spread.

The following methods and technical means are actively used to extinguish forest fires:

- ◆ knocking down the fire along the fire contour with branches;
- ◆ covering the fire with soil along the fire contour;
- ◆ start of annealing (counter bottom and top fires);
- ◆ extinguishing the burning circuit with water;
- ◆ use of special chemicals;
- ◆ causing artificial precipitation;
- ◆ laying barrier strips (ditches) on the path of fire spread.

The timing of firefighting operations is also important. The most appropriate times for this are evening and early morning. Recently, immersive technologies have become particularly popular as components of management systems, including in the field of environmental protection. The most popular immersive technologies include augmented reality (AR) and virtual reality (VR). These technologies create the preconditions for effective interaction, modelling and forecasting in three dimensions. In this case, a regular smartphone is used to create augmented reality, and a helmet and glasses are used for virtual reality.

Immersive technologies are identified as a way of integrating virtual content into the physical environment, which creates conditions for effective interaction. At the same time, the user is aware of the virtual components as

an integral part. The spectrum of immersive technologies covers several different applications and tools that can be used to integrate, immerse or interact with simulated environments and objects (Sahal *et al.*, 2021). The Australian start-up FLAIM Systems is positioned as a successful functional model of virtual reality applications for practical purposes. The primary product of the company is the FLAIM Trainer virtual reality firefighting training system. It provides a safe and cost-effective way to replicate the stress and uncertainty of real-life situations to better prepare a professional for a challenge. FLAIM Trainer conveys not only visuals but also tactile sensations. The complex simulates behaviour by heating the user with a thermal vest, reproducing the experience of actions in scenarios with different locations of flame sources (Abid, 2020; Khan *et al.*, 2022).

The trainer monitors real-time training data, including task speed, air and water usage, stress levels, trainee movements and attention, and interaction with objects such as gas meters, electrical boxes, and the fire itself (van Wees *et al.*, 2021). VR realistically displays all the fire, smoke, water and extinguisher foam, as well as heat, thanks to a special thermal suit that can heat the firefighter depending on proximity to the virtual fire. A virtual reality program was also used, which involved a classroom (a room in the complex was used, which made it possible to implement a 360° digital projection) (Pang *et al.*, 2022). By crossing the boundaries of traditional educational methods, 3D modelling, and virtual reality help students intensify the development of critical thinking, imagination, and stress resistance. The immersive environment was used to teach ecology classes on forest fire prevention.

Among the main qualitative characteristics of the implemented virtual reality technologies in the process of implementing the innovative concept of forest fire prevention and management

in an immersive environment are the immersion effect, immersive visual and auditory experience, stimulation of creativity and optimisation of operational management decision-making. The technologies under study provide users with a realistic visual and audio experience that mimics reality; and helps students better understand abstract concepts by creating interactive visualisations of complex processes, objects and phenomena. Virtual reality can immerse in a virtual environment to explore and learn about various subjects with greater detail and realism. The immersive environment will provide the effect of the so-called “live presence” of the subject, which will facilitate the perception of the learning material (Sivrikaya & Küçük, 2022). Immersive technologies are being integrated into the educational process to improve learning and create an immersive experience. Their interactivity and ability to create realistic situations allow learners to experience the material more deeply and engagingly.

Despite a range of positive aspects of the effects of immersive technologies, the use of the latter is accompanied by several risks, disadvantages and challenges. Among them, it is worth highlighting the rather high cost and difficult availability of the necessary technical equipment. The vast majority of virtual reality technologies are quite expensive, especially in the context of financial constraints and structured budgeting (Nesterov, 2023). In addition, the implementation of virtual reality technologies in the educational and administrative environment requires specialists to have the necessary skills and proper training to use these technologies in practice. A separate risk is the destruction of the connection with reality, as virtual reality technologies can focus attention on virtual scenarios, distracting from real-life situations. Prolonged use of immersive technologies can cause health deterioration in the form of discomfort, and impaired vision

and memory. There is also a risk that the active implementation of virtual reality technologies may lead to an over-reliance on digital learning and management tools, which will negatively affect the development of other skills and social skills. In addition, given the rapid development of immersive technologies, it is currently difficult to define standards and criteria for the use of these technologies in educational and administrative processes.

The implementation of the technology with the addition and clarification of appropriate content and visual models actively motivates the development of spatial imagination and intensifies the understanding of

the essence of the problem helps to assimilate content through visual representation, identifies the creation of imaginary spaces for unsolved problems, and reproduces real-life situations (Hantson *et al.*, 2022). As a result of an experiment in the educational environment involving virtual reality technology on forest fire prevention and management, students realised several important truths and dispelled several myths. They clarified that forest fires are caused not only by human negligence. Lightning or summer drought in the forest are situations where humans do not influence the outbreak of a fire, but the fire can instantly break out and spread (Fig. 1-3).

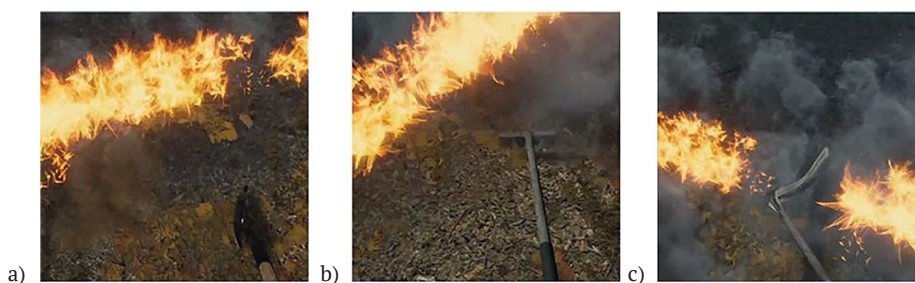


**Figure 1.** Visualisation of a forest fire using VR technology

**Source:** compiled by the authors

As a result of an experiment in the educational environment involving virtual reality technology on forest fire prevention and management, students realised several important truths and dispelled several myths. They

clarified that forest fires are caused not only by human negligence. Lightning or summer drought in the forest are situations where humans do not influence the outbreak of a fire, but the fire can instantly break out and spread.



**Figure 2.** Visualising the impact of different tools on the scenario using VR technology

**Note:** a – a shovel, b– rake to remove fuel and stop the fire from spreading, c – a poker on the flames to remove oxygen and smother the fire

**Source:** compiled by the authors



**Figure 3.** Practicing firefighting measures in the forest using VR technology

**Source:** compiled by the authors

The experiment involved the use of a 3D interactive educational environment based on immersive technologies. Using virtual reality technology that simulates realistic disaster scenarios, combined with embodied cognition theory, which suggests that cognition is not only a function of the brain but also depends on the body and its interaction with the environment, this research has the potential to create a more realistic and effective learning experience. By combining virtual reality technology with

embodied cognition theory, the experiment aimed to create a more effective and efficient training experience for disaster response. Innovative principles aimed at optimising the mitigation and prevention of the causes of forest fires, with the identification of the most effective measures for their preventive prevention, are considered relevant. The latest principles establish the priority of preventive measures that should be effectively implemented through the state forest management system.

In addition, in an integrated global community, member states can receive additional targeted funding to increase the resilience of territories to wildfires and to vary joint project cooperation in the identified area at the level of the global community.

The guiding principles of the modern wildfire management paradigm stipulate the need to forecast future trends in wildfires and actively implement innovative tools for their monitoring at the global and national levels. This concept of wildfire management should be coordinated with the goals of effective afforestation, as well as maximum conservation and regeneration of forest resources. This approach will help reduce the scale and frequency of forest fires. Forest fires are ranked as one of the four biggest potential environmental threats of the future, along with the effects of irreversible climate change, risks to food security and the spread of unknown diseases. This requires proper equipment for effective prevention and rapid response to large forest fires, which cause the most serious damage to forest biodiversity and put its existence at risk. An effective approach to wildfire management within the modern management paradigm implies the priority of preventive measures, which should be implemented both at the national level and at the regional and local management levels, depending on the range of responsibilities of the relevant authorities and officials. An effective management paradigm in the field of wildfires can practically increase the resilience of forest landscapes to fire. The structure of the management system in the field of forest fires is positioned as the basic concept of forest fire prevention. It identifies the boundaries of responsibility for protection against forest fires, including their prevention and management, and defines the functions of responsible persons and bodies for planning and practical forest management. These responsibilities are

often assigned to different organisations or departments, which necessitates effective communication between them, the establishment of a system of rapid information exchange to develop common approaches and division of competence, and the development of a common strategy for risk and improved forest fire management.

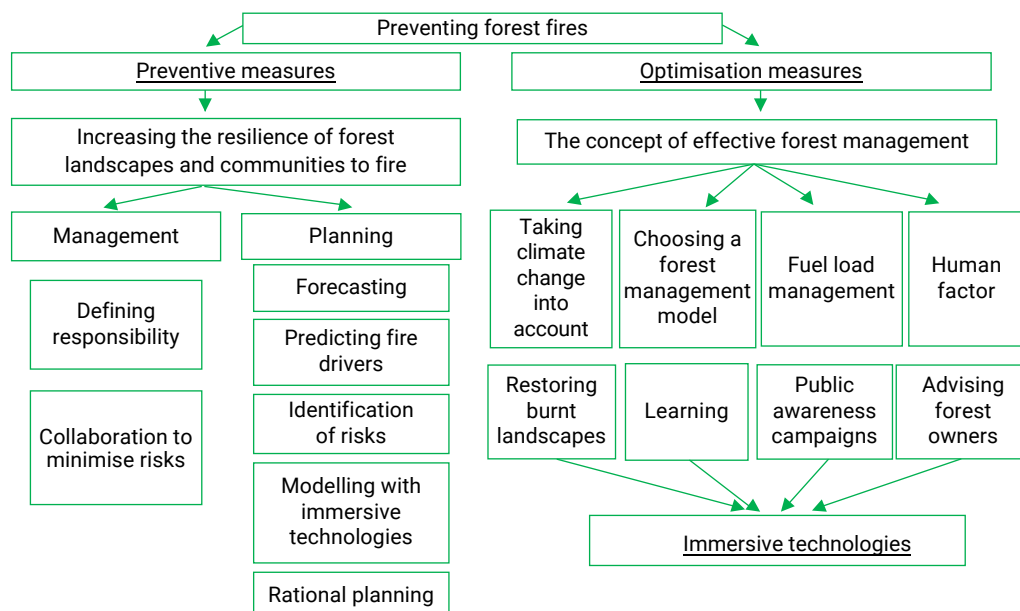
Forecasting the drivers and potential risks of forest fires is seen as a necessary part of forest management. The implementation of an effective forecasting system contributes to the formation and maintenance of sustainable forest landscapes based on a reliable preliminary assessment of forest fire risks in synergy with effective forest management and anthropogenic impacts. The rational planning strategy includes several stages, including identification of the forest area to be surveyed, assessment of related risks, and ongoing monitoring and control. Furthermore, a specific contingency plan is necessary to ensure that the relevant services and authorised managers are prepared to respond promptly and effectively to unforeseen events. Since climate and weather conditions often have a decisive influence on the development of wildfires, the selection of planning strategies requires that indicators of changing climate conditions and their consequences be addressed (Yerzhanova *et al.*, 2021). In addition, when designing infrastructure development and urban planning activities in areas adjacent to fire-prone forests, potential risks should be considered, and real dangers identified. The planning system is comprehensive and involves extensive consultations with stakeholders and authorised representatives to raise their awareness and agree on the aspects of interaction. For managing existing forest resources and planning the creation or regeneration of future forest plantations, the right choice of forest management model is crucial for managing their vulnerability to wildfire. Several nuances,

addressed or ignored in the practical implementation of the management paradigm in the field of forest fires, have a significant impact on the success of preventing large-scale destructive consequences. When planting trees, it should be borne in mind that, in the best-case scenario, the tree species chosen for planting should be adapted to the current and, especially, the forecast climatic conditions. In this regard, preference should be given to deciduous species that demonstrate more resistant properties to forest fires. In addition, appropriate varieties of native species adapted to the local soil and water conditions should be selected.

It is considered expedient to maintain the proper condition of old-growth forests, which have significant benefits for biodiversity conservation and regulation of carbon content in the atmosphere. In addition, old-growth forests create a locally more humid microclimate, which potentially reduces the risk of forest fires. Competent management of fuel loads plays an important role in the effective prevention of forest fires. The fuel can intensively support the combustion process during a forest fire. Fuel management can minimise the additional risks of intensified burning, and therefore planned and controlled burning and collection of woody biomasses for heating are often used as preventive measures. Given this, the skills of managing forest fuel loads and their distribution are considered necessary for optimising the forest fire management system, understanding the dynamics of their spread and developing appropriate effective methods of fighting forest fires. The human factor within the management paradigm of wildfires is considered in different concepts. Humans are often both the cause and

the victim of forest fires, so the anthropogenic factor has a significant niche in any forest fire prevention strategy. Awareness of potentially hazardous activities and the preconditions for uncontrolled forest fires significantly reduces the risk of the latter occurring. The problem of forest fires is characterised on a global scale, so the relevant authorities should work to raise public awareness. This is especially true for tourism when travelling across the continent, as tourists are mostly unaware of local risks, do not speak the local language and do not have emergency communication information, which increases the risk of uncontrolled fires in forests (Mashika *et al.*, 2024).

At the global level, joint efforts to combat the spread of forest fires are being implemented on an ongoing basis. The global community regularly demonstrates solidarity in the form of firefighting helicopters and aircraft, firefighting equipment and teams of experts. The modern global integrated environment offers several opportunities for financing the implementation of practical measures that contribute to preventive forest fire management. Existing financial instruments can be effectively used by stakeholders or authorities to improve forest management to intensify forest resilience, implement targeted campaigns to establish local fire brigades, and raise public awareness. In addition to active financial and practical support for forest fire prevention, the international community is also developing programmes to regenerate forest lands destroyed by fire. An important role is played by advising land and forest managers and forest owners. The conceptual model of the forest fire prevention system in modern society is shown in Figure 4.



**Figure 4.** Conceptual model of forest fire prevention using immersive technologies

**Source:** compiled by the authors

During the experiment, inferential statistics were used to test hypotheses and draw conclusions about the general population based on the samples. A paired-sample t-test was conducted to determine whether there was a statistically significant difference between the pre-training and post-training knowledge scores, indicating whether the training programme was effective in improving the knowledge of the participants. The null and alternative hypotheses are formulated. The null hypothesis was that there would be no difference between the pre-training and post-training knowledge assessment. The alternative hypothesis was that there would be a difference between the pre-training and post-training knowledge assessment. The average difference between the pre-training knowledge assessment and the post-training knowledge assessment was calculated: Average difference = Post-training knowledge score – Pre-training knowledge score.

Average difference =  $8.5 - 5.6 = 2.9$ . Calculate the standard deviation of the difference (1):

$$SD = \sqrt{[(\text{sum}(\text{Post-training knowledge score} - \text{Pre-training knowledge score})^2) / (n - 1)]}. \quad (1)$$

The t-value was calculated using the formula (2):

$$t = (\text{Mean difference} - \text{hypothetical difference}) / (\text{SD} / \sqrt{n}). \quad (2)$$

A hypothetical difference of 0 was used, as the proposed null hypothesis states that there is no difference between the pre-training and post-training knowledge assessment (3):

$$t = (2.9 - 0) / (1.01 / \sqrt{10}) = 9.08. \quad (3)$$

The degrees of freedom were determined:

$$df = n - 1 = 9. \quad (4)$$

A critical t-value was found in the t-distribution table with 9 degrees of freedom and a

significance level of 0.05. The critical t-value is 2.306. The calculated t-value was compared with the critical t-value. If the calculated t-value is greater than the critical t-value, the null hypothesis is rejected, and it is concluded that there is a statistically significant difference between the pre-training and post-training knowledge assessment. Descriptive statistics were used to summarise and describe the characteristics of the data, such as mean, median, mode, standard deviation and range. This identified patterns and trends in the data. In addition, inferential statistics were used to conclude the larger population from the sample data. Regression analysis can also be used in the future to model the relationship between two or more variables and predict future results. For example, linear regression can be used to determine the relationship between game performance and user satisfaction. Machine learning can be used to analyse and predict data patterns, such as a decision tree algorithm to identify the factors that are most important in predicting user satisfaction. Network analysis can be used within the framework of immersive technologies to study the structure and dynamics of a social network to identify key players or communities in the network.

The study convincingly demonstrates that the use of virtual reality technologies in the educational and management process has significant advantages over the traditional process methodology, as it actively involves the sensory system and the emotional sphere. The experiment determined that roads in forested areas are not always in satisfactory condition, which can cause sparking or vehicle failure. The need to comply with the ban on open fires, bonfires and the use of grills in forests and open fields was emphasised. The study emphasised that it is unacceptable to leave the forest as is, as well as to leave garbage in the forest, as it can become a source of fire. The app can be used to

monitor the weather forecast and determine when the weather becomes too hot and dry, as the forest is particularly vulnerable to fires on these days. The skills of promptly reporting a fire were practised. The author proves the inexpediency of attempts to extinguish a forest fire on their own, given the potential danger to life and health. This situational awareness, enhanced by the virtual reality programme, highlighted the fact that fire prevention is not only about individual awareness and responsibility but also about a range of random factors that require systematic and technical training to overcome the consequences quickly.

### Discussion

Understanding the dynamics of the environment, particularly the forest environment, can be challenging, especially when using traditional representations such as graphs, maps or photographs. Immersive visualisations and experiences using virtual reality technologies offer an intuitive approach to abstract concepts, but they are difficult to create scientifically. The experiment managed to combine environmental modelling and virtual reality to provide an immersive experience for sustainable forest management.

The results of the study position the phenomenon of immersive technologies as an innovative promising element of the system of effective implementation of the concept of sustainable forest management. According to the results of scientific research by modern scientists, in particular, B.T. Pham *et al.* (2020), integrated management of the prevention of destructive phenomena in the system of environmental protection is, in particular, a systematic and coordinated approach to the management and prevention of forest fires. The latter is positioned as a convergence of the potential of various methods and practices for preventive protection, timely identification and

effective control of forest fire risks. These conclusions correlate with the modelling implemented in the experimental part of the current study, opening new vectors of synergy potential between integrated management and virtual reality technologies.

Given the outlined concept of sustainable development of forest resources, some scientists, in particular, J.C. Sanabria & J. Arámburo-Lizárraga (2017), emphasise the need to transform the existing management system into sectoral management. Modern scientists of relevant scientific fields, in particular E. Zhu *et al.* (2015), confirm that one of the most effective means to optimise the situation is the active use of modern tools of virtual reality technologies. S. Perey *et al.* (2011) also addressed the need to develop effective tools for integrated management processes based on the maximum disclosure of the interaction potential of modern innovative solutions developed using virtual reality technologies. Analysing the conclusions of the researchers in the concept of preventive training and educational systems based on virtual reality technologies, the study determined that there is a strategic opportunity to optimise the management paradigm in the field of forest fires based on immersive learning technologies.

According to Y. Arifin *et al.* (2018), the priority and the basis of user experience in the field of virtual reality technologies in management will belong to augmented reality applications. At the same time, some researchers, in particular Y.M. Tang *et al.* (2022), emphasise the obvious intensification of forest management efficiency through integrated management using virtual reality technologies, arguing that such conclusions can be made by using a combination of different methods and strategies, which leads to greater efficiency in controlling forest fires. According to the researchers, the optimal combination of a set of methods creates a reliable barrier against the spread of destructive

phenomena. The results of the researchers correlate with the conclusions of the experiment implemented in the current study, since the methodology of integrated forest fire management contributes to the conservation and rational use of resources, since within the framework of the studied approach, natural resources are controlled as accurately as possible and in the smallest practicable areas.

According to S.O. Semerikov *et al.* (2021), the management concept involving the potential of virtual reality technologies should level the phenomenon of imbalance in the field under study. Scientists define integrated forest fire management as a means of reducing costs. The opinion of the scientists is noteworthy, as despite the cost of implementing integrated management systems using VR tools, in the long run, this approach minimises forest loss and prevents significant regeneration costs. During the analytical part of the study, a close relationship was established between the level of integration of forest ecosystem monitoring processes and the effectiveness of the fire safety system. The conclusions of scientists confirm the expediency of integrating VR technology tools into a significant part of management processes in the field of forest fire management (Maroungkas *et al.*, 2023).

According to Y. Shen *et al.* (2022), the main goal of the preventive management paradigm for fire prevention is to increase environmental awareness and education of the population. Scientists emphasise that insufficient access to modern technologies and innovative solutions involving the potential of virtual reality technologies and unreadiness for their practical implementation are the most significant factors limiting the potential of integrated management in the field of research. According to scientists, ensuring fire safety in the forest environment involves the implementation of an effective policy to minimise anthropogenic

impact on natural resources and maximise the ecological compatibility of forest management processes. These conclusions are consistent with the results of the current study in terms of positioning a comprehensive integrated approach as the only effective solution in the process of transforming the forest management system. At the same time, virtual reality technologies are assigned a range of functions to increase the environmental awareness of society and develop the necessary actions to prevent and respond quickly to forest fires (Belytskyi *et al.*, 2023), as proven by the current study.

The results of the current study led to the conclusion that it is necessary to ensure effective interaction between authorities at different levels of government, society and business involved in forestry production to implement integrated approaches to forest fire management. The scientific positions of E. Erturk & G.B. Reynolds (2020), and K.H. Cheng (2021) synergise the proposed approach in terms of accelerating the positive dynamics of the process of transformation of the management paradigm in the field of convergence of effective management and environmental safety in the forest. According to the researchers, integrated forest management contributes to human well-being. Reducing the number of forest fires minimises the risk of poisoning for people and biodiversity. At the same time, C. Seufert *et al.* (2022) identify specific prerequisites for the functioning of an effective educational and management paradigm in the field of environmental protection and the basis of an integrated approach, focusing on the need for an appropriate resource base and the readiness of society for dynamic change. The author is convinced that it is possible to ensure high efficiency of implementation of integrated forest fire management using economic methods while noting that the process is inversely related since the economic and environmental

spheres of activity have determining factors of mutual influence. The opinion of the author is noteworthy, as the current study proved that maximum results in the field of research can be achieved as a result of the convergence of traditional and innovative approaches to monitoring the state of forest lands and environmental indicators in general.

The issue of integrated wildfire management is becoming more urgent in parallel with the trend of increasing dependence on forestry efficiency in the management decision-making system, and in this context, the principle of environmental safety should be a top priority. Sustainable management in an unstable environmental situation has significantly expanded its scope of operation, confirming the effectiveness of implementing innovative technological solutions and opportunities to optimise most areas of life (Kerimkhulle *et al.*, 2023). At the same time, scientists M. Coban *et al.* (2022) addressed the vectoriality of integrated management in forestry, and the need to form effective mechanisms and carry out comprehensive measures to prevent forest fires. According to scientists, the integrated management of the latter is positioned as a basic modern tool in the control and monitoring system that successfully combines efficiency with the principles of environmental sustainability. Abandoning outdated, exhausting approaches to forest management in favour of integrated management helps ensure an appropriate level of fire safety, helps preserve resource potential and stimulates sustainable development of the industry. Additionally, N. Enyedy & S. Yoon (2021) propose to use the potential of VR tools in the form of training technologies for forest fire management within the framework of sustainable management, revealing its functionality in terms of increasing the effectiveness of preventive measures, creating safe and reasonable approaches to forest

management, and optimising the handling of targeted protective equipment. In addition, the study highlights priority areas for targeted investment that intensify the environmental sustainability of integrated management systems in the field of forest fire prevention. The authors emphasise that the proposed concept does not have any potential negative environmental consequences. According to the researchers, national forestry development strategies should include synchronisation with the concepts of the green development course. The opinion of the authors is noteworthy, as the results of the current study confirm the effectiveness of integrated solutions in the process of fighting forest fires, monitoring environmental parameters, and greening forestry production, which should be used to the maximum extent possible in the further development of educational processes.

