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Macrofungal diversity and ecological distribution along altitudinal gradients in coniferous forests of Bjeshkët e Nemuna National Park (Kosovo)

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ABSTRACT

Macrofungi are key functional components of forest ecosystems, contributing to nutrient cycling, organic matter decomposition and ecosystem stability. This study assessed macrofungal diversity and ecological distribution patterns in coniferous forests of "Bjeshkët e Nemuna" National Park (western Kosovo) during autumn 2025. Systematic sampling along altitudinal gradients was conducted across three localities using standardized 10 × 10 m plots. All visible fruiting bodies were recorded and identified through morphological and microscopic analyses. A total of 146 collections were examined, representing 108 species newly recorded for Kosovo, significantly expanding the knowledge of the national mycobiota. Functional analysis showed ectomycorrhizal fungi as the dominant ecological group, followed by terricolous and lignicolous taxa, highlighting their essential role in forest nutrient dynamics and soil processes. Diversity indices indicated high species diversity and low dominance (Shannon $H' = 3.50–3.99$; Simpson's $1 - D > 0.96$), while Jaccard similarity (0.293–0.412) demonstrated moderate spatial turnover. Species richness decreased with increasing elevation, suggesting that microclimatic variability and habitat heterogeneity strongly influence fungal distribution patterns. These results substantially expand the known macrofungal diversity of Kosovo by documenting 108 species newly recorded for the country and reveal clear ecological and altitudinal patterns in coniferous forest communities, providing an important baseline for future biodiversity monitoring and conservation in mountainous ecosystems.

Keywords: macrofungal diversity, monitoring, forest ecosystem, environmental assessment.

INTRODUCTION

Forests represent highly complex ecosystems characterized by exceptional biodiversity and dynamic ecological processes. Among their most important biological components are macrofungi, which play a crucial role in maintaining ecological balance (Liu et al., 2019). As primary decomposers, macrofungi facilitate the breakdown of organic matter and drive nutrient cycling, thereby sustaining soil fertility and supporting vegetation dynamics (Osono, 2015). Through symbiotic associations with plants, particularly in the form of mycorrhizae, they enhance nutrient and water uptake, contributing to forest productivity and resilience (Bahram and Netherway, 2022). Due to their sensitivity to environmental changes, fungal communities are increasingly recognized as reliable indicators of ecosystem health and environmental quality (Liu et al., 2023). Monitoring fungal diversity, abundance, and functional composition is therefore essential for evaluating forest condition and guiding sustainable management strategies (Giauque and Hawkes, 2016). Macrofungi, defined as fungi producing conspicuous fruiting bodies visible to the naked eye, include representatives of Basidiomycetes and Ascomycetes (Roda, 2010). Ecologically, they are categorized as saprotrophic, symbiotic (mainly mycorrhizal), or parasitic species (Mueller et al., 2007).

Kosovo is situated in the central part of the Balkan Peninsula and is characterized by diverse natural features that support a wide range of vegetation types and ecological habitats, distributed across three biogeographic regions: Alpine, Continental and sub-Mediterranean (Berisha et al., 2025). These environmental conditions, together with pronounced altitudinal gradients and varied climatic influences, create a mosaic of habitats capable of supporting diverse fungal communities. Despite the ecological importance of fungi in forest ecosystems, macrofungal diversity in Kosovo remains insufficiently investigated. Early studies reported only a limited number of species and were largely based on sporadic collections rather than systematic ecological surveys (Tortic and Sylejmani, 1982). Although more recent studies have increased the number of recorded taxa, including several ecologically important and newly documented species (Ramshaj et al., 2021, 2022; Ramshaj and Karadelev, 2025), current knowledge of macrofungal diversity, ecological distribution and community structure in Kosovo remains fragmentary. Kosovo represents one of the least studied regions in the Balkans with respect to fungal biodiversity. In particular, mountain forest ecosystems have received limited scientific attention, despite their potential to support diverse fungal communities due to pronounced altitudinal gradients, heterogeneous habitats and varied microclimatic conditions. Understanding macrofungal diversity and ecological distribution in these environments is essential for improving current knowledge of fungal biodiversity and for supporting conservation and sustainable forest management. National Park "Bjeshkët e Nemuna," located in the western and southwestern part of Kosovo, represents one of the country's most important protected mountainous ecosystems. Covering more than 63,000 ha, the park is characterized by diverse forest cover, including extensive coniferous stands alongside mixed and deciduous forest types together with marked altitudinal variation and distinct microclimatic conditions that provide favorable environments for fungal development and ecological differentiation (Berisha and Bytyqi, 2021). Spatial variability in climate, soil properties and vegetation structure generates heterogeneous habitats that may strongly influence macrofungal diversity and distribution patterns. The present study aims to investigate macrofungal diversity and ecological distribution patterns along altitudinal gradients in coniferous forests of Bjeshkët e Nemuna National Park. Specifically, the objectives of this study are to document macrofungal species occurring in selected forest habitats, analyze the ecological composition of fungal communities and to examine patterns of species richness along elevation gradients. By providing new distribution records and ecological data, this research contributes to improving current knowledge of fungal diversity in Kosovo and strengthens the scientific basis for biodiversity monitoring and conservation of forest ecosystems in the Balkan region.

MATERIAL AND METHODS

Study area

The study was conducted in coniferous forest ecosystems of National Park "Bjeshkët e Nemuna", located in the western part of Kosovo, during the autumn season of 2025 (Figure 1). The area is characterized by complex mountainous topography with montane and subalpine forest zones and pronounced altitudinal variation. Field sampling was carried out at three localities: Kuqishtë (42°41′09.8″N, 20°04′42.4″E; 1290 m a.s.l.), Bogë (42°45′17.5″N, 20°03′18.6″E; 1480 m a.s.l.) and Koshutan (42°43′43.0″N, 20°06′20.0″E; 1250 m a.s.l.). The investigated sites were situated within an elevation range of 1250–1480 m a.s.l., representing montane coniferous forest habitats. Every sampling site is located in alpine climate conditions. In Kuqishtë, the average annual precipitation ranges from 1000 to 1100 mm, with an average annual temperature of 6.5 °C. Bogë experiences precipitation between 970 and 1030 mm and temperatures from 5.8 to 6.8 °C, while Koshutan receives 1000–1070 mm of precipitation with an average temperature of 6.7 °C. The substrate at all three sites consists of shallow brown soil over compact limestone. The dominant tree species in these forests included

