UDC 630*228:502.753

SPONTANEOUS FORESTS AS BIODIVERSITY CONSERVATION HOTSPOTS ON ABANDONED AGRICULTURAL LANDS

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This article presents an assessment of natural forest regeneration occurring on abandoned agricultural lands in the lowland part of the Ivano-Frankivsk region, where spontaneous forests have expanded markedly over recent decades. Against the background of increasing landscape fragmentation and the urgent need for biodiversity conservation in Ukraine, evaluating the ecological significance and successional pathways of such forests is of high relevance. Field surveys conducted in 2024–2025 across 27 sample plots included comprehensive measurements of tree, shrub and herb-layer composition, age structure assessment, and identification of rare, characteristic and invasive plant species. The study demonstrates that early-successional stands are dominated by pioneer species such as Betula pendula, Populus tremula, and Salix spp., forming relatively homogeneous canopies typical of initial post-agricultural stages. In contrast, older stands reveal active recruitment of shade-tolerant mesophilous species (Carpinus betulus, Quercus robur, Acer platanoides), indicating structural differentiation and progression toward mixed temperate forests. A total of 143 vascular plant species from 44 families were recorded, reflecting substantial floristic richness within spontaneous forests despite their relatively young age and anthropogenic history. Six species listed in the Red Data Book of Ukraine – including Galanthus nivalis, Leucojum vernum, and Cephalanthera longifolia, – were documented, with their occurrence strongly associated with proximity to primary forest patches and presence of semi-natural microhabitats. The study also identifies several invasive taxa, although their abundance decreases as canopy closure increases, illustrating natural biotic resistance development. Overall, the findings highlight that spontaneously regenerated forests function as important biodiversity reservoirs and ecological connectors within post-agricultural landscapes. The results underline the practical value of incorporating such forests into regional conservation planning, restoration strategies and sustainable land-management frameworks.

Key words: *spontaneous forests, natural succession, abandoned farmlands, vascular plants, rare species, invasive species, biodiversity conservation.*

DOI https://doi.org/10.32782/agrobio.2025.4.1

Introduction. Natural regeneration of forests on abandoned agricultural lands has become an visible ecological process in Ukraine over the past several decades. Following demographic shifts, changes in land-use priorities, and the decline of traditional farming systems, large areas of former arable fields have undergone spontaneous overgrowth (Gorodnucha, 2022; Openko & Gorodnucha, 2024). Unlike artificially planted forests, these spontaneous woodlands develop through self-sown tree recruitment and natural successional dynamics, reflecting the ecological potential of landscapes to recover without direct human intervention. This trend places Ukraine within a broader European context, where land abandonment and secondary forest succession have been widely documented and assessed in relation to biodiversity, climate adaptation, and restoration policy (Ustaoglu & Collier, 2018; Martín-Forés et al., 2020; Biró et al., 2022; Frei et al., 2024; Williams et al., 2024; Nadal-Romero et al., 2025).

While many European countries have already incorporated naturally regenerating forests into strategic conservation and restoration frameworks (Linser et al., 2023), in Ukraine such ecosystems only recently began receiving formal recognition. Legislative changes adopted in 2022 created a mechanism for including spontaneously regenerated woodlands into the national forest fund, signalling a shift toward acknowledging their ecological value (Law of Ukraine No. 2321-IX, 2022). Yet, compared to Western and Central Europe, systematic scientific assessments of these forests in Ukraine remain limited. This is especially important given that post-agricultural succession may proceed differently under Ukrainian climatic, edaphic, and socio-economic conditions than in other regions of Europe.