Despite significant scientific achievements in the field of integrated wildfire management as a basis for building environmental resilience, the issue of their large-scale practical adaptation to the realities of Thailand remains unresolved. The development of an innovative approach to the management paradigm in the field of forestry management in the concept of convergence of the most effective immersive technologies, tools and methods for optimising the industry under study in the direction of sustainable development is considered promising. In addition, modelling modern educational content with immersion in the virtual reality of the forest environment leads to better results in intensifying environmental awareness, as an immersive environment with a sense of real presence leads to higher engagement and motivation, and deeper cognitive processing of educational material. The use of virtual reality educational applications has significant opportunities that are not available when using traditional educational technologies.

## Conclusions

The rapid innovative development of the modern information society is closely linked to the adaptive renewal and intensive transformation of the environmental management system, the effectiveness of which is based on deep immersion in the digital information environment. Immersive education and training technologies can become an important functional tool in the forest management process, helping to minimise the number of forest fires. At the moment, this is not the cheapest way to study and not everyone can afford it. Nevertheless, the number of VR and AR products indicates the demand for this format. These technologies, such as others, will become more accessible over time and can truly become a regular part of the educational process.

The study determined that immersive technologies are currently developing rapidly from the position of innovation to a practical range of tools. Their implementation in the paradigm of environmental management policy is positioned as a promising necessity and a factor in intensifying the quality of preventive environmental protection. As a result of specifying the essence of the phenomenon of immersive technologies, their components, in particular, objective, virtual and augmented reality, are allocated. The study presents an example of the use of virtual reality technologies in the process of modelling the situation of fire prevention in a certain forest area using a virtual reality application (VR application) in an educational environment. In the process of studying the features of virtual reality technologies in environmental modelling, the advantages and risks of their integration are highlighted. Based on the data obtained, the article analyses the potential of immersive technologies to minimise the risks of forest fires, while introducing the latest control and monitoring systems.

The experiment was conducted with the use of virtual reality technologies in the educational school environment. A certain area of the forest was selected, where a fire prevention situation was modelled using the FLAIM Systems VR software, focusing on the preconditions, factors and consequences of forest fires. FLAIM Trainer was used to recreate the stress and uncertainty of real-life situations, conveying not only visuals but also tactile sensations. As a result of the experiment, the situation was analysed using a virtual reality programme, which made it possible to understand several important factors that require systemic and technical training to quickly overcome the consequences and prevent forest fires. Given the experiment, it is worth noting certain limitations of the study, which are due to the limited sample and statistical methods used. In this regard, the variability of certain indicators, such as the relationship between two or more variables and the prediction of future outcomes, could not be fully considered in the experiment, which is worth

testing in future studies. In the future, regression and network analysis and machine learning can be used for modelling and forecasting, determining relationships and decision tree algorithms. Network analysis should be used within the framework of immersive technologies to study the structure and dynamics of a social network.

Thus, the use of immersive technologies in the management of the forest fire prevention system significantly expands the toolkit of a modern specialist. Virtual reality technologies can be used to design a virtual environment, and develop a scenario for interacting with visual interactive material, which helps to improve the efficiency of the educational and management process.

### Acknowledgements

None.

### Conflict of Interest

None.

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## Запобігання та управління лісовими пожежами в імерсивному середовищі

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**Анотація.** Глобальний тренд інноваційного розвитку суспільства позиціонує технології віртуальної реальності (VR) як невід'ємний інструмент в управлінському процесі. Метою дослідження є аналіз потенціалу використання імерсивних технологій у системі запобігання та ліквідації лісових пожеж. Дослідження проводилося з використанням спеціальних наукових методів – експерименту та статистичних методів описової та інференційної статистики. У ході дослідження визначено, що імерсивні технології зараз стрімко розвиваються від позиції інновації до практичного спектру інструментів. Встановлено, що їх впровадження в парадигмі політики природокористування позиціонується як перспективна необхідність і чинник інтенсифікації якості превентивної охорони довкілля. Уточнено сутність феномену

імерсивних технологій та охарактеризовано їх складові, зокрема, об'єктивну, віртуальну та доповнену реальність. Досліджено потенціал імерсивних технологій в концепції розширення інструментарію сучасного фахівця галузі. Дослідження довело, що використання VR-додатків має значний потенціал позитивного впливу на зменшення кількості лісових пожеж та покращення стану лісових екосистем. У дослідженні проаналізовано специфіку використання імерсивних технологій у концепції запобігання та управління лісовими пожежами. Наведено приклад використання технологій віртуальної реальності в процесі моделювання ситуації запобігання пожежі на певній лісовій ділянці за допомогою VR-додатку в освітньому середовищі. У процесі дослідження особливостей використання технологій віртуальної реальності в екологічному моделюванні виокремлено переваги та ризики їх інтеграції. Результати дослідження можуть бути ефективно використані в практичному процесі реалізації концепції забезпечення сталого розвитку довкілля в частині профілактики лісових пожеж

**Ключові слова:** віртуальна реальність; доповнена реальність; застосування; моделювання; превентивний захист

UDC 634.0:336.22

DOI: 10.31548/forest/2.2024.79

## **Economic efficiency and finance in the development of the forest economy within the framework of legal restrictions**

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**Abstract.** The present study aims to analyse the factors that determine the economic efficiency and optimal models of forestry financing in the context of the current legal framework. The article discusses the critical importance of forestry for global environmental sustainability and economic development. It is determined that economic efficiency in this area is to achieve the maximum economic result while minimizing costs and making optimal use of resources. The main indicators of economic efficiency are the productivity of forest resources, which depends on the ability to maintain and restore forest plantations, as well as on cost optimization, including operating costs and investments in modern technologies. Economic efficiency is also determined by financial results, including revenues from the sale of forest products and profitability of enterprises. An important aspect was the consideration of environmental and social aspects, such as the impact of forestry on ecosystems and employment. The article emphasized the role of innovative technologies, such as geographic information systems and remote sensing, in improving the efficiency of forest management. The article analyses the impact of access to financial resources, level of technological

### ***Suggested Citation:***

Sejdiu, S., Zeqiraj, V., & Nimani, A. (2024). Economic efficiency and finance in the development of the forest economy within the framework of legal restrictions. *Ukrainian Journal of Forest and Wood Science*, 15(2), 79-96. doi: 10.31548/forest/2.2024.79.

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development, management approaches, legislative framework, environmental sustainability and market conditions on the economic efficiency of forestry in Kosovo. As a result, recommendations were made to improve the economic efficiency of forestry, including increasing financial support, attracting international investment, improving the legal framework and developing international cooperation. Implementation of these measures will contribute to the conservation and efficient use of forest resources, ensuring economic stability and environmental safety of the country

**Keywords:** legislative norms; resource efficiency; environmental standards; innovation; public-private partnership

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## Introduction

Forestry plays a key role in ensuring environmental sustainability and economic development in many countries around the world. It not only supplies important resources such as timber and other forest products, but also contributes to biodiversity conservation, climate regulation and the maintenance of ecosystem services. In the face of global challenges such as climate change, forest degradation and population growth, the issue of effective forest management and financing is becoming increasingly important.

The relevance of researching the economic efficiency and financing of forestry is due to the growing challenges associated with the conservation of natural resources and ensuring sustainable economic development. In today's climate change and increasing environmental crises, effective forest management is of particular importance. Forestry plays a pivotal role in maintaining ecosystem services, regulating the carbon balance and providing raw materials for many industries. One of the main problems is insufficient funding for the forestry sector. Many countries face a shortage of investment in forest restoration, technology modernization and infrastructure development (Baraban *et al.*, 2023). This leads to a decline in the productivity of forest resources and increased risks of their depletion. In addition, there is a problem of imperfect mechanisms for

controlling and monitoring compliance with legal norms, which limits the possibility of effective forest management.

The economic efficiency of forestry depends on many factors, including access to financial resources, the level of technological development, management approaches and the legislative framework. One of the most important aspects is the introduction of innovative technologies that increase the productivity of forest resources and reduce costs. Financial management in the forestry sector includes planning, control and analysis of financial flows aimed at supporting and developing forestry. This involves the efficient use of budgetary and extra-budgetary funds, attracting investments and grants, and developing partnerships with the private sector. One of the most promising areas is the introduction of public-private partnership mechanisms, which allows attracting additional resources for forestry development. Legislation governing forestry varies from country to country and from one country to another, and from one international agreement to another (Malchyk, 2024). They may include requirements for harvesting, reforestation, biodiversity, and landscape conservation. Meeting these requirements requires additional efforts and resources from forestry enterprises, which may affect their economic efficiency.

The works of leading scientists reveal various aspects of the impact of legislative norms on the economic profitability of forestry, the role of state funding, the use of innovative technologies, the importance of public-private partnerships, the impact of international agreements and economic analysis of costs and benefits. E. Makrickiene *et al.* (2019) and H. Bekteshi (2020) analysed the impact of legislation on the economic profitability of forestry in their studies. Their research shows that strict legal restrictions can significantly reduce the profitability of forestry enterprises, while stimulating the introduction of more sustainable forest management practices. M.R. Fisher *et al.* (2019) studied the role of public funding in forestry development, arguing that adequate funding from the state is critical to maintaining sustainable forest development, while it lacks leads to degradation of forest resources and a decrease in their productivity. A. McEwan *et al.* (2020) considered the use of innovative technologies to improve the efficiency of forestry. C. Yang & H. Shang (2023) studied the impact of public-private partnerships on forestry financing and showed that such partnerships can provide additional resources for the development of the forest sector, increasing management efficiency and reducing the burden on public budgets. A. Näyhä (2019) and J. Eggers *et al.* (2020) studied the economic aspects of forest restoration after deforestation. Their work shows that investments in reforestation have long-term economic benefits, including improved ecosystem services and increased biodiversity, which in turn contributes to the economic stability of regions. F.A. Taye *et al.* (2021) reviewed the economic analysis of costs and benefits in forestry, emphasizing the importance of a detailed analysis of economic activities for making informed management decisions.

The analysis of previous studies points to various aspects of the impact of legislation,

public funding, use of innovative technologies, public-private partnerships and international agreements on the economic efficiency of forestry. Various authors have concluded that adequate financing, innovation, partnerships and international commitments are important for the sustainable development of the forestry sector. However, the impact of mass industrialization and growing demand for forest resources on economic efficiency and environmental sustainability, the role of regulators in ensuring compliance with legal norms, and the assessment of risks and opportunities associated with climate change on the financial strategies of forestry enterprises remain insufficiently researched.

The purpose of the study was to reveal the relationship between economic efficiency, financing and legal restrictions in forestry. The main objectives of the study were to analyse the impact of legal restrictions on the economic efficiency of forestry, to examine the role of financing in the development of the forestry sector, and to identify possible ways to optimize costs and revenues in the context of strict legal regulations.

## Materials and Methods

This study used data from various sources to provide a comprehensive analysis of the economic efficiency of forestry in Kosovo. The main data source was official reports from the Ministry of Agriculture, Forestry and Rural Development of Kosovo (2021). Also, data from national and international organizations such as the World Bank (n.d.) and the European Investment Bank (2022). The following key indicators were used for the analysis: the area of forest plantations and their distribution between the public and private sectors; financial indicators, including enterprise turnover, the number of active enterprises and the number of employees in the forestry sector; data on the planning and implementation of forest resource use plans in public and private forests;

information on the level of technological development, including the use of modern technologies such as geographic information systems (GIS) and remote sensing (RS).

Data collection included the use of official reports and statistics collected from the official reports of the Ministry of Agriculture, Forestry and Rural Development of Kosovo for the period 2019-2021. This included information on forest area, forest condition, and financial performance of forest enterprises. The data for this study was analysed until 2021, as the official reports of the Ministry did not contain complete data for later periods. The data analysis included quantitative analysis, which used descriptive statistics to analyse quantitative data such as forest area, financial indicators and forest productivity. To compare the economic efficiency between state and private forests, differences in the implementation of forest resource use plans and financial indicators between the two sectors were analysed. The level of implementation of modern technologies in forestry, such as GIS and remote sensing, was also assessed, including the impact of these technologies on the productivity and economic efficiency of forest enterprises. The activities of Geo&Land (2017) and Kosovo Forest Agency (Ministry of Agriculture Forestry..., n.d.) were analysed. The analysis included an assessment of their activities, use of modern technologies and cooperation with international organizations.

The assessment of the impact of external factors included an analysis of financial resources, legal frameworks and market conditions. The analysis of the impact of access to financial resources on the ability of forestry enterprises to modernize equipment, introduce new technologies and carry out reforestation activities was an important element. The legal framework was analysed through the Kosovo Forest Law and subsequent amendments (Law of Kosovo No. 2003/3..., 2003; Law of Kosovo

No. 03/L-153..., 2010; Law of Kosovo No. 08/L-137..., 2023). This analysis encompassed an assessment of the impact of legislative changes on the effectiveness of forest management and the operations of forest enterprises. In particular, the provisions of the law aimed at protecting forests, preventing illegal logging and maintaining biodiversity were considered. The effectiveness of the control and monitoring mechanisms provided for by the law and how they affect the operations of forestry enterprises were also assessed. Particular attention was paid to changes aimed at strengthening liability for violations of forestry legislation, as well as at promoting the sustainable use of forest resources.

## Results

Forestry is a critical sector that makes a significant contribution to global environmental sustainability and economic development. Economic efficiency in this context means achieving the maximum economic result while making optimal use of resources and minimizing costs. However, economic efficiency in forestry should be balanced with environmental and social aspects, which makes it a multifaceted and complex concept (Ayala-Niño & Emmet-Booth, 2022). One of the key indicators of economic efficiency is the productivity of forest resources. It refers to the quantity and quality of timber and other forest products that can be obtained from a unit area. High productivity means that forest resources are used as efficiently as possible, providing high returns at minimal costs. Productivity also depends on the ability to maintain and regenerate forests, which guarantees the long-term sustainability and productivity of forest resources. An important aspect of economic efficiency is the cost of forestry. This includes operating costs for growing, maintaining, harvesting and transporting forest products. In addition, it includes investments in the modernization of

technologies and equipment that are necessary for the efficient management of forest resources. Cost optimization is critical to improving the economic efficiency of forestry. Economic efficiency is also determined by financial performance (Chen *et al.*, 2020). This encompasses revenues from the sale of forest products and services, as well as profitability and profitability of forestry enterprises. A high financial result indicates the efficient use of resources and the success of forestry as an economic sector.

Economic efficiency in forestry cannot be considered without taking into account environmental aspects. The impact of forestry activities on ecosystems and biodiversity is an important indicator. Sustainable forest management practices and reforestation measures contribute to maintaining the ecological balance and long-term productivity of forests. Environmental sustainability is an integral part of economic efficiency, as it ensures the long-term availability of forest resources (Melaku *et al.*, 2023). Forestry also has a significant social impact. This includes creating jobs and improving the well-being of local communities, especially in rural and remote areas. The social responsibility of forestry enterprises and the involvement of local people in forest management contribute to social stability and support for environmental initiatives. Consideration of social aspects helps to ensure support for local communities and sustainable forest management (Santika *et al.*, 2019). Innovation plays a crucial role in improving the economic efficiency of forestry. The use of GIS and RS can significantly improve the efficiency of monitoring and management of forest resources. These technologies help reduce costs and improve data accuracy, which is key to effective forest planning and management. Innovative methods can optimize resource use and increase productivity, which ultimately contributes to economic efficiency (Raihan *et al.*, 2022).

The main factors affecting the economic efficiency of forestry are access to financial resources, the level of technological development, management approaches, legislative frameworks, environmental sustainability and market conditions. Access to financial resources determines the ability of forestry enterprises to make the necessary investments in equipment modernization, introduction of new technologies and forest restoration. A high level of technological development allows increasing productivity and reducing costs through the use of innovative solutions, GIS and remote sensing. Management approaches play a critical role in planning, controlling and analysing financial flows, which contributes to the efficient use of resources and informed management decisions. The legal framework, including logging requirements, reforestation and biodiversity protection measures, creates the legal environment in which forestry enterprises operate (Jhariya *et al.*, 2019). Meeting these requirements may require additional effort and resources, but it also incentivizes the implementation of sustainable forest management practices.

Environmental sustainability is an important factor that affects the long-term productivity of forest resources and the maintenance of ecological balance. Market conditions, including supply and demand for forest products, prices and competition, also have a significant impact on economic performance. Stable demand for high-quality forest products and favourable prices can provide high revenues and profits, while changes in the market can cause financial difficulties for enterprises (Santosa *et al.*, 2024). These factors together determine the opportunities and constraints for improving the economic efficiency of forestry, making their consideration essential for the sustainable development of the sector. Financing plays a key role in the forest sector, providing the necessary resources to maintain and develop

forestry enterprises. It affects all aspects of operations, from growing and caring for forests to harvesting, rehabilitation and modernization of production processes. First and foremost, adequate funding allows for investments in modern technologies that increase the productivity and efficiency of forest management. This, in turn, helps to optimize operating costs and increase overall economic efficiency. Financing is critical for forest restoration. Restoration processes, including planting new trees, caring for young forests, and protecting them from pests and diseases, require significant financial investments (Rode *et al.*, 2019). Without adequate funding, these measures may not be effective enough, leading to the degradation of forest resources and reduced productivity in the future.

Financing contributes to the development of infrastructure necessary for efficient forestry operations. This includes the construction and maintenance of forest roads, warehouses, processing plants and other facilities that ensure efficient harvesting, transportation, and processing of forest products. A well-developed infrastructure helps to reduce logistics costs and increase the profitability of enterprises. In addition, financing plays an important role in ensuring compliance with legal regulations and standards. Compliance with environmental requirements, sustainable forest management standards and international agreements requires additional financial resources. Ensuring the necessary level of financing allows companies to meet these standards, which contributes to the conservation of biodiversity and the maintenance of ecological balance. Funding is also important to stimulate research and innovation in the forest sector. Investments in research and development contribute to the development of new forest management methods, increased resource efficiency and improved environmental practices. Attracting private capital through public-private partnerships (PPPs)

is another important aspect of financing. PPPs allow attracting additional resources for forestry development by sharing risks and ensuring effective project management. This helps to increase the investment attractiveness of the sector and reduce the burden on the state budget (Popoola *et al.*, 2020).

Forest cover in Kosovo covers 40.9% of the country's total land area, which demonstrates the significant role of forests in the environmental and economic context. These forests are not only a source of timber and other forest products, but also an important element of biodiversity conservation. In Kosovo, there are a total of 464,800 ha of forests, of which 60% are publicly owned by the Kosovo Forestry Administration and 40% are controlled by the private sector. However, it should be noted that the state of the country's forestry fund has its challenges: certain areas of forests have remained in fairly good condition, while others have already suffered from degradation caused by illegal logging and insufficient attention to rehabilitation. As of 2021, the turnover of forestry and logging-related enterprises was EUR 6,626 thousand. The number of active enterprises was 46, and the number of employees was 134 (Ministry of Agriculture Forestry..., 2021).

One of the key challenges for Kosovo's forestry sector is insufficient funding, which severely limits the sector's development opportunities. For example, investments in the forestry sector remain limited, which negatively affects the implementation of necessary reforestation measures. Without sufficient funding, it is difficult to implement large-scale reforestation projects, including planting new trees, caring for young plantations and protecting forests from pests and diseases. One of the reforestation projects in the Shar Planina area is facing difficulties due to a lack of funding, which is slowing down its implementation and reducing the effectiveness of the greening measures. In

addition, limited financial resources make it difficult to modernize equipment used in forestry. Many companies operate with outdated equipment, which reduces productivity and increases costs. For example, logging companies in the Pecs region use equipment that requires frequent repairs and does not meet modern standards, resulting in high logging costs (Müller *et al.*, 2023). Insufficient funding also limits opportunities for research and development of innovative forest management practices. Forestry research is critical to developing effective management strategies that can ensure the sustainable use of forest resources and increase their productivity.

The level of technological development in Kosovo's forestry sector is relatively low, which is a significant obstacle to improving the efficiency of the sector. Many forestry enterprises

do not have access to modern technology. The lack of modern technology reduces productivity and increases the cost of logging and reforestation. The use of outdated methods and equipment leads to less efficient use of resources, increasing the cost per unit of production and reducing the profitability of enterprises. Management approaches in Kosovo's forestry sector need to be significantly improved to ensure its economic efficiency and sustainable development. In practice, there may be a lack of qualified personnel capable of effectively planning, controlling and analysing financial flows. The lack of proper coordination between different levels of government also hampers decision-making and the implementation of effective strategies. Table 1 shows the level of implementation of the plan for the extraction of forest resources in state-owned forests.

**Table 1.** Implementation of the plan for the extraction of forest resources in state-owned forests in Kosovo from 2019 to 2021

Assortment	2019			2020			2021		
	Plan, m <sup>3</sup>	Sales, m <sup>3</sup>	Index, %	Plan, m <sup>3</sup>	Sales, m <sup>3</sup>	Index, %	Plan, m <sup>3</sup>	Sales, m <sup>3</sup>	Index, %
Technical wood	6,292	2,721	43	7,868	2,379	30	8,481	4,322	51
Firewood	58,399	20,713	35	55,443	23,634	43	55,199	22,542	41
Waste	4,115	1,052	26	4,203	216	5	4,292	357	8
Total	68,806	24,486	36	67,513	26,229	39	67,972	27,221	40

**Source:** developed by the author based on the Ministry of Agriculture, Forestry and Rural Development (2021)

Analysing the data in the table, it can be seen that the implementation of the forest resource extraction plan in Kosovo is significantly below the planned level for all three categories over the three years. The best results were achieved in 2021, when the plan was imple-

mented at 40%. These indicators indicate that there are significant challenges and problems in Kosovo's forest sector that may hinder the effective management and use of forest resources. Table 2 shows the level of implementation of the plan for the use of private forests.

**Table 2.** Implementation of the forest resource extraction plan in private forests in Kosovo in 2020 and 2021

District	2020			2021		
	Plan, m <sup>3</sup>	Sales, m <sup>3</sup>	Index, %	Plan, m <sup>3</sup>	Sales, m <sup>3</sup>	Index, %
Prishtina	43,540	25,842	59	43,450	21,881	50
Mitrovica	72,230	41,622	58	83,850	49,509	59

Table 2, Continued

District	2020			2021		
	Plan, m <sup>3</sup>	Sales, m <sup>3</sup>	Index, %	Plan, m <sup>3</sup>	Sales, m <sup>3</sup>	Index, %
Peja	10,400	2,348	23	4,580	3,758	82
Prizren	4,190	2,297	55	3,960	2,530	64
Ferizaj	10,900	5,773	53	10,900	5,220	48
Gjilan	58,260	53,576	92	44,800	57,396	128
Gjakova	750	283	38	750	295	39
Total	200,180	131,742	66	192,290	140,589	73

**Source:** developed by the author based on the Ministry of Agriculture, Forestry and Rural Development (2021)

Table 2 shows that the level of plan implementation in Kosovo's private forests varies considerably between districts. The best results were achieved in Gielansky district, where the plan implementation rate was 92% in 2020 and 128% in 2021, exceeding the planned targets. This reflects effective management and monitoring in this district. The worst performance was in Djakovitsky district, where plan implementation was only 38% and 39%, indicating serious problems or constraints that could have prevented the achievement of the targets. Overall, there was an improvement in plan implementation in 2021 compared to 2020, which may be the result of adaptation to previous challenges or improved conditions in the private forestry sector. It is also worth noting that the overall implementation of the harvesting plan in the country's private forests significantly exceeds the implementation of the plan in state forests, both in 2021 and 2020.