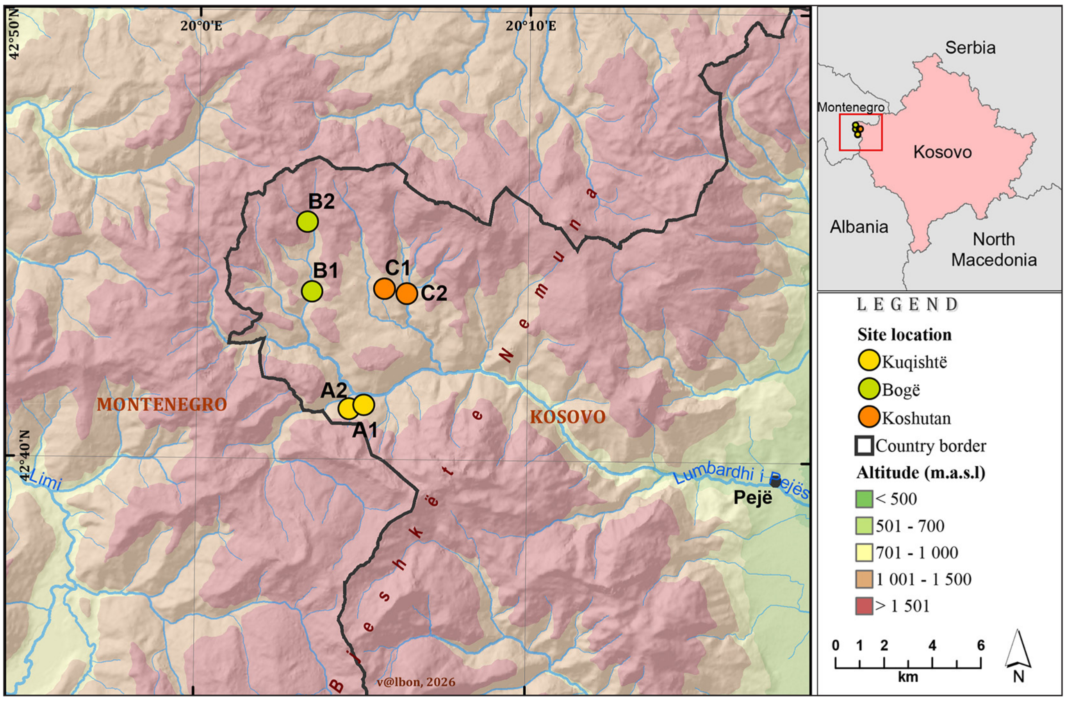

Figure 1. Geographic distribution of study sites sampled for fungal collections in Kosovo

Picea abies and *Abies alba*, forming relatively homogeneous coniferous stands suitable for comparative assessment of macrofungal diversity. Sampling sites were selected along the altitudinal gradient at spatially distinct locations to capture potential variability in fungal community composition under differing microenvironmental conditions. The regional climate is mountainous, characterized by cold winters and mild summers, with relatively high annual precipitation typical of high-elevation forest ecosystems in the western Balkan region. Soils in the area are predominantly mountain forest soils developed on mixed geological substrates, providing suitable conditions for diverse fungal communities.

Sampling design and collection

Sampling was conducted along predetermined transects combined with random placement of plots to ensure representative coverage of habitat types and elevational gradients. At each locality (Kuqishtë, Bogë and Koshutan), three transects were established, and five 10 × 10 m plots were laid out along each transect, with plots spaced approximately 50 m apart, resulting in 15 plots per locality and a total of 45 plots (4500 m^2) across all sites. An adaptive plot-based sampling approach was applied following Prayudi et al. (2019). Sampling was carried out during two field surveys, on 25 September and 1 November 2025, to capture temporal variation in macrofungal fruiting. All visible macrofungi within the plots were recorded, photographed in situ and carefully collected using sterilized knives to minimize disturbance to the substrate. Fresh specimens were wrapped in aluminum foil, whereas dried material was stored in brown paper bags for further laboratory examination.

Identification and preservation

Collected specimens were transported to the laboratory and processed within 24 hours, with priority given to the identification of fresh basidiomata. All specimens were photographed in situ prior to collection to document macroscopic features and additional photographs of fresh basidiocarps were taken for each voucher. Macroscopic characters were recorded before drying. Morphological identification was carried out using standard European keys and monographs (Breitenbach and Kränzlin, 1984–2000; Knudsen and Vesterholt, 2012; Laessøe and Petersen, 2019; Bernicchia and Gorjón, 2010). Diagnostic macrocharacters included pileus shape, size, surface texture and coloration, lamellae attachment and spacing, margin characteristics, stipe morphology, context, presence or absence of annulus, basal structures, basidiocarp consistency and spore print colour.

Microscopic observations were performed using a light microscope (Optika B-800) at magnifications of ×600 and ×1000, equipped with an OPTIKA C-P20 digital camera (20 megapixels; 5440 × 3648 resolution). Microscopic preparations were mounted in Melzer's reagent, Congo Red and 3–5% KOH to examine spore size, shape, ornamentation, amyloid or dextrinoid reactions and the presence of cystidia and other hymenial structures. Species occurrence and distributional records were cross-checked using the Global Biodiversity Information Facility (GBIF, 2026). Further taxonomic and ecological information was gathered from bibliographic databases such as Google Scholar (2026) as well as from authoritative online resources, including the USDA Fungal Databases (2026) and CAB International (2026). Taxonomic names and nomenclature were verified using online databases, including MycoBank (2026) and Index Fungorum (2026).

Voucher specimens were dried at 45–50 °C for 12 hours using a hot-air dryer and deposited in the Herbarium of the Faculty of Mathematical and Natural Sciences, University of Prishtina, under RQPC collection numbers.

RESULTS

Across 45 plots in Kuqishtë, Bogë and Koshutan, surveyed in September and November 2025, a total of 146 fungal specimens were collected. Of these, 108 species represent new records for the mycobiota of Kosovo (Table 1). Table 1 summarizes species occurrence by sampling site, month and elevation range.

These specimens encompassed 56 genera, 42 families and 15 orders. Figure 3 presents the distribution of the number of taxa per family. For clarity and improved visualization, families represented by only a single species were not individually displayed in the figure. These families include *Amanitaceae, Auriculariaceae, Auriscalpiaceae, Bankeraceae, Clavariaceae, Clavariadelphaceae, Clitocybaceae, Exidiaceae, Gomphaceae, Gomphidiaceae, Hygrophoropsidaceae, Hymenochaetaceae, Lycoperdaceae, Lyophyllaceae, Melanoleucaceae, Omphalinaceae, Paxillaceae, Peniophoraceae, Podoscyphaceae, Polyporaceae, Pyronemataceae, Rickenellaceae, Tremellaceae, Trichaptaceae* and *Trichiaceae,* each represented by a single recorded taxon in the present study.