Current European studies provide valuable conceptual and methodological references for analysing the potential of spontaneous forests. Research from Central-European region shows that naturally regenerated stands can exhibit high structural complexity and support diverse assemblages of forest species, particularly where previous land-use pressures have ceased (Martín-Forés et al., 2020; Hampe et al., 2020; Navarro & Pereira, 2022; Maes et al., 2023; Ertunç & Janus, 2025; Dyderski et al., 2025). Mediterranean and mountain landscapes demonstrate that natural forest

expansion may restore ecological functions and reconnect fragmented habitats, strengthening biodiversity networks (Muys et al., 2022; Dollinger et al., 2023; Nadal-Romero et al., 2025). Within Natura 2000 territories, spontaneous forests have been linked to improvements in habitat quality and long-term conservation outcomes (Oikonomakis & Ganatsas, 2020; Santoro et al., 2024). Case studies from the Alps illustrate that early-successional secondary woodlands play a crucial role for sensitive bird species by providing structurally dense habitat unavailable in mature forests (Scridel et al., 2022). These examples highlight how spontaneous forests can contribute to multiple conservation objectives – from species protection to carbon sequestration – depending on regional context and landscape configuration.

In Ukraine, however, the dynamics and ecological significance of spontaneous forests are still poorly quantified. Preliminary expert assessments suggest that hundreds of thousands of hectares of such forests may exist (Gorodnucha, 2022), yet their structure, species composition, and ecological functions remain insufficiently studied. The Carpathian region is particularly relevant for this topic – due to complex topography, historical mosaic land-use, and high biodiversity, abandoned farmlands in these regions offer favourable conditions for natural tree colonisation. The Ivano-Frankivsk region contains distinctly separated lowland, foothill, and mountainous zones of the Ukrainian Carpathians, forming one of the country's key areas of biological richness. The proximity of mature forests, availability of seed sources, and varied terrain further accelerate spontaneous colonisation processes. As these regenerating tree stands develop, they have the potential to increase habitat continuity, enhance ecological permeability across the landscape, and provide refugia for species sensitive to fragmentation. Similar ecological outcomes resulting from spontaneous afforestation on abandoned agricultural land have been documented across European regions (Kolecka et al., 2017; Martín-Forés et al., 2020; Zarzycki et al., 2022; Nadal-Romero et al., 2025; Ertunç & Janus, 2025). However, despite the region's favourable preconditions and ecological significance, such dynamics in Ukraine remain understudied and require systematic scientific evaluation to understand their implications for biodiversity conservation and landscape management.

Furthermore, climate-change projections for Eastern Europe indicate that natural regeneration processes may accelerate or shift in trajectory depending on temperature and precipitation patterns, soil moisture regimes, and disturbance frequency (Maes et al., 2023; Derci Augustynczik et al., 2025). Understanding how these factors influence post-agricultural succession in the Ukrainian Carpathians is essential for predicting future landscape changes and developing informed management strategies (Verkerk et al, 2022; Janišová et al., 2024). The absence of targeted research limits the ability of regional authorities and conservation practitioners to integrate spontaneous forests into broader biodiversity, forestry, and land-use policies.

Given this gap, there is a clear need for comprehensive studies that document the composition, structure, and ecological functions of naturally regenerated forests in Ukraine. The present research focuses on spontaneous forests of the Ivano-Frankivsk region and aims to contribute to national scientific understanding of post-agricultural succession. The specific objectives include: (1) analyse the structural and floristic characteristics of spontaneous forests at different successional stages; (2) identify rare and protected species of flora and fauna associated with these habitats; (3) evaluate the ecological importance of spontaneous forests within regional landscape systems and their potential role in biodiversity conservation.

Materials and methods. The research was conducted during 2024–2025 within the lowland sector of the Ivano-Frankivsk region, focusing on areas where spontaneous forest regeneration has occurred on abandoned agricultural lands. Field observations were carried out within the Ivano-Frankivsk district, which represents characteristic Pre-Carpathian lowland environments with diverse land-use legacies and varying stages of natural succession. The study area is defined by a spatial mosaic of forest patches, shrub communities, meadow systems, and agricultural parcels, forming habitat conditions that support a comparatively high richness of vascular plant species, and faunal biodiversity (Prykhodko, 2009). The gradual decline in agricultural intensity in the lowland and foothill landscapes, as well as the withdrawal of croplands, hayfields, and pastures from active management, has created favourable ecological conditions for the establishment and expansion of naturally regenerated woody vegetation.