The legal framework for forestry in Kosovo is underdeveloped, which poses significant challenges for the conservation and sustainable use of forest resources. Existing laws and regulations often do not adequately protect forests from illegal logging and other forms of illegal activities. For example, the Law of Kosovo No. 03/L-153 "On Amending and Supplementing the Law No. 2003/3 On Kosovo Forests" (2010) and subsequent amendments and supplements, although aimed at regulating

forestry activities, has several shortcomings in ensuring effective control over the use of forest resources. The imperfection of legal mechanisms for control and monitoring of compliance with legal norms also limits the possibilities for effective forest management. For example, the responsibility for controlling forest resources is often dispersed among different authorities, leading to insufficient coordination and duplication of efforts. This is evident in the case of the Kosovo Environmental Protection Agency, which lacks the resources to conduct regular inspections and monitor forest conditions.

Illegal logging remains one of the most serious threats to Kosovo's forests. The lack of effective legal mechanisms to combat this problem leads to significant losses of forest resources. Despite the existence of the Criminal Code of the Republic of Kosovo (2019), which provides for punishment for illegal deforestation, in practice, the application of these norms is limited. A lack of qualified inspectors and insufficient funding to conduct proper investigations make the fight against illegal logging ineffective. For example, in the Shar Planina region, illegal logging remains a serious problem despite numerous attempts by the authorities to introduce stricter controls (Pandurska-Dramikjanin, n.d.). International legislation that affects forestry in Kosovo includes various conventions and agreements, including the Convention on Biological Diversity (1992)

and the UN Convention to Combat Desertification (1994). Kosovo is also striving to meet European Union (EU) standards as part of its European integration process, which includes the adaptation of national legislation to EU requirements in the field of environmental protection and sustainable management of natural resources. However, the development of the legal framework is hampered by a lack of adequate cooperation with international organizations and programmes that could provide the necessary knowledge and resources to improve legislation. For example, Kosovo's participation in the EU European Green Deal (2019) programme could help to develop more effective legal mechanisms and introduce best practices in forest management.

Enterprises must invest in reforestation after harvesting, which includes planting new trees, caring for young plantations, and protecting them from pests and diseases. This places an additional financial burden on companies, especially given the limited funding available in this sector. In addition, the requirements for forest certification to meet international standards such as the Forest Stewardship Council (FSC) require companies to incur additional costs for certification procedures and compliance monitoring. This can be particularly difficult for smaller enterprises with limited financial resources. The Kosovo Forest Agency (KFA) (Ministry of Agriculture Forestry..., n.d.) is a state-owned enterprise responsible for the management of state forests in Kosovo. Their tasks include forest protection, combating illegal logging, reforestation, and ensuring sustainable use of forest resources (Law of Kosovo No. 08/L-137..., 2023). As a state-owned enterprise, KFA is funded mainly from the state budget, which ensures stability but also limits the scope for significant investments in modernization and development. The economic efficiency of the agency is enhanced by international assistance

programmes and cooperation with other government agencies. KFA provides employment for the local population, especially in rural areas where other opportunities are limited. The agency also conducts educational programmes on environmental protection and sustainable use of resources, which helps to raise environmental awareness among the population.

The KFA is governed by national legislation and international agreements, such as the United Nations Framework Convention on Climate Change (1992). These legal constraints oblige the agency to adhere to strict environmental protection standards, which often increase costs and make it difficult to respond quickly to challenges. For example, legal requirements to protect biodiversity and restore forests may impose additional financial burdens on the agency. However, compliance with these standards is essential to ensure sustainable development and preserve ecological balance. One of the examples of KFA's successful activities is their participation in reforestation projects funded by international organizations. These projects include planting new trees, combating soil erosion and creating protective forest belts. These initiatives not only improve the condition of forests but also ensure the long-term environmental sustainability of the region. Cooperation with international partners allows KFA to attract the necessary resources and expertise, which contributes to the efficiency of their activities.

Geo&Land (2017) is a private company in Kosovo that specializes in providing geoinformation services and implementing the latest technologies in various sectors, including forestry. The main tasks of the company are monitoring of forest resources, support of forest management and environmental management. The use of GIS and remote sensing will allow the company to conduct a detailed analysis of the state of forests, track changes in ecosystems, and respond quickly to illegal

logging. The company provides services not only to government agencies, but also to private enterprises, which contributes to revenue diversification and a stable financial position. The use of innovative approaches allows Geo&Land to reduce costs and increase productivity, which has a positive impact on economic development. Legal constraints and regulatory mechanisms also have a significant impact on Geo&Land's operations. These constraints include requirements for the conservation of forest resources, regulations on the use of geographic information systems and remote sensing, and mandatory environmental reporting and monitoring standards (Law of Kosovo No. 08/L-137..., 2023). Like other companies in Kosovo's forestry sector, Geo&Land must comply with national legal requirements and international standards, particularly those related to environmental protection and sustainable forest management. The existing legal framework may limit the company's ability to implement some innovations due to the additional costs of regulatory compliance. However, the same framework ensures the protection of forest resources, which in the long run contributes to the sustainable development of forestry in the country.

Several recommendations were made to improve the economic efficiency and finance of forestry development within the legal constraints. To ensure sustainable development of the sector, the government should increase financial support and introduce targeted subsidies. For example, the government of Kosovo could introduce grants for forestry enterprises to upgrade equipment and technologies needed for efficient and environmentally friendly harvesting. Such subsidies could also be used to support reforestation programmes for forests affected by illegal logging. Attracting international investment is critical to overcoming financial constraints in Kosovo's forestry

sector. Cooperation with international organizations such as the World Bank, the European Investment Bank and the Food and Agriculture Organization (FAO) can provide access to additional financial resources. In addition, public-private partnerships (PPPs) can significantly improve the financing and management of forest resources. Public-private cooperation programmes facilitate investment and increase the efficiency of forest management. The Kosovo government should create an enabling environment for PPPs by developing appropriate legislation and regulatory mechanisms. This includes the introduction of tax incentives for companies investing in forestry. Joint projects with private investors could include the construction of new timber processing plants or the modernization of existing ones, which would increase the productivity and economic efficiency of the forestry sector.

To increase the economic efficiency of forestry, it is necessary to improve the methods of planning and cost control. For example, the use of route planning and resource allocation software can help reduce the time and cost of transporting timber from the forest to processing facilities. Furthermore, the introduction of cost control systems will help identify areas where savings can be made. Increasing productivity is another key aspect of improving the economic efficiency of forestry. The introduction of new methods of logging and wood processing will increase production and reduce waste. For example, the use of modern logging equipment, such as high-performance logging machines, will significantly increase the speed and efficiency of operations, while reducing labour and fuel costs. Creating conditions for the development of ecotourism will generate additional revenue and increase the attractiveness of forest areas for visitors. For instance, the development of additional hiking trails and recreation areas will help attract tourists. Kosovo's forestry

legislation should be subjected to a comprehensive review to meet modern requirements and industry needs. Simplifying licensing procedures and developing more flexible regulations is a step forward in facilitating the business environment for the forestry sector. For instance, an automated online application system could be introduced to replace complex and time-consuming licensing procedures, which would simplify access to licensing procedures for forestry enterprises. The use of modern technologies, such as geographic information systems and satellite sensing, will allow for more accurate and timely monitoring of changes in forest cover. The creation of an electronic timber accounting system will increase transparency and control over logging, preventing illegal activities (Coops *et al.*, 2021). Strengthening accountability and introducing incentives for compliance with the law can have a positive impact on the economic efficiency of the forestry sector. Tax breaks or subsidies can be provided to companies that comply with the environmental management of forest resources or implement environmentally friendly technologies.

The introduction of a forest certification system based on international standards, such as FSC, is critical to promoting sustainable forest management. FSC certification not only increases the environmental responsibility of companies, but also makes Kosovo's forest products more competitive on international markets. Developing cooperation with international environmental and forestry organizations, such as the FAO and the World Bank, can provide access to new knowledge, technology, and financing. Joint projects and initiatives will help Kosovo implement best practices in forest management. Improving the economic and financial performance of forestry development in Kosovo requires a comprehensive approach. The introduction of modern technologies, improvement of the legal framework, attraction of

investments and international cooperation are key steps to achieve sustainable development. Implementation of these recommendations will contribute to the conservation and efficient use of forest resources, ensuring economic stability and environmental safety of the country.

## Discussion

The results of the study indicate the importance of forestry for Kosovo's economy and environment, but the challenges that exist significantly limit the sector's effectiveness. Covering 40.9% of the country's territory, forests are not only a source of timber and other forest products, but also an important element of biodiversity conservation and environmental sustainability. Despite its considerable potential, insufficient funding and outdated technology pose serious obstacles to the industry's development. With this in mind, it is important to understand how to use the available resources more efficiently and what steps need to be taken to overcome the existing problems. In his paper, K.M. Mator *et al.* (2020) focused on the study of specific methods of forest management, such as the development of forest ecosystem management strategies or the implementation of effective forest monitoring and assessment systems. R.P. Acharya *et al.* (2019) also studied the impact of different management practices on biodiversity conservation, reforestation after deforestation, and wildfire management. Compared to the current study, which places more emphasis on balancing economic efficiency with environmental and social aspects, the authors' work is aimed at greater optimization of management processes and improving the efficiency of internal operations.

One of the key aspects of economic efficiency is the productivity of forest resources, which depends on the ability to maintain and regenerate forest plantations (Kerimkhulle *et al.*, 2023). Data shows that the implementation

of harvesting plans is significantly below the planned level, indicating problems in the management and use of resources. For example, in state forests, the plan implementation rate was only 40% in 2021, indicating the need to improve planning and control of forestry operations. It also points to potential problems with logistics, insufficient coordination between different levels of government, and a possible lack of adequate funding. C. Ammer (2019) also studied the productivity of forest resources, with a focus on analysing the impact of anthropogenic impacts on the natural balance of ecosystems. Similarly, C. Li *et al.* (2020) conducted research aimed at studying how deforestation, land use change, and other human activities affect the productivity of forest ecosystems. The authors' results include an analysis of the growth and development of forest stands under the influence of various factors, such as air pollution, climate change and other anthropogenic factors. Compared to the current results, which also examine the productivity of forest resources, the authors' research shows the impact of human activity on ecological processes in forests. They highlighted that anthropogenic factor has a significant impact on the productivity of forest ecosystems, which may differ from a more technical analysis.

Financing is a critical factor for ensuring effective forest management. The results show that insufficient funding limits the ability to carry out necessary reforestation activities and equipment upgrades. Reforestation projects face difficulties due to lack of funding, which slows down their implementation and reduces the effectiveness of measures. Enterprises use outdated equipment, which leads to high logging costs. Insufficient funding also hinders research, which is essential for developing new methods of forest management and increasing productivity. P.K. Bhandari *et al.* (2019) also noted that financing is a key factor for forestry

development. R.P. Chudy & F.W. Cabbage (2020) pointed out that efficient use of resources and attraction of investments can have a positive impact on the economic productivity of the sector. Their study emphasized that without adequate funding, it becomes difficult to implement the necessary reforms and modernization. The authors highlighted financing as a key factor that can have a significant impact on the economic productivity of forestry. This is in line with current findings, which also highlight the importance of financing for achieving sustainable development of the sector.

The social aspect also plays an important role in forestry. Creating jobs and improving the well-being of local communities are important factors that contribute to social stability and support for environmental initiatives (Yatsiv *et al.*, 2024). However, the study shows that there is often a lack of coordination between different levels of government, which complicates decision-making and the implementation of effective strategies. Insufficient coordination between local and central governments in planning forestry activities leads to delays in project implementation and low efficiency of forest management measures. H.F. Kaufman & L.C. Kaufman (2019) studied the impact of forestry on local communities and social stability, with a focus on analysing the relationship between forest resources and local livelihoods. The authors studied the impact of forests on providing jobs and income to local residents through logging companies and other forestry enterprises. The authors pointed to the need to create jobs in rural areas through forestry development and relationships with local communities, which was not addressed in the current study. Environmental sustainability is an integral part of the economic efficiency of forestry. Illegal logging remains one of the most serious threats to Kosovo's forest resources. Despite the existence of legal provisions such

as the Criminal Code of the Republic of Kosovo (2019), the lack of qualified inspectors and limited funding make the fight against illegal logging ineffective. J. Oettel & K. Lapin (2021) focused on researching the impact of forestry on environmental sustainability and biodiversity conservation. He studied the ecosystem services provided by forests, such as soil conservation, air and water purification, and climate regulation. In contrast to the current results, which focused on the ecological aspects of forestry, the author's research is more focused on the conservation of the natural environment and ecosystems, as well as on factors that affect biodiversity conservation.

Innovation and modern technology can significantly improve the economic efficiency of forestry. The use of GIS and remote sensing can improve data accuracy and reduce the cost of monitoring and managing forest resources. However, the level of technological development in Kosovo's forestry sector is relatively low, which hinders efficiency gains. Many enterprises do not have access to modern technology, which reduces productivity and increases the cost of harvesting and reforestation. C. Gollob *et al.* (2020) also focused on the use of modern technologies in forestry and their impact on increasing productivity and reducing costs. The authors investigated the effectiveness of technologies such as geographic information systems and remote sensing. In turn, J. Călina *et al.* (2020) studied drones, automated control systems, data analytics, and other innovative solutions. The authors analysed how these technologies can facilitate forest management processes, ensure the accuracy and speed of data collection and processing, and help solve various forest management tasks. The authors studied mainly the technological aspects of forestry, but it is also worthwhile to cover various areas such as economic efficiency, social responsibility and environmental sustainability in forestry.

In general, forestry is a complex system in which economic, environmental and social aspects are interconnected and interdependent. It is important to balance these aspects to achieve sustainable development of the sector. The results of the study confirm the need to increase funding, use effective management practices, introduce modern technologies and take into account the needs of local communities in the process of forest management. Additional research and practical measures can help improve forestry efficiency and ensure sustainable use of forest resources in the future.

### Conclusions

Forestry is a key sector that plays a crucial role in ensuring environmental sustainability and economic development. The study showed that economic efficiency in forestry involves achieving maximum economic output while optimizing resource use and minimizing costs. However, in order to achieve this efficiency, it is important to ensure a balance between economic, environmental and social aspects. One of the key aspects of economic efficiency is the productivity of forest resources. It is determined by the quality and quantity of timber and other forest products that can be obtained from a unit area. Ensuring high productivity is important for ensuring the sustainability and efficient use of forest resources. Another important aspect of economic efficiency is the costs associated with forestry, including operating costs and investments in modernization of technologies and equipment.

The study also confirmed that the economic efficiency of forestry cannot be considered separately from environmental and social aspects. It is important to ensure the sustainable use of forest resources and the preservation of ecological balance, as well as to create favourable conditions for the development of local communities and improve their well-being. The

overall performance of forestry also depends on financial resources, technological development, management approaches, legislation, environmental sustainability and market conditions. It is necessary to ensure financing, the use of modern technologies and improved management approaches to increase the economic efficiency of forestry. Forestry in Kosovo plays an important role in ensuring environmental sustainability and economic development. Given the large forest area in Kosovo – 40.9% of the country's total area – forests are a key element of the ecosystem and play an important role in biodiversity conservation. One of the key challenges for forestry in Kosovo is the lack of funding, which significantly limits the sector's development. For example, investments in forestry remain limited, which negatively affects the implementation of the necessary reconstruction and reforestation works. The study also found that the level of technological development in the forestry sector in Kosovo is relatively low, which is a significant obstacle to improving the efficiency of the sector. Many forestry enterprises do not have access to modern technologies.

The recommendations for improving the economic efficiency of the forestry sector

include measures to increase financial support, develop innovations and modern technologies, improve management approaches and the legal framework, and attract international resources and cooperation. Their implementation will contribute to the sustainable development of forestry in Kosovo and ensure economic stability and environmental security of the country. It is important to develop an integrated approach to forest management to ensure the sustainable use and economic sustainability of the sector. A limitation of the study is the lack of up-to-date data and the inability to conduct a detailed analysis. For further research, it is recommended to extend the analysis to other aspects of forestry, in particular, to focus on the social impact and environmental consequences of forestry activities. It is also important to conduct a detailed study of the effectiveness of innovative technologies in forestry and their impact on economic productivity.

### Acknowledgements

None.

### Conflict of Interest

The authors of this study declare no conflict of interest.

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## **Економічна ефективність і фінанси в розвитку лісового господарства в рамках правових обмежень**

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**Анотація.** Метою даного дослідження є аналіз факторів, що визначають економічну ефективність та оптимальні моделі фінансування лісового господарства в контексті чинної законодавчої бази. У статті обговорюється критичне значення лісового господарства для глобальної екологічної стійкості та економічного розвитку. Визначено, що економічна ефективність у цій сфері полягає в досягненні максимального економічного результату при мінімізації витрат та оптимальному використанні ресурсів. Основними показниками економічної ефективності є продуктивність лісових ресурсів, яка залежить від можливості підтримувати та відновлювати лісові насадження, а також від оптимізації витрат, у тому числі експлуатаційних витрат та інвестицій у сучасні технології. Економічна ефективність визначається також фінансовими результатами, зокрема виручкою від реалізації лісопродукції та рентабельністю підприємств. Важливим аспектом було врахування екологічних і соціальних аспектів, таких як вплив лісового господарства на екосистеми та зайнятість. У статті підкреслено роль інноваційних технологій, таких як геоінформаційні системи та дистанційне зондування, у підвищенні ефективності управління лісами. У статті аналізується вплив доступу до фінансових ресурсів, рівня технологічного розвитку, підходів до управління, законодавчої бази, екологічної стійкості та ринкових умов на економічну ефективність лісового господарства в Косово. За результатами надано рекомендації щодо підвищення економічної ефективності лісового господарства, зокрема збільшення фінансової підтримки, залучення міжнародних інвестицій, удосконалення законодавчої бази та розвитку міжнародного співробітництва. Реалізація цих заходів сприятиме збереженню та ефективному використанню лісових ресурсів, забезпеченню економічної стабільності та екологічної безпеки країни

**Ключові слова:** законодавчі норми; ефективність використання ресурсів; екологічні стандарти; інноваційність; державно-приватне партнерство

UDC 630.1:349.6

DOI: 10.31548/forest/2.2024.97

## Legal regulation of the use of forest resources

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**Abstract.** The purpose of the study was to carry out a comprehensive analysis of the legislative framework in the field of forest resource management in Albania in the context of forest ecology, and species diversity, and to identify the main problems and prospects for sustainable development of the country's forestry. The research methodology included the analysis of statistical data from the National Institute of Statistics of Albania on the structure of forest ecosystems and forms of their management. The results of studies conducted by international organizations such as the World Bank, Global Environment Facility, and Oikon d.o.o. were also used. The structure and composition of Albania's forest resources, including those of natural and semi-natural origin, are analysed. The legal framework in the field of forest management in Albania is summarized. Different management structures for forestry land are characterized, with the identification of the specifics of use for different forms of ownership. The main problems of forest management are identified, including intensive exploitation of private forests, lack of subsidies and investments, as well as imperfect legislative regulation. Adaptation measures to increase the sustainability of Albania's forests within the framework of the Albanian Forest Policy Document for the period 2019-2030 are substantiated. Strategic areas of development, such as the expansion of protected areas, the development of ecotourism and the attraction of green investments, are proposed. The study also emphasizes the importance of international cooperation for financial and technical support, which will facilitate the implementation of sustainable forest management practices and biodiversity conservation. The practical significance of the study is that these results can be used to develop strategic directions for the development of the forest sector in Albania, aimed at ensuring sustainable management and conservation of forest resources, which is a key factor for the country's economic and environmental well-being

**Keywords:** integrated management; ecosystem services of forests; legislative framework for nature protection; agroforestry; biodiversity protection

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### **Suggested Citation:**

Kullolli, B. (2024). Legal regulation of the use of forest resources. *Ukrainian Journal of Forest and Wood Science*, 15(2), 97-117. doi: 10.31548/forest/2.2024.97.

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## Introduction

Forest resources are one of Albania's key natural assets and play an important role in the country's environmental and economic development. The diversity of the forests is due to climatic conditions that range from Mediterranean in the coastal lowlands to continental in the highlands and contribute to the presence of more than one hundred species of trees, such as beech, oak, fir, spruce, pine, as well as acacia, poplar, maple, willow, chestnut, walnut, and fruit trees. Despite this diversity, Albania has become one of the few European countries where, since the 2000s and over the next 20 years, approximately 100 thousand ha of forest have been lost to intensive logging, landslides, soil erosion, overgrazing and firewood collection. These processes exceed the natural annual growth rate of forests, leading to a reduction in timber stocks and a deterioration in timber quality. Economic constraints also make it difficult to access a large part of the forests (AGT International, n.d.).

Albanian forests are under pressure from increasing demand for land-based products and services, leading to their conversion or degradation to unsustainable land uses. The loss or severe degradation of forests reduces their ability to perform important ecological functions such as regulating the water cycle, providing safe drinking water, producing biomass and controlling water erosion. This increases flood risks, reduces soil fertility and contributes to biodiversity loss, making the supply of forest goods and services unstable (Petrovic, 2023). The legal regulation of the use of forest resources in Albania includes numerous challenges that need to be addressed to ensure effective forest management and sustainable use. Despite the existing legislative framework aimed at protecting and preserving forest resources, its implementation in practice remains insufficiently effective. The main problem is that the

legal framework is outdated and incomplete, and does not take into account modern international standards and best practices in forest management.

Another important aspect is the insufficient integration of environmental issues into the legal system governing forest use. Environmental aspects, such as biodiversity conservation and climate change mitigation, are often overlooked by legislators. Prior to the creation of the Albanian nation-state in 1912, both the rural population and the local elite actively exploited forests without due attention to their restoration, as A.R. Hoxha (2018) indicates. In the interwar period, the Tirana governments tried to control the population's access to forest resources. After the communists came to power, the problems only worsened due to excessive deforestation for industrialization and the inability to stop misuse. In the first decade after the fall of communism in 1991, Albania had the highest percentage of illegal logging in Eastern Europe. This situation shows that problems with legal mechanisms for sustainable forest management have existed in the country for more than 30 years.

Since the 2000s, the Albanian government has been trying to implement effective forest management programmes, which include a number of measures aimed at strengthening the overall management of forests and rangelands. D. Suli *et al.* (2020) substantiate in their work the peculiarities of improving the methods of managing forest resources and protected areas. The authors note that an important aspect of forestry sector development programmes is to support local communities in benefiting from forest resources, which contributes to poverty reduction. G. Fanelli *et al.* (2020) emphasize in their works the fact that although mesophilic forests of Albania, in particular *Fagus sylvatica* forests and *Corylus avellana* foothill forests, are

important ecosystems, they remain little known and have not been included in the latest syn-taxonomic revisions at the European level. This situation calls for the development of special legal mechanisms that would ensure the protection of different types of forests in accordance with their ecological characteristics and needs.