The recorded taxa were categorized according to their ecological strategy into 54 mycorrhizal, 29 lignicolous and 25 terricolous species (Figure 2). Mycorrhizal fungi represented the dominant ecological category and included species belonging to the genera *Cortinarius, Lactarius, Russula* and *Tricholoma*, which were commonly associated with forest stands. Terricolous species were also well represented, with taxa such as *Aleuria, Clavariadelphus, Hydnum* and *Melanoleuca* occurring on soil and leaf litter. In contrast, lignicolous taxa, including *Abortiporus, Armillaria, Gloeophyllum* and *Panellus*, were found on decaying wood, reflecting their specialized ecological niches.

DISCUSSION

Among the recorded taxa, several species are of particular ecological, biogeographical, and conservation interest. These include rare species, taxa included in national Red Lists of European countries, and species with restricted or poorly documented distributions in southeastern Europe. Their occurrence in the coniferous forests of the Bjeshkët e Nemuna Mountains highlights the ecological integrity of these habitats and underlines the importance of this region as a potential refugium for sensitive macrofungal taxa. The following section discusses these noteworthy species in greater detail, focusing on their distributional significance, conservation status, and ecological associations.

Diversity and community structure of macrofungi

Alpha diversity: Shannon and Simpson indices

Macrofungal diversity across the sampled localities was quantified using the Shannon-Wiener diversity index (H′) (Wang et al., 2021), based on species occurrence data obtained from the systematic field surveys (Table 1). Because the dataset was structured in a presence-absence format, each species was treated as contributing equally within a given site. Under these conditions, Shannon diversity simplifies to: $H'=\ln(S)$, where S represents the total number of species recorded at each locality. Shannon diversity values were consistently high across all three sites, reflecting species-rich communities within the

Table 1. Occurrence and distribution of fungal taxa

Fungal taxa	Collection site			Collection month		Elevation (m a.s.l.)		
	Site A	Site B	Site C	Sep	Nov	1200–1300	1300–1400	1400–1500
Abortiporus biennis	▪			▪		▪		
Aleuria aurantia	▪				▪	▪		
Aleurodiscus amorphus			▪	▪				▪
Amanita gemmata	▪			▪		▪		
Armillaria cepistipes	▪				▪	▪		
Armillaria ostoyae	▪		▪	▪		▪		▪
Boletus edulis		▪		▪				▪
Boletus edulis f. albus		▪		▪				▪
Calocera cornea			▪		▪	▪		
Calocera viscosa	▪	▪	▪	▪	▪	▪	▪	▪
Calonarius cupreorufus		▪		▪				▪
Cantharellus amethysteus	▪			▪		▪		
Chalciporus piperatus			▪	▪				▪
Chalciporus rubinellus	▪			▪		▪		
Chamaemyces fracidus	▪				▪	▪		
Chroogomphus helveticus	▪		▪	▪	▪	▪		▪
Chrysomphalina grossula			▪		▪	▪		
Clavaria acuta	▪				▪	▪		
Clavariadelphus truncatus			▪		▪	▪		
Clavulina coralloides			▪		▪	▪		
Collybia nuda		▪			▪	▪		
Cortinarius cinnamomeus			▪	▪				▪
Cortinarius collinitus		▪			▪	▪		
Cortinarius cumatilis			▪	▪				▪
Cortinarius sanguineus	▪			▪		▪		
Cortinarius semisanguineus	▪			▪		▪		
Cortinarius varius	▪				▪		▪	
Craterellus lutescens		▪			▪	▪		
Cyanosporus caesius			▪		▪	▪		
Cystodermella terryi	▪				▪		▪	
Dacrymyces stillatus		▪		▪				▪
Exidia pithya	▪			▪		▪		
Fuscospina nigrescens			▪	▪				▪
Galerina autumnalis	▪			▪		▪		
Galerina stylifera		▪			▪			▪
Globulicium hiemale	▪			▪		▪		
Gloeophyllum abietinum			▪		▪	▪		
Gloeophyllum sepiarium			▪	▪				▪
Gloiothele citrina	▪				▪		▪	
Gymnopilus bellulus	▪	▪			▪	▪	▪	
Hebeloma cavipes			▪		▪	▪		
Hemitrichia decipiens		▪			▪	▪		
Hydnum repandum		▪			▪	▪		
Hygrophoropsis aurantiaca		▪	▪		▪	▪		▪
Hygrophorus agathosmus		▪		▪				▪
Hygrophorus discoideus		▪			▪	▪		

Table 1. Cont.

Hygrophorus discoxanthus		▪			▪	▪		
Hygrophorus piceae	▪				▪		▪	
Hygrophorus pudorinus		▪	▪		▪	▪		▪
Hypholoma capnoides		▪	▪	▪	▪	▪		▪
Hypomyces lactifluorum		▪		▪		▪		
Inocybe mixtilis	▪			▪		▪		
Inocybe nitidiuscula		▪			▪	▪		
Inocybe sindonia	▪				▪		▪	
Inocybe splendens	▪				▪		▪	
Inocybe whitei	▪				▪		▪	
Lactarius aurantiacus	▪				▪		▪	
Lactarius deterrimus	▪			▪		▪		
Lactarius salmonicolor	▪		▪	▪	▪		▪	▪
Lactifluus volemus	▪				▪		▪	
Lentinellus castoreus	▪		▪	▪	▪	▪	▪	
Lepiota ignivolvata		▪		▪				▪
Lyophyllum decastes		▪			▪	▪		
Macrolepiota mastoidea			▪		▪	▪		
Melanoleuca cognata		▪	▪		▪	▪		
Mycena crocata			▪		▪	▪		
Mycena epipterygia	▪	▪	▪		▪	▪	▪	
Mycena flavescens	▪				▪		▪	
Mycena flos-nivium	▪				▪		▪	
Mycena rosea		▪			▪	▪		
Mycena stipata			▪	▪				▪
Mycetinis scorodonius			▪	▪	▪	▪	▪	
Neolentinus adhaerens	▪				▪		▪	
Omphalina subhepatica		▪		▪				▪
Omphalina sphagnicola			▪	▪				▪
Panellus mitis		▪	▪		▪	▪		
Paragymnopus perforans	▪				▪		▪	
Paxillus involutus	▪		▪	▪	▪	▪		▪
Phaeotremella foliacea		▪			▪	▪		
Phellinus hartigii		▪		▪				▪
Phlegmacium glaucopus	▪	▪		▪	▪	▪	▪	
Pholiota lenta	▪				▪	▪		
Pholiota squarrosa		▪		▪				▪
Pholiota subochracea			▪	▪				▪
Pseudohydnum gelatinosum			▪	▪	▪	▪		▪
Ramaria flavescens	▪			▪		▪		
Russula atrorubens	▪	▪		▪	▪	▪		
Russula badia	▪	▪		▪		▪		▪
Russula cavipes	▪			▪		▪		
Russula firmula			▪	▪				▪
Russula mustelina	▪	▪		▪	▪	▪		
Russula postiana	▪			▪		▪		
Russula pseudo-olivascens	▪			▪		▪		

Table 1. Cont.