Sampling plots were selected according to the principle of representativeness to ensure inclusion of spontaneous forests that developed on former arable land, grazing areas, and hay meadows. The sites differed in soil type, successional advancement, and degree of past anthropogenic disturbance, which enabled the characterization of variation in floristic composition among regenerating forest stands (in total – 27 study sites). The investigated territory is predominantly underlain by grey forest soils. The comparison of agricultural and semi-natural habitats provides suitable ecological niches for the recruitment and establishment of early-successional tree and shrub species, forming conditions necessary for the development of self-sown forest ecosystems in the region.

Field investigations were carried out using the route method and detailed floristic sampling, following methodological approaches widely used in botanical research (Yakubenko, 2020). Surveys were performed during vegetation periods (June–September). Routes were established to cover the main types of spontaneous forest patches: young birch–aspen, mixed willow–birch stands on abandoned fields, and ecotones between spontaneous forests and active agricultural fields. In each location, special attention was given to compiling complete floristic species lists, estimating species frequency and projective cover, describing the vertical structure of the community, and noting ecological indicators associated with moisture, soil fertility, and disturbance. Spontaneous forests aged 15–30 years were examined by establishing temporary sample plots, which allowed for the analysis of vegetation structure at the stand level.

The determination of vascular plant species was carried out using the Vascular Plants of Ukraine: A Nomenclatural Checklist (Mosyakin & Fedoronchuk, 1999) together with the Red Data Book of Ukraine (Didukh, 2009) and the official lists approved by the Order of the Ministry of Environmental Protection and Natural Resources of Ukraine No. 111 of 15 February 2021, which defines plant and fungal species included in and excluded from the Red Data Book of Ukraine. Taxonomic nomenclature was aligned with the standards adopted in Plants of the World Online (POWO, 2025). During species verification, emphasis was placed on taxa typical of mid-successional forest communities, species indicative of former agricultural management, native pioneer woody plants, and invasive species that may reflect disturbance, soil alteration, or competitive displacement. Special attention was devoted to registering taxa listed in the Red Data Book of Ukraine, locally uncommon species characteristic of the Precarpathian region, and invasive plants that often signal anthropogenic pressure and successional restructuring. The occurrence of invasive species served as an ecological marker of transformation within spontaneous forest stands situated near cultivated landscapes.

Geographic coordinates of all sampling sites and vegetation plots were collected using handheld GPS devices with an accuracy of ± 3 m. Spatial interpretation and preliminary landscape assessment were undertaken using topographic maps, high-resolution imagery accessed through Google Maps, and field sketches that documented boundaries of spontaneously regenerated forest patches, transition zones, and remnants of former agricultural parcels. These spatial datasets allowed verification of historical land-use trajectories and ensured that the studied forest stands originated exclusively through natural regeneration processes.

Vegetation data were further processed to quantify community diversity and invasive species incidence at the plot level. Species richness (S) and the Shannon diversity index (H′) were calculated using proportional cover values for all recorded vascular plant taxa, following standard approaches applied in vegetation ecology. Invasive species metrics included invasive species richness per plot and percentage cover based on projective vegetation estimates. Canopy closure was assessed visually and verified through vertical structure descriptions recorded in the field. Statistical analyses included Pearson correlation procedures to evaluate relationships among stand age, canopy closure, species diversity, and invasive species abundance, while differences between stand age classes were tested using parametric significance thresholds ($\alpha = 0.05$).

Results. Analysis of the spontaneous forest stands formed on abandoned agricultural lands in the lowland part of the Ivano-Frankivsk region revealed clear structural and compositional patterns associated with the successional age of the communities and the type of former land use. Across all surveyed sites, the tree layer demonstrated a predictable trajectory of natural regeneration characteristic of early- to mid-successional stages in post-agricultural landscapes.