It is worth noting the significant potential of the Teti National Park for the development of geotourism, in particular the recognition and promotion of geosites such as canyons, waterfalls, glacial lakes and karst caves, as noted by M. Dollma (2019). To achieve this goal, it is important to introduce effective legal mechanisms that would ensure the preservation of natural landscapes, avoid overexploitation of forest resources, and support the development of infrastructure that meets environmental standards. At the same time, F. Pazari & M. Dollma (2019) mentioned in their research web-based geographic information systems (GIS) applications to inform tourists and local residents about the availability of forest resources in the Zall Gjoçaj Park. In the authors' opinion, it is crucial to ensure legal regulation of access to public information in order to preserve their ecological condition and avoid excessive tourist pressure on these forests. The importance of local ecological knowledge (LEK) for the monitoring and management of useful medicinal plant species in Prespa National Park in Albania remains important. S. Tomasini & I. Theilade (2019) note that from the point of view of legal regulation of forest management, it is important to develop a legal framework that would integrate LEK into official programmes of monitoring and management of forest resources.

The purpose of the study is to substantiate the legal aspects of forestry regulation in Albania, with a focus on creating incentives for sustainable use of forest resources and integration of environmental components into the

country's legal system. To achieve the study's objective, several tasks were performed, in particular: analysis of Albania's forest resources, their classification, environmental status, as well as justification of the system of monitoring and evaluation of the effectiveness of implemented measures to ensure sustainable forest use; detailed analysis of the current legal framework and regulations governing forest use, identification of gaps and shortcomings in the legislation; development of proposals for legal and economic mechanisms to stimulate sustainable forest use, taking into account the needs of local communities.

## Materials and Methods

In order to achieve the research objective, various sources were used, which allowed for a comprehensive analysis of various aspects of forestry, the ratio of different types of natural forests in Albania, including legislation, forms of management, governance, as well as environmental, social and economic factors affecting the state of forest resources. In particular, we used the reports of the National Agency for Protected Areas (NAPA) (AGT International, n.d.), the National Institute of Statistics of Albania (2022), reports of international organizations such as the World Bank (n.d.), the Ministry of Tourism and Environment (2023), as well as statistical reports of local governments and scientific institutions.

The content analysis of legislative documents was used to identify the main problems of using Albania's privately owned forest resources. Legislative acts regulating forest management were analysed, with a particular focus on legislative changes and their impact on local communities. New legislative initiatives, such as the transfer of ownership of forest areas to local communities, were studied to determine how they have affected forest con-

servation and productivity. The study focused on the analysis of changes in the legal framework governing forestry in Albania, in particular Law of the Republic of Albania No. 57/2020 “On Forests” (2020) and Law of the Republic of Albania No. 5/2016 “On the Moratorium on Commercial Forestry Activities in the Republic of Albania” (2016). The study analysed the impact of these legislative acts on forest management, the effectiveness of their implementation and the implications for the sustainable development of the forest sector. The study also included a comparison of current legislative norms with international standards, such as the European Green Deal (2019) and the Regulation of the European Parliament and of the Council No. 2018/841 “On the Inclusion of Greenhouse Gas Emissions and removals from Land Use, Land Use Change and Forestry in the 2030 Climate and Energy Framework” (2018).

The study was carried out in the context of Albania’s regional characteristics, including both urban and rural areas, and took into account the different forms of forest management, including state, communal and private management. The analysis of the forest ownership structure in Albania in terms of percentage and distribution of the total area of forests and pastures by management type was carried out on the basis of statistical analysis. The collected data were subjected to quantitative analysis to identify the main trends and structural changes in forest ownership.

Monitoring of the environmental impacts of forest management was carried out based on the results of remote sensing using topographic maps of the area and satellite images. These geoinformation tools provided accurate data on the ecological state of forest resources, their environmental impact, and the specifics of biodiversity conservation, water cycle regulation, and soil protection. A socio-economic analysis was conducted to summarize the impact of for-

estry on local livelihoods, including the impact of forestry on the economic activities and welfare of local communities, especially in rural areas where forest management is integrated with agroforestry systems.

The classification analysis was applied to justify a separate classification of Albania’s forest resources, which includes several main categories in terms of current legal issues and forest ecology. This allowed systematizing forest resources according to different criteria, including legal status, environmental characteristics and management forms. In the course of the study, adaptation measures to increase the sustainability of Albania’s forests were specified within the framework of the Albanian Forest Policy Document (2018). In particular, the main problems and challenges of legal regulation of forest use in Albania are summarized.

## Results

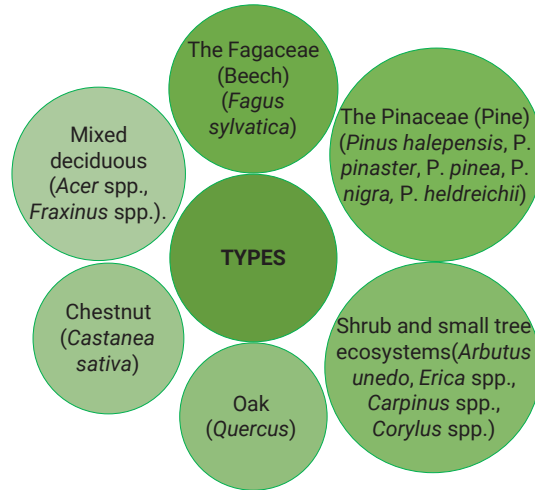
Albania’s forest ecosystems are characterized by significant species diversity, which depends on altitude and distance from the coast. Most of Albania’s forest ecosystems have structures typical of Southeast European countries, with numerous deciduous forests (Fig. 1).

According to the Institute of Statistics Albania (2022), about 83% of forests consist of semi-natural plantations that have emerged as a result of natural regeneration (Fig. 2).

Forest management practices in Albania include both traditional and newer approaches aimed at ensuring the sustainability and productivity of forests and rangelands. Traditionally, forest management in Albania has been centralized, with control exercised by state authorities. Integrated forest and rangeland management plans developed for several municipalities in Albania are also an important component of modern forest management. These plans take into account economic, social and environmental aspects, and

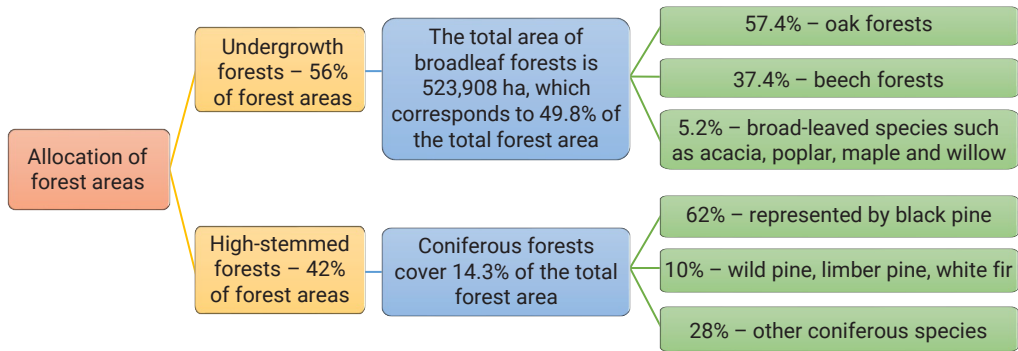
their implementation involves the active participation of local residents and the enhancement of their capacity to manage natural

resources. In particular, Table 1 presents data on the area of forests and pastures in Albania by different forms of management.



**Figure 1.** Main types of forest ecosystems in Albania

Source: developed by the author based on AGT International (n.d.)



**Figure 2.** Percentage of different types of natural forests in Albania

Source: developed by the author based on Institute of Statistics Albania (2022)

**Table 1.** Distribution of the total area of forests and pastures in Albania by management type

Form of business	Area (ha)	Area (%)
Total area of forests and pastures	1,703,545.87	100%
Forests, of them	1,197,258.41	70.28% of the total area
High forests	387,941.44	22.77% of the total area, 32% of the forest area
Undergrowth forests	552,989.03	32.46% of the total area, 46% of the forest area
Shrubs	256,327.93	15.05% of the total area, 21% of the forest area

Table 1, Continued

Form of business	Area (ha)	Area (%)
Pastures, of course	506,287.47	29.72% of the total area
Summer pastures	294,007.61	17.26% of the total area, 58% of the pasture area
Winter pastures	181,499.28	10.65% of the total area, 36% of the pasture area
Secondary pastures	30,780.58	1.81% of the total area, 6% of the pasture area

Source: developed by the author based on Institute of Statistics Albania (2022)

Thus, most of the country's territory is covered by forests, of which the largest share is made up of primary forests. Pastures cover a smaller part of the territory, with summer pastures accounting for the largest part of this area (58%). Forestry, pasture, and crop production are the main land uses in rural Albania. In this area, it is common practice for local people to manage both agricultural and forest resources within agroforestry systems, where crops, trees, and livestock are integrated into a single management system. The legal regulation of the use of forest resources in Albania is aimed at ensuring the sustainability and efficiency of such systems. Land use change remains one of the main challenges affecting forestry and rural development. Legal regulation in this context is important for stable and efficient land management, taking into account demographic and migration trends, as well as economic development in rural areas. Legislative initiatives are aimed at ensuring that changes in land use do not harm the preservation and maintenance of land productivity, but also contribute to the provision of ecosystem services and the maintenance of social structures, traditional knowledge and practices. The development of agroforestry requires a clear identification of potential areas for its

implementation and appropriate legal regulation. In Albania, there is positive experience in developing agroforestry systems on agricultural land, for example, in Korca, where some private individuals plant fast-growing trees on agricultural land. This not only increases land productivity, but also integrates forestry with other forms of land use, which is an important component of sustainable rural development. The legal regulation of the use of forest resources in Albania also includes support from international organizations and government programmes that promote a participatory approach to forest and rangeland management. For example, projects supported by the World Bank (n.d.) promote the transfer of forest management rights to local communities, which increases their responsibility and involvement in forest conservation and restoration.

The current structure of forest land and ownership in Albania has been shaped by the significant political and historical events that the country has experienced. Until 1990, all forests and pastures were state-owned (Forest Policy Document..., 2018). However, after the political, economic and social changes of the 1990s, three forms of ownership were introduced: state, communal and private (Table 2).

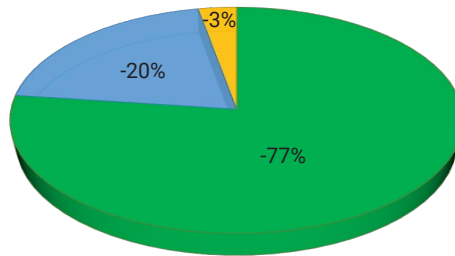
Table 2. Changes in the structure of forest land ownership

Property type	Description
State	Forests and pastures owned by the state before the reforms of the 1990s
Communal	Forests and pastures transferred to local communities after the reforms of the 1990s
Private	Forests and pastures that became private property after the reforms of the 1990s
Municipal	Forests and pastures that became private property after the reforms of the 1990s

Source: developed by the author based on Forest Policy Document in Albania – 2030 (2018)

Between 2009 and 2024, one of the most significant policy decisions in the forestry sector was the transfer of ownership of forest areas from the state to local governments. The newly created function of forestry services in 2016 assigned municipalities ownership of forests and pastures located in their administrative territory. This has strengthened local management

of forest resources, ensuring greater responsibility and participation of local communities in their conservation and restoration. The results of the forest land transfer policy have changed the ownership structure in Albania, turning municipalities into the main owners of forests and pastures located in their administrative territories (Fig. 3).



**Figure 3.** Forest ownership structure in Albania

**Source:** developed by the author based on Forest Policy Document in Albania – 2030 (2018)

The structure in Figure 3 reflects the result of political and economic reforms that have taken place in the country, as well as the process of transferring ownership of forest areas from the state to local governments and private owners. The vast majority of forest land in Albania is state-owned. The share of private forests is only 3%, and this area has remained stable at 28,780 ha since 2014. Public forests are mostly (77%) managed by municipalities, except for protected areas (20%), which are controlled by the National Agency for Protected Areas (NAPA) (Petrovic, 2023). Private forests are mainly owned by individuals and, in some cases, institutions. NAPA, established in 2015, is responsible for managing protected areas and natural resources within them. Forests within protected areas are not transferred to municipalities and are the responsibility of NAPA, which also provides advisory services to support municipalities in managing forest resources. At the local level, NAPA is organized into 12 regional protected area administrations, each

of which is responsible for managing protected areas in their respective region.

Privatization of the forestry sector in Albania is not allowed, as it is considered strategically important, including shrubbery and degraded forests. According to the current legislation, only those forests that were privately owned before the establishment of the communist regime in 1944 are subject to restitution, and only up to 100 ha for each former owner. This is the main reason why private forests account for only 3% of the total forest area in Albania (AGT International, n.d.). The main goals of associations of private forest owners are to meet their needs and interests, assist in the management of private forests, protect forests and the environment, increase the tourist and recreational value of forests, and disseminate information materials. Although the area of private forests is very small, they have been intensively exploited in recent years (Table 3). Owners try to maximize profits without considering the long-term prospects for their forests.

**Table 3.** Main problems of Albania’s privately owned forest resources

Problem	Characteristics
Intensive use	Owners seek to maximize profits without considering long-term prospects
No subsidies	Absence of incentives for responsible management of private forests
Imperfect legislative regulation	Lack of clear legal regulations on the management of private forests
Lack of technical manuals	Absence of available manuals on technical aspects of forestry
Insufficient investment flows	Lack of investment in private forests, which hinders their development
Illegal logging	Illegal exploitation and deforestation are serious problems
Conflicts over property rights	Conflicts often arise due to bureaucratic and corrupt obstacles in the registration of property rights
Forest degradation	Irregular management leads to forest degradation, reduced income and increased frequency of fires

**Source:** developed by the author based on AGT International (n.d.)

The analysis highlights the need to improve the management of forest resources, especially private forests, to ensure their sustainable development and the conservation of ecosystem services. Albania’s forests are among the areas in Europe that require significant improvements in natural resource management. According to the new forest policy, since 2016, municipalities have become the owners of forests and are solely responsible for their management. However, a significant number of municipal forestries are not provided with the necessary office space and qualified staff, which negatively affects the effective management of these resources. Insufficient technical capacity and staff shortages make it difficult to carry out important functions such as national forest policy development, national reporting and monitoring. Although municipalities own forest and pasture resources, these functions still require centralized management at the national level. It is also important that municipalities do not have the authority to levy fines for violations in the forestry sector, which remains the responsibility of the relevant ministry. Fire protection is a new function of local governments that was decentralized without prior analysis of local capacities to perform this function. In terms of modern legal issues and forest ecology in

Albania, a separate classification of forest resources can be distinguished, which includes several main categories:

- ◆ natural forests. Albania’s natural forests cover a variety of ecosystems that have experienced minimal human intervention. They are important for the conservation of biodiversity and the provision of ecosystem services. Efforts to conserve and restore such forests are a priority of the state policy (World Bank, n.d.);

- ◆ degraded forests. Large areas of forests in Albania are characterized by high levels of degradation due to illegal logging, overuse for fuelwood and uncontrolled grazing. Restoring these forests is a key objective for the government and international projects. For example, the Albania Natural Resource Development Project supports the rehabilitation of degraded areas through the introduction of sustainable management practices;

- ◆ protected areas. Forests that are part of national protected areas are managed by the NAPA. These areas contribute to the conservation of biodiversity and the development of ecotourism. Protecting and maintaining such areas is an important aspect of Albania’s environmental policy;

- ◆ community forests. Communal forests are managed by local communities, which has proven to be effective in ensuring sustainable

management and restoration of forests. Studies have shown that reforestation is 2-3 times more effective when managed by local users rather than by government agencies. This approach has been supported by the World Bank and other international organizations.

Thus, the key factors affecting forests are largely related to anthropogenic activities, including land use, landscape fragmentation, pollution, nutrient inputs, changes in soil chemistry, suppression of natural fires, changes in herbivore populations, species loss, invasive alien species, and climate change. Legislative regulation in the context of forest ecology should take these factors into account to ensure sustainable management and conservation of forest resources. Climate change, in particular, can reduce forest productivity by increasing summer temperatures and decreasing precipitation, which increases the risk of forest fires. This requires the creation of legislation that will facilitate effective fire risk management and adaptation of forest ecosystems to new climate conditions.

Albania's forests provide numerous ecosystem services that are vital to the country's environmental and economic sustainability. One of the key services is the regulation of the water cycle. Forests help to reduce soil erosion, maintain water quality and regulate water flow, which is important for flood prevention and sustainable water supply. As a result, forest ecosystems play a critical role in maintaining the hydrological balance, especially in the mountainous regions of Albania, where soil erosion is a significant problem (Forest Policy Document..., 2018). Carbon storage is another important ecosystem service of Albanian forests. Forests absorb and store significant amounts of carbon dioxide, which helps to mitigate the effects of climate change. This carbon sequestration capacity of forests contributes to the reduction of greenhouse gas concentrations in

the atmosphere, thereby reducing global warming (World Bank, n.d.). Forests also provide important recreational and cultural services. They provide opportunities for tourism, recreation and cultural activities that are important to the spiritual and cultural life of local communities. Ecotourism, in particular, is becoming an increasingly important source of income for many regions, contributing to economic development and improving the quality of life. In addition, Albania's forests support agroforestry by integrating trees and shrubs into agricultural systems. This increases land productivity, improves biodiversity and reduces environmental risks. Soil protection is an important part of this ecosystem service, as tree roots help prevent erosion and maintain soil fertility (Law of the Republic..., 2017).

The forest sector in Albania is regulated by a number of laws covering various aspects of forest management. These legislative acts provide comprehensive regulation of forestry, nature protection and biodiversity, contributing to the sustainable development and conservation of Albania's natural resources. The main legislative act is Law of the Republic of Albania No. 57/2020 (2020), which aims to protect forests as an important resource, given their irreplaceable value for climate protection, soil protection, preservation, and improvement of productive potential, natural ecological balance, biodiversity, genetic resources and water regime. This law is in line with national and international commitments and contributes to the sustainable development of the forest sector, ensuring a better life for modern society and future generations. It regulates relations in the forestry sector that have a significant impact on the quality of the natural environment, agricultural development, energy, tourism, poverty reduction, population displacement, conflict mitigation, social and gender inequality, and national security.

Law of the Republic of Albania No. 5/2016 (2016) was introduced to reduce interventions in forests degraded by overexploitation and other damage, with the aim of improving and restoring their condition. This law is valid for 10 years from the date of its entry into force. In addition to these laws, the forestry sector and nature protection in Albania are regulated by additional legislation:

◆ Law of the Republic of Albania No. 81/2017 (2017) aims to proclaim, preserve and manage the sustainable use of protected areas and their natural and biological resources;

◆ Law of the Republic of Albania No. 139/2015 (2015) defines the functions of municipalities in the field of forest and pasture management;

◆ Criminal Code of the Republic of Albania (1995) contains provisions on crimes against forests, which are classified as crimes against the environment;

◆ Law of the Republic of Albania No. 10431 “On Environment Protection” (2011) aims to providing a high-level protection for the environment, its preservation and improvement;

◆ Law of the Republic of Albania No. 9587 “On Biodiversity Protection” (2006) aims at preserving and protecting biological diversity by regulating the sustainable use of its elements;

◆ Law of the Republic of Albania No. 10006 “On Wild Fauna Protection” (2008) is protect, manage and control wild fauna with a view to ensuring the conservation of species, populations and their habitats;

◆ Law of the Republic of Albania No. 10120 “On the Protection of Natural Medicinal, Ether Oil and Tanifer Plants” (2009) aims at protecting medicinal and ether oil plants. It sets out the conditions governing their collection and harvest and further promotes activities aimed at their cultivation and rehabilitation.

Direct powers in the field of forestry are at the municipal level. Institutions at this level are responsible for implementing forest policy and

enforcing legislation. The effectiveness of individual municipalities varies considerably, depending on their administrative and economic capacity and the state of their forest resources. Important stakeholders are the Forest and Pasture User Associations (FPUAs) (Ministry of Tourism and Environment, 2023) established in each municipality to assist in the management of forests and pastures, and to assist municipalities in ensuring the management of forest areas within their administrative boundaries. FPUAs are organized at the local level and coordinate forest management activities at the village level. They are also represented at the regional level in the form of the Regional Federation of Forests and Pastures, which is part of the National Federation of Forests and Pastures. These are non-profit organizations representing the interests of all forest and rangeland users in Albania.

Connecting Natural Values and People (CNVP) is another important partner for forest development in Albania. The organization works with public, private, and donor organizations using evidence-based analysis to improve the sustainable livelihoods of rural communities. CNVP’s activities cover six main areas: sustainable forest management, climate change, environment and natural resources management, agricultural development, renewable energy and waste management. The Forest Policy Document in Albania (2018) defines four strategic directions for the future development of the country’s forest sector:

1. Good governance, which involves positioning forests as one of the government’s top priorities and raising awareness of their importance. The importance of forests is recognized at the national level, which promotes their protection and sustainable use.

2. Functional organization, which involves establishing and strengthening an effective organizational system from the central level to the

most remote villages based on best standards and practices. This ensures proper management and use of forest resources at the local level.

3. Sustainable extraction, which includes the use of forest resources on a sustainable basis and their balanced multiple use. This involves the economically efficient and environmentally sound use of forests, which contrib-

utes to the conservation of biodiversity and the improvement of the ecological state (Table 4).

4. Defining the provision of quality services aimed at improving the protection, quality, and use of forests. This includes improving the quality of forest management and the use of fast-growing species to improve the economic efficiency of the forest sector.

**Table 4.** Adaptation measures to increase the resilience of Albania's forests within the framework of the Albanian Forest Policy Document for the period 2019-2030

Tool	Description
Research programmes	Forest management based on genetic research, adaptation to climate change
Assessment of forest condition	Analysis of the current state of forests in the context of climate change
Expansion of protected areas	Increase in the area of protected forests for biodiversity conservation
Reducing illegal logging	Reducing illegal deforestation, assessing firewood needs
Increasing forest productivity	Rehabilitation of degraded forests, transformation into high-stemmed forests, planting of new species
Reforestation programme	Increase in forest area by planting new trees

**Source:** developed by the author based on Forest Policy Document in Albania – 2030 (2018)

The European Green Deal (2019) provides for a set of policy initiatives aimed at sustainable land use and rural resource management, which can have a significant impact on climate change mitigation. In accordance with these initiatives, Albania should adapt its regulations to the requirements of the European Green Deal (2019), in particular with regard to the sustainable use of forest resources. Legal regulation in this area should ensure environmental sustainability, economic viability, and social support for rural communities, which are important aspects for achieving climate goals. The Regulation of the European Parliament and of the Council No. 2018/841 “On the Inclusion of Greenhouse Gas Emissions and removals from Land Use, Land Use Change and Forestry in the 2030 Climate and Energy Framework” (2018) establishes new rules for accounting for emissions and removals in this sector. In order to meet these requirements, Albania needs to develop legal mechanisms that take

into account the specifics of its forestry sector. In particular, this includes the introduction of criteria to assess compliance with greenhouse gas emissions and removals, which is critical for the land sector's contribution to climate change mitigation goals.