Russula viscida		▪		▪				▪
Sarcodon imbricatus		▪		▪				▪
Stereum sanguinolentum	▪	▪	▪	▪	▪	▪	▪	▪
Stropharia aeruginosa		▪		▪				▪
Stropharia caerulea	▪		▪		▪	▪	▪	
Thaxterogaster turmalis	▪				▪		▪	
Trichaptum abietinum	▪		▪	▪	▪		▪	▪
Tricholoma atrosquamosum		▪			▪	▪		
Tricholoma bufonium	▪	▪	▪	▪	▪	▪	▪	
Tricholoma fracticum	▪			▪		▪		
Tricholoma pardinum	▪			▪		▪		
Tricholoma saponaceum	▪	▪			▪	▪	▪	
Tricholoma scalpturatum			▪		▪	▪		
Tricholoma vaccinum			▪	▪				▪
Tricholomopsis rutilans	▪		▪	▪	▪	▪	▪	▪
Total	54	41	40	58	65	68	27	37
Relative abundance (%)	50	37.9	37.0	53.7	60.1	62.9	35.0	34.2

Note: occurrence (%) = total number of fungal taxa occurred/total number of fungal taxa) × 100; (▪) = present.

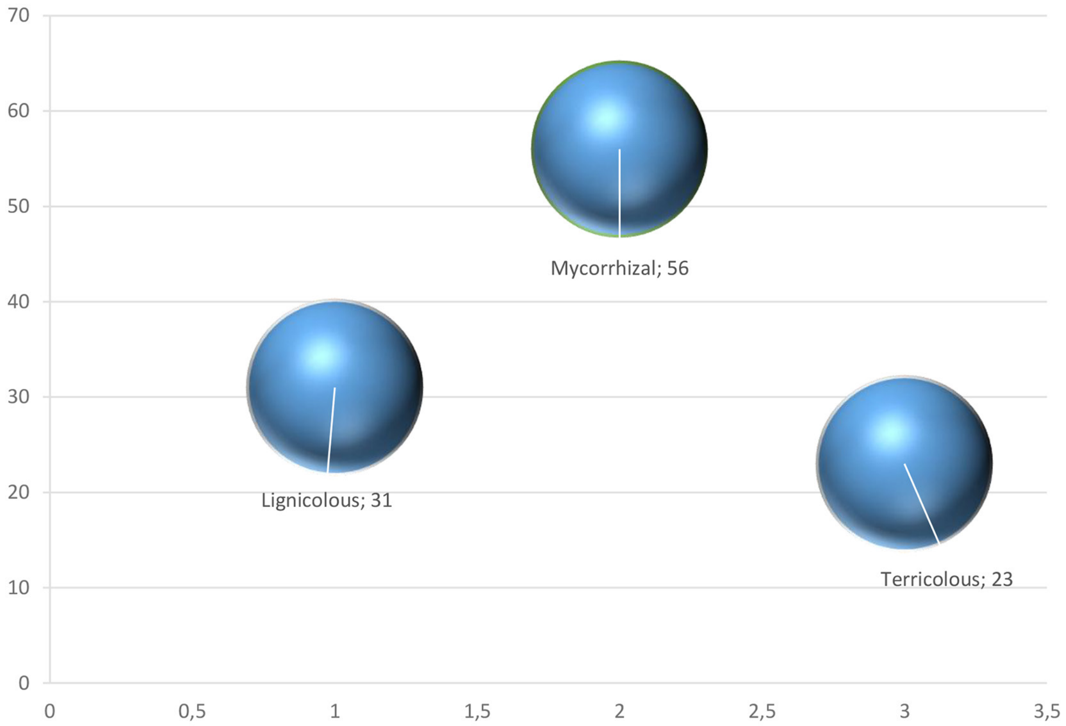

Figure 2. Ecological structure of the fungal community across the study area

coniferous forests of Bjeshkët e Nemuna National Park. Site A, with 54 recorded taxa, exhibited the highest diversity (H′ = 3.99), followed by Site C (42 taxa; H′ = 3.74) and Site B (33 taxa; H′ = 3.50). All values exceeded 3.0, indicating well-structured and ecologically robust macrofungal assemblages. The elevated diversity at Site A primarily reflects greater species richness and may be associated with increased habitat heterogeneity, substrate variability, and microclimatic complexity. In contrast, the comparatively lower diversity at Site B could be influenced by local

