INTL J BONOROWO WETLANDS
Volume 15, Number 2, December 2025
Pages: 86-102

P-ISSN: 2775-8052
E-ISSN: 2775-8044
DOI: 10.13057/bonorowo/w150203

Diversity and potential utilization of macrofungi in the riparian area of the Samin River, Central Java, Indonesia

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Manuscript received: 26 June 2025. Revision accepted: 13 September 2025.

Abstract. *Putri RRA, Fajri R, Rahmadhani SE, Salsabila S, Himawan W, Septiasari A, Yap CK, Setyawan AD. 2025. Diversity and potential utilization of macrofungi in the riparian area of the Samin River, Central Java, Indonesia. Intl J Bonorowo Wetlands 15: 86-102.* Macrofungi play essential roles in decomposition, nutrient cycling, and ecosystem functioning, yet their diversity in the riparian habitats of Java (Indonesia) remains poorly documented. This study provides a comprehensive assessment of macrofungal communities along the Samin River, Central Java, covering upstream, middle, and downstream segments. Surveys were conducted in March-April 2024 using belt-transect observations (10 m × 100 m per station) across six locations. All encountered fruiting bodies were recorded, photographed, and identified based on macromorphological and microscopical features, with substrate type categorized into weathered logs (W), leaf litter (L), soil (S), tree bark (T), and animal dung (A). Diversity indices (Shannon–Wiener H', Simpson D, Margalef R, and Evenness E) and substrate distributions were analyzed to evaluate spatial patterns in community structure. A total of 98 macrofungal species belonging to 38 families, 13 orders, and two phyla (Ascomycota and Basidiomycota) were confirmed, with Basidiomycota predominating. The most species-rich families were Mycenaceae, Polyporaceae, Marasmiaceae, and Agaricaceae. Species richness was comparable between the upstream and middle sections (41 species each), but the upstream section exhibited the highest ecological diversity as reflected by diversity indices (H' = 3.03, R = 6.40), whereas downstream areas showed lower diversity values (H' = 2.29, R = 3.88). These patterns reflect environmental gradients in humidity, canopy cover, light intensity, and substrate availability along the river continuum. Weathered logs were the most frequently colonized substrate, supporting more than half of all species, including ecologically important lignicolous taxa (e.g., *Xylaria*, *Crepidotus*, *Cerrena*, *Schizophyllum*). Several species displayed multi-substrate flexibility (e.g., *Marasmius elegans*), indicating functional adaptability to riparian microhabitats. Edible and medicinal taxa—such as *Auricularia auricula-judae*, *Termitomyces* sp., and *Schizophyllum commune* —highlight the biocultural and biotechnological value of riparian macrofungi. The Samin River corridor serves as a biodiversity reservoir that merits greater conservation attention and provides promising opportunities for sustainable fungal utilization.

Keywords: Lignicolous fungi, macrofungal diversity, riparian ecosystem, Samin River, substrate ecology

INTRODUCTION

Macrofungi play an essential role in maintaining ecological processes across terrestrial landscapes, particularly in humid tropical environments where organic matter decomposes rapidly. These organisms function as primary decomposers capable of breaking down lignin, cellulose, and other complex organic compounds, thereby facilitating nutrient cycling and maintaining soil fertility (Boa 2004; Miles and Chang 2004). Their presence often reflects the ecological condition of an ecosystem since macrofungi respond sensitively to microclimatic variation, substrate availability, and habitat disturbance. As a result, macrofungal communities provide valuable insights into environmental stability and habitat quality in both natural and human-modified ecosystems (Boddy and Heilmann-Clausen 2018).

Beyond their fundamental ecological roles, many macrofungal taxa possess substantial potential for utilization as food, medicine, and sources of bioactive compounds. Species belonging to genera such as *Auricularia*, *Termitomyces*, *Ganoderma*, and *Schizophyllum* are well known for their nutritional, antimicrobial, immunomodulatory, and antioxidant properties (Elkhateeb and Daba 2021; Bibi et al. 2023; Mayra et al. 2024). Several saprophytic taxa have also attracted scientific interest due to their biotechnological applications, such as enzyme production, bioconversion of agricultural waste, and environmental remediation (Cohen et al. 2002). Despite this potential, baseline information on macrofungal richness, distribution patterns, and substrate associations remains limited in many tropical regions, including Indonesia. Such knowledge gaps constrain the development of sustainable resource utilization and ecological monitoring frameworks.

Riparian ecosystems function as transitional ecotones where terrestrial and aquatic processes intersect, creating unique microhabitats that support diverse fungal communities. Continuous input of woody debris, leaf litter, and organic sediment provides a wide variety of substrates for colonization, while fluctuating humidity and canopy structure further enhance habitat heterogeneity. Studies in tropical forest systems have shown that macrofungal assemblages are strongly structured by substrate type and habitat heterogeneity, with woody debris and leaf litter supporting a large proportion of recorded taxa and driving patterns of fungal diversity and ecological function (Kumar et al. 2013). These conditions are favorable for saprophytic, lignicolous, and soil-dwelling macrofungi, many of which depend on stable moisture regimes and shaded microenvironments for sporocarp formation (Rahmi et al. 2021; Mahardhika et al. 2022). In tropical riparian systems, the interplay between hydrology, vegetation, and substrate dynamics produces fungal assemblages distinct from those found in upland forests or agricultural ecosystems. However, such habitats remain understudied compared with forest reserves, mangroves, or highland ecosystems.

In Indonesia, research on macrofungi has predominantly focused on forested regions, community-based foraging practices, or market surveys. Studies that document macrofungal diversity in riparian landscapes are rare, particularly those employing quantitative ecological indices such as Shannon-Wiener, Simpson, species richness, and evenness metrics. Moreover, existing works often emphasize taxonomic inventories without integrating analyses of substrate-specific distribution or ecological function (Putra 2020; Yusran et al. 2024). This imbalance limits understanding of how environmental gradients, land-use patterns, and substrate availability shape macrofungal assemblages across different habitat types.

The Samin River in Central Java represents a critical ecological corridor flowing through a heterogeneous landscape composed of mixed agriculture, community forests, and rural settlements. Such mosaics generate varied microhabitats that potentially influence macrofungal distribution, especially in terms of substrate availability, disturbance intensity, and moisture conditions. Despite its ecological significance, no comprehensive assessment has been conducted to document macrofungal diversity along the this river. In particular, information on substrate associations-whether species prefers weathered logs, leaf litter, soil, tree trunks, or animal dung-remains unavailable. This gap restricts efforts to compare riparian fungal communities with other habitats and inhibits the identification of species with potential nutritional or medicinal value.

Given the ecological importance of macrofungi and the lack of systematic studies in riparian environments of Central Java, therefore, this study aims to: (i) document macrofungal species occurring along upstream, middle, and downstream sections of the Samin River, (ii) evaluate community structure using Shannon-Wiener, Simpson, richness, and evenness indices (Madsen and Crook 2021), and (iii) analyze substrate-specific associations and their implications for ecological function and potential utilization. We hypothesize that macrofungal diversity and community composition decrease from upstream to downstream sections of the river, with upstream zones exhibiting higher richness, diversity, and substrate heterogeneity due to more stable microclimatic conditions and greater availability of coarse woody debris, whereas fewer, disturbance-tolerant species dominate downstream zones. This research provides the first integrated baseline on riparian macrofungi in the Samin River and contributes to broader efforts to understand, conserve, and sustainably utilize fungal diversity in tropical ecosystems.

MATERIALS AND METHODS

Study area

The research was conducted along the riparian zone of the Samin River, a tributary of the Bengawan Solo, located in Central Java, Indonesia. The main river originates in the highlands of Tawangmangu Sub-district, Karanganyar District, and flows westward through Matesih and Karanganyar Sub-districts before reaching the lowland agricultural-urban interface of Sukoharjo District in the border area between Mojolaban and Grogol Sub-districts. This geographical setting forms a natural ecological gradient from upland montane environments to increasingly modified downstream landscapes. Sampling encompassed six stations distributed across three river sections-upstream, middle, and downstream-to capture spatial variation in habitat structure and fungal substrates (Figure 1, Table 1).