Forestry plays a key role in achieving the goal of zero net greenhouse gas emissions by 2050, mainly by reducing emissions and increasing carbon sequestration. The legal framework in Albania should promote sustainable forest management that recognizes the importance of forests as carbon sinks. It is important that legislation ensures the conservation and protection of forest resources from overexploitation and various threats, both biotic and abiotic. Thus, the legal regulation of the use of forest resources in Albania should be aimed at supporting and implementing the principles of sustainable development, integrating the requirements of the European Green Deal and introducing mechanisms

for assessing and controlling greenhouse gas emissions. This will contribute to the conservation of biodiversity, improve environmental sustainability and support the economic viability of rural areas. It is essential to note that forestry in Albania plays an important role in

the country's economy, providing raw materials for industry and important ecosystem services. However, the legal regulation of forest management faces numerous challenges that affect the efficiency of forest management and sustainable use (Table 5).

**Table 5.** Main problems and challenges of legal regulation of forest use in Albania

Problem	Characteristics
Outdated legal framework	Laws are not adapted to modern international standards, do not integrate environmental and social aspects
Illegal logging	Lack of effective control and monitoring, insufficient funding
Institutional challenges	Limited capacity of government agencies, lack of qualified personnel, modern technology and funding
Lack of community participation	Limited participation of local communities in decision-making, which reduces the effectiveness of forest protection measures
Challenges of international obligations	Difficulty in implementing international agreements due to domestic legal and institutional problems, lack of coordination by the government

**Source:** developed by the author

Forestry is an important component of Albania's economy, providing raw materials for industry and performing key ecosystem functions such as biodiversity conservation, climate regulation and soil protection. However, forest governance in the country faces numerous

challenges, including a weak legal framework, widespread illegal logging, institutional weaknesses, and limited local community participation. These factors significantly hamper effective and sustainable forest management and require improvement measures (Table 6).

**Table 6.** Proposals and strategic directions for improving the legal regulation of the forestry sector in Albania

I	
Suggestions for improving legislation and governance	Description
Updating and harmonizing legislation	Improving licensing mechanisms, introducing strict sanctions, integrating environmental and social aspects
Improving the effectiveness of law enforcement	Strengthening control, increasing funding, using modern technologies, training staff
Involvement of local communities	Establishment of local forest associations, training programmes, awareness raising
II	
Strategic directions for the development of the forestry sector	Description
Development of ecotourism	Creation of tourist routes, recreational areas, and educational programmes for tourists
Green investments	Restoration of degraded land, reforestation, implementation of sustainable practices, and attraction of private investment
Expansion of protected areas	Expanding the network of national parks and nature reserves, supported by international funding and technical assistance programmes

Table 6, Continued

III	
The role of international cooperation	Description
Financial support	Assistance from the World Bank, EU, UN Environment Programme, Instrument for Pre-Accession Assistance (IPA23)*
Technical assistance and exchange of experience	Training programmes, technical seminars, consultations
Joint research projects	Research on the impact of climate change, development of reforestation methods, rehabilitation of degraded land

**Note:** Instrument for Pre-Accession Assistance (IPA23) is a financial assistance programme established by the European Union to support the Western Balkan countries, including Albania, on their path to EU membership  
**Source:** developed by the author based on E. Serrano-Ramírez *et al.* (2021), C. Basnou *et al.* (2020), J. Naime *et al.* (2020), N.B. Olén *et al.* (2021), Instrument for Pre-Accession Assistance (n.d.)

The legal framework governing forest management in Albania needs to be significantly updated and harmonized with European standards. Existing laws often do not meet modern requirements for sustainable forest management, resulting in insufficient protection against illegal logging and other damage. In particular, the lack of integration of environmental and social aspects into forest management processes threatens the long-term sustainability of forest ecosystems. To overcome these challenges, it is important to increase the effectiveness of law enforcement, ensure proper control and monitoring of forest resources, and involve local communities in forest management processes. The introduction of modern technologies, such as remote sensing and the use of drones, can significantly improve the monitoring and management of forest resources. In addition, the establishment of local forest associations and training programmes will help to raise awareness among local residents about the importance of forest conservation. Effective legal regulation and management of forest resources are key to ensuring the sustainable development of the forest sector in Albania. Developing ecotourism, attracting green investments and expanding protected areas are strategic areas that can contribute to this goal. International cooperation, including financial and technical assistance, plays an important

role in supporting Albania's efforts to protect forests and implement sustainable forest management practices.

### Discussion

The results of the study indicate the importance of implementing measures to improve the principles of legislation and management of forest resources in Albania in the context of updating and harmonizing existing legislation. In particular, improving licensing mechanisms, introducing strict sanctions for violations, and integrating environmental and social aspects into legal norms will contribute to more efficient and sustainable use of forests. Improving the effectiveness of law enforcement includes strengthening control over compliance with forestry legislation, increasing funding for the relevant authorities, using modern monitoring and management technologies, and training staff to improve their competence.

The strategic directions for the development of the forestry sector in Albania include the development of ecotourism, attraction of green investments and expansion of protected areas. The development of ecotourism includes the creation of tourist routes, recreational areas and educational programmes for tourists, which will help raise awareness of the importance of forest conservation and its ecological value. Green investments include restoration

of degraded land, reforestation, and implementation of sustainable forest management practices, as well as attracting private investment. Expanding the network of national parks and reserves with the support of international funding and technical assistance programmes will help to preserve biodiversity and the ecological sustainability of forest ecosystems.

International cooperation plays a pivotal role in the implementation of strategic initiatives in the forest sector in Albania. Financial support from the World Bank, the European Union, the United Nations Environment Programme and other programmes such as IPA23 is critical for the implementation of large-scale projects. Technical assistance and exchange of experience through training programmes, technical seminars and consultations will help to improve the professional level of specialists. Joint research projects, including studies on climate change impacts, development of reforestation methods and rehabilitation of degraded land, are essential to achieve the long-term sustainability goals of the forest sector.

The legal framework for the use of forest resources in Albania requires further improvements to ensure sustainable development and the conservation of ecosystem services. Stakeholder involvement, provision of necessary infrastructure and qualified personnel, as well as a differentiated approach to forest management are key aspects that can contribute to effective forest management in the country. This aspect is confirmed by the study of D. Pérez-Sánchez *et al.* (2021), who note that effective forest management requires clear and fair conditions of use that take into account both environmental and social aspects. The study found that formalization of forest rights in Albania often leads to conflicts and misappropriation of common property. Formalization does not always guarantee transparency and security for owners, but rather creates new

vulnerabilities and uncertainties in legal documents, which facilitates the misappropriation of common property. In particular, S. Voicu & M. Vasile (2022) study the process of formalizing communal rights to use forest resources in the Romanian Carpathians and identify similar problems with conflicts and misappropriation of common property.

Forest management usually requires the involvement of various stakeholders, including government agencies, tourism promoters and private actors. This helps to reduce conflicts and increase public acceptance of decisions. M. Crivellaro *et al.* (2020) also emphasize the importance of involving stakeholders in forest management to reduce conflicts and increase public acceptance of decisions. The study also found that a differentiated approach that takes into account different categories of forests and forms of ownership is needed to achieve policy goals and effective forest management. A similar statement is present in the works of G. Weiss *et al.* (2019). The authors consider the impact of different categories of forests and forms of ownership on forest management, emphasizing the need for a differentiated approach. An important aspect for Albania is the implementation of local government initiatives and legislative measures aimed at forest conservation, and the creation of support programmes for forest owners, which will help improve their management and preserve ecosystem services. Similar research findings have been observed for Brazil and provide useful context and methodological approaches. In particular, D. Pinillos *et al.* (2021) note that Brazilian legislation requires farmers to maintain and protect forest areas known as legal reserves.

Automated forest classification is an important tool for improving forest management in Albania. This complements the economic and social approaches used in other countries, such as Benin, where the importance of economic

valuation of the environment and the willingness of farmers to pay to reduce forest degradation are key aspects. R. Sourokou *et al.* (2023) studied economic valuation of the environment in Benin and found that users are interested in improving soil fertility and combating erosion of coastal forests. This study has established that the use of machine learning methods and automated classification of legal texts is important for improving forest management, which will help in analysing and improving legal regulation. H. Chen *et al.* (2022) emphasize the need to use methods of automated classification of legal texts, which is important for the technical improvement of forest management.

To ensure the sustainable management of genetic resources and forests in Albania, it is necessary to harmonize policies at different levels, ensure adequate funding, raise awareness and cooperation, and minimize the negative impacts of urbanization. These recommendations can be useful for improving the legal regulation of forest resources in Albania, as they are based on research that has been shown to be effective in different contexts. Similar results can be seen in the study of N. Lovrić *et al.* (2023), which reveal the lack of consensus on the need to harmonize policies at the national and European levels within the framework of the Genetic Resources Strategy for Europe (GRSE). S. Yeasmin *et al.* (2021) also emphasize the importance of policy coherence for the effective management of forest resources, which is essential for economic and environmental well-being. At the same time, G. Zegeye *et al.* (2023) point out the importance of financing to minimize the negative impact of urbanization on biodiversity, which also requires appropriate investment in infrastructure.

In particular, T.M. Issii *et al.* (2020) assessed the effectiveness of environmental legislation in Brazil and concluded that increased cooperation between different stakeholders is key to

preserving forests and creating less fragmented landscapes. According to E.Z. Başkent (2021), the impact of urbanization on forest resources directly depends on compliance with legal obligations, which can reduce landscape fragmentation, although existing legislation is not always effective enough in preventing this trend. Based on the analysis, it is worth noting that in order to ensure sustainable forest management in Albania, several key aspects need to be taken into account: conservation of forest ecosystems, economic valuation of ecosystem services, application of meta-analysis and use of market instruments to reduce pressure on forest ecosystems. D. Saha & A. Taron (2023) also emphasize the importance of conserving forest ecosystems and take into account the value that local people place on ecosystem services in India. At the same time, F. Dashtbozorgi *et al.* (2023) highlight the need for effective governance and legal regulation for forest conservation, which are key aspects for ensuring sustainable use of forest resources.

It is important to emphasize the need for economic valuation of forest ecosystem services as one of the elements of effective forest management policy. F.A. Taye *et al.* (2021) note that it is worthwhile to assess several ecosystem services together, as a separate assessment may lead to an overestimation of industrial forests and an underestimation of natural forests that provide more ecosystem services. Due to the ongoing challenges in forest management, it is necessary to reduce the pressure on forest ecosystems through additional market instruments that encourage reduced consumption in the private transport sector and energy and food models.

An analysis of the impact of European legislation on forestry and nature conservation is useful for the development of a similar regulatory framework in Albania, taking into account local environmental and economic conditions.

European laws such as the Renewable Energy Directive and nature conservation legislation, including the Natura 2000 network. For instance, T. Li (2024) explores the innovative and promising value of gene editing technology for the conservation of endangered plants and animals, as well as the environmental and bioethical issues involved. The author analyses the impact of gene editing on China's legal system for the protection of plants and animals, proposing to develop special legislation to regulate this technology.

K.P. Sahoo *et al.* (2023) examine the impact of forest legislation on indigenous tribal communities dependent on forest ecosystems in Jhargram district, West Bengal. The authors analyse how various regulations introduced before and after India's independence have restricted these communities' access to forest ecosystem services. Analysing the impact of legislation on livelihoods and access to forest resources is important for the development of effective forest management policies in Albania, particularly in the context of ensuring ecological balance and socio-economic stability of local communities.

Thus, scientists put an emphasis on the importance of improving the legal and governance framework for the effective conservation of forest resources in different countries of the world, including Albania. The above-analysed studies point to the need to harmonize existing legislation, introduce strict sanctions for violations, integrate environmental and social aspects, and use modern monitoring technologies. Attention is focused on the importance of international cooperation, attracting green investments, developing ecotourism and supporting local communities. These approaches can be adapted to analyse and improve the legal regulation of forest resources in Albania, contributing to the conservation of biodiversity and sustainable use of natural resources.

## Conclusions

Forest ecosystems in Albania are characterized by significant species diversity, which depends on altitude and distance from the coast. It was found that about 83% of the forests consist of semi-natural plantations that have emerged as a result of natural regeneration. Most of Albania's forest ecosystems have structures typical of Southeast European countries, with numerous deciduous forests. The study also found that forest management practices in Albania include both traditional and newer approaches aimed at ensuring the sustainability and productivity of forests and rangelands. In particular, the integrated forest and rangeland management plans developed for several municipalities take into account economic, social and environmental aspects, involving local residents in the management of natural resources. It has been established that most of the country's territory is covered by forests, of which the largest share is made up of regenerating forests, while pastures cover a smaller part of the territory.

It has been found that the main problems affecting the development of forestry and rural areas are land use change and the need for legal regulation to ensure sustainability and effective land management. It was found that the current structure of forest land and property in Albania was formed under the influence of political and historical events, which led to the introduction of three forms of ownership: state, communal and private. It is noted that over the past 15 years, one of the most important political decisions in the forestry sector has been the transfer of ownership of forest areas from the State to local governments. The qualitative indicators obtained during the study include statistics on the area and structure of forests, forms of ownership, as well as the level of participation of local communities in forest management. It was found that private forests account for only 3% of the total forest

area in Albania, which is due to restrictions on the privatization of the forest fund. The main challenges during the study were the limited number of scientific studies that dealt specifically with the legal regulation of forest use in Albania and some statistical data. In particular, there were difficulties in collecting primary information due to the geographical and administrative features of the region.

Prospects for further research include the need to improve the legislative framework for the management of privately owned forest

resources to ensure their sustainable development and preservation of ecosystem services. The impact of climate change on forest ecosystems should be studied, and adaptation measures should be developed.

### Acknowledgements

None.

### Conflict of Interest

The author of this study declares no conflict of interest.

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## Правове регулювання використання лісових ресурсів

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**Анотація.** Метою дослідження було проведення комплексного аналізу законодавчої бази у сфері управління лісовими ресурсами Албанії в контексті екології лісів та видового різноманіття, а також визначення основних проблем та перспектив сталого розвитку лісового господарства країни. Методологія дослідження включала аналіз статистичних даних Національного інституту статистики Албанії щодо структури лісових екосистем та форм управління ними. Також були використані результати досліджень, проведених міжнародними організаціями, такими як Світовий банк, Глобальний екологічний фонд та Oikon d.o.o. Проаналізовано структуру та склад лісових ресурсів Албанії, в тому числі природного та напівприродного походження. Узагальнено нормативно-правову базу у сфері управління лісовим господарством в Албанії. Охарактеризовано різні структури управління землями лісогосподарського призначення з визначенням специфіки використання для різних форм власності. Визначено основні проблеми ведення лісового господарства, серед яких інтенсивна експлуатація приватних лісів, брак субсидій та інвестицій, а також недосконале законодавче регулювання. Обґрунтовано адаптаційні заходи для підвищення стійкості лісів Албанії в рамках Документа про лісову політику Албанії на період 2019-2030 років. Запропоновано стратегічні напрямки розвитку, такі як розширення природоохоронних територій, розвиток екотуризму та залучення зелених інвестицій. У дослідженні також підкреслено важливість міжнародного співробітництва для фінансової та технічної підтримки, що сприятиме впровадженню практик сталого лісокористування та збереженню біорізноманіття. Практичне значення дослідження полягає в тому, що отримані результати можуть бути використані для розробки стратегічних напрямів розвитку лісового сектору Албанії, спрямованих на забезпечення сталого управління та збереження лісових ресурсів, що є ключовим фактором економічного та екологічного добробуту країни

**Ключові слова:** інтегроване управління; екосистемні послуги лісів; законодавча база охорони природи; агролісомеліорація; охорона біорізноманіття

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.

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## 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<sup>2</sup> 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 ( $\chi^2$ ) 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	
<i>Pinus sylvestris</i>	+	+	+				+	+		+	+					+						+		+	
<i>Quercus robur</i>	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+					+		+	
<i>Acer platanoides</i>	+			+				+					+			+	+	+	+	+	+		+	+	

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
<i>Betula pendula</i>	+	+	+	+	+		+	+	+	+	+		+	+		+		+			+	+	+	+
<i>Tilia cordata</i>										+										+				
<i>Populus tremula</i>	+				+		+		+	+				+			+			+			+	+

**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) coryloso (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  $\chi_2$  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  $\chi^2$  criterion for the understory of the main forest-forming species

	Types					
	<i>Pinus sylvestris</i>	<i>Betula pendula</i>	<i>Populus tremula</i>	<i>Quercus robur</i>	<i>Acer platanoides</i>	<i>Tilia cordata</i>
X <sup>2</sup> 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 sub-yearlings of these species by association groups is insignificant (4.2-12.5%), and the  $\chi^2$  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. pendula* 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	<i>Pinus sylvestris</i>			<i>Quercus robur</i>			<i>Acer platanoides</i>		
		Small	Medium	Big	Small	Medium	Big	Small	Medium	Big
1	<i>Pineta (sylvestris) hylocomiosa</i>	4456.3	321 3.1	1606.6	4081	2763.7	913.2	2218.1	1625.8	-
2	<i>Pineta (sylvestris) calamagrostidosa (epigeioris)</i>	719.1	812.9	-	594.3	481.9	-	-	-	-

Table 3, Continued

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

Table 3, Continued

	Groups of associations	<i>Pinus sylvestris</i>			<i>Quercus robur</i>			<i>Acer platanoides</i>		
		Small	Medium	Big	Small	Medium	Big	Small	Medium	Big
19	<i>Acereto (platanoiditis) – Querceta (roboris) stellariosa (holosteae)</i>	-	-	-	-	-	-	3494.9	3294.3	3194.8
20	<i>Tilieta (cordatae) – Querceta (roboris) stellariosa (holosteae)</i>	-	-	-	-	-	-	5750.3	-	119.5
21	<i>Betuleta (pendulae) vacciniosa (myrtilli)</i>	3631.1	2550.8	1638.4	1856.5	-	-	-	-	-
22	<i>Betuleta (pendulae) cariosa (pilosae)</i>	-	-	-	-	-	-	1613.7	1763.9	-
23	<i>Betuleta (pendulae) stellariosa (holosteae)</i>	887.2	1619.1	-	1613.7	-	-	1294.2	1825.8	-
	<i>p-level</i>	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:** compiled 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. pendula* 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. pendula* 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. pendula* – 800.5-1694.1 pcs/ha, and *T. cordata* – 213.2 pcs/ha. In the phytocoenoses of the *Querceto (roboris) – Pineta (sylvestris) corylosa (avellanae) sparsa 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. pendula* 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. pendula*, *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 stand 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. pendula* 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. pendula*. 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
<i>Pinus sylvestris</i>	58.3	33.3	-	8.4
<i>Quercus robur</i>	58.8	35.3	5.9	-
<i>Acer platanoides</i>	66.7	25	8.3	-
<i>Betula pendula</i>	40	46.6	6.7	6.7
<i>Populus tremula</i>	33.3	50	16.7	-
<i>Tilia cordata</i>	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 realizing 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 Polissya of Ukraine according to the scale of assessment of

the success of natural seed regeneration mostly varies from insufficient to satisfactory (Yanitskiy, 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. Pragma & 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 Polissya 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 phytocenotic 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 насінневого 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; біорізноманіття; *Pinus sylvestris* L.; *Quercus robur* L.

UDC 332.3

DOI: 10.31548/forest/2.2024.135

## Planning of rational use of forest resources in Ukraine based on the improvement of ecosystem services

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**Abstract.** The study of land conservation methods for forest conservation and restoration is important and relevant from the standpoint of balanced use of natural resources and biodiversity conservation. The purpose of the study was to investigate effective strategies for the exploitation of land with self-forested areas to meet the needs of the agricultural sector of the Zolochiv

### **Suggested Citation:**

Stoiko, N., Cherechon, O., Dudych, H., Kostyshyn, O., & Soltys, O. (2024). Planning of rational use of forest resources in Ukraine based on the improvement of ecosystem services. *Ukrainian Journal of Forest and Wood Science*, 15(2), 135-152. doi: 10.31548/forest/2.2024.135.

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District of the Lviv Oblast. In the course of the study, the following methods were used: analysis; geographical method; statistical method; cartographic method; geoinformation method. It is worth noting that for the land plot No. 1 within the Buska territorial community of Lviv Oblast, it was recommended to conserve the land, with its subsequent renaturalisation. According to the results of the analysis, it is shown that in 2011 the processes of independent afforestation of agricultural land within the Busk territorial community were insignificant. In 2023, the situation improved, as the area of afforded land increased significantly. To the soils of the land plot No. 2, which was part of the Brody urban community, it was advisable to use conservation and transformation. In the Zolochiv community, 14.2 hectares of land should be rehabilitated, 27.3 hectares should be transformed into pasture, and 3.5 hectares should be alkalised. The paper suggests the introduction of innovative approaches for integrated planning of the use of forest resources: creation of forest farms, development of forest tourism, creation of special forest stands for air filtration, application of bio-refining technology, etc. The findings can be used by local communities to develop and implement a draft of measures for the comprehensive development plan of the territory of the Lviv Oblast to improve forest ecosystem services

**Keywords:** inventory; conservation areas; agricultural areas; self-forested land; soil cover; remote sensing

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## Introduction

Regular studies of methods for analysing the soil cover of land massifs were important for maintaining a favourable condition of land plots with self-seeded forest vegetation within the Lviv Oblast. The problem of the presence of a significant area of unaccounted forests exists because a large amount of forest land (the presence of about 800 thousand hectares has been established) located on state and municipal property lands was not transferred to permanent forest users in time due to the lack of procedures for state registration of forests and forest cadastre (Public report of..., 2023).

The results of the study of the restoration of destroyed forest vegetation in pine plantations of fresh coniferous forest in Zhytomyr Oblast after clear-cutting, which are presented in the paper by H.R. Talakh & V.P. Krasnov (2023), point out the need to introduce comprehensive measures for the restoration of forest crops. According to researchers, artificial reforestation may be a possible way to solve the problem of

vegetation destruction and deforestation after continuous logging.

During the study of forests of the state enterprise "Dovzhansk forest enterprise", where the dominant part of the forest fund (more than 80%) was accounted for by beech trees, the paper by V.V. Batryn & V.P. Kichura (2020) provided important methodological approaches to evaluating the effectiveness of various methods for restoring forest stands. In particular, the method of natural restoration of tree species can also be applied on the territory of woodlands within the Lviv Oblast.

The study conducted by O.H. Chaskovskyy & H.H. Hrynyk (2020) analysed changes in forest cover on the territory of the national nature park "Skolivski Beskydy" in the Ukrainian Carpathians. It was revealed that the main losses of forest cover are associated with logging, the vast majority of which occurred at an altitude of more than 1100 m above sea level (A.S.L.). To be able to respond to changes in forest cover in

real time, the researchers suggested using data from satellite images of the Sentinel-2 system, since comparative analysis with open data from the Global Forest Watch portal (GFW) showed that these images were characterised by good spatial and temporal resolution.

The study by V. Fesyuk *et al.* (2023) was devoted to the assessment of the state of forest cover and its changes in the Volyn Oblast. In the Manevychi administrative district, the highest rates of forest losses (deforestation) were recorded – 27.6 thousand hectares. Researchers have proposed to solve the issue of rational use and protection of forests through the introduction of forest monitoring measures using remote sensing of the Earth methods and reforestation, in particular natural renewal.

Based on the results of a study of forest cover losses in Ukraine, which are described by N. Stoiko *et al.* (2023), the need to implement measures for the protection and restoration of forests in Ukraine were identified. According to researchers, a possible way to solve the problem of forest loss may be the introduction of a programme of independent afforestation, in particular, on agricultural land that is not fertile, degraded, or unproductive.