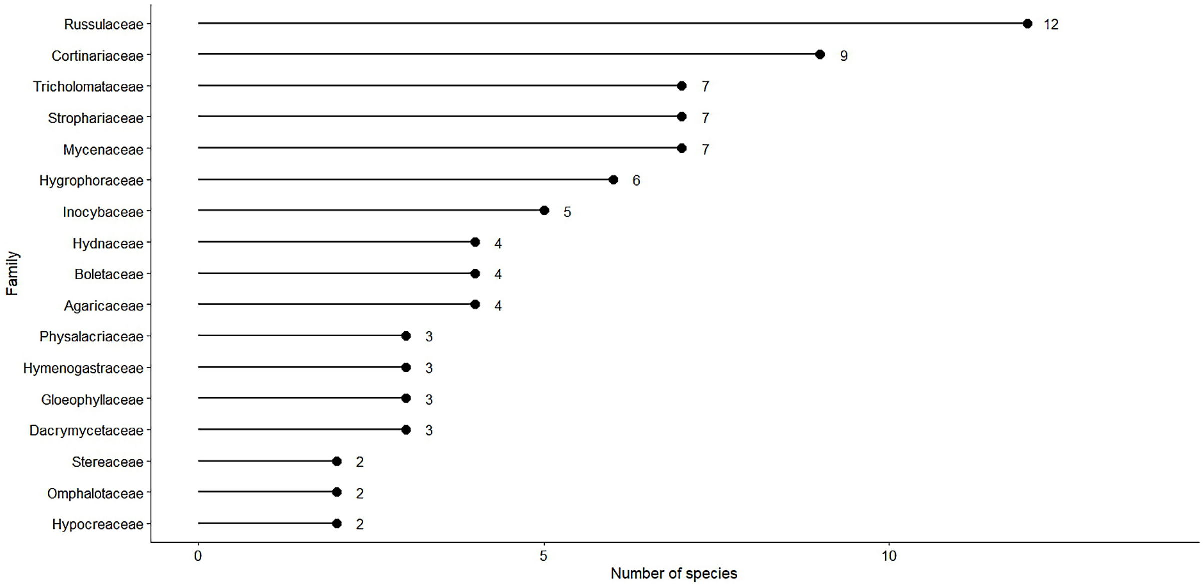

Figure 3. Distribution of recorded fungal taxa by family

environmental constraints such as higher elevation, reduced substrate diversity, or more uniform microclimatic conditions. Overall, the Shannon index highlights the ecological importance of these montane coniferous forests as significant reservoirs of fungal biodiversity.

To complement Shannon diversity, Simpson's diversity index was also calculated. Simpson's index is particularly useful because it is more sensitive to dominance patterns, detecting whether a community is structured around a few prevalent taxa. Under the presence-absence assumption, Simpson's dominance simplifies to: $D=1/S$ and Simpson's diversity to: $1-D=1-(1/S)$. Simpson's diversity values were uniformly high across sites, indicating low dominance and broad species distribution. Site A again showed the highest value ($1 - D = 0.9815$), followed by Site C ($1 - D = 0.9762$), and Site B ($1 - D = 0.9697$). The consistency between Shannon and Simpson indices strengthens the interpretation that Site A supports the most diverse and structurally complex macrofungal community within the study area. Ecologically, the high Simpson values suggest that no single taxon overwhelmingly structures the communities under the current data framework. Though, because the calculations are based on presence-absence data rather than quantitative abundance, the dominance structure likely represents a conservative estimate. Future incorporation of abundance data would allow a more refined evaluation of competitive hierarchies and community evenness.

Beta diversity: Community similarity and species turnover

To assess compositional similarity among localities, the Jaccard similarity index (Orgiazzi et al., 2013), was calculated using the presence–absence matrix. Jaccard values ranged from 0.293 to 0.412, indicating moderate levels of species turnover among sites. The highest similarity was observed between Sites A and C ($J = 0.412$), suggesting relatively comparable community composition, potentially reflecting similar environmental conditions or partially overlapping elevational ranges. The Site B displayed lower similarity with both Site A ($J = 0.318$) and Site C ($J = 0.293$), indicating greater compositional differentiation. The results reveal substantial beta diversity within the study area. The moderate overlap among sites implies that each locality contributes uniquely to overall macrofungal richness. The observed differentiation likely reflects the influence of microenvironmental variation, substrate heterogeneity, and altitudinal gradients, which collectively shape fungal community structure across the mountainous landscape of Bjeshkët e Nemuna National Park.

The following section discusses these noteworthy species in greater detail, focusing on their distributional significance, conservation status and ecological associations.

Chrysomphalina grossula (Pers.) Norvell (Figure 4 – f), is a bright yellow to greenish-yellow mushroom producing small basidiomata with a 2–35 mm (up to 60 mm) hygrophanous, striate cap and strongly decurrent, distant lamellae that often fade paler with age (Norvell et al., 1994). It grows saprobically on decaying conifer wood, especially pine, breaking down dead timber, and fruits from summer to autumn (EnglishFungi, 2020). Across Europe, the species has been recorded in Luxembourg and Catalonia, growing on highly decomposed conifer wood, particularly *A. alba*, often in association with *Picea* species (Garnier-Delcourt et al., 2012). In the Czech Republic, it has been found on decayed trunks, woody debris, and moss-covered stumps (Holec et al., 2015). In Germany, *Ch. grossula* is listed as LC in the national Red List of macrofungi (Dämmrich et al., 2016). In Denmark, it grows on mossy, decaying trunks and woody debris of conifers, particularly spruce and pine (Naturenbasen, 2018). In Serbia, it occurs in post-glacial peat bogs with preserved sinkholes and primeval-type vegetation, including rare habitats of Serbian spruce – *Picea omorika* (Karaman et al., 2023).

Clavariadelphus truncatus Donk (Figure 5g), has a club-shaped fruiting body with a flattened tip, vaguely resembling a yellow chanterelle but lacking its ridged, cross-veined hymenium. This species produces erect, club-shaped fruiting bodies up to 15 cm tall with a flattened apex, pale yellow-orange to brownish at maturity. The flesh is firm to spongy, nearly odorless, mild in taste, and the spore print is white, yellowing when dry (Franchi et al., 2025). Its basidiospores measure 10–13 × 5.5–7 µm, variable in shape from ellipsoid to subcylindrical or slightly clavate, with a prominent apiculus and smooth, thin walls. Basidia are narrowly clavate (~80 × 10–12 µm), and the monomitic hyphal system has cylindrical, 7–13 µm wide, grows scattered to gregariously on soil or duff beneath mixed conifers, fruiting from July through November (Antonín and Dvořák, 2010). Across Europe, it has been documented in a variety of habitats: in the Czech Republic, within mixed forests of *Abies alba* and *Acer pseudoplatanus*, with undergrowth of young *Fagus sylvatica*, *Picea abies* and *Salix caprea*, on calcareous soils (Antonín and Dvořák, 2010); in Italy, in *Picea abies* woods (Funghi Italiani, 2016); in Poland, in spruce and mixed beech – fir forests, on moist, shaded soil surfaces (Chachuła, 2012); in Bulgaria, on mossy, humusrich soil under coniferous forests of *Pinus sylvestris*, *Pinus nigra*, *Picea abies*, *Abies alba* and *Pinus peuce* (Denchev and Assyoy, 2010) and from North Macedonia, on meadow soil (Karadelev et al., 2008)..