In the youngest forest stands (15–20 years), canopy formation was dominated by fast-growing pioneer species capable of rapid colonisation of open habitats. Silver birch (*Betula pendula* Roth) constituted the largest proportion of the tree layer, accounting for 44–57% of all recorded individuals. *Populus* spp. (*Populus tremula* L., *Populus nigra* L.) represented 23–31%, while *Salix* spp. formed additional components of the pioneer assemblage. These species reached heights of 9–13 m, with mean diameters of 10–15 cm, reflecting high growth rates under conditions of abundant light and soil nutrient levels typical of former agricultural fields. In forest stands aged 21–25 years, a gradual decline in the dominance of pioneer species was observed, accompanied by an increase in the frequency of *Acer pseudoplatanus* L. and *Acer platanoides* L., which collectively formed 6–12% of the tree layer. Their occurrence marks the beginning of a shift towards mixed-forest succession.

The oldest spontaneous forests (after 25 years) maintained a canopy still largely composed of birch and aspen, although both species exhibited signs of early canopy stratification and the emergence of gaps. Within these stands, a well-developed subcanopy of shade-tolerant broadleaved species was recorded. European hornbeam (*Carpinus betulus* L.) showed the highest frequency among late-successional species (22–29%), followed by maples (*A. platanoides* and *A. pseudoplatanus*), european ash (*Fraxinus excelsior* L.), pedunculate oak (*Quercus robur* L.), and lime (*Tilia cordata* Mill.). Although not yet reaching the upper canopy, these species demonstrate active recruitment, indicating the long-term transition of spontaneous forests toward mixed mesophytic communities typical of the region.

The shrub layer exhibited high structural variability and contributed significantly to the overall complexity of the communities. *Corylus avellana* L. achieved the highest projective cover (28–32%), followed by *Sambucus nigra* L., *Crataegus monogyna* Jacq., *Viburnum opulus* L., and *Euonymus europaeus* L. Shrub cover increased with stand age, suggesting progressive shading of the herb layer.

Floristic analysis of the herb layer identified 143 vascular plant species belonging to 44 families, with the highest species richness recorded in stands aged 26–30 years. *Asteraceae* (18 species), *Poaceae* (15 species), *Rosaceae* (12 species), and *Fabaceae* (9 species) were the most species-rich families. Projective cover in the herb layer ranged from 55–62% in the youngest stands to 32–40% in the oldest ones. Species diversity, as measured by the Shannon index, increased significantly with stand age ($H' = 3.28 \pm 0.21$ for 15–20-year stands; $H' = 4.11 \pm 0.24$ for 26–30-year stands; $p < 0.01$), indicating the progressive recovery of herbaceous diversity as forest structure developed.

Spontaneous forests also harbored a range of invasive and adventive plant species, most notably within plots situated near actively managed farmland and structurally disturbed ecotones. In total, eleven invasive taxa were recorded across the sampling network. *Heracleum sosnowskyi Manden.* was detected in 32% of plots, forming patches with 5–18% cover, particularly in areas with high light availability and soil disturbance. Separately, *Impatiens parviflora* DC. occurred with similar frequency, occupying shaded edges and moist microhabitats, where it reached comparable lev-

els of cover. *Solidago canadensis* L. was primarily associated with younger stands, displaying cover values of 3–12%. Additional invasive species included the woody taxon *Acer negundo* L., whose presence showed a clear affinity for reduced canopy closure and spatial proximity to cropland. The cumulative cover of invasive species declined substantially with stand development, decreasing from 22–28% in 15–20-year-old forests to 15–18% in 21–25-year-old stands ($p < 0.01$), indicating that advancing canopy shading and increasing competitive pressure enhance the capacity of spontaneous forests to suppress invasive flora.

Despite the presence of invasive species, spontaneous forests on post-agricultural lands in the Ivano-Frankivsk region have been found to harbor six species listed in the Red Data Book of Ukraine, including *Galanthus nivalis* L. Populations of *G. nivalis* varied in density, ranging from small clonal groups to large aggregations exceeding 42 individuals per plot. This species is typically associated with semi-shaded microhabitats featuring stable soil moisture, conditions characteristic of aging spontaneous forests. Other rare taxa identified include *Leucojum vernum* L., *Cephalanthera longifolia* (L.) Fritsch, *Epipactis atrorubens* (Hoffm.) Besser, *Platanthera bifolia* (L.) Rich., and *Allium ursinum* L., which generally inhabit similar microenvironments.