The study by Yu. Zaitsev *et al.* (2003) considered the main indicators of soil fertility based on the results of an agrochemical survey of agricultural land in the Lviv Oblast. It was found that in terms of the acidity of the soil solution, the vast majority of land had a neutral reaction of the soil solution (pH value 7), but the largest area in the region was found under medium-quality soils.

O. Dorosh & I.O. Zastulka (2022) investigated effective strategies and methods for regulating self-afforestation on agricultural land within territorial communities. The scientific approaches proposed in the researchers to solve the problem of excessive self-afforestation were based on the prevention of exceeding

the forest cover by more than 50% and the predominance of forest land areas by more than twice over agricultural land.

Insufficient attention has been paid to the development of measures for the conservation of degraded and unproductive agricultural land from a technical, economic and environmental standpoint. The purpose of the study was to develop practical proposals for the exploitation of agricultural land with self-afforested and unaccounted forests in modern conditions of land relations development.

### Materials and Methods

In conducting the study, research methods were used to analyse agricultural land with self-seeding forests, the use of which was established by regulatory documents: Land Code of Ukraine (2024), Law of Ukraine No. 858-IV “On Land Management” (2003), Law of Ukraine No. 2321-IX “On Amendments to Certain Legislative Acts of Ukraine on Forest Conservation” (2022), Resolution of the Cabinet of Ministers of Ukraine No. 476 “On Approval of the Procedure for Conducting Land Inventory and Cancellation of Certain Resolutions of the Cabinet of Ministers of Ukraine” (2019), Resolution of the Cabinet of Ministers of Ukraine No. 1051 “On Approval of the Procedure for Maintaining the State Land Cadastre” (2012).

The study used the analysis for investigating agricultural land with self-afforestation. Geographical method was used for analysing the distribution of woodlands in space. Statistical method considered changes in the size of woodlands. Cartographic method was used for visualising self-forested areas. Geoinformation method for describing the geospatial location of objects and processes related to the self-afforestation of agricultural land. The research was conducted during 2022-2023 on the territory of the Zolochiv District of the Lviv Oblast. Zolochiv District united 7 territorial

communities. The soils of the district were mainly sod-podzolic soils and chernozems.

The object of the land inventory was the territory where agricultural land and certain land plots with self-seeded forest vegetation are located. Land area No. 1. The plots were located between the villages of Zastavye, Yosypivka, Kutu on the territory of the Busk urban community. Agricultural land was located in the natural area of Small Polissia and the forest-steppe zone (south-eastern part of the community's land use). The plots had a total area of 218.7 hectares and were used for hay-making, pasture, and arable land. Form of ownership – state property transferred to the communal ownership of a territorial community, private property.

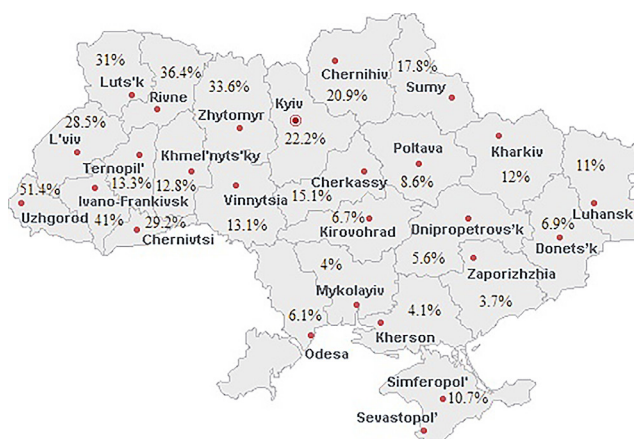
Land area No. 2. It was located near the village of Biliavtsi within the Brody territorial community. The location of agricultural land plots is determined within Small Polissia (central part of the community's land use). The land

plots had a total area of 48.2 hectares, the land was used for pasture, and the ownership was communal property of the community.

Land area No. 3. It was represented by arable land near the village of Bilyi Kamin within the Zolochiv territorial community. The plot was located in the forest-steppe zone (northern part of the community's land use). The plots had a total area of 45 hectares. 19 plots were examined. The purpose of the land plot – arable land, and the form of ownership – private property in the form of land shares. During the study, the Convention on Biological Diversity (1992) and Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973) standards were observed.

## Results

The territory of Ukraine has a small forest cover, but despite this, it ranks 9<sup>th</sup> in Europe in terms of forest area and ranks 6<sup>th</sup> in terms of wood reserves (Fig. 1). Notably, forest areas of the steppe zone have the lowest forest value.



**Figure 1.** Forest cover of administrative regions of Ukraine

**Source:** developed by the authors based on data from the official website of the State Forest Resources Agency of Ukraine (General characteristics of..., 2024)

Forest cover varied from 3.7% in the Zaporizhzhia Oblast to 51.4% in the Zakarpattia Oblast (Announcement on the..., 2020). According to the areas with the smallest forest area

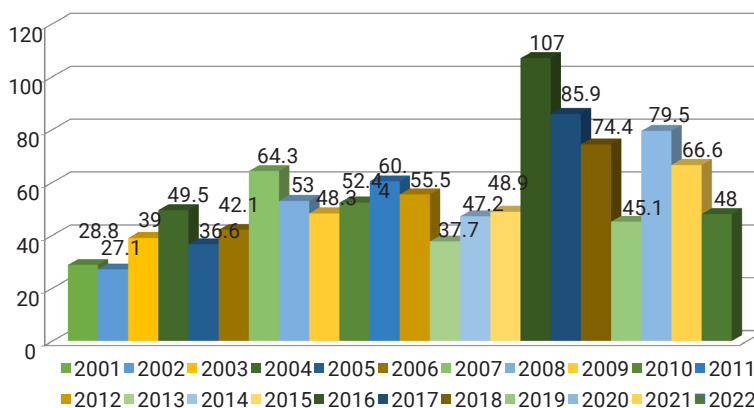
size, Zaporizhzhia (3.7%), Mykolaiv (4%), and Kherson Oblasts (4.1%) belong to them. Half of the Woodlands in Ukraine (about 56%) were created artificially. About 0.8 million hectares

of Ukrainian forests are classified as a reserve and are in a disordered state due to unauthorised logging, forest fires, plant diseases, and soil pests (State Forest Management..., 2020).

One of the objectives of the sustainable development programme of Ukraine until 2030 provides for the expansion of forest cover in the country from 15.9% to 20% (Sustainable Development Goals..., 2024). Since 2021, Ukraine has continued the process of conducting a national forest inventory. The main purpose of such an inventory was to ensure

proper management of forest funds, control their use, and protect natural ecosystems. For the period 2021-2023, a survey of 4,135 thousand inventory sites was conducted (Public report of..., 2023).

According to the GFW website, in Ukraine, as of 2000, natural forests occupied 11.1 million hectares (18% of the area) (Ukraine Interactive Forest..., 2024). However, from 2001 to 2022, Ukraine lost 1.2 million hectares of forest cover, including 48 thousand hectares (0.43%) of natural forests lost in 2022 (Fig. 2).



**Figure 2.** Data on tree cover losses in Ukraine from 2001 to 2022, thousand hectares  
**Source:** developed by the authors based on GFW data (Ukraine Interactive Forest..., 2024)

From 2000 to 2022, there was an 11% decrease in forest cover. For the period 2001-2012, the growth of tree cover amounted to 353 thousand hectares, while losses – 557 thousand hectares (Ukraine Interactive Forest..., 2024). The main factors causing a decrease in forest cover from 2001 to 2022 include illegal felling of trees, negligent forest management, changes in the use of land plots for construction and agriculture.

The state statistics service of Ukraine published data that the area of forest reproduction in 2022 was 36.9 thousand hectares (33.2 thousand hectares less than in 2010), including by planting and sowing – 26.5 thousand hectares

(29.6 thousand hectares less than in 2010), as a result of natural renewal – 10.4 thousand hectares (3.6 thousand hectares less than in 2010) (Environment of Ukraine..., 2023).

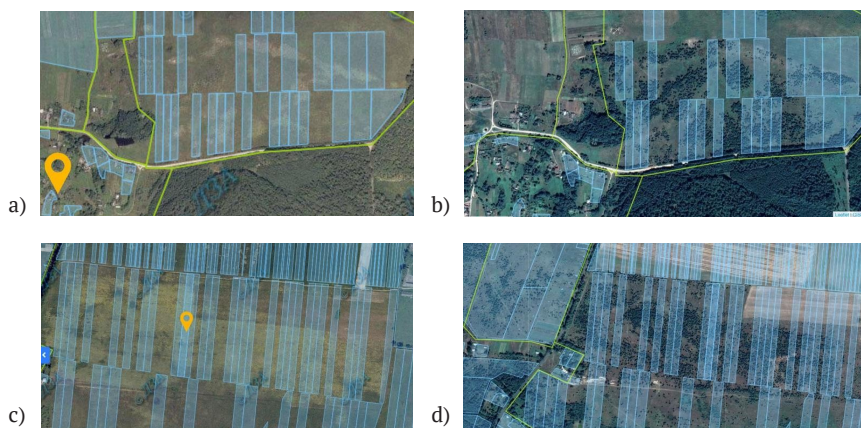
According to official data of the State Forest Resources Agency of Ukraine (State Forestry Agency) in 2023, the area of plots with forest vegetation of the forest fund of Ukraine amounted to 9.6 million hectares. Positive changes in forest reproduction were identified, according to which in 2023, compared to 2022, they increased by 3.1 thousand hectares (9.7%) (Public report of..., 2023). As of 2022, as part of the implementation of the Green Country

programme, enterprises of the State Forestry Agency planted 174.8 million trees on an area of 16,890.8 hectares, while 5,691.47 thousand trees per hectare were planted in Lviv Oblast (Green country, 2021).

According to the GFW website, in 2000, natural forest covered 743,000 hectares (34% of the area) in Lviv and Lviv Oblast. From 2001 to 2022, 79.6 thousand hectares of forest cover were lost in the city and region, including 1.92 thousand hectares (0.26%) of natural forests were lost in 2022. From 2000 to 2022, the forest cover of the region decreased by 11% (Ukraine Interactive Forest..., 2024). Notably, in Ukraine and the Lviv Oblast, the level of forest losses exceeded the volume of their restoration. It is also worth noting the tendency to increase the area of for-

ests in a natural way due to self-afforestation, including on agricultural land.

According to the legislation of Ukraine, degraded and unproductive land is subject to conservation. Land conservation measures include rehabilitation, transformation, and renaturalisation. The possibility of introducing each conservation area is considered on the example of three massifs of agricultural land in the Zolochiv District of the Lviv Oblast. When using remote sensing data, an analysis of the state of soil cover of agricultural land with self-seeded forest vegetation and unoccupied areas in the Zolochiv District was carried out. Figure 3 shows the privately owned land plots of area No. 1 with self-seeded forest vegetation within the Busk territorial community of Lviv Oblast.



**Figure 3.** Private land plots with self-seeded forest vegetation within the Busk territorial community of Lviv Oblast

**Note:** 01.01 plots for commercial agricultural production, private property, land-pasture: a, c) copy from the public cadastral map of Ukraine (orthophotoplane 2011); b, d) copy from the GISFILE geoportal (space image of Google Satelite 2023)

**Source:** compiled by the authors

According to the results of the analysis, it was revealed that the self-afforestation of plots within the Busk territorial community occurred mainly on natural forage lands. There is no development of livestock farming in these areas, which is probably why the study

sites were not used. These land plots were privately owned, outside the settlement and near existing Woodlands.

Based on the results of visual comparative analysis of figures 1a, 1b and 2a, 2b, it is noticeable that in 2011 the processes of independent

afforestation of agricultural land on the studied plots were insignificant (Statistical Yearbook of..., 2017). However, after a twelve-year period of time, a large area of agricultural land was covered with forests. On the territory covered with forests, the presence of private land plots with an area of 0.7 to 1.5 hectares was noted.

According to the state land cadastre, these land plots are intended “for commercial agricultural production”. On the ground there are ravines with slopes of 3-5°, which, with intensive agricultural use, can cause erosion. Information on the soil cover of the land areas of the plots under study is shown in Figure 4.



**Figure 4.** Ground cover of the land area No. 1 with self-seeded forest vegetation within the Buska urban community of Lviv Oblast

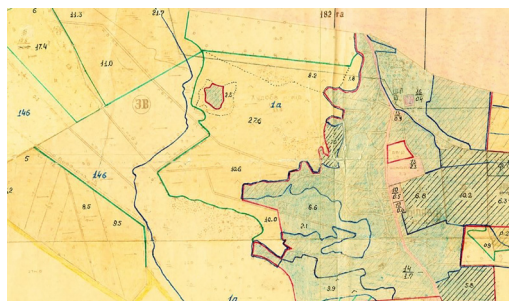
**Note:** with the code of the agricultural production group of soils – 158. Copy from the GISFILE Geoportal (2023 Google Satellite satellite image)

**Source:** compiled by the authors

Analysing the data on the soil cover of the area under study, it should be noted that the soil conditions represented by low-fertile swamp soils, meadow-swamp soils are vulnerable to flooding and erosion. Meadow-swamp soils were characterised by low productivity due to limited oxygen access to plant roots, high acidity and insufficient supply of nutrients, insufficiently deep underground water, flooding in the spring, autumn, and summer. Most often, such soils were used for natural forage land, and drained massifs – partially for arable land or vegetable growing. To solve the problems of low fertility, insufficient moisture supply and uneven distribution of nutrients on drained soils, various types of fertilisers should be applied, such as organic, manganese and copper microfertilisers, as well as potash and

phosphorous fertilisers (Litvinova *et al.*, 2023). Marsh soils can be used for growing agricultural and vegetable plant species, provided that proper reclamation, fertilisation, and selection of agricultural crops capable of growing in conditions of waterlogging and cooling of the soil are observed. In the future, a swamp can be created on them as a valuable land for the ecosystem.

On the swampy soils of the land mass under study, it is advisable to carry out land conservation with their subsequent renaturalisation. For anthropogenically flooded soils of the automorphic range, land conservation should be applied by means of their alkalisation for a period of 10 to 20 years. Data on the soil cover of the land area No. 2 of the studied areas are shown in Figure 5.



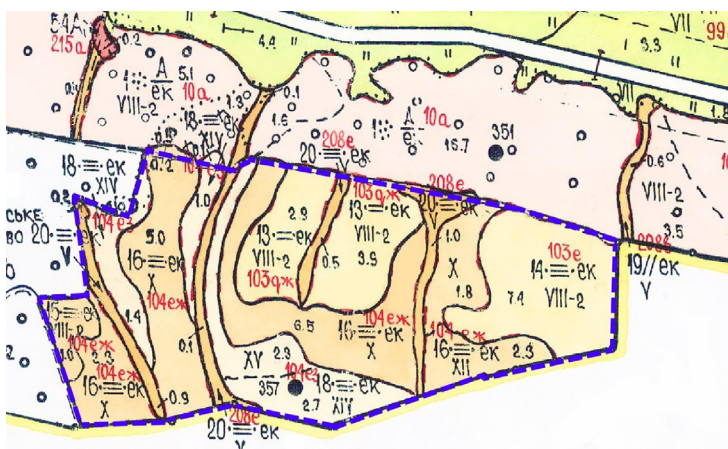
**Figure 5.** Ground cover of the land area no. 2 within the Brody urban community of Lviv Oblast

**Note:** with the code of the agricultural production group of soils – 1a

**Source:** compiled by the authors

The analysis identified land not covered with forest vegetation (non-forested areas) within the Brody urban community. Analysis of

soil cover data of the land area No. 2 showed that these areas are represented by hidden sod-podzolic sandy soils on water-glacial deposits. These soils should be allocated for conservation and transformation, namely, subjected to the afforestation process. The land area is located near forest lands, so under such conditions, afforestation will unite existing woodlands, which is very important for maintaining biological diversity, in particular, migration of forest fauna. Using these areas with unproductive soils, the territorial boundaries of a locality can be expanded. However, the studied area near the village of Biliavtsi cannot be recommended as an attractive area for settlement, since the land mass is located at a fairly large distance from the city of Brody. Scheme of soil cover of land plots No. 3 is shown in Figure 6.



**Figure 6.** Ground cover of the land area No. 3 within the Zolochiv urban community of Lviv Oblast

**Note:** with the code of the agricultural production group of soils – 103 dj (sod-carbonate weakly eroded medium-chipped sandy-medium loamy soils on the alluvium of dense carbonate rocks); 103 e (sod-carbonate weakly eroded slightly crushed sand-heavy loamy soils on the alluvium of dense carbonate rocks); 104 ej (sod-carbonate weakly eroded slightly crushed soils with spots of medium eroded soils (30-50%) and sod-carbonate medium eroded medium crushed sand-heavy loamy soils on alluvium of dense carbonate rocks); 104 ez (sod-carbonate underdeveloped strongly crushed soils, sod-carbonate medium eroded medium crushed soils with spots of strongly eroded (30-50%) and sod-carbonate strongly eroded medium crushed sand-heavy loamy soils on the alluvium of dense carbonate rocks); 208 e (sod-carbonate alluvial sandy-heavy loamy soils on the alluvium of dense carbonate rocks)

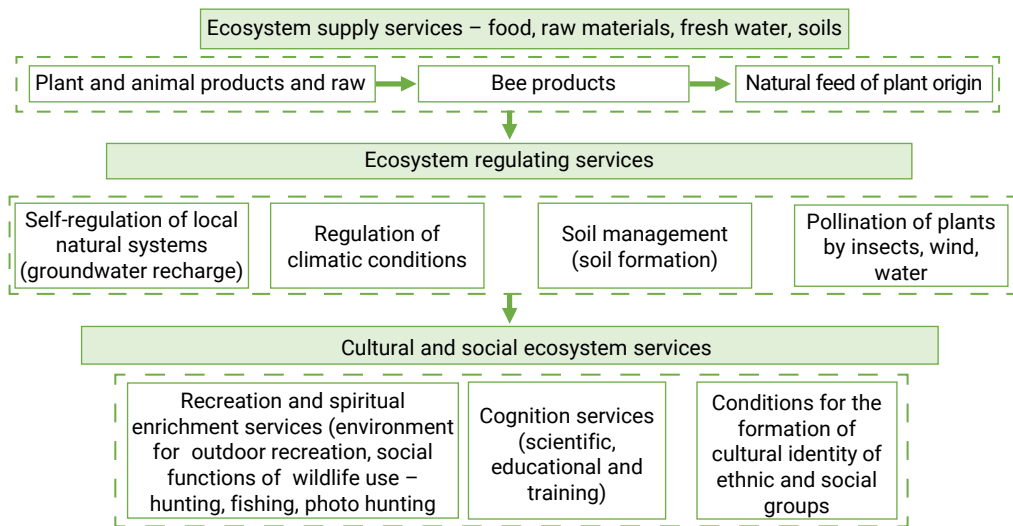
**Source:** developed by the authors based on data from the Main Department of StateGeoCadastre in the Lviv Oblast

For the rehabilitation process, ground covers were allocated with codes of agricultural groups 103 dj and 103 e (with a slope steepness of 2-3°), codes 104 ej (with a slope steepness of 3-7°) and 104 ez (with a slope steepness of 7-15°) for transformation into pasture, and code 208 e (with a slope steepness of 0-1°) for alkalisation.

Thus, within the Zolochiv urban community, 14.2 hectares were subject to rehabilitation, 27.3 hectares were recommended to be transformed into pasture, and 3.5 hectares were to be subjected to the alkalisation process. Self-afforestation of agricultural land occurred for two reasons: land (arable land), the soil of which is degraded, unproductive and was not

used for crops (categories of reserve land or unclaimed land shares (units); land plots for commercial agricultural production, which were not cultivated and were abandoned state (land in private ownership) (Santosa *et al.*, 2024).

The problem of self-seeded forests on agricultural land should be solved at the state level, but the final decisions on the use of such land plots should be made at the local government level when developing comprehensive plans for the spatial development of territorial communities. The global Millennium Ecosystem Assessment report, published in 2005, examines the fundamentals of the concept of ecosystem services (Guide to the..., 2005). Figure 7 shows the three main groups of ecosystem services.



**Figure 7.** Ecosystem services group

**Source:** developed by the author based on the TEEB Manual for Cities: Ecosystem Services in Urban Management (2011)

Ecosystem services are benefits that people receive from ecosystems that can be tangible, such as food, building materials, water, or intangible, such as climate regulation, air and water purification, flood management, and recreational opportunities (Lipińska *et al.*, 2023b). Lviv Regional Department of Forestry and Hunting

(RDFH) is located in Lviv. The total area of Lviv RDFH is 478.021 ha, including 431.8 ha covered with forest vegetation, of which 213.42 ha are used for forest crops. Air pollution data was measured at post No. 1 Rava-Ruska of the Lviv Regional Centre for Hydrometeorology. Table 1 shows the cost of forest ecosystem services.

**Table 1.** Assessment of the cost of forest ecosystem services

Ecosystem service	Amount	Unit price, UAH	Service cost, UAH/ha
Carbon dioxide assimilation, t/ha	5.04	420	2,117
Oxygen production, m <sup>3</sup> /ha	350	110	38,500
Assimilation of pollutants, in particular:			
Sulphur dioxide (SO <sub>2</sub> ), mg/m <sup>3</sup>	0.003	8,273.63	25
Nitrogen dioxide (NO <sub>2</sub> ), mg/m <sup>3</sup>	0.03	2,574.43	77
Dust (suspended matter), t/ha	100	369.52 92.37	36,952
Total			77,671

**Source:** developed by the authors based on Environmental tax rates in 2022 (2022), Regional report on the state of the NPS (2023)

The total annual growth of wood reserves in the Lviv Oblast was 5.6 m<sup>3</sup>/ha. The study assumes that the specific gravity of wood is about 0.5 t/m<sup>3</sup> (this may vary depending on the type of forest and tree species.) Then the growth of wood in tonnes per hectare will be equal to 5.6 m<sup>3</sup>/ha \* 0.5 t/m<sup>3</sup> = 2.8 t/ha. Assuming that each tonne of wood absorbs about 1.8 tonnes of CO<sub>2</sub> (carbon dioxide) during its lifetime, then the assimilation capacity of the forest in tonnes of carbon dioxide per hectare will be 2.8 t/ha \* 1.8 t CO<sub>2</sub>/t of wood will be equal to 5.04 t of CO<sub>2</sub>/ha. Therefore, the calculation of the amount of carbon dioxide absorbed determines the assimilation capacity of the forest at 5.04 t/ha. At the current rate of UAH 420 per tonne, the price of the assimilation service was UAH 2,117 per hectare.

In the forests of the Lviv Oblast, the annual release, minus oxygen respiration, was estimated at 350 m<sup>3</sup>/ha. Considering that the cost of industrial oxygen production is UAH 110 per m<sup>3</sup>, the cost of the service was UAH 38,500 per hectare. On average, 1 ha of forest per year retained up to 100 tonnes of dust per year. Subject to the fee rate for 1 tonne of suspended matter emissions of UAH 369.52 per tonne, the price of the dust absorption service was UAH 36,952 per hectare. The calculation of the total value of regulating ecosystem services of the forest was UAH 77,671 per hectare.