Globulicium hiemale (Laurila) Hjortstam is a North European species known for its occurrence in coniferous forests. It grows primarily on *Picea abies* trunks lying on the ground and on dead branches of standing trees (Lepšová and Pouska, 2014), and has also been reported on *Pinus rotundata* (Holec, 1999) and on well-decayed stumps of old *Pinus sylvestris* within *Picea* forests dominated by *Pinus-Hylocomium vegetation* (Yurchenko and Kotiranta, 2007). Basidiocarps are most frequently observed from mid-summer to early autumn, typically between July and September in temperate European regions (Lepšová and Pouska, 2014). The basidioma is effused, small, very thin, farinaceous, pale cream-colored, and fragile when old. The hyphal system is monomitic with a poorly developed subiculum; subicular hyphae are slender, moderately branched, sinuous, and clamped. Basidia are large, urniform, basally clamped, with four conspicuous sterigmata. Basidiospores are globose to subglobose, slightly angular, 9.3–12.5 × 8.3–10 µm, thin- to slightly thick-walled, iodine-negative, with a prominent rounded apiculus (~1 µm) (Yurchenko and Kotiranta, 2007). In Europe, *G. hiemale* has been found in coniferous woods in Spain, Norway, North Macedonia and indicate that the species is primarily associated with coniferous trees such as *Picea abies* and *Pinus sylvestris*, often occurring on dead or decaying trunks, stumps, and branches, and thriving in boreal and temperate forest zones (Jülich, 1984; Ryvarden et al., 2003; Karadelev et al., 2018).

Lactifluus volemus (Fr.) Kuntze, the species of the genus *Lactifluus* (Pers.) Roussel, was originally described from Sweden and is morphologically distinct and unique in Europe (Bera and Das, 2021). It is a well-recognized morphological species, characterized by a dry, clay-buff to orange-brown or reddish-brown cap, fishy odor, extremely abundant and sticky white latex that stains brown, abundant hymenial lamprocystidia, reticulate spore ornamentation, and a lampropalisade structure in the pilei- and stipitipellis. Basidiospores are globose to subglobose with amyloid ornamentation, basidia are clavate and 4-spored, and pleuropseudocystidia are present, sometimes scarce or abundant. *L. volemus* grows in deciduous, coniferous, and mixed forests on both acidic and nutrient-rich soils, primarily in association with trees from the *Fagaceae* and *Pinaceae* families (Van de Putte et al., 2016). Across Europe, *L. volemus* occurs in several countries and is generally rare or locally threatened. In France, it is considered vulnerable (Larent-Dargent, 2009), while in in the Netherlands, the species is considered extinct, with the last confirmed observation in 1960 (Arnolds et al., 1995). In Belgium, *L. volemus* is primarily a summer species, appearing from June to August and occasionally until September or October, mostly on calcareous soils. It grows in deciduous and coniferous forests, forming mycorrhizal associations mainly with oak (*Quercus*), beech (*Fagus*), hornbeam (*Carpinus*) and some conifers such as *Picea*, and although it was once relatively common, it is now locally threatened due to habitat loss, nutrient enrichment, and human collection (Verbeken et al., 2001).

Neolentinus adhaerens (Alb. and Schwein.) Redhead and Ginns, is a basidiomycete in the order Gloeophyllales, typically growing as a saprotroph on dead coniferous wood such as *Picea* and *Abies*. It forms viscid, adhesive fruiting bodies with pale to cream-colored gills, which often appear "sticking" to the substrate, and contributes to wood decomposition through brown rot, breaking down cellulose and hemicellulose while leaving lignin partially intact (Myco, 2026). Basidiospores are cylindrical to ellipsoid, smooth, hyaline, and thin-walled (Hrouda, 2001). The pileus is 3–5 cm, convex with a central depression, whitish to buff with a darker centre, and becomes sticky and resinous when wet; lamellae are pale cream, broad, decurrent, and have saw-toothed edges; basidiospores are whitish and cylindrical (Ainsworth, 2003). The species grows on several conifer stumps within mixed forests of *Picea* and *Quercus*, typically on older stumps, probably of *Picea*, where it forms wet, sticky basidiocarps (Garnier Delcourt et al., 2013). Two main fruiting peaks are observed: one in spring, peaking in April, and another in autumn, peaking in October. In colder mountainous regions, the species fruits mainly in autumn and is not considered a winter fungus (Yue et al., 2023). It is relatively common in the Czech Republic but rarer in Slovakia (Hrouda, 2001). In Europe, *N. adhaerens* is known from a limited number of localities, including records from countries such as Austria, Poland, Switzerland, and Bulgaria, indicating a scattered and relatively rare distribution with only a few sites showing good ecological integrity (OBIC, 2017). The species has narrow environmental tolerance and, although not widely assessed continent-wide, it is considered vulnerable in France, highlighting regional conservation concern (Laurent-Dargent, 2009).

Tricholoma atrosquamosum Sacc., belongs to the section *Atrosquamosa* of the genus *Tricholoma*. It is characterized by a dark brown to black-scaled cap, white to cream gills, and a sturdy stem often showing similar scaling as the cap. The flesh is white, with a mild odor and taste. This species typically grows in forests with oak (*Quercus*), beech (*Fagus*), or pine (*Pinus*) and is mainly distributed across Northern and Central Europe, where it is considered relatively rare (Christensen and Noordeloos, 1999). It occurs in forested habitats, typically associated with oak (*Quercus*) and found in shaded, humid areas with rich organic soil (Mao et al., 2025). Spores are 5–9 × 3.5–5 µm, elliptic to narrowly elliptic (Bessette et al., 2013). In central-southern Italy, it was recorded in forest ecosystems, occurring in calcicolous deciduous oak woods, which are forests growing on calcareous (limestone-rich) soils. It was associated with shaded, humid areas, reflecting its preference for specific soil and microclimatic conditions within oak-dominated forests (Laganá, 1999). Furthermore, it is included in the national Red List of fungi (macromycetes) of the Czech Republic, where it is assessed as Endangered (Zíbarová, 2024), and it is also documented in Poland, occurring in forested habitats (Wojewoda, 2003).