These findings confirm the significance of spontaneous forests on post-agricultural lands as refugia for rare and protected species, particularly highlighting the conservation importance of *G. nivalis* populations. Such habitats provide valuable natural microhabitats essential for the preservation of regional flora. Spatial analysis revealed opposing patterns in the distribution of rare and invasive species. The richness of Red Book taxa exhibited a strong negative correlation with distance from mature forest stands ($r = – 0.71$, $p < 0.001$), with the highest concentrations found in spontaneous forests located within 500 m of natural mixed or broadleaved forest fragments. By contrast, invasive species richness and cover showed a positive correlation with proximity to active agricultural lands ($r = 0.64$, $p < 0.001$) and a negative correlation with canopy closure ($r = – 0.58$, $p < 0.01$). These complementary patterns emphasise the dual ecological role of spontaneous forests: on the one hand, acting as corridors and buffer zones that support the dispersal and establishment of rare species; on the other, gradually reducing the prevalence of invasive taxa as successional processes progress.

Discussion. The patterns of natural forest regeneration observed on abandoned agricultural lands in the lowland zone of Ivano-Frankivsk region exhibit strong convergence with recognised successional pathways documented for post-agricultural landscapes throughout temperate Europe. Similar to findings from Central European cultural landscapes and Carpathian foothills, early forest development is characterised by the dominance of light-demanding pioneer taxa, notably *B. pendula* and *P. tremula*, which rapidly colonise open terrain and initiate canopy formation – supported for wider European contexts by Santoro et al. (2024) and Bortnyk et al. (2025). This pioneer dominance reflects broader ecological mechanisms where nutrient-enriched soils, reduced competition and residual agricultural structure accelerate the establishment processes, a dynamic repeatedly confirmed in European secondary forests following spontaneous regrowth (Nadal-Romero et al., 2016).

With increasing stand age, recruitment of late-successional broadleaved species (e.g., *C. betulus*, *Q. robur*, *A. platanoides*) signals a directional shift towards structurally complex communities. This transition is closely linked to proximity of seed sources and remnant mature forest fragments, as suggested by Williams et al. (2024), with field studies and remote sensing consistently highlighting the importance of nearby woodland for promoting succession and characteristic forest flora. Our findings echo continent-wide analyses, indicating that natural regeneration can be an effective, low-input pathway to forest landscape restoration – particularly where seed dispersal from mature woodland is ensured (INRAE, 2024; Linser et al., 2023).

The impressive floristic richness, with 143 vascular plant species from 44 families recorded in the herb layer, underscores the ecological value of spontaneous forests in post-agricultural terrain. Such levels of diversity parallel results from the Polish Carpathians and Eastern Carpathian grassland mosaics, where land abandonment fosters structurally heterogeneous communities within a few decades (Kolecka et al., 2017; Janišová et al., 2024). The observed increase in diversity metrics over time aligns with European-wide models indicating advancing succession enhances recruitment of forest-associated herbs and shrubs and reduces ruderal dominance (Nadal-Romero et al., 2016).

Patterns involving invasive species provide insight into disturbance-mediated processes. The higher prevalence of Impatiens parviflora and Solidago spp. in younger stands fits with regional data showing that invasive taxa flourish in high-light, open-canopy conditions typical of early post-agricultural succession phases, but decline with increased canopy density (Perera et al., 2021; Zarzycki et al., 2022). This supports the principle that canopy closure naturally limits invasion pressure via shading and competition – a robust mechanism established in Poland, Slovakia and Germany.

The spatial separation between rare and invasive taxa underlines important conservation implications. Red-listed species, such as *G. nivalis*, *P. bifolia*, most frequently occur in spontaneous forests adjacent to mature stands, operating as ecological corridors and microrefugia supporting dispersal and persistence of sensitive rare species (Williams et al., 2024). In contrast, proximity to agricultural land correlates with higher invasive presence due to ongoing propagule inflow, a pattern recognised in continental analyses of land abandonment dynamics (Nadal-Romero et al., 2016).