The strategy of sustainable, scientifically based use of forest resources consists of plans

and innovative approaches aimed at preserving and effectively using forest ecosystems, considering their sustainability and productivity for the long term. The introduction and application of innovative approaches for integrated planning of forest resources is proposed: creation of forest farms – the process of growing forest for the purpose of obtaining wood, improving the ecological state of the territory, preserving biodiversity and other ecosystem services; development of forest tourism – the process of promoting tourists to visit forest areas for rest, recreation, healthcare, and training (may include various activities such as hiking, cycling, camping, wildlife observation, excursions with educational purposes, photographing natural landscapes, etc.); the use of forest resources waste for the creation of biomass and biofuel production allows for more efficient use of woodlands, which can contribute to their economic sustainability and conservation; the creation of special forest stands for efficient air filtration and carbon reduction (oak, maple, fir, pine, and birch have a high capacity in carbon removal and air filtration); the use of modern drones to monitor forest ecosystems and control the use of forest resources; the use of artificial intelligence (AI) can be extremely useful for improving the efficiency of forest resources management and ensuring their sustainable development; the use of bio-refineries for processing forest resources when using all components of the stand (bark, leaves).

## Discussion

Analysing the results of the study, it can be concluded that it is necessary to pay special attention to the implementation of integrated measures for the management of forest resources and land areas aimed at preserving environmental sustainability and maintaining the biodiversity of the region. The study by N. Reid *et al.* (2023), using examples of reforestation and forest rehabilitation in temperate regions, showed that the effectiveness of forest restoration depended on factors such as local climatic conditions and available financial resources. Ukraine could benefit from the experience of growing exotic plants mentioned N. Reid *et al.* (2023), such as the silver fern (*Punga (Cyathea dealbata)*), which grows in shade and humidity, and “New Zealand Christmas tree” (*Pohutukawa (Metrosideros excelsa)*) with red flowers blooming in winter. In addition, a native New Zealand plant known as rivea or “New Zealand violet”, which has bright flowers and large leaves, can adapt to temperate climates.

J. Kuttippurath & R. Kashyap (2023) analysed changes in India’s green cover, in particular, to increase the normalised difference vegetation index (NDVI), leaf area index (LAI) and (SiF) plant photosynthetic activity index. Approaches for assessing changes in India’s green cover described by J. Kuttippurath & R. Kashyap (2023) can be useful for analysing the situation in Ukraine. In particular, the use of satellite field monitoring data, such as NDVI, LAI, and SiF indices, can help in assessing crop yield dynamics and studying the photosynthetic activity of the root system of plant crops.

M. Rosa *et al.* (2021) found that despite the relative constancy of indigenous forest cover in the Atlantic Forest of Brazil, there was a constant loss of old indigenous forests, mainly on the plain. Geographical and statistical research methods for analysing changes in the size of woodlands and their distribution in space and

geoinformation analysis methods for mapping and determining the dynamics of changes in forest cover in the study area, which were used by M. Rosa *et al.* (2021), can be adapted to the conditions of Ukrainian forests.

A.K. Fernandes *et al.* (2023) reviewed scientific papers that assess the genetic diversity of restored areas in comparison with natural forest. In forest restoration programmes for the conservation of biodiversity in Ukraine, it is advisable to include commercial trees for growing, such as Scots pine (*Pinus sylvestrus*) ‘Fastigiata’ with a narrow columnar crown, common oak (*Quercus robur* L.), the white fir (*Abies alba*).

Proposal of G. Davidson *et al.* (2024) regarding the inclusion in future research of modern technologies, such as restoration of degraded natural forests in a closed canopy, can be considered justified, since the innovation will contribute to the strategy to combat monkey malaria. This new method of renewal of forest ecosystems can be implemented in Ukraine, but this requires the creation of protective forest zones around renewable woodlands, which may require significant financial resources compared to the renewal of forests in more favourable climatic conditions (Panfilova & Byelov, 2022). One of the necessary steps to restore such forests in Ukraine may be the removal of invasive plant species, which will help prevent the loss of native species (Lipińska *et al.*, 2023a).

S. Stephens *et al.* (2023) investigated the impact of various forest management methods on their recovery after a fire. The study by S. Stephens *et al.* (2023) found that the use of the combined Mech+Fire treatment was the most effective option that provided resistance to forest fires. The proposed forest management approaches, such as Mech, Fire or a combination of them, can also be applied in Ukraine and, in particular, include the removal of dry and diseased trees, selective felling to reduce competition between trees and increase forest recovery.

D. Pragya & P. Jaiswal (2022) proposed the implementation of forest restoration strategies such as rehabilitation, reconstruction, reclamation, and replacement. Compared to reconstruction, reclamation, and replacement of forests in terms of financial cost, forest rehabilitation in Ukraine may be less expensive, since natural restoration does not require human intervention and costs for planting material, but this process takes longer.

D. Evison & S. Wyse (2023) found that the survival rate of planted mountain beech seedlings was 75%, which indicated the effectiveness of forest restoration measures. The project is recommended in the study by D. Evison & S. Wyse, which aims to restore the forest by using the method of planting seedlings and using digital technologies to monitor and investigate the effectiveness of the restoration process, can be successfully implemented in Ukraine. This was due to the fact that the country is actively developing the latest technologies, such as the use of drones and satellite images for monitoring agricultural land (Fedoniuk *et al.*, 2024).

Project to restore ecological functions in degraded natural forests, implemented by H. Qu *et al.* (2024) can only be effectively applied on the southern coast of Crimea, as the peninsula is characterised by a mild subtropical climate favourable for oak and cypress forests that have adapted to prolonged summer droughts. The reason for the territorial restriction is the climatic conditions, according to which the mainland of Ukraine is characterised by a temperate continental climate with cold winters and warm summers, while in China the climate varies from tropical in the south to subtropical and temperate in the north. In the mountainous Crimea, 65% of the area of all forests is occupied by oak forests, beech – 14%, while in the forests of the Ukrainian Carpathians, spruce (41%) and beech (35% of the area is covered) predominate.

K. Lee *et al.* (2023) reviewed the use of the remote sensing method for monitoring, evaluating, and restoring damaged forests. The researchers highlighted an important topic of ecological forest restoration, which is becoming increasingly relevant in the context of the aggravation of the problems of forest destruction and loss of biodiversity in the Lviv Oblast. Recently in the Lviv Oblast, the development of a platform for forest restoration of Ukraine has begun, which will help restore and increase the area of plantings, and calculate the area of self-seeded forests using decoding satellite images.

The study by M. Heenatigala & G. Duh (2022) was conducted to identify the most effective forest restoration strategies in Sri Lanka, particularly, in the context of increasing forest cover to 30% by the end of 2025. Agreeing with the scientific theses of M. Heenatigala & G. Duh (2022), it can be noted that increasing forest cover is important for preserving biodiversity and reducing greenhouse gas emissions. However, it is also important to consider the potential negative consequences of such actions, in particular, possible disruption of the ecological balance and loss of natural ecosystems (Kotykova, 2022).

To map China's potential forest cover, X. Jiang *et al.* (2022) developed a random forest regression model to assess potential forest recovery zones and their impact on carbon uptake. This innovative model, proposed by X. Jiang *et al.* (2022), is successfully used in Ukraine in the field of ecology for predicting climate change, analysing environmental indicators and assessing the risk to ecosystems.

Thus, this section conducted a literature review and considered studies on such aspects as the impact of land use changes on biodiversity, forest management methods after fires, the impact of climate change on forest restoration, the effectiveness of various forest restoration strategies, the use of remote sensing for forest

monitoring, and geospatial analysis to assess forest restoration in specific regions.

### Conclusions

As a result of the study, it was found that the total area of woodlands in Ukraine in 2022 amounted to 36.9 thousand hectares, while in 2023, compared to 2022, they increased by 3.1 thousand hectares (or 9.7%). According to GFW data, during the period from 2001 to 2022 in Lviv and the Lviv Oblast, the total volume of forest cover losses amounted to 79.6 thousand hectares, including 1.92 thousand hectares of natural forests in 2022, which led to a decrease in the forest cover of the region by 11% for the period from 2000 to 2022. According to the calculation, the total cost of forest ecosystem services was UAH 77,671 per hectare.

Scientifically based areas of land conservation in the form of rehabilitation, transformation, and renaturalisation were important measures for preserving the natural environment and maintaining the ecological sustainability of the region.

The strategy of sustainable use of forest resources included an inventory of forests to determine the amount of wood that can be cut down without harming the ecosystem, and the development of forest management plans considering the conservation of biodiversity and the restoration of forest ecosystems. The main principles of this strategy included the following activities: development and implementation of a comprehensive forest management system that considers the needs of the ecosystem, society, and economy; preservation

and restoration of the diversity of species, ecosystems, and genetic resources in forests; minimisation of the impact of human activities on forest ecosystems to preserve their value and stability; involvement of all stakeholders in the forest management process, including public organisations, local governments, industrial representatives, etc; constant monitoring of the state of forest ecosystems and assessment of the impact of human activities on them, to make adjustments to the management strategy; application of the latest technologies, innovative methods, and scientific research for improving the efficiency of forest management.

Consequently, the introduction of the proposed latest technologies will contribute to the creation of sustainable and efficient management on land with self-seeded forest stands, ensuring a balanced development of community territories, considering environmental and economic aspects.

The areas of further research in the areas of rehabilitation, renaturalisation, and transformation can be a detailed analysis of the impact of these measures on the preservation of soil cover, restoration of biodiversity, and the study of the relationship between measures for the conservation of land masses and changes in climatic conditions and the hydrological cycle.

### Acknowledgements

None.

### Conflict of Interest

None.

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## Планування раціонального використання лісових ресурсів в Україні на основі поліпшення екосистемних послуг

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**Анотація.** Дослідження способів консервації земель для збереження та відновлення лісових масивів є важливим і актуальним з погляду збалансованого користування природними ресурсами та збереження біорізноманіття. Метою дослідження є вивчення ефективних стратегій експлуатації земельних угідь із самозалісненими ділянками для забезпечення потреб аграрного сектору Золочівського району Львівської області. В ході дослідження застосовувались методи: метод аналізу; географічний метод; статистичний метод; картографічний метод; геоінформаційний метод. Варто відзначити, що для земельної ділянки масиву No. 1 у межах Буської територіальної громади Львівської області було рекомендовано проведення консервації земель, з подальшою їх ренатуралізацією. Згідно результатів аналізу показано, що в 2011 році процеси самостійного заліснення сільськогосподарських угідь у межах Буської територіальної громади були малозначними. В 2023 році ситуація покращилась, оскільки площа заліснених земельних угідь значно збільшилась. До ґрунтів земельного масиву No. 2, що знаходився у складі Бродівської міської громади, було доцільним застосування консервації-трансформації. В Золочівській громаді на ділянці No. 3 необхідно відвести 14,2 гектарів під реабілітацію, 27,3 гектарів трансформувати у пасовище та 3,5 гектарів

залужити. В роботі запропоноване впровадження інноваційних підходів для комплексного планування використання лісових ресурсів: створення лісових ферм, розвиток лісового туризму, створення спеціальних лісових насаджень для фільтрації повітря, застосування технології біоафінерії та інше. Результати дослідження можуть бути використані місцевими громадами для розробки та впровадження проекту заходів комплексного плану розвитку території Львівського регіону з метою покращення екосистемних послуг лісу

**Ключові слова:** інвентаризація; напрями консервації; сільськогосподарські масиви; самозалісені землі; ґрунтовий покрив; дистанційне зондування

UDC 394.46:502-047.22(477)

DOI: 10.31548/forest/2.2024.153

## Monumental trees of Ukraine and public awareness of them

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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), 153-169. doi: 10.31548/forest/2.2024.153.

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**Abstract.** Studying the species diversity and condition of monumental trees contributes to their preservation and is important for public awareness of their role in ecosystems and the country's ecological heritage. The purpose of the study was to reveal the significance of such trees for society. The task of the work was to research the characteristics of monumental trees in Ukraine. The history of environmental protection is analysed and the features of monumental tree preservation in Ukraine are presented. The beginning of environmental protection activity related to the preservation of trees in Ukraine and the most active periods have been revealed of it. The national features of the popularization of monumental trees are given. Based on the analysis of botanical natural monuments cadastres of Ukraine and Kyiv, quantitative and species composition of monumental trees were established. The most common (*Quercus robur*), common, less common and rare (*Buxus sempervirens*, *Catalpa bignonioides*, *Metasequoia glyptostroboides*, *Pseudotsuga menziesii*, *Rhododendron myrtifolium*, *Sequoiadendron giganteum* and others) species of monumental trees have been established, and important issues regarding their conservation are indicated. According to the types of street plantings, the majority (68%) are single trees. To assess the awareness of the population about ancient trees, the method of sociological survey of respondents was used. The most significant values of monumental trees for the population were studied. The importance of the populations' awareness of old trees through the development of an emotional connection with them, which contributes to their protection, has been established. The obtained results can be used in future environmental protection activity, exchanging of scientists' experience from different countries regarding the preservation of such trees, enrichment of information about growth characteristics, historical facts or other issues related to these trees

**Keywords:** Nature Reserve Fund of Ukraine; genera and species; preservation; protection; popularization; social and cultural value

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## Introduction

Urban trees in big cities exist in stressful and harsh habitat conditions. The compact urban form has a heavy load on green spaces and limits the future tree growth in big cities. The main causes of tree death are injuries received during road and construction works, associated with soil disturbance and root damage. Trees commonly suffer from human abuse or improper care. Many old trees decay and die prematurely. The number of trees that manage to survive and reach a respectable age is much smaller, and only separate trees can live for many centuries.

According to C.H. Cannon *et al.* (2022), only 1% of trees achieve an age that is 10-20 times greater than the average tree age, and a quarter of all trees can have ages that are 3-4 times greater than the average tree age. In urban

spaces, it is more difficult to care for trees and protect them from adverse environmental conditions. Ordinary measures to support old trees will not be enough, and more efforts are needed to preserve them. Losses resulting from the death of ancient trees cannot be compensated or replaced.

The intangible value of monumental trees includes elements related to history, culture, folklore, traditions, religion, etc. According to I. Camarda & G. Brundu (2021), monumental trees are ecologically important keystone organisms that have characteristics fundamental for sustaining biological assemblages or individual species. Monumental trees often provide a range of rich and scarce habitats, supporting many rare and endangered species, and are

an indispensable part of every country's landscape and biological heritage. M. Gilhen-Baker *et al.* (2022) emphasize that old trees create microclimates that slow global warming and produce phytochemicals with many biomedical properties. Such trees are valuable to the community, they are given special attention and care, and they are given a special status of protection. Preservation and protection of monumental trees facilitate the connection between the past, present, and future of communities. Therefore, according to K. Kabassi *et al.* (2021), many natural monuments have been preserved through the coordinated actions of local communities and organizations. Heritage trees in different countries are identified and valued based on their important historical, cultural, and physical criteria. M. Ritchie *et al.* (2021) suggest a standardized evaluation system to combine heritage trees from separate countries into a unified network.

In the research, K. Vandekerkhove *et al.* (2019) explained the densities and sizes of the old trees by the favourable climate and site conditions combined with the successful previous management interventions of care and pruning that led to continuous, unsuppressed growth. Also, X. Chi *et al.* (2020) note that the distribution of old trees is limited by microclimatic and soil conditions, and their density is determined by human activity. The study by J. Dong *et al.* (2021) provides insight into the main factors that threaten to old trees (natural disasters, urbanization, and pests). D.B. Lindenmayer *et al.* (2018) highlight the need for ancient tree management that includes increasing and expanding protection for all existing large old trees. D. Yin *et al.* (2024) confirm that modern technologies, especially unmanned aerial vehicles, could help in monitoring the growth status of old trees and strengthening pest control.

Ancient trees have an important value for science. S. Popovych & A. Dzyba (2022) researched

ancient trees and concluded that separate regions could be potentially most favourable for the introduction and acclimatization of some species. An important study of the old tree age estimation was conducted by J.J. Camarero *et al.* (2021) concerning the olive trees.

The purpose of this study was to assess residents' awareness of ancient trees. The task was to introduce the characteristics of monumental trees in Ukraine. It was determined directions for their popularization and responsible treatment of these trees since the preservation of ancient trees depends on more informed management. Until now, public awareness of ancient trees has not been assessed in Ukraine, and this study, using a scientific and objective approach, hopes to contribute to this cause.

## Materials and Methods

In the scientific literature, various terms are used to describe trees that differ from others in age, status, importance, and appearance: ancient, champion, famous, heritage, long-lived, monumental, notable, and precious trees (Jim, 2017; Lai, 2019). In this work, it was used in the most common terms: ancient, heritage, monumental and old trees (Pushkar *et al.*, 2021).

The assessment of monumental trees was made due to the analysis of databases of the Nature Reserve Fund of Ukraine (n.d.) and the Nature Reserve Fund of Kyiv (n.d.). Based on a combination with another extensive database of the Public Ukrainian Ecological Organization "Kyiv Ecological and Cultural Centre" (n.d.), a comprehensive overview of the monumental trees was compiled.

The research program included the following categories (Kushnir *et al.*, 1995):

1. Lost historical trees. Information about them is of great importance.
2. Trees that grow in places of famous historical events.
3. Trees named after prominent figures.

4. Trees planted by famous people.

5. Trees with unique biological properties.

They are divided into the following groups:

a) “plus” and “elite” trees, which are characterized by enhanced growth, a trunk of good quality, a correctly formed crown, etc.;

b) trees over a hundred years old;

c) trees with unique decorative properties.

The methodology of the study consisted of a review and identification of monumental trees. Four frequency classes of trees were grouped: dominant (>500 trees per species), common (30-500 trees per species), less common (10-30 trees per species), and rare (few per species). The study complied with the standards specified in the Convention on Biological Diversity (1992), and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973).

The importance of the study was to promote the preservation of ancient trees' preservation by using sociological components. An online survey using Google Forms was carried out in the period between June 5 and July 6, 2023. The total number of respondents was 748. Participation was anonymous and voluntary. The survey was conducted following the ethical norms specified in the ICC/ESOMAR International Code on Market, Opinion and Social Research and Data Analytics (2016). The surveys were conducted anonymously, with only one question about any affiliation with the natural sciences that allowed dividing all respondents into two groups. People whose activities are related to natural sciences (members of environmental groups, students of natural sciences, teachers of biological and environmental disciplines, etc.) accounted for 39% of all respondents. Accordingly, the other group of respondents, those who are not into nature, accounted for 61%. The questionnaire was developed based on methods of sociological research. There were five questions, including one open one. The key question is whether the

respondent knows about ancient trees or not. The questions about the location of heritage trees and their value were included in the questionnaire. The survey was distributed among social media group members across Ukraine. The data were analysed with Excel statistical functions using Microsoft Office XP software and Statistical Package for Social Sciences, version 11.5 (SPSS Inc., Chicago, 2002).

## Results and Discussion

### *History of trees' protection in Ukraine*

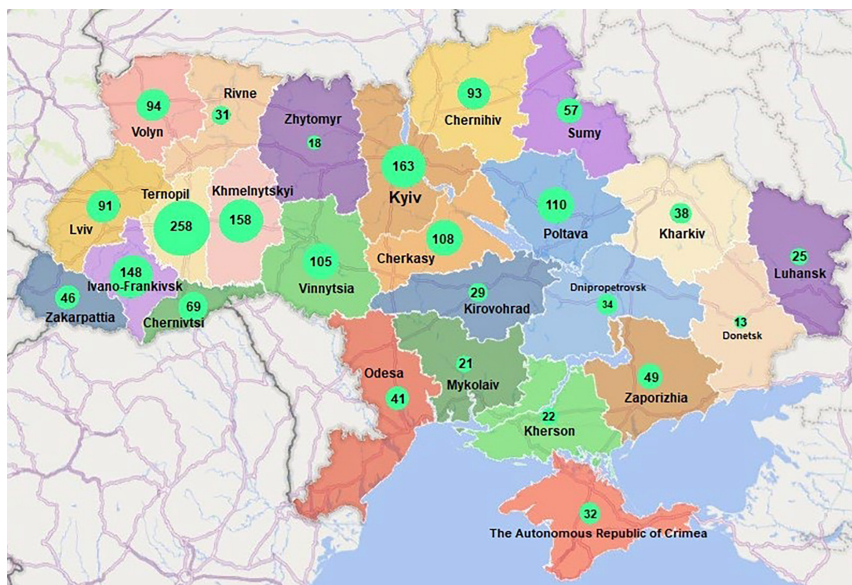
The Nature Reserve Fund of Ukraine is represented by botanical, geological, hydrological, and complex (which includes the previous three) natural monuments. All ancient trees are classified as biological natural monuments. The legal bases for monumental trees' protection are several nature protection laws in Ukraine: Law of Ukraine No. 1264-XII “On Environmental Protection” (1991), Law of Ukraine No. 2456-XII “On Nature Reserve Fund of Ukraine” (1992), and Law of Ukraine No. 1805-III “On Protection of Cultural Heritage (2000). According to the laws, natural monuments can be of national or local importance. Most of the monumental trees in Ukraine have local importance.

The botanical nature monuments are present in each Oblast of Ukraine (Fig. 1), but the number of them varies significantly by Oblast. This is due to historical factors (who owned the territory and how it was maintained) and growing conditions (a greater number of old trees have survived in areas with more forest cover and rainfall). Ancient trees often grow in historical places, large parks, and nature reserves. The condition of the monumental trees in the occupied territories (parts of Donetsk, Zaporizhzhia, Luhansk, Kherson Oblasts and the Autonomous Republic of Crimea) is unknown.

Old trees are being put into protection, taking into account many factors in Ukraine. Special trees can get protected status, and then

they are named monumental trees. Single monumental trees, alleys, and groups of such trees,

or forests with monumental trees could be under protection.



**Figure 1.** The map of the expansion of botanical nature monuments in Ukraine

**Source:** developed by the authors based on the Nature Reserve Fund of Ukraine (n.d.)

The first information about the protection of ancient trees in Ukraine dates back to 1883 and concerns Crimean trees (Shnayder *et al.*, 2011). Protection of old trees in the territory of Ukraine began in 1964. *Quercus robur* and *Tilia cordata*, which grow in Vinnytsia, Zhytomyr, Poltava, and Chernihiv Ukraine Oblasts, were the first tree species to receive protected status. The first mass protection activities of old trees took place in 1972 (191 places of growing ancient trees), followed by 1984 (278 places of growing ancient trees). According to the diagram (Fig. 2), 250 growing places of ancient trees got special protected status during 2010–2019.

Most of the trees in Ukraine were put into protection by the initiative of the Public Ukrainian Ecological Organization “Kyiv Ecological and Cultural Centre”, which since 1989 has been engaged in law-making and ecological

educational activities, including regarding ancient trees (Shnayder, *et al.*, 2011).

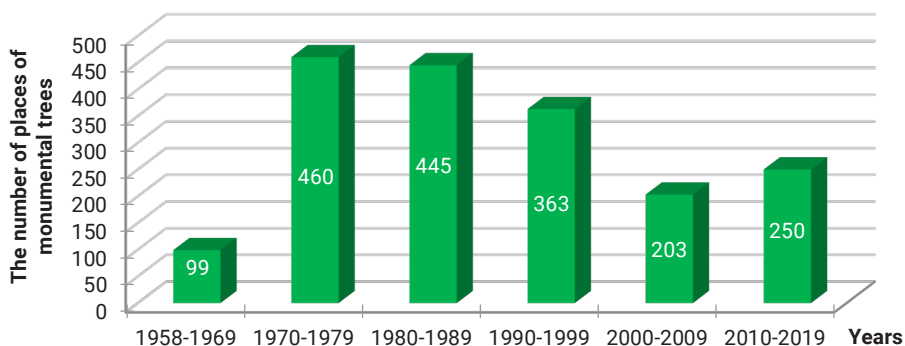
Low environmental protection activity since 2020, due to anti-COVID measures, and later – a large-scale invasion of the territory of Ukraine, has led to a halt in the protection of new trees. The trees were last given the status of monumental trees in 2019 in Vinnytsia, Kyiv, Poltava, Sumy and Ternopil Oblasts.