Phellinus hartigii (Allesch. and Schnabl) Pat. (Figure 5 – i) is a pathogenic basidiomycete that primarily infects fir (*Abies*) trees, inducing trunk cankers and progressive wood decay after entering through wounds or weakened tissues. It forms persistent, sessile to effused-reflexed basidiomata with a pale yellow-brown upper surface and pore layers ranging from grey to purplish-brown (Breitenbach and Kränzlin, 1986). Ecologically, the species occurs mainly on *Abies* across Europe, but has also been recorded on *Juniperus, Picea, Pinus, Taxus* and *Tsuga*. It is regarded as a circumpolar taxon typical of boreal coniferous zones and although not frequently encountered, is widely distributed (Karadelev et al., 1998). Occasional records on *Quercus aegilops* demonstrate that it can also colonize deciduous hosts. The species is perennial, fruiting year-round and capable of persisting on its substrate for exceptionally long periods, with individual fruit bodies remaining viable for up to 20 years (Ohubach, 2010). Regionally within Europe, *P. hartigii* has been documented in the western Balkan area, specifically Croatia, Bosnia and Herzegovina and

Serbia, where it occurs predominantly on *Abies* and only sporadically on *Picea* or *Pinus* peuce, reflecting a strong ecological affinity for fir-dominated montane forests (Tortić, 1991). It is also recorded in North Macedonia, where it is listed in a national checklist of Basidiomycota macrofungi (Karadelev et al., 2018).

Cyanosporus caesius (Schrad.) McGint is a saprotrophic fungus that grows year-round, typically from July to December, on large wood residues of both deciduous and coniferous trees, with a preference for conifers, especially spruce. The species is typically found on fallen trunks of *Abies* and *Picea* (Shen et al., 2019). Across Europe, it has been recorded on fallen *Picea* trunks in Finland and on fallen *Abies* trunks in Spain (Liu et al., 2021); in Denmark it has been observed growing on *Fagus sylvatica* (Miettinen et al., 2018); in France, the species occurs as a lignicolous necrotroph, primarily inhabiting dead conifer wood, although it is very rarely found on hardwoods (Gavériaux and Aleksandrowicz, 2004); in Slovakia, it is reported from old spruce forests, where it develops on fallen trunks of *Picea abies* (Červenka, 2019). Recently, in Bulgaria, the species is found in coniferous forests dominated by *Pinus sylvestris*, *Pinus nigra*, *Picea abies*, *Abies alba*, and *Pinus peuce* (Denchev and Assyov, 2010).

Panellus mitis (Pers.) Singer (Figure 5 – f), grows saprotrophically, forming scattered populations on conifer branches and twigs without affecting living trees. Its mycelium causes white rot, with spruce (*Picea*) being a common host (ForestPests, 2018). In Europe, *P. mitis* occurs across

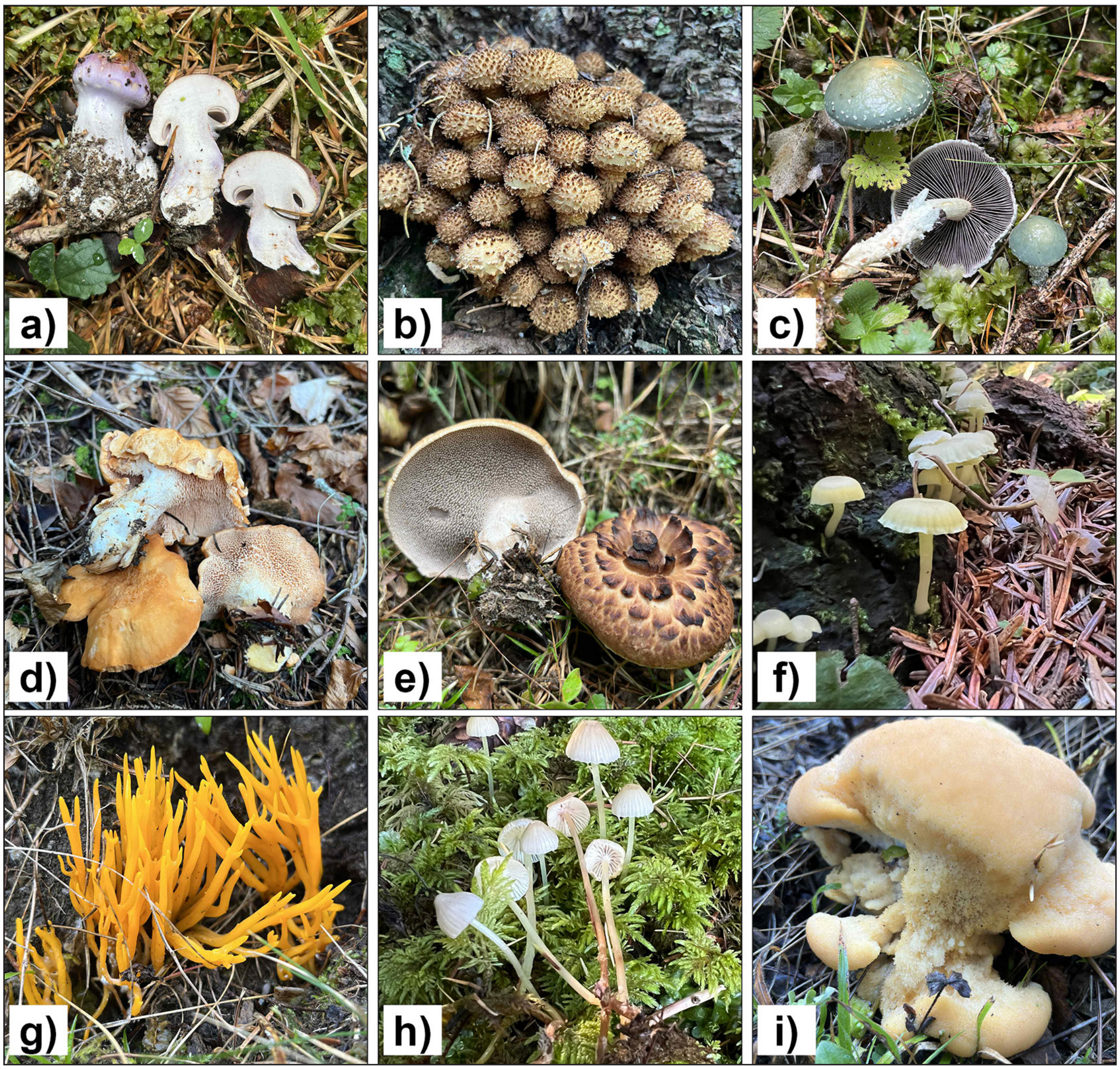

Figure 4. Representative macrofungal species recorded in Bjeshkët e Nemuna National Park (Part I): (a) *Thaxterogaster turmalis* – Koshutan; (b) *Pholiota squarrosa* – Bogë; (c) *Stropharia aeruginosa* – Bogë; (d) *Hydnum rufescens* – Bogë; (e) *Sarcodon imbricatus* – Bogë; (f) *Chrysomphalina grossula* – Koshutan; (g) *Calocera viscosa* – Koshutan; (h) *Mycena epipterygia* – Kuqishtë and (i) *Abortiporus biennis* – Kuqishtë