Climatically, the region falls under the tropical monsoon system with pronounced wet and dry seasons. Annual rainfall typically ranges between 2,200-2,800 mm, while average temperatures vary from 22-30°C (BMKG 2025). Field sampling was conducted in March-April 2024, a transitional period from the rainy to the dry season, during which humidity remained high and sporadic rainfall still occurred, conditions known to promote macrofungal fruiting (Miles and Chang 2004; Stamets 2005). Riparian vegetation includes secondary forest patches, bamboo stands, agroforestry plots dominated by *Albizia chinensis*, *Tectona grandis*, and *Swietenia* spp., and mixed shrub assemblages. These vegetation types continuously supply organic substrates such as coarse woody debris, leaf litter, and weathered logs, forming microhabitats favorable for saprophytic and lignicolous fungi.

The upstream stations (Kalisoro and Nglurah, Tawangmangu) are situated in cooler, more forested environments characterized by steep terrain and dense canopy cover. Middle stations (Girilayu and Plosorejo, Matesih) represent mixed agroforestry and semi-residential areas where vegetation is patchy and substrate availability is shaped by human management. Downstream stations (Telukan, Grogol, and Tegalmade, Mojolaban) occur in more open and warmer conditions influenced by agriculture and peri-urban land use, resulting in reduced tree cover and altered substrate composition. These contrasts allow examination of how macrofungal richness and substrate specificity vary along the river's environmental gradient.

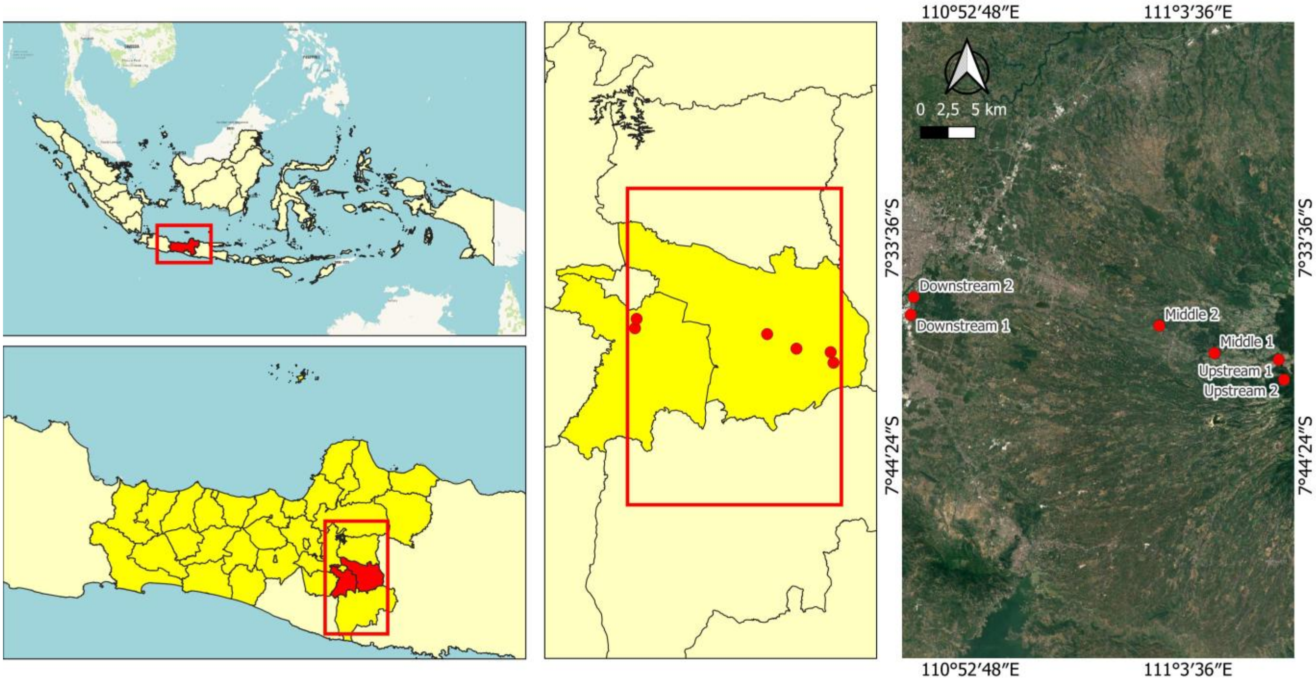

Figure 1. Map of the Samin River showing upstream, middle, and downstream sampling zones in Central Java, Indonesia

Table 1. Samin river location data in Central Java, Indonesia

River section	Location	Coordinate
Upstream	Kalisoro, Tawangmangu, Karanganyar	7°39'37.8"S 111°08'07.5"E
	Nglurah, Tawangmangu, Karanganyar	7°40'37.2"S 111°08'23.4"E
Middle	Girilayu, Matesih, Karanganyar	7°39'18.3"S 111°04'55.8"E
	Plosorejo, Matesih, Karanganyar	7°37'56.7"S 111°02'11.6"E
Downstream	Telukan, Grogol, Sukoharjo	7°37'23.9"S 110°49'51.1"E
	Tegalmade, Mojolaban, Sukoharjo	7°36'31.2"S 110°50'00.3"E

Sampling and identification

Macrofungal sampling was conducted systematically across six stations representing the upstream, middle, and downstream sections of the Samin River. Each station contained one belt transect measuring 10 × 100 m (1,000 m²), resulting in a total surveyed area of 6,000 m². Belt transects were selected because they enable efficient detection of sporocarps across heterogeneous microhabitats and are widely applied in macrofungal ecological studies (Mueller et al. 2004). Field surveys were carried out during March-April 2024, a transitional period known for high humidity and active substrate decomposition, which together promote optimal fruiting of many tropical macrofungi. Observations were conducted in the morning and late afternoon to reduce the likelihood of missing sporocarps that desiccate during midday hours.

Macrofungal observation methods

All visible sporocarps within each transect were recorded, photographed, and collected when necessary. Sampling followed a modified opportunistic-systematic approach in which observers walked slowly along the transect line and examined diverse microhabitats, including leaf litter layers, woody debris, soil patches, and the bases of living trees. This method is particularly suitable for riparian systems, where substrate distribution is highly variable, and microhabitats change rapidly with hydrological conditions (Lodge et al. 2004). Only macrofungi with mature, identifiable fruiting bodies were included to ensure accuracy in taxonomic determination.

Substrate-based sampling procedure

To evaluate substrate specificity, each encountered sporocarp was assigned to the substrate from which it emerged. Substrates were categorized as: (i) weathered logs (W), including decayed trunks, branches, and coarse woody debris, (ii) leaf litter (L), comprising decomposing leaves and small organic detritus, (iii) soil (S), including mineral soil and humus-rich layers, (iv) tree (T), consisting of living bark or standing trunks, and (v) animal dung (A), typically from herbivores common along riparian margins. Substrate type was recorded at the point of collection following the guidelines of Lodge et al. (2004). In cases where sporocarps occurred at the interface of multiple substrates-such as wood partially embedded in soil-the dominant supporting substrate was determined based on visual assessment. Species capable of emerging from more than one substrate type were noted for subsequent ecological interpretation.

Documentation and morphological identification

All macrofungi were photographed in situ using a digital camera equipped with scale markers to document diagnostic morphological features, including pileus form, stipe structure, hymenophore type, color changes, and substrate association. Specimens requiring detailed examination were collected and stored in paper envelopes to maintain dryness and prevent rapid decay. Identification was conducted using macroscopic and microscopic criteria based on established taxonomic keys such as Largent (1977), McKnight and McKnight 1987, and Kibby (2006). Diagnostic traits were further verified through comparison with authoritative nomenclatural databases, including MycoBank and Index Fungorum, ensuring accuracy and consistency in species recognition.

Substrate classification for analysis

For analytical purposes, each species was assigned to one or more substrate categories (W, L, S, T, A), allowing quantification of substrate-specific richness and assessment of ecological allocation along the riparian gradient. Substrate-based grouping is essential because many saprotrophic fungi show strong microhabitat preferences shaped by moisture levels, decomposition stages, and substrate chemistry (Lodge et al. 2004). Species recorded on multiple substrates were retained across categories, acknowledging their ecological plasticity and potential roles as generalist decomposers within the riparian ecosystem.

Data analysis

Data analysis focused on quantifying macrofungal diversity, evaluating substrate-use patterns, and assessing potential utilization of recorded species. All observations from the six transects were compiled into a master dataset that included species identity, family, substrate category, and collection location. Analytical procedures were conducted using Microsoft Excel and R version 4.2.2, following widely adopted ecological frameworks for macrofungal community studies (Magurran 2004).

Diversity index calculations (H', D, R, E)

Several diversity indices were computed to characterize macrofungal community structure across the upstream, middle, and downstream sections of the Samin River.