A monumental tree is a tree that has a biological, cultural, or aesthetic value of considerable age and size. In addition, monumental trees are a witness to history and the former landscape. Therefore, monumental trees are also often named after a famous historical event or a person who visited it (in reality or according to legend).

In Ukraine during the procedure of putting trees into protection, the trees are often given

the names of famous historical, scientific, and cultural figures: “Oak of Pero Mohyla”, “Mulberry of Shevchenko”, “Chestnuts of Grishka”, “Ginkgo of Sikorsky”, “Yew of Lesya Ukrainka”, “Oak of Bohdan Khmelnytskyi”, “Mulberry of

Stus”, “Oak of Boleslav”, “Oak of Simon Petliura”, “Oak of Prus”, “Oaks of Exupery”, “Oak of Ivan Franko”, “Oak of Franz Joseph”, “Pine of Nesterov”, “Three beech trees of Oleksiy Burachynsky”.



**Figure 2.** The history of granting nature protection status to monumental trees

**Source:** developed by the authors based on the Nature Reserve Fund of Ukraine (n.d.)

Often, not only historical facts but also myths and legends are associated with such trees. Sometimes, in order to increase understanding of the heritage trees’ value, Christian icons are hung on them, or creative events or contests are held near or with them.

To attract the attention of residents to the monumental trees, in 2010 the state authorities held an All-Ukrainian contest “National tree of Ukraine” the nominations “The oldest tree of Ukraine”, “Memorial tree of Ukraine”, “Historical tree of Ukraine”, “Aesthetically valuable tree of Ukraine”. Then 17 trees were chosen, including a 2000-year-old olive tree, a

1700-year-old pistachio tree, a 1300-year-old oak tree, a 1300-year-old strawberry tree, and an 800-year-old linden tree (Order of Ukraine No. 611..., 2011).

More than 3,000 monumental trees grow in big or small groups, as single trees and in alleys in Ukraine. The dominant species of monumental trees is *Quercus robur* (Table 1). There are 29 places where monumental trees grow in alleys, which mostly represented by species: *Aesculus hippocastanum*, *Fagus sylvatica*, *Juglans ailantifolia*, *Juglans nigra*, *Juglans regia*, *Larix decidua*, *Picea abies*, *Pinus strobus*, *Pinus sylvestris*, *Salix alba*, *Tilia cordata*, *Quercus robur*, *Quercus rubra*.

**Table 1.** Frequency of species of monumental trees

Dominant species	Common species	Less common species	Rare species
<i>Quercus robur</i>	<i>Aesculus hippocastanum</i> , <i>Fagus sylvatica</i> , <i>Fraxinus excelsior</i> , <i>Juglans nigra</i> , <i>Larix spp.</i> , <i>Pinus sylvestris</i> ,	<i>Abies alba</i> , <i>Acer spp.</i> , <i>Alnus glutinosa</i> , <i>Carya alba</i> , <i>Carpinus betulus</i> , <i>Ginkgo biloba</i> ,	<i>Ailanthus altissima</i> , <i>Arbutus spp.</i> , <i>Betula nigra</i> , <i>Buxus sempervirens</i> , <i>Calocedrus decurrens</i> , <i>Castanea sativa</i> ,

Table 1, Continued

Dominant species	Common species	Less common species	Rare species
	<i>Picea abies</i> , <i>Platanus orientalis</i> , <i>Populus alba</i> , <i>Quercus rubra</i> , <i>Tilia cordata</i>	<i>Juglans regia</i> , <i>Juniperus virginiana</i> , <i>Magnolia spp.</i> , <i>Morus alba</i> , <i>Pinus strobus</i> , <i>Pinus nigra</i> , <i>Pyrus communis</i> , <i>Styphnolobium japonicum</i> , <i>Taxus spp.</i> , <i>Thuja spp.</i>	<i>Catalpa bignonioides</i> , <i>Corylus spp.</i> , <i>Cotinus coggygria</i> , <i>Crataegus monogyna</i> , <i>Cupressus spp.</i> , <i>Fraxinus americana</i> , <i>Gleditsia triacanthos</i> , <i>Gymnocladus dioicus</i> , <i>Juglans cinerea</i> , <i>Juglans mandshurica</i> , <i>Laurus nobilis</i> , <i>Liriodendron tulipifera</i> , <i>Malus spp.</i> , <i>Metasequoia glyptostroboides</i> , <i>Pinus cembra</i> , <i>Pinus peuce</i> , <i>Pinus sibirica</i> , <i>Picea pungens</i> , <i>Pistacia spp.</i> , <i>Phellodendron amurense</i> , <i>Platyclusus orientalis</i> , <i>Prunus padus</i> , <i>Pseudotsuga menziesii</i> , <i>Quercus petraea</i> , <i>Rhododendron myrtifolium</i> , <i>Rhus typhina</i> , <i>Robinia pseudoacacia</i> , <i>Sequoiadendron giganteum</i> , <i>Sorbus spp.</i> , <i>Syringa josikaea</i> , <i>Tilia tomentosa</i> , <i>Ulmus minor</i> , <i>Viburnum opulus</i>

**Source:** developed by the authors based on the Nature Reserve Fund of Ukraine (n.d.)

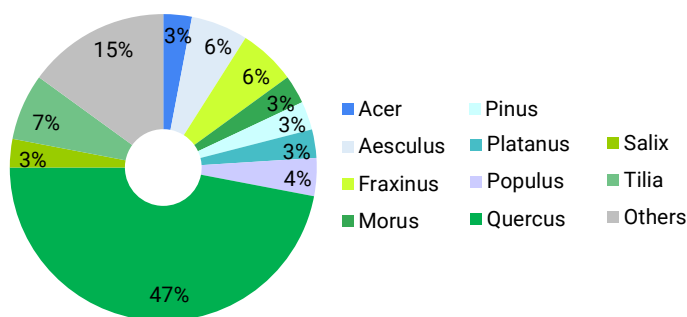
Dozens of ancient trees have been destroyed due to untimely maintenance and vandalism in Ukraine. Naturally, time does not stand still, and new ancient trees must be added to the nature reserve fund. Thus, hundreds of trees need to be protected.

### **Monumental trees in Kyiv**

Kyiv is a large urbanized city with significant air pollution, so trees grow under the pressure of anthropogenic influence (Tokarieva, 2004). At the same time, Kyiv is rich in unique ancient and monumental trees. Currently, in Kyiv,

almost 100 places where heritage trees grow, with a total number of 500 trees, which have been put under protection. The monumental trees in Kyiv are represented by 23 genera, most of which belong to the phylum of *Magnoliophyta* (Fig. 3). The most common species among

monumental trees are *Aesculus hippocastanum*, *Fraxinus excelsior*, *Tilia cordata*, *Quercus robur*. The genera *Abies*, *Cornus*, *Fagus*, *Ginkgo*, *Larix*, *Metasequoia*, *Picea*, *Prunus*, *Pyrus*, *Robinia*, *Sorbus*, *Styphnolobium*, *Thuja* are represented by a smaller number of trees.



**Figure 3.** Distribution of monumental trees by genera in Kyiv

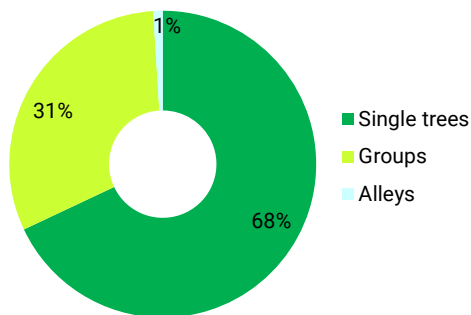
**Source:** developed by the authors, based on Nature Reserve Fund of Kyiv (n.d.)

The oldest districts accommodate more ancient trees, whereas newer districts have notably fewer. Most of the monumental trees (68%) are single trees (Fig. 4). Trees growing in groups make up 37% of all monumental trees. The smallest number of monumental trees (1%) grows in the alleys.

Some heritage trees are in an unsatisfactory condition. However, they have survived to the present day and, with proper care, can continue to exist. A handful of these heritage trees face challenges such as diseases, pests, or even anthropogenic factors. Nevertheless, their unique characteristics and historical significance should be identified as objects for priority conservation. The research on the condition of these trees not only reveals issues but also indicates the necessity of taking measures for their preservation and restoration.

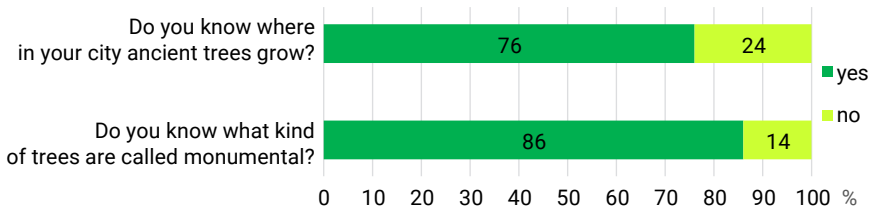
**Public awareness of the ancient trees' value**

Sociological research is an integral part of designing the development of the urban environment. To study the impact of phenomena on people, it is necessary to understand the level of their awareness of these phenomena. The respondents who took part in the survey were generally interested in it and showed an active position. At the list, 86% of respondents said that they knew about ancient trees and 76% of respondents knew where they grow (Fig. 5).



**Figure 4.** Distribution of monumental trees by types of planting

**Source:** developed by the authors, based on Nature Reserve Fund of Kyiv (n.d.)

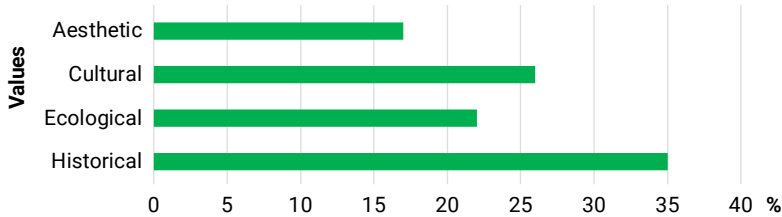


**Figure 5.** Public awareness of ancient trees in Ukraine

**Source:** developed by the authors

When choosing the values, only 15% of respondents gave completely correct answers (mentioned every value: aesthetic, cultural, ecological, and historical values). When

respondents assessed the importance of the values of such trees, the historical value was chosen as the main one, and the aesthetic value as the least important (Fig. 6).



**Figure 6.** The importance of the values of the ancient tree according to the respondents

**Source:** developed by the authors

*Respondents, whose activities are related to the natural sciences.* Among people who are involved in nature, everyone knows what an ancient tree is, but not everyone knows where such trees grow in their immediate vicinity. This means that even specialists do not have sufficient information about the notable trees. Along with the existing interest in ancient trees, respondents do not always have a correct understanding of their value. For example, 81% of respondents chose the wrong answer among all the values of ancient trees – “they have economic value”. Even people interested in nature conservation sometimes have an inaccurate understanding of the value of ancient trees.

*Respondents, whose activities are not related to natural sciences.* Respondents from the other group, whose activities are not related to

natural sciences, obviously have less knowledge about ancient trees. Thus, 22% of respondents in this group do not know what kind of trees are called ancient trees, and 30% of respondents could not answer the question “Where do such trees grow?”.

The results of the survey on the values of ancient trees showed that there is awareness of the importance of such trees, although 84% of respondents selected all the answers together with the wrong ones.

Sociological research has shown that people actively participated in the survey, were interested in gaining new knowledge about ancient trees, and were ready to join in the campaigns for their preservation. The significant number of responses to the optional open-ended question confirms this. 82% of

respondents described the actions they consider necessary for the conservation, necessary care, and promotion of “green giants”. Among the most answers interesting were: “It is necessary to organize informative, creative lectures and excursions for young people, disseminate information on the geographical location of ancient trees and other historically and culturally important plants in our country, their important role in society”, “It is necessary to conduct timely inspection and treatment, inform the younger generation about such trees as cultural heritage”, “An effective state policy on this issue is needed. Strengthening responsibility for the destruction or damage to heritage trees”. These answers emphasize the demand of people for more action by the authorities, ecoactivists, environmentalists, etc. The responses also confirm the need to spread knowledge about ancient trees, the organization of environmental events, and the promotion of environmental knowledge.

Therefore, ancient trees can only be preserved if the population is aware of their value. All other means of maintaining such trees are additional. Therefore, it is necessary to educate people about environmental behaviour using social and environmental sciences.

Monumental trees are special historical, natural and cultural assets of countries. They can contribute substantially to social welfare through the provision of ecological, aesthetic, and cultural benefits. In urban environments, monumental trees serve as pivotal structures that offer essential habitat resources for wildlife (Yaacob *et al.*, 2016). The loss of monumental trees will lead to adverse effects on the biodiversity and ecosystem services within a particular area. Additionally, these trees play a significant role in the cultural heritage of the country. Monumental trees, which are put into protection, help residents to realize the importance and value of such trees. The analysis of

existing databases (cadastres) of monumental trees in different countries reveals their diversity of species, sizes, and values (Dreslerová, 2017; Zhang *et al.*, 2017).

The study of M. Blicharska & G. Mikusis-ki (2014) emphasizes that ancient trees are part of a social realm, but their social significance is often neglected. The authors argue that recognizing ancient trees as integral to human identity is crucial for addressing the global decline of such trees. While the social significance of these trees is frequently overlooked in environmental conservation efforts, it ought to be a fundamental aspect of conservation policy (Pietrzak-Zawadka, 2016). The study by L. Hu *et al.* (2011) confirmed that local cultural beliefs and practices contribute to the preservation of large old trees. M. Kowalski (2020) suggests that heritage trees should be of interest not only to naturalists but also to sociologists. The author tried to analyse the reasons for the lack of public interest in heritage trees. M. Suchocka *et al.* (2022) conducted research aimed at revealing the population’s perception of ancient trees and establishing certain dependencies. The findings showed that there is a connection between how often people visit natural areas and how much they care about old trees. Moreover, older respondents (aged 56 and above) were more inclined to want to safeguard and nurture ancient trees. The study suggested that engaging in outdoor activities in urban forests could foster an emotional bond with ancient trees, potentially leading to greater efforts to protect them.

The number of monumental trees is rapidly decreasing in various parts of the world, with serious consequences for ecosystems and biodiversity. It is clear that a global coalition is needed to protect monumental trees. G. Piovesan *et al.* (2022) call for international efforts to conserve, identify and protect ancient trees as they may disappear. In the scientific environment, questions regarding the creation of cadastres

are raised not only at the local and national levels but also at the European and world levels. In the work of P. Zarzyński & A. Grzywacz (2019), it was proposed to give unique trees the status of a National Natural Monument and a European Natural Monument. It would also be good to unify the criteria that should be taken into account when assessing the historical, cultural, aesthetic, social and other values of monumental trees in different countries. Updating legislative and administrative systems and regular tree care can increase the long-term survival of monumental trees. Scientists T. Green (2002), L. Chiara (2011) also emphasize the need to regulate the terminology related to unique trees not only at the state level but also at the international level, which will contribute to such trees' preservation. Moreover, they argue that establishing standardized terminology for distinctive trees is crucial not just within individual states, but also on a global scale. This standardization at the international level is seen as instrumental in enhancing the preservation efforts of these exceptional trees. N. Becker & S. Freeman (2009) tried to understand the value of monumental trees through the economic component and established that funds should be allocated for the preservation of such trees.

W.Y. Chen (2015) found that there was a great need for unique trees to be interpreted by the public in a way that reflects their true value to society. He identified a significant demand for the public to comprehend unique trees in a manner that accurately reflects their genuine societal value. This underscores the importance of effective communication and public awareness campaigns to highlight the true worth of these distinctive trees in the broader context of societal well-being. X. Arnan *et al.* (2012) and C.Y. Jim (2017) highlight that community involvement is critical to the preservation and management of ancient trees. They underscore the critical role of community involvement in

the preservation and management of ancient trees. Their research emphasizes that engaging local communities is essential for fostering a sense of responsibility and shared commitment towards the protection of these significant natural assets. Therefore, J. Liu *et al.* (2019) recommend mobilizing citizens to participate in environmental protection activities. Hence, it was recommended to mobilise citizens to actively participate in environmental protection activities. Their suggestion underscores the pivotal role of public engagement in fostering collective responsibility for environmental conservation, including the safeguarding of ancient trees. In addition, H. Lin *et al.* (2020) suggested improving young citizens' knowledge of local monumental trees by linking them to local culture. C. Ordóñez-Barona *et al.* (2021) emphasized the importance of protecting and preserving such trees on private lands. N. Yao *et al.* (2024) introduced a conceptual framework aimed at evaluating the socio-cultural value of old trees and implementing multiscale protection measures. This framework offers insights that could inform enhancements to existing conservation policies.

Monumental trees serve as habitats for numerous rare and endangered species and represent an irreplaceable component of Ukraine's landscape and biological heritage. The authorities often provide administrative and professional support in the preservation of natural monuments' preservation. The city authorities of Kyiv take special measures to manage and protect them by publishing official reports with detailed information on the characteristics of the trees, their location, and measures to preserve them. A tree protection law makes sense if it can be implemented in an efficient and professional (Schmied & Pillmann, 2003). Therefore, the preservation of monumental trees depends on better management, and the awareness of residents and the encouragement

of responsibility for these trees are incredibly important. This study may initiate other lines of research to improve the management of unique trees.

### Conclusions

There are more than 3,000 monumental trees in Ukraine, 500 of which grow in Kyiv and its surroundings. The distribution of monumental trees varies across Oblasts, which is influenced by historical and climatic factors. The condition of more than 100 monumental trees in the occupied part of the country is unknown.

The dominant species of monumental trees is *Quercus robur*, the common species are represented by *Aesculus*, *Fraxinus*, *Populus*, *Tilia* and other genera in Ukraine. Monumental trees are usually single trees and only 29 places where monumental trees grow in alleys. Monumental trees of Kyiv are represented by 23 genera, most of which belong to the type *Magnoliophyta* and grow as single trees (68%). The richest species composition of rare species is represented by *Ailanthus altissima*, *Betula nigra*, *Buxus sempervirens*, *Calocedrus decurrens*, *Castanea sativa*, *Catalpa bignonioides*, *Cotinus coggygria*, *Craetagus monogyna*, *Fraxinus americana*, *Gleditsia triacanthos*, *Gymnocladus dioicus*, *Laurus nobilis*, *Liriodendron tulipifera*, *Metasequoia glyptostroboides*, *Phellodendron amurense*, *Platyclusus orientalis*, *Prunus padus*, *Pseudotsuga menziesii*, *Quercus petraea*, *Rhododendron myrtifolium*, *Rhus typhina*, *Robinia pseudoacacia*, *Sequoiadendron giganteum*, *Syringa josikaea*, *Tilia*

*tomentosa*, *Ulmus minor*, *Viburnum opulus*. Some genera are represented by several rare species (*Arbutus*, *Corylus*, *Cupressus*, *Juglans*, *Malus*, *Pinus*, *Pistacia*, *Sorbus*).

Ukrainian environmental NGOs often initiate the protection of ancient trees. Sociological research has shown a lack of public awareness of monumental trees. People's interest in nature, and monumental trees in particular, can be stimulated by local and regional authorities through cultural and environmental education activities. Positive experience in promoting monumental trees was gained by naming them after famous cultural and historical figures. Such "named trees" are often revered by residents. Involving the public in environmental protection activities through education and other programmes could raise awareness of the special value of monumental trees and promote their preservation. Thus, the preservation of monumental trees is only possible with the support and awareness of the value of the population.

Stabilization of the monumental trees' condition and care of them, the development of methods of monitoring their sanitary condition, and the formation of a responsible attitude of the population towards them are promising areas for further research.

### Acknowledgements

None.

### Conflict of Interest

None.

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## Дерева-пам'ятки природи України та обізнаність громадськості про них

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**Анотація.** Вивчення видового розмаїття та стану дерев-пам'яток природи сприяє їхньому збереженню та важливе для усвідомлення громадськістю їхньої ролі в екосистемах та екологічному спадку країни. Мета дослідження полягала в розкритті значення дерев-пам'яток природи для суспільства. Завданням цього дослідження було ознайомлення з характеристиками дерев-пам'яток природи в Україні. Проаналізовано історію заповідання та представлені особливості охорони та збереження таких дерев в Україні. Виявлено початок природоохоронної діяльності щодо заповідання дерев в Україні та найактивніші періоди. Наведені національні особливості популяризації дерев-пам'яток природи. На основі аналізу кадастрів ботанічних пам'яток природи України та Києва встановлено їх кількісний та видовий склад. Встановлені найбільш поширені (*Quercus robur*), поширені, менш поширені та рідкісні (*Buxus sempervirens*, *Catalpa bignonioides*, *Metasequoia glyptostroboides*, *Pseudotsuga menziesii*, *Rhododendron myrtifolium*, *Sequoiadendron giganteum* та

інші) види дерев-пам'яток природи, наведені основні проблеми щодо їхнього збереження. За типами вуличних посадок більшість дерев-пам'яток природи (68 %) – це солітери. Для оцінки обізнаності населення використано метод соціологічного опитування респондентів. Виявлені цінності вікових дерев, які є найбільш важливими для населення. Встановлено важливість обізнаності населення про вікові дерева через розвиток емоційного зв'язку з ними, що сприяє захисту дерев. Отримані результати можуть бути використані у подальшій заповідальній діяльності, при обміні досвідом науковців різних країн щодо збереження таких дерев, збагаченні інформації про особливості росту, історичні факти чи інші питання, пов'язані з цими деревами

**Ключові слова:** природно-заповідний фонд України; роди та види; збереження; охорона; популяризація; соціокультурна цінність

# УКРАЇНСЬКИЙ ЖУРНАЛ ЛІСІВНИЦТВА ТА ДЕРЕВИНОЗНАВСТВА

*Науковий журнал*

**Том 15, № 2. 2024**

Заснований у 2010 р. Виходить чотири рази на рік

Оригінал-макет видання виготовлено  
у відділі науково-технічної інформації  
Національного університету біоресурсів і природокористування України

**Відповідальний редактор:**

Г. Івченко

**Редагування англomовних текстів:**

С. Воровський, К. Касьянов

**Комп'ютерна верстка:**

О. Глінченко

Підписано до друку 29 травня 2024 р. Формат 70\*100/16

Умов. друк. арк. 13,8

Наклад 50 прим.

**Адреса видавництва:**

Національний університет біоресурсів і природокористування України

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**UKRAINIAN JOURNAL OF FOREST  
AND WOOD SCIENCE**

*Scientific journal*

**Volume 15, No. 2. 2024**

Founded in 2010. Published four times per year

The original layout of the publication is made in the Department of Scientific  
and Technical Information of National University of Life  
and Environmental Sciences of Ukraine

**Managing Editor:**

H. Ivchenko

**Editing English-language texts:**

S. Vorovsky, K. Kasianov

**Desktop publishing:**

O. Glinchenko

Signed for print of May 29, 2024. Format 70\*100/16  
Conventional printed pages 13.8  
Circulation 50 copies

**Editors office address:**

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