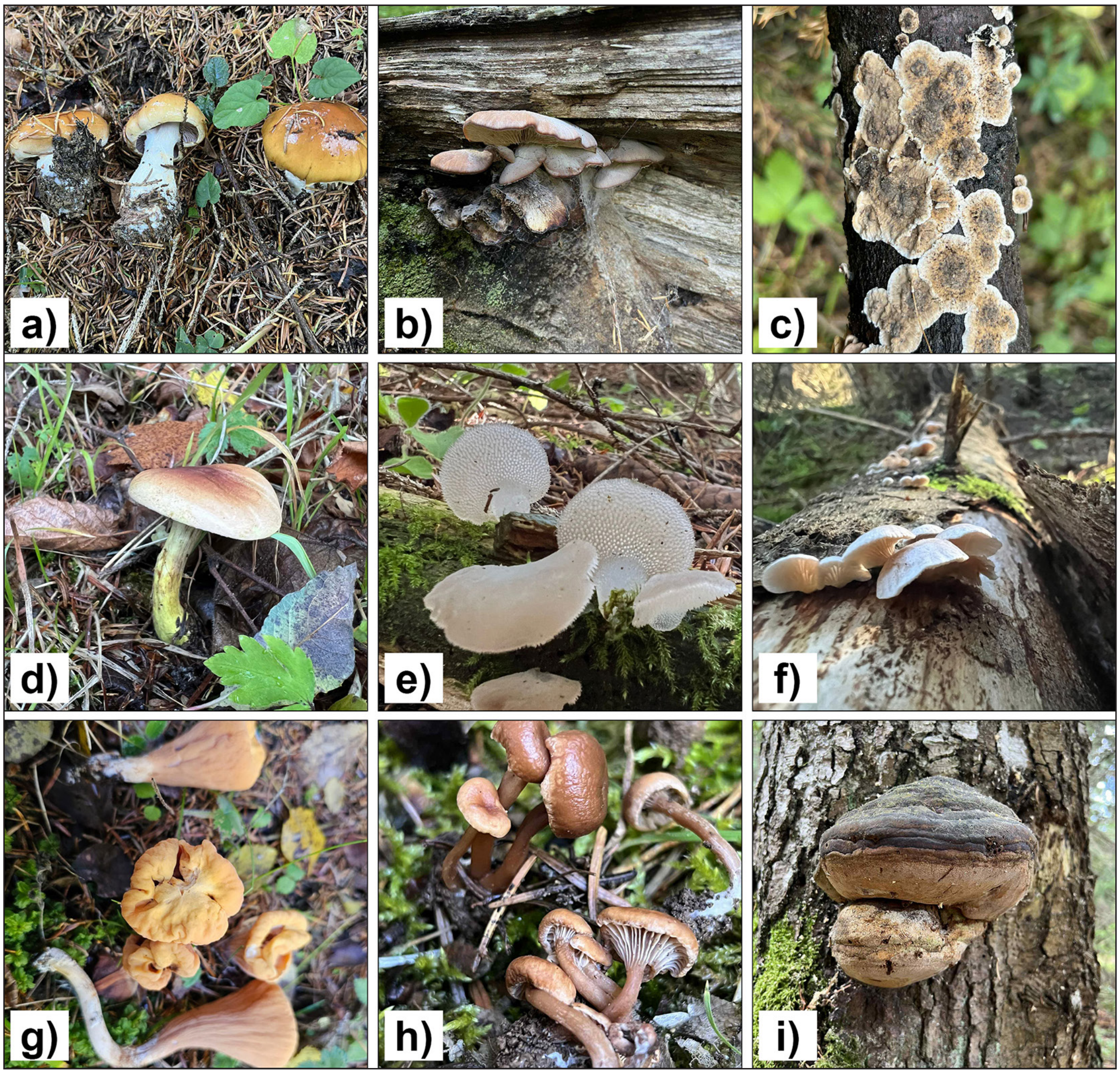

Figure 5. Representative macrofungal species recorded in Bjeshkët e Nemuna National Park (Part II): (a) *Phlegmacium glaucopus* – Bogë; (b) *Lentinellus castoreus* – Kuqishtë; (c) *Stereum sanguinolentum* – Koshutan; (d) *Tricholoma bufonium* – Bogë; (e) *Pseudohydnum gelatinosum* – Koshutan; (f) *Panellus mitis* – Koshutan; (g) *Clavariadelphus truncatus* – Koshutan; (h) *Omphalina subhepatica* – Bogë and (i) *Phellinus hartigii* – Koshutan

a range of coniferous and mixed forest habitats. In Spain, the species was recorded on remaining wood of *Pinus sylvestris* (Merino Alcántara, 2018). In Finland, it has been observed on fallen trunks of *Pinus sylvestris* and *Picea abies* subsp. *obovata* (Renvall, 1995), and in Estonia, it was recorded on wood of *Pinus sylvestris* (Bresinsky, 2006). In Poland, it occurs in forests dominated by *Abies alba*, *Fagus sylvatica* and various *Pinus* species (Chachuła, 2010–2014). In Italy, the fungus grows saprotrophically on fallen branches and trunks of *Abies* species, primarily in forested park areas, colonizing dead wood and most commonly observed during the summer and autumn months (Padovan, 2009). In Bulgaria, *P. mitis* completes its European range by thriving in coniferous forests, predominantly colonizing the branches and twigs of *Pinus sylvestris*, *Picea abies*, *Abies alba* and *Pinus peuce* (Denchev and Assyov, 2010).

CONCLUSIONS

This study provides the first systematic assessment of macrofungal diversity in the coniferous forests of Bjeshkët e Nemuna National Park along an altitudinal gradient. A total of 146 specimens recorded, including 108 species newly documented for Kosovo, representing a substantial contribution to the national mycobiota and highlighting the park as a center of fungal biodiversity. Ectomycorrhizal fungi were identified as the dominant ecological group, confirming their key functional role in forest nutrient dynamics and symbiotic associations with host trees. The study fills a knowledge gap regarding the composition, ecological strategies and elevation-related distribution patterns of macrofungi in western Kosovo, which were previously poorly documented. These findings provide essential baseline data for long-term biodiversity monitoring, inform conservation strategies, and open prospects for future research on fungal ecology, functional roles, and ecosystem management in montane forests.

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