Shannon-Wiener Diversity Index (H')

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where *pi* is the proportion of individuals belonging to species *i*. This index integrates both richness and evenness and is widely used in fungal diversity studies due to its sensitivity to infrequent species (Shannon and Weaver 1963; Magurran 2004).

Simpson Diversity Index (D)

$$D = 1 - \sum p_i^2$$

This metric emphasizes dominance patterns, with higher values indicating more even communities and lower dominance by a few taxa (Simpson 1949).

Species Richness Index (R)

The Margalef index was applied:

$$R = \frac{S-1}{\ln N}$$

Where *S* represents the total number of species and *N* the total number of individuals recorded (Odum 1971).

Evenness Index (E)

$$E = \frac{H'}{\ln S}$$

This index measures how evenly species are distributed within each river section (Pielou 1966). These indices enabled comparative assessment of macrofungal community composition along the environmental gradient of the Samin River.

Substrate distribution analysis

Each species was assigned to one or more of the five substrate categories: weathered logs (W), leaf litter (L), soil (S), tree (T), and animal dung (A). The frequency of species associated with each substrate was tabulated, with multi-substrate species recorded across all relevant categories. Substrate preferences were interpreted to infer ecological roles, including lignicolous, litter-decomposing, humicolous, or coprophilous tendencies (Lodge et al. 2004). A substrate composition pie chart was produced to visualize the relative contribution of each substrate type to overall species richness.

Assessment of potential utilization

Species with documented ethnomycological, nutritional, medicinal, or biotechnological value-such as *Auricularia*, *Termitomyces*, *Lentinus*, and *Ganoderma*- were identified through literature reviews (Miles and Chang 2004; Hyde et al. 2018). Information on edibility, pharmacological activity, enzymatic properties, and ecosystem services was compiled to highlight the applied significance of macrofungi found along the Samin River corridor.

Data visualization

Two primary visualizations were generated to support ecological interpretation: (i) A histogram of species counts per family, illustrating the taxonomic distribution of macrofungi across the study area. (ii) A pie chart of substrate composition, showing relative species richness associated with W, L, S, T, and A substrates. Together, these graphical outputs reinforce the analysis of spatial patterns and ecological associations within the macrofungal community.

Ethical and permitting statement

All field activities were conducted with permission from local authorities and land managers in Karanganyar, Matesih, and Sukoharjo, Central Java, Indonesia. Access to the Samin River riparian zone was coordinated with village leaders, and sampling was restricted to publicly accessible and community-managed lands, avoiding strictly protected conservation areas. Macrofungal sampling followed non-destructive survey practices. Only a limited number of fruiting bodies were collected for taxonomic confirmation, while most specimens were documented in situ. Substrates such as coarse woody debris, leaf litter, and soil were minimally disturbed, and no vegetation was intentionally damaged (Miles and Chang 2004; Lodge et al. 2004). Based on available national and regional checklists, none of the recorded taxa were legally protected or critically endangered in Indonesia at the time of the study.

RESULTS AND DISCUSSION

Species richness and taxonomic composition

A total of 98 macrofungal species were recorded along the Samin River riparian ecosystem, representing 38 families, 13 orders, and two major phyla (Ascomycota and Basidiomycota) (Table 2), with species richness distributed unevenly across the riparian zones, comprising 41 species in the upstream section, 41 species in the midstream section, and 24 species in the downstream section. Basidiomycota predominated, comprising the vast majority of taxa, while Ascomycota contributed a smaller but ecologically significant proportion of decomposer lineages. This broad taxonomic representation reflects the environmental heterogeneity of riparian habitats, where variations in canopy cover, moisture, and substrate availability support diverse assemblages of both lignicolous and litter-dwelling fungi. The distribution of species across families (summarized in Figure 2) highlights Mycenaceae, Polyporaceae, and Marasmiaceae as the most species-rich families, underscoring the dominance of wood- and litter-decaying functional groups in this system.

Several families dominated the macrofungal community. Mycenaceae, Polyporaceae, and Marasmiaceae emerged as the three most species-rich families, collectively accounting for 40 species (approximately 40% of the total taxa). Members of the Mycenaceae, particularly species of *Mycena* and *Hemimycena*, were abundant on weathered wood and leaf litter, demonstrating their strong role as early colonizers of decaying plant material. The Polyporaceae, which include *Trametes*, *Cerrena*, *Ganoderma*, and *Pycnoporus*, were widespread on well-decomposed logs, functioning as major agents of lignin degradation. Meanwhile, the Marasmiaceae-represented by *Marasmius*, *Crinipellis*, and *Tetrapyrgos*-occurred primarily on fine woody debris and moist litter substrates, consistent with their ecological niche in forest-floor decomposition.

The dominance of Basidiomycota over Ascomycota aligns with patterns observed in other humid tropical riparian zones, where wood-decaying basidiomycetes thrive under high humidity and continuous litter input. Ascomycota, although less diverse in this study, were represented by ecologically significant groups such as the Xylariaceae (e.g., *Xylaria longiana*, *X. filiformis*), Nectriaceae (*Tubercularia lateritia*), and Pezizaceae (*Peziza* sp.). These genera are typically associated with early to mid-stage decomposition, contributing to cellulose degradation and substrate fragmentation that facilitate colonization by basidiomycetes. The presence of multiple *Xylaria* and *Scutellinia* species indicates that the Samin River riparian zone supports a well-structured decomposition continuum.

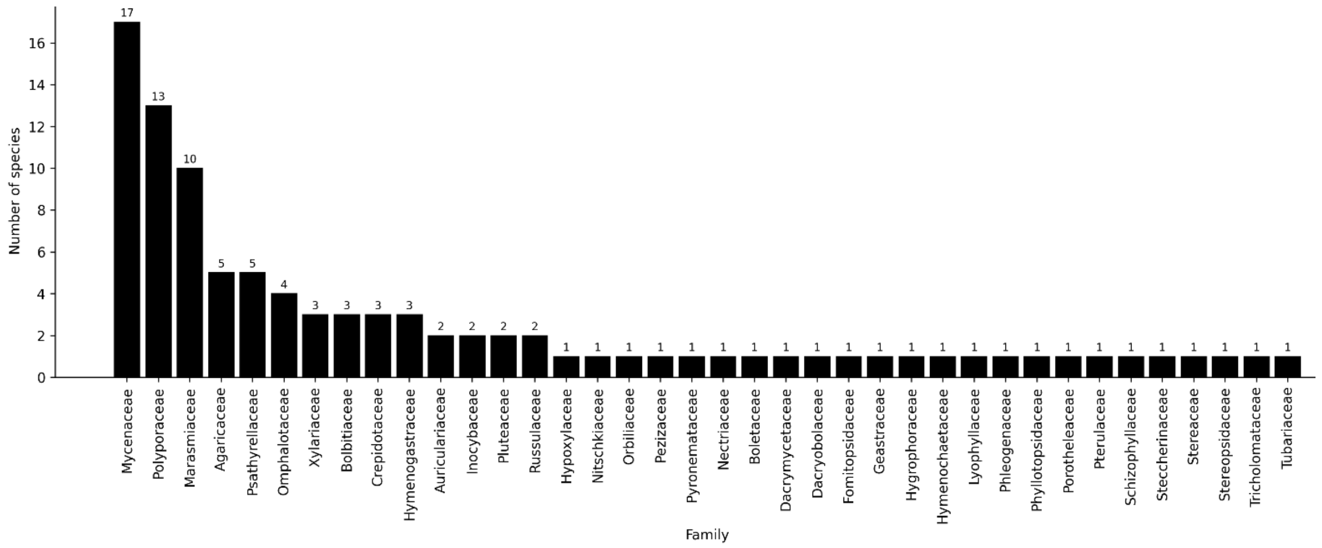

Figure 2. The number of macrofungi species for each family documented in the study sites of Samin River, Central Java, Indonesia

Table 2. Macrofungi found at the research location in Samin River, Central Java, Indonesia

Phylum **Order**	**Family**	**Species**	**Substrates**	**Location**			**Potential utilization**	
				Upstream	**Middle**	**Down**	**Use**	**Reference**
Ascomycota								
Xylariales	Hypoxylaceae	*Daldinia concentrica* (Bolton) Ces. & De Not.	W			✓	M	Feng et al. (2013)
Xylariales	Nitschkiaceae	*Nitschkia* sp.	W	✓			-	-
Orbiliales	Orbiliaceae	*Orbilia xanthostigma* (Fr.) Fr.	W		✓		-	-
Pezizales	Pezizaceae	*Peziza* sp.	L	✓			P	Madsen and Crook (2021)
Pezizales	Pyronemataceae	*Scutellinia scutellata* (L.) Lambotte	W		✓		P	Elkhateeb and Daba (2021)
Xylariales	Xylariaceae	*Xylaria filiformis* (Alb. & Schwein.) Fr.	L		✓		-	-
Xylariales	Xylariaceae	*Xylaria longiana* Rehm	L, W		✓		-	-
Xylariales	Xylariaceae	*Xylaria longipes* Nitschke	W			✓	M	Fikri et al. (2023)
Hypocreales	Nectriaceae	*Tubercularia lateritia* (Berk.) Seifert	W		✓	✓	-	-
Basidiomycota								
Agaricales	Agaricaceae	*Lepiota* sp.1	L			✓	-	-
Agaricales	Agaricaceae	*Lepiota* sp.2	W		✓		-	-
Agaricales	Agaricaceae	*Lepiota* sp.3	S		✓		-	-
Agaricales	Agaricaceae	*Leucocoprinus* sp.	S			✓	-	-
Agaricales	Agaricaceae	*Micropsalliota* sp.	S		✓		-	-
Auriculariales	Auriculariaceae	*Auricularia auricula-judae* (Bull.) Quél.	W	✓			F, M	Miles and Chang (2004), Mayra et al. (2024), Yusran et al. (2024),
Auriculariales	Auriculariaceae	*Auricularia nigricans* (Sw.) Birkebak, Looney & Sánchez-García	W	✓	✓	✓	F, M	Elkhateeb and Daba (2021)
Agaricales	Bolbitiaceae	*Bolbitius coprophilus* (Peck) Hongo	A	✓			-	-
Agaricales	Bolbitiaceae	*Conocybe* sp.1	L	✓			-	-
Agaricales	Bolbitiaceae	*Conocybe* sp.2	L	✓			-	-
Boletales	Boletaceae	*Hortiboletus* sp.	S	✓			-	-
Agaricales	Crepidotaceae	*Crepidotus cesatii* (Rabenh.) Sacc.	L		✓		-	-
Agaricales	Crepidotaceae	*Crepidotus mollis* (Schaeff.) Staude	W	✓			M	On et al. (2021)
Agaricales	Crepidotaceae	*Crepidotus* sp.	W	✓			-	-
Dacrymycetales	Dacrymycetaceae	*Dacryopinax spathularia* (Schwein.) G.W.Martin	W			✓	M, F	Kumar et al. (2019)
Dacryobolales	Dacryobolaceae	*Ptychogaster albus* Corda	W		✓		-	-
Fomitopsidales	Fomitopsidaceae	*Pilatoporus hemitephrus* (Berk.) Zmitr.	T		✓		-	-
Geastrales	Geastraceae	*Geastrum saccatum* Fr.	S		✓		M	Amaral-Machado et al. (2020)
Agaricales	Hygrophoraceae	*Hygrocybe miniata* (Fr.) P. Kumm.	S		✓		-	-
Hymenochaetales	Hymenochaetaceae	*Coltricia perennis* (L.) Murrill	S	✓			-	-
Agaricales	Hymenogastraceae	*Gymnopilus* sp.	W		✓		-	-
Agaricales	Hymenogastraceae	*Gymnopilus penetrans* (Fr.) Murrill	W	✓			M	Mahardhika et al. (2022)
Agaricales	Hymenogastraceae	*Psilocybe* sp.	A	✓			-	-

Agaricales	Inocybaceae	*Inocybe geophylla* P.Kumm.	L	✓			P	Benjamin (1995), Patocka et al. (2021)
Agaricales	Inocybaceae	*Inocybe lacera* (Fr.) P.Kumm.	L			✓	P	Michelot and Melendez-Howell (2003), Al-Momany (2025)
Agaricales	Lyophyllaceae	*Termitomyces* sp.	S	✓			M, F	Boa (2004), Sitotaw et al. (2020), Yusran et al. (2024)
Agaricales	Marasmiaceae	*Crinipellis setipes* (Peck) Singer	W	✓			-	-
Agaricales	Marasmiaceae	*Marasmius elegans* (Cleland) Grgur.	L, W	✓	✓		-	-
Agaricales	Marasmiaceae	*Marasmius siccus* (Schwein.) Fr.	W	✓			M	Ryoo and Lee (2024)
Agaricales	Marasmiaceae	*Marasmius sullivantii* Mont.	L, W	✓			-	-
Agaricales	Marasmiaceae	*Marasmius* sp.1	L			✓	M	Putra (2020)
Agaricales	Marasmiaceae	*Marasmius* sp.2	L		✓		M	Putra (2020)
Agaricales	Marasmiaceae	*Marasmius* sp.3	W		✓		M	Putra (2020)
Agaricales	Marasmiaceae	*Marasmius* sp.4	W	✓			-	-
Agaricales	Marasmiaceae	*Marasmius* sp.5	L	✓			-	-
Agaricales	Marasmiaceae	*Tetrapyrgos nigripes* (Corner) Pegler	W			✓	P	Mahardhika et al. (2022)
Agaricales	Mycenaceae	*Hemimycena lactea* (Pers.) Singer	L		✓		P	Kirk et al. (2008)
Agaricales	Mycenaceae	*Favolaschia* sp.	T		✓		-	-
Agaricales	Mycenaceae	*Hemimycena* sp.	W		✓		-	-
Agaricales	Mycenaceae	*Mycena tenerrima* (Berk.) Quél.	W	✓			-	-
Agaricales	Mycenaceae	*Mycena adscendens* Maas Geest.	L, W	✓			-	-
Agaricales	Mycenaceae	*Mycena chlorophos* (Berk. & M.A. Curtis) Sacc.	L, W	✓			-	-
Agaricales	Mycenaceae	*Mycena fumosa* (Pers.) Quél.	L, W	✓			-	-
Agaricales	Mycenaceae	*Mycena leptocephala* (Pers.) Gillet	W	✓			-	-
Agaricales	Mycenaceae	*Mycena galericulata* (Scop.) Gray	W	✓			-	-
Agaricales	Mycenaceae	*Mycena leptophylla* (Peck) Sacc.	W	✓			-	-
Agaricales	Mycenaceae	*Mycena* sp.1	W			✓	-	-
Agaricales	Mycenaceae	*Mycena* sp.2	W			✓	-	-
Agaricales	Mycenaceae	*Mycena* sp.3	L		✓		-	-
Agaricales	Mycenaceae	*Mycena* sp.4	W		✓		-	-
Agaricales	Mycenaceae	*Mycena* sp.5	W		✓		-	-
Agaricales	Mycenaceae	*Mycena* sp.6	W	✓			-	-
Agaricales	Mycenaceae	*Mycena* sp.7	L	✓			-	-
Agaricales	Omphalotaceae	*Marasmiellus candidus* (Fr.) Singer	L, W		✓		-	-
Agaricales	Omphalotaceae	*Marasmiellus* sp.	L		✓		F	Armadhan et al. (2023)
Agaricales	Omphalotaceae	*Gymnopus ceraceicola* J.A.Cooper & P.Leonard	W		✓		-	-
Agaricales	Omphalotaceae	*Gymnopus* sp.	W	✓			-	-
Pterulales	Phleogenaceae	*Phleogena* sp.	T		✓		-	-
Agaricales	Phyllotopsidaceae	*Phyllotopsis nidulans* (Pers.) Singer	W			✓	-	-

Agaricales	Pluteaceae	*Pluteus umbrosus* (Pers.) P.Kumm.	W		✓		F	Abdalla et al. (2016)
Agaricales	Pluteaceae	*Pluteus salicinus* (Pers.) P.Kumm.	W			✓	-	-
Polyporales	Polyporaceae	*Cerrena unicolor* (Bull.) Murrill	W		✓		M	Sondej et al. (2025)
Polyporales	Polyporaceae	*Datronia* sp.	W			✓	-	-
Polyporales	Polyporaceae	*Lentinus arcularius* (Batsch) Zmitr.	W			✓	M	Le et al. (2022)
Polyporales	Polyporaceae	*Hexagonia tenuis* (Fr.) Fr.	W		✓		-	-
Polyporales	Polyporaceae	*Perenniporia ohiensis* (Berk.) Ryvarden	W			✓	-	-
Polyporales	Polyporaceae	*Coriolopsis gallica* (Fr.) Ryvarden	W			✓	M	Staita et al. (2024)
Polyporales	Polyporaceae	*Fomes fasciatus* (Sw.) Cooke	W		✓		-	-
Polyporales	Polyporaceae	*Ganoderma* sp.	W		✓		M	Bibi et al. (2023)
Polyporales	Polyporaceae	*Neofavolus alveolaris* (DC.) Sotome & T. Hatt.	W			✓	F	Fawwaz et al. (2024)
Polyporales	Polyporaceae	*Pycnoporus sanguineus* (L.) Murrill	W		✓		M	Huang et al. (2023)
Polyporales	Polyporaceae	*Trametes* sp.	W			✓	M	Srivastava et al. (2024)
Polyporales	Polyporaceae	*Bresadolia uda* (Jungh.) Audet	W	✓			-	-
Polyporales	Polyporaceae	*Favolus grammocephalus* (Berk.) Imazeki	W	✓			-	-
Agaricales	Porotheleaceae	*Phloeomana speirea* (Fr.) Redhead	W		✓		-	-
Agaricales	Psathyrellaceae	*Coprinellus disseminatus* (Pers.) J.E.Lange	W	✓	✓		F	Boa (2004)
Agaricales	Psathyrellaceae	*Coprinopsis lagopus* (Fr.) Redhead, Vilgalys & Moncalvo	L, W			✓	P	Benjamin (1995)
Agaricales	Psathyrellaceae	*Coprinopsis* sp.	W		✓		-	-
Agaricales	Psathyrellaceae	*Cystoagaricus* sp.	S		✓		-	-
Agaricales	Psathyrellaceae	*Parasola plicatilis* (Curtis) Redhead, Vilgalys & Hopple	L, W	✓		✓	-	-
Pterulales	Pterulaceae	*Pterula multifida* (Fr.) Bon	L, W			✓	-	-
Russulales	Russulaceae	*Lactarius* sp.	S	✓			-	-
Russulales	Russulaceae	*Russula* sp.	S	✓			P	Beug et al. (2014)
Hymenochaetales	Schizophyllaceae	*Schizophyllum commune* Fr.	W	✓	✓	✓	M, F	Kumar et al. (2019)
Hymenochaetales	Steccherinaceae	*Nigroporus vinosus* (Berk.) Murrill	W	✓			-	-
Hymenochaetales	Stereaceae	*Stereum ostrea* (Blume & T. Nees) Fr.	W	✓			P	Rahmi et al. (2021)
Hymenochaetales	Stereopsidaceae	*Stereopsis hiscens* (Mont.) D.A.Reid	S		✓		-	-
Agaricales	Tricholomataceae	*Collybia* sp.	T	✓			-	-
Agaricales	Tubariaceae	*Tubaria* sp.	S		✓		-	-
Total: 13	38	98						

Note: Taxonomic nomenclature and family assignments follow MycoBank and Index Fungorum (accessed 2024-2025). Potential utilization: F: Food, M: Medicine, P: Poisonous, -: unknown. Substrates: W: Weathered logs, S: soil, T: Tree, L: Leaf litters, A: Animal dung

Spatial patterns of species composition revealed clear contrasts among upstream, middle, and downstream sites. Species richness was similarly high in the upstream and middle sections (41 species each), while the downstream zone supported substantially fewer species (24 species) (Table 2). The relatively high richness in the middle zone likely reflects its heterogeneous habitat structure, combining agroforestry vegetation with semi-open riparian conditions. In contrast, the upstream zone, characterized by cooler temperatures, higher humidity, and denser canopy cover, supported numerous moisture- and shade-associated taxa such as *Marasmius elegans*, *Inocybe geophylla*, and *Mycena adscendens*. The downstream zone, influenced by greater human activity and more open vegetation, exhibited lower overall richness but was dominated by widespread generalist species including *Auricularia nigricans*, *Dacryopinax spathularia*, and *Schizophyllum commune*.

At the species level, several taxa were identified as ecological indicators of riparian habitats. *Xylaria* spp., often detected on partially decomposed logs, signify stable moisture regimes and continuous woody substrate availability. *Crepidotus* and *Pluteus* species reflect the presence of fine decomposing debris on shaded banks. The widespread occurrence of *S. commune* across all three zones indicates disturbance-tolerant conditions, as this species readily colonizes both natural and anthropogenic woody substrates. Meanwhile, *Auricularia* spp., which appeared in multiple locations, highlight the presence of well-decayed logs and sustained humidity, conditions typical of tropical riparian forests.

An important ecological feature in the Samin River fungal community is the presence of multi-substrate species, which exhibit flexible colonization strategies. Based on Table 2, species such as *Coprinopsis lagopus, M. elegans, Marasmius sullivantii, Marasmiellus candidus, M. adscendens, Mycena chlorophos, Mycena fumosa, Parasola plicatilis, Pterula multifida,* dan *X. longiana* were found on more than one substrate type, including combinations of weathered wood (W), leaf litter (L), and soil (S). This versatility suggests that these taxa play key roles in maintaining decomposition continuity across microhabitats. Multi-substrate species also help stabilize ecosystem functions by sustaining decomposition even under conditions of fluctuating substrate availability.

Several taxa exhibited restricted distributions and may represent location-specific specialists. For example, *Hortiboletus* sp., *Peziza* sp. and *Lactarius* sp. were recorded only in the upstream zone, while *Scutellinia scutellata* occurred exclusively in the middle zone. These patterns may relate to differences in canopy cover, soil moisture, and organic matter accumulation across river sections.

The species richness and taxonomic composition of macrofungi along the Samin River reflect a complex interaction between environmental gradients, substrate diversity, and habitat structure. The dominance of decomposer families, the presence of indicator species, and the occurrence of multi-substrate taxa underscore the ecological importance of riparian zones as reservoirs of fungal diversity in tropical landscapes.

Spatial patterns of diversity and community structure

Macrofungal diversity varied distinctly across the three river sections, with measurable differences in species richness, dominance patterns, and community evenness. The diversity indices presented in Table 3 show that macrofungal assemblages in the upstream, middle, and downstream zones form a clear ecological gradient aligned with environmental heterogeneity and substrate availability along the Samin River.

The upstream zone exhibited the highest overall diversity, with a Shannon-Wiener Index (H') of 3.03, categorized as high diversity. This section also recorded the highest Simpson Index (D = 0.93), Species Richness Index (R = 6.40), and Evenness Index (E = 0.81). These values indicate not only a large number of species but also a relatively balanced distribution among species, with no single taxonomic group exerting strong dominance. The upstream assemblage was characterized by a mixture of lignicolous taxa-such as *Ganoderma*, *Xylaria,* and *Auricularia* -and numerous litter- and soil-associated species (*Marasmius*, *Mycena*, *Inocybe*), reflecting substrate and microhabitat diversity.

In contrast, the middle zone displayed moderate but substantial diversity (H' = 2.57, D = 0.86, R = 6.02, E = 0.68). Species richness in the middle zone was only slightly lower than in the upstream section, yet community evenness showed a greater skew toward a few abundant taxa. This section harbored several species not observed upstream, including *S. scutellata*, *Crepidotus cesatii*, and *Gymnopus ceraceicola*, which were associated with mixed agroforestry substrates and semi-open habitats. The presence of both shaded and open microsites contributed to a heterogeneous species pool but also allowed certain species, such as *A. nigricans* and *Coprinellus disseminatus*, to occur more frequently and reduce evenness.

Table 3. Summary of macrofungal diversity indices at the Samin River riparian area, Central Java, Indonesia

Location	Shannon-Wiener (H')	Category	Simpson (D)	Category	Richness (R)	Category	Evenness (E)	Category
Upstream	3.03	High	0.93	High	6.40	High	0.81	High
Middle	2.57	Moderate	0.86	High	6.02	High	0.68	High
Downstream	2.29	Moderate	0.85	High	3.88	Moderate	0.71	High

Table 4. Results of abiotic factor measurements at Samin River riparian area, Central Java, Indonesia

Abiotic factors	**Locations**		
	Upstream	**Middle**	**Down**
Soil Temperature (°C)	21-23	24-28	28-31
Soil pH	6.3-6.7	6.7-7.0	6.9-7.2
Soil Moisture (%)	7.5-10.5	6.5-8.5	5.5-7.5
Wind Speed (m/s)	0.2-1.0	1.2-3.0	1.0-2.5
Light intensity (lux)	4,000-9,000	10,000-22,000	25,000-32,000
Air Humidity (%)	85-91	61-81	40-51
Air Temperature (°C)	23.2-25.5	28.3-30.2	31.7-33.4
Height (masl)	1,116-1,123	360-614	89-91

The downstream zone supported the lowest macrofungal diversity, with H' = 2.29, D = 0.85, R = 3.88, and E = 0.71. Although evenness remained relatively high, species richness was markedly lower than in the upstream and middle zones. The downstream community was dominated by disturbance-tolerant species such as *S. commune*, *D. spathularia*, and *Trametes*, many of which colonize exposed or degraded woody substrates. Generalist saprotrophs comprised a greater proportion of the community in this section, reflecting simplified habitat structure.

The spatial variation in diversity aligns closely with differences in environmental conditions along the river gradient. Table 4 shows that upstream sites were characterized by lower temperatures (23-25.5°C), higher humidity (85-91%), and markedly lower light intensity (4,000-9,000 lux), conditions that favor the fruiting of lignicolous and litter-decaying fungi. In contrast, downstream sites experienced higher temperatures (31.7-33.4°C), lower humidity (40-51%), and much stronger illumination (25,000-32,000 lux), conditions that reduce moisture-dependent fungal fruiting and limit the availability of intact decomposing substrates.

Differences in substrate composition also contributed to the observed diversity patterns. The upstream section contained abundant weathered logs and dense leaf litter, supporting both Basidiomycota (Polyporaceae, Mycenaceae) and Ascomycota (Xylariaceae, Pyronemataceae). The middle zone had a mixture of woody debris, riparian vegetation, and agroforestry inputs, leading to a broader but uneven species distribution. In the downstream zone, reduced tree cover and increased anthropogenic activity limited substrate diversity, with many specimens found on small woody fragments or scattered leaf litter rather than on large decaying logs. Correspondingly, the number of multi-substrate species (see Table 2) declined downstream, while upstream zones recorded more substrate-flexible taxa such as *M. sullivantii*, *M. adscendens*, and *P. plicatilis*.

The diversity indices demonstrate a clear ecological trend: upstream > middle > downstream for most metrics, despite comparable species richness between the upstream and middle sections, indicating that structural habitat complexity and microclimatic stability strongly shape macrofungal community patterns along the Samin River. These results highlight the spatially structured nature of fungal assemblages in riparian ecosystems and provide a quantitative foundation for understanding the ecological drivers of macrofungal diversity in subsequent discussion sections.

Substrate-specific distribution and ecological allocation

Macrofungal occurrence along the Samin River showed strong variation in substrate preference, reflecting the structural heterogeneity of riparian habitats. Substrate distribution is summarized in Figure 3, which illustrates that the majority of species were associated with weathered logs (W), followed by leaf litter (L), soil (S), tree trunks (T), and animal dung (A). This pattern aligns with the availability and stability of organic materials found in the riparian zone.

Weathered logs (W) constituted the dominant substrate category, representing the highest proportion of recorded species. Numerous taxa in Table 2 were exclusively or predominantly lignicolous, including *Crepidotus mollis*, *Ganoderma* sp., *Trametes* sp., *Coriolopsis gallica*, *Hexagonia tenuis*, and *Cerrena unicolor*. Weathered logs provide long-lasting moisture retention, structural stability, and complex microhabitats that support extended fungal colonization. Their abundance in the upstream and middle zones, where canopy cover is dense, further explains the dominance of W-associated species. Several indicator species of decomposing woody substrates-such as *S. commune*, *Pycnoporus sanguineus*, and *Mycena galericulata*-were consistently found on logs and stumps, reinforcing the significance of lignicolous niches in the river corridor.

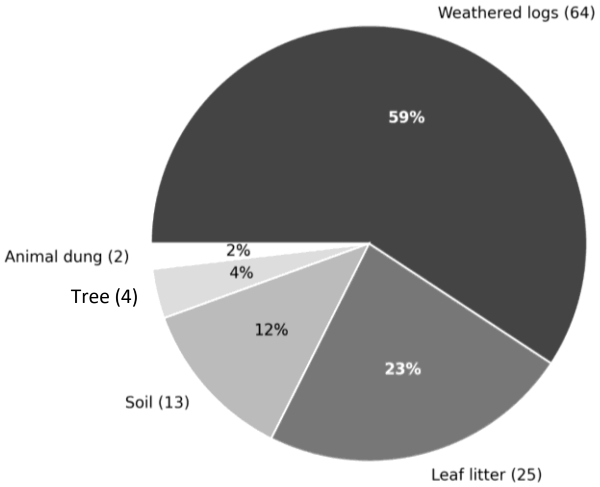

Figure 3. Diagram of types of fungal substrates in the Samin River riparian area, Central Java, Indonesia. Some species occupied multiple substrate types, each substrate was counted separately (see Table 2). Note: Species occurring on multiple substrates were counted separately (total substrate records, n = 108)

Leaf litter (L) formed the second most important substrate, supporting numerous saprotrophic species adapted to rapidly decomposing organic layers. Representative taxa include *Peziza* sp., *Conocybe* sp.1, *I. geophylla*, *Marasmius* sp.2, *Mycena* sp.3 and *Hemimycena lactea*. Leaf litter substrates were particularly abundant in the upstream zone, where mixed broadleaf vegetation and high moisture favored the development of litter-decaying communities. Several species occupied both litter and wood substrates-such as *M. elegans*, *M. adscendens*, and *P. plicatilis*-demonstrating substrate flexibility in taxa adapted to fluctuating riparian conditions.

Soil (S) substrates supported a smaller but ecologically distinct group of macrofungi. Species occurring exclusively on soil included *Geastrum saccatum*, *Hygrocybe miniata*, *Lactarius* sp., and *Russula* sp.. Soil-based occurrences were more frequent in the middle zone, where open areas and reduced canopy cover increased direct contact between fruiting bodies and exposed ground surfaces. The presence of genera such as *Geastrum* and *Russula* indicates the coexistence of both saprotrophic and ectomycorrhizal guilds in localized patches of the riparian system.

Tree trunks (T) represented a minor but specialized substrate category. Tree-associated species included *Pilatoporus hemitephrus*, *Favolaschia* sp., *Phleogena* sp., and *Collybia* sp. (Table 2). These taxa were primarily found in the middle zone, where riparian trees such as bamboo, Albizia, and Mahogany produced shaded, moisture-rich stem surfaces. Although less abundant, T-substrates contributed to overall substrate diversity and supported species not observed on other materials.

Animal dung (A) hosted the smallest number of species, exemplified by *Bolbitius coprophilus* and *Psilocybe* sp. (Table 2). Their restricted occurrence reflects the limited and patchy availability of dung substrates along the sampling transects, mainly in areas where livestock occasionally entered the riparian zone. These species serve as clear indicators of nutrient-rich ephemeral substrates and were found predominantly in the upstream sites.

A notable feature of the Samin River macrofungal assemblage is the presence of multi-substrate species, which occupied more than one substrate category and contributed to increased flexibility in habitat use. Examples include *X. longiana* (L, W), *M. chlorophos* (L, W), *M. fumosa* (L, W), *M. candidus* (L, W), *C. lagopus* (L, W), *P. plicatilis* (L, W), and *P. multifida* (L, W). These species generally occurred in humid microsites where mixed organic materials accumulated, a characteristic feature of riparian habitats influenced by periodic flooding, litter deposition, and vegetation turnover. Substrate-specific patterns underscore the importance of organic material heterogeneity in structuring macrofungal distribution along the Samin River. Weathered logs remain the most critical resource, while leaf litter and soil provide additional niche opportunities supporting a diverse assemblage across the riparian gradient.

Potential utilization of recorded macrofungi

Several macrofungal species documented along the Samin River possess notable potential for food, medicinal, and biotechnological applications, while a smaller subset is known to be toxic. Information extracted from Table 2 indicates that the riparian habitats support a functionally diverse fungal assemblage, reflecting both ecological and practical importance for local communities.

Food-related species (F)

Edible macrofungi comprised a meaningful portion of the recorded taxa, particularly those belonging to saprotrophic and lignicolous guilds. *Auricularia auricula-judae* and *A. nigricans*, both marked as food species (F), are among the most widely consumed wild mushrooms in Indonesia and globally. Their gelatinous texture and rich polysaccharide content contribute to their popularity, and previous studies highlight their potential in immune modulation and dietary fiber supplementation (Miles and Chang 2004; Mayra et al. 2024). *Termitomyces* sp. also categorized as edible-holds exceptionally high cultural and economic value, as members of this genus are regarded as delicacies with substantial protein content and antioxidant activity (Boa 2004; Sitotaw et al. 2020).

A few species from the genus *Mycena* have been reported to contain bioactive pigments and aromatic compounds, suggesting potential as functional food or natural colorants, although their edibility remains species-specific and requires further verification. The presence of edible taxa in upstream and middle zones indicates that riparian environments may serve as accessible foraging sites, particularly during humid months that support abundant fruiting.

Medicinally important species (M)

Medicinal macrofungi were relatively well represented in the Samin River dataset. *Ganoderma* sp., *P. sanguineus*, and *C. unicolor* are notable examples, each marked as medicinal (M) in Table 2 and widely studied for pharmacologically active compounds. *Ganoderma* species are renowned for triterpenoids, polysaccharides, and immunomodulatory agents with documented anticancer, antiviral, and hepatoprotective properties (Bibi et al. 2023). *Pycnoporus sanguineus* is a potent source of laccase and other ligninolytic enzymes used in bioremediation, textile processing, and biodegradation of phenolic pollutants (Huang et al. 2023). Similarly, *C. unicolor* produces bioactive metabolites with antimicrobial and antioxidant activity, and its enzymatic repertoire makes it a candidate for biotechnological applications in the green industry and waste decomposition (Sondej et al. 2025). The presence of these medicinal taxa across multiple habitat zones suggests that riparian wood resources support stable populations of pharmaceutically valuable fungi, highlighting opportunities for conservation-based sustainable utilization.

Toxic and inedible species (P)

Species categorized as poisonous (P) include *I. geophylla*, *Tetrapyrgos nigripes*, and *Peziza* sp., all of which are known to contain toxic alkaloids or irritant compounds (Benjamin 1995: Madsen and Crook 2021). *I. geophylla* is widely recognized as a muscarine-rich species associated with severe cholinergic poisoning. *Tetrapyrgos* *nigripes* and several *Peziza* species are also reported to cause gastrointestinal distress. These toxic taxa highlight the need for careful identification in potential foraging activities, especially in areas where edible species co-occur with morphologically similar toxic forms.

Local and biotechnological relevance

The macrofungal community of the Samin River includes species with substantial potential for food security, traditional medicine, and modern biotechnology. Edible taxa may support community-based harvesting programs, while medicinal and enzyme-producing species could be explored for pharmaceutical development, organic waste management, and environmental remediation. The coexistence of edible, medicinal, and toxic species underscores the ecological richness of the riparian corridor and emphasizes the value of accurate species documentation for sustainable resource utilization.

Discussion

Drivers of macrofungal diversity in riparian habitats

The interplay of microclimatic stability, substrate availability, and riparian hydrological dynamics strongly shapes macrofungal diversity in the Samin River corridor. Although species richness in the upstream section was comparable to that of the middle section (41 species each), the upstream zone exhibited the highest ecological diversity as indicated by the Shannon–Wiener and Margalef Indices (H' = 3.03, R = 6.40), a pattern that corresponds closely with the cooler temperatures, persistently high humidity (85-91%), and dense canopy structure characteristic of montane riparian ecosystems (Table 4). Numerous studies have shown that macrofungi respond sensitively to moisture and shade, which are critical for sporocarp formation, mycelial extension, and substrate decomposition rates (Lodge et al. 2004; Miles and Chang 2004). Similar environmental controls were reported from the Banyak Mountain Forest, Central Java, where macrofungal richness was closely associated with high humidity (67-80%), moderate temperatures (28-32°C), and shaded forest conditions (Nurzahra et al. 2025). In this study, the relatively stable humid microenvironment in the upstream zone created ideal conditions for various wood-decaying fungi. Genera such as *Xylaria, Crepidotus, Mycena,* and *Schizophyllum* were particularly abundant in these shaded, moisture-rich patches, likely because consistent moisture is essential for maintaining the enzymatic activity required for lignocellulose breakdown (Kumar et al. 2019; Fikri et al. 2023). Thus, the microclimatic buffering capacity of the upstream riparian forest appears to be a key driver sustaining both high ecological diversity and critical wood decomposition functions.

Light availability also played a significant role. The upstream canopy, with light intensity ranging only 4,000-9,000 lux, supports fungal communities that thrive under reduced irradiance. Shaded conditions slow substrate desiccation and enhance the persistence of fruiting bodies-particularly among taxa with delicate sporocarps such as *Marasmius*, *Hemimycena*, and several *Mycena* species. Similar patterns were documented in riparian forests in Vietnam (Le et al. 2022) and subtropical China, where low-light understories were associated with high basidiomycete richness. In forested ecosystems of Central Java, dense canopy cover was likewise linked to prolonged substrate moisture and the dominance of wood-inhabiting Basidiomycota, particularly Polyporales (Nurzahra et al. 2025). Conversely, in the downstream section of Samin River, elevated temperatures (31-33°C) and high light intensity (25,000-32,000 lux) likely contributed to lower fungal richness by accelerating substrate drying and reducing sporocarp longevity. This ecological gradient parallels observations by Muchane et al. (2021), who reported that macrofungal community indicators (abundance, species richness, and diversity) were lower in more open and degraded habitats than in more favorable habitats within riparian landscapes.

Hydrological dynamics further shape community composition. Riparian zones undergo periodic flooding and sediment deposition, processes known to influence the distribution of fungi associated with soil, litter, and woody debris. In the Samin River, periodic high-flow events in the middle and downstream areas result in substrate turnover and mechanical disturbance, potentially reducing habitat stability for fungi requiring long-term colonization, such as species of *Ganoderma*, *Cerrena*, and *Perenniporia* (Huang et al. 2023; Sondej et al. 2025). In contrast, the upstream segment-with its steeper slopes and faster drainage-experiences less substrate inundation, enabling sustained colonization by wood-decaying taxa. Studies from tropical riparian forests in Malaysia and the Philippines also highlight that stable, well-drained slopes foster richer macrofungal communities relative to more frequently disturbed lower reaches (Boa 2004).

Comparisons with other Indonesian macrofungal studies reveal both consistencies and distinctive patterns. Putra (2020) documented the dominance of Marasmiaceae and Mycenaceae in shaded forested habitats in Sumatra, a trend mirrored in the Samin dataset, where these families contained some of the highest species numbers (Figure 2). Similarly, Yusran et al. (2024) recorded a high abundance of *Auricularia* and *Termitomyces* in humid riparian-agroforestry mosaics in Sulawesi. However, the Samin River community is unique in its strong representation of both Ascomycota (*Xylaria*, *Peziza*, *Scutellinia*) and Basidiomycota, suggesting a mixed system where microhabitat heterogeneity-particularly diverse woody and litter substrates-supports a broad taxonomic profile. This differs from several lowland studies in Java and Bali, where Basidiomycota overwhelmingly dominate in more uniform forest conditions (Rahmi et al. 2021; Mahardhika et al. 2022).

Another driver of diversity is the mosaic of substrate types across the river sections. As later elaborated in Section 3.3, weathered logs (W) were the most prevalent substrate, and numerous species-such as *Xylaria longipes*, *S. commune*, *Mycena tenerrima*, and *C. mollis*-are well-adapted to colonize decomposing woody material. Substrate heterogeneity is widely acknowledged as a primary determinant of fungal richness (Ghosh et al. 2021), and the abundance of coarse woody debris in the upstream and middle zones likely contributed to higher species turnover and niche specialization.

In summary, macrofungal diversity along the Samin River is shaped by a combination of microclimatic gradients, substrate stability, canopy structure, and hydrological patterns. When compared with regional and global studies, the Samin River assemblage aligns with broader ecological principles governing fungal richness in humid riparian systems, while also displaying distinct features tied to its montane-to-lowland environmental transition.

Substrate ecology and functional interpretation

The dominance of weathered logs (W) as the primary substrate for macrofungi in the Samin River riparian area reflects a combination of ecological opportunity, microhabitat stability, and enzymatic specialization among lignicolous taxa. As shown in Figure 3, more than half of all recorded species occurred on W, including members of *Xylaria*, *Crepidotus*, *Mycena*, *Schizophyllum*, *Cerrena*, *Pycnoporus*, and *Ganoderma*. This pattern is consistent with global observations that riparian corridors with high humidity and moderate disturbance regimes accumulate Coarse Woody Debris (CWD), which supports rich communities of saprotrophic fungi (Boddy and Heilmann-Clausen 2008). In the upper Samin River, dense canopy cover and continuous litterfall further promote the formation of partially decomposed logs, creating long-lasting substrates that retain moisture throughout the year-conditions ideal for wood-decaying Basidiomycota.

Wood-inhabiting fungi play an essential role in carbon cycling, lignocellulose breakdown, and nutrient turnover. Genera such as *Xylaria* (Ascomycota) and *Crepidotus*, *Cerrena*, *Ganoderma*, and *Fomes* (Basidiomycota) possess enzyme systems capable of degrading cellulose, hemicellulose, and lignin (Kumar et al. 2019; Sondej et al. 2025). For example, *P. sanguineus* produces high levels of laccase, an oxidizing enzyme crucial in lignin decomposition, making it a cornerstone species in both natural and industrial biodegradation processes (Huang et al. 2023). Similarly, *S. commune* is known for its versatile ligninolytic activity and tolerance to fluctuating moisture, which explains its presence across all three river zones. These taxa exemplify the ecological importance of wood-decomposing fungi in maintaining riparian forest function, especially in systems with high organic input and variable hydrology.

The prevalence of wood substrates contrasts with the lower representation of soil (S), litter (L), tree bark (T), and animal dung (A). Soil fungi tend to require stable microenvironments and may be less likely to produce conspicuous fruiting bodies outside wetter seasons. Only a few species, such as *G. saccatum* and *H. miniata*, were restricted to soil substrates-a pattern consistent with studies from other tropical riparian forests (Amaral-Machado et al. 2020; Le et al. 2022). Leaf litter, although abundant along the Samin River, appears to support fewer specialists, dominated mainly by *Marasmius*, *Mycena*, and *Inocybe* species, which are known litter decomposers with relatively short-lived sporocarps (Patocka et al. 2021; Lodge and Cantrell 2023). Tree substrates (T) supported only a small subset of species, such as *P. hemitephrus* and *Phleogena* sp., consistent with their known preferences for living or recently dead woody tissues rather than fully decayed logs (Gilbert and Sousa 2002).

Animal dung (A) was the rarest substrate and hosted only two taxa, *B. coprophilus* and *Psilocybe* sp., mirroring patterns reported from Java, Sumatra, and Sulawesi, where dung fungi form small but ecologically distinct assemblages (Boa 2004; Yusran et al. 2024). Their presence indicates microhabitat heterogeneity within the riparian matrix and suggests that livestock movement contributes to organic micro-patches that foster niche specialists.

A notable feature of the Samin River macrofungal assemblage is the presence of multi-substrate species, such as *X. longiana* (W, L), *M. elegans* (L, W), *M. sullivantii* (L, W), *M. adscendens* (L, W), *M. chlorophos* (L, W), *M. fumosa* (L, W), *P. plicatilis* (L, W), and *P. multifida* (L, W), as documented in Table 2. Multi-substrate occupancy is generally interpreted as an indicator of ecological flexibility and adaptive foraging strategy by mycelial networks (Ovaskainen et al. 2013; Bässler et al. 2015; Shigyo and Hirao 2021). Species capable of colonizing both wood and litter may exploit transitional decay stages or microhabitats with shifting moisture levels-conditions typical of riparian slopes where periodic runoff redistributes organic material. This flexibility also enhances community resilience, as multi-substrate fungi can persist despite spatial or temporal fluctuations in substrate availability.

Comparisons with similar tropical studies reveal parallel trends. In Vietnam, Le et al. (2022) reported dominance of lignicolous taxa in humid riparian forests, while in West Java, Rahmi et al. (2021) observed that *Schizophyllum*, *Marasmius*, and *Mycena* thrived in mixed wood-litter substrates. The Samin River system aligns with these findings but further stands out because of its strong substrate gradient from upland to lowland sites, resulting in higher representation of lignicolous and flexible species in the upstream and middle zones.

The substrate ecology of the Samin River macrofungi underscores the functional importance of decaying wood as the backbone of fungal diversity in riparian ecosystems. The dominance of W, the presence of highly specialized lignicolous taxa, and the occurrence of multi-substrate species together highlight an ecologically dynamic system shaped by moisture, organic inputs, and microhabitat heterogeneity.

Comparison with other regions

Patterns of macrofungal diversity observed in the Samin River riparian area align with, yet also diverge in key ways from, studies conducted in other Indonesian landscapes and in tropical Asia. The dominance of Basidiomycota-particularly families such as Mycenaceae, Marasmiaceae, Polyporaceae, and Auriculariaceae-has also been reported in riparian or forest-edge environments elsewhere in Indonesia. For example, Putra (2020) documented

Marasmius, *Mycena*, and *Crepidotus* as the most common genera in West Java, reflecting similar ecological preferences for shaded, moist substrates rich in decomposing organic matter. Likewise, Yusran et al. (2024) noted strong representation of lignicolous taxa in Sulawesi's agroforestry-riparian mosaics, particularly *Auricularia*, *Termitomyces*, and *Ganoderma*, which mirrors the taxa recorded in Samin River (e.g., *A. auricula-judae*, *Termitomyces* sp., and *Ganoderma* sp.).

However, the Samin River assemblage exhibits a stronger association with weathered logs (W) compared to datasets from West Java and Sulawesi, where litter substrates (L) and soil (S) supported higher proportions of species. This may reflect differences in hydrological regime, canopy density, and organic input: the upland regions of Tawangmangu provide continuous wood debris deposition and stable humidity, conditions that promote extensive colonization by *Xylaria*, *Mycena*, *S. commune*, *C. unicolor*, and *P. sanguineus*-taxa consistently associated with high-moisture, high-lignin environments (Kumar et al. 2019; Sondej et al. 2025). In contrast, Putra's (2020) sites were dominated by mixed homegardens and secondary forest edges where leaf litter decomposition is the primary nutrient pathway.

At the regional scale, macrofungal surveys across Southeast Asia show similar structural patterns but with notable biogeographical variation. Studies in Thailand, Vietnam, Peninsular Malaysia, and the Philippines frequently report Mycenaceae and Polyporaceae as dominant families, consistent with the Samin River patterns (Hyde et al. 2018; Dell et al. 2020; Le et al. 2022). In Vietnam, Le et al. (2022) documented extensive colonization of decomposing logs by *Mycena*, *Marasmius*, and *Fomes* species in humid riparian forests, paralleling the strong wood-dependence observed in Samin River. In contrast, studies in seasonal tropical forests of Thailand and Northern Laos found a larger proportion of soil-associated taxa such as *Russula*, *Lactarius*, and *Amanita*, likely due to more pronounced dry seasons and higher rates of ectomycorrhizal activity (Dai et al. 2006; Li et al. 2018).

Globally, the macrofungal diversity structure of the Samin River riparian corridor aligns strongly with patterns recorded in other humid riparian or temperate-tropical transition zones. Riparian forests in the Pacific Northwest, Amazonia, and parts of East Africa similarly show a strong dominance of lignicolous fungi driven by abundant coarse woody debris and stable microclimates (Boddy and Heilmann-Clausen 2008; Guerin-Laguette et al. 2014). The representation of multi-substrate species such as *M. elegans*, *M. adscendens*, *P. plicatilis*, and *P. multifida* reflects broad functional strategies comparable to those reported in Costa Rican and Brazilian Atlantic forests, where microhabitat heterogeneity drives community resilience (Teixeira-Silva et al. 2024).

Despite these similarities, the Samin River system is distinctive for its sharp environmental gradient across relatively short spatial scales. Elevation shifts from >1,100 masl in the upstream to <100 masl in the downstream zone, accompanied by major changes in humidity, canopy cover, substrate availability, and anthropogenic pressure. This degree of environmental contrast-paired with the persistence of moisture-retaining woody substrates-appears to enhance overall macrofungal richness compared to more environmentally homogeneous riparian systems in Southeast Asia. While the macrofungal assemblage of Samin River is broadly consistent with regional and global patterns of tropical riparian mycobiota, it also displays unique features shaped by its elevational gradient, substrate composition, and landscape mosaic. These findings emphasize the ecological value of Javanese riparian corridors as biodiversity reservoirs within increasingly human-modified ecosystems.

Implications for conservation and utilization

The macrofungal diversity documented along the Samin River underscores the importance of riparian corridors as ecological refugia within increasingly fragmented landscapes. Riparian systems-characterized by consistently higher humidity, moderated temperatures, and periodic nutrient deposition-serve as stable microhabitats that buffer fungal communities against environmental fluctuations (Naiman and Décamps 1997; Fischer et al. 2019). The presence of 100+ macrofungal species across only six sampling stations suggests that even narrow riparian strips can sustain remarkably high taxonomic and functional diversity. This is especially relevant in Java, where forest cover outside protected areas is limited, and riparian vegetation often forms the last remaining continuum of semi-natural habitat. The strong dominance of lignicolous taxa such as *Xylaria*, *Mycena*, *Schizophyllum*, and *Cerrena* further indicates that riparian wood