Taken together, these results demonstrate that spontaneous forests in the Pre-Carpathian lowlands act as self-organising systems capable of restoring structural heterogeneity, improving habitat quality, supporting protected flora, and suppressing invasive species. Recent Europe-wide assessments stress the substantial role of natural regeneration in meeting biodiversity and climate adaptation objectives, as well as in restoration policy frameworks (Muys et al., 2022; Verkerk et al., 2022; Linser et al., 2023). In regions marked by ongoing agricultural abandonment, formally

incorporating spontaneous forests into conservation policy and sustainable land-use planning promises substantial ecological and socio-economic gains.

Conclusions. The study demonstrated that spontaneous forests forming on abandoned agricultural lands in the lowland part of the Ivano-Frankivsk region follow a predictable and ecologically robust successional trajectory leading toward structurally complex mixed-forest communities. The results revealed high floristic richness and rapid accumulation of forest-specialist species already within the first 30 years of natural regeneration, highlighting the substantial recovery potential of post-agricultural soils in the Pre-Carpathian lowland region. A novel contribution of this research is the documented co-occurrence of rare Red Book species and the gradual suppression of invasive taxa as canopy closure and stand maturity increase. The findings confirm that spontaneous forests function as effective ecological corridors, supporting connectivity with nearby mature forests while simultaneously buffering agricultural landscapes from biological invasions. These insights hold practical value for regional land-use planning, demonstrating that naturally regenerated forests represent a high-benefit tool for biodiversity conservation and landscape restoration. Future research should focus on long-term monitoring of successional dynamics, assessment of ecosystem services provided by spontaneous forests, and evaluation of their potential integration into national afforestation and climate adaptation programmes.

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Самосійні ліси як осередки збереження біорізноманіття на покинутих сільськогосподарських землях

У статті представлено результати дослідження процесів природного лісовідновлення на занедбаних сільськогосподарських угіддях рівнинної частини Івано-Франківської області. На тлі посилення фрагментації ландшафтів та нагальної потреби збереження біорізноманіття в Україні, визначення екологічного значення та сукцесійних траєкторій таких лісів набуває особливої актуальності. Польові дослідження, проведені у 2024–2025 рр. на 27 пробних ділянках, охоплювали комплексне вивчення складу деревного, чагарникового та трав'яного ярусів, аналіз вікової структури, а також ідентифікацію видового різноманіття, у тому числі рідкісних та інвазійних видів. Дослідження показало, що ліси ранніх сукцесійних стадій характеризуються домінуванням піонерних видів, зокрема Betula pendula, Populus tremula та Salix spp., які формують відносно однорідний полог, типовий для початкових постаграрних етапів відновлення екосистем. Натомість у старших деревостанах спостерігається активне залучення тіньовитривалих мезофільних порід (Carpinus betulus, Quercus robur, Acer platanoides), що свідчить про структурну диференціацію та поступовий перехід до змішаних неморальних лісів. Загалом виявлено 143 види судинних рослин, що належать до 44 родин, що відображає значний флористичний потенціал самосійних

лісів попри їх відносно молодий вік та антропогенне втручання в минулому. Зафіксовано шість видів, включених до Червоної книги України, серед них Galanthus nivalis, Leucojum vernum та Cephalanthera longifolia – їх трапляння скорельоване із близькістю до ділянок корінних лісів та наявністю природних біотопів. У ході дослідження також ідентифіковано кілька інвазійних таксонів, однак їх поширення зменшується зі зростанням зімкненості намету, що демонструє формування природної біотичної резистентності самосійних лісів. Загалом результати засвідчують, що самосійні ліси функціонують як важливі резервуари біорізноманіття та екологічні коридори в аграрних ландшафтах. Отримані дані підкреслюють практичну цінність включення таких лісів до регіонального природоохоронного планування, стратегій екологічного відновлення та систем сталого землекористування.

Ключові слова: *самосійні ліси, природна сукцесія, покинуті сільськогосподарські землі, судинні рослини, рідкісні види, інвазійні види, збереження біорізноманіття.*

Дата першого надходження рукопису до видання: 21.11.2025
Дата прийнятого до друку рукопису після рецензування: 25.12.2025
Дата публікації: 31.12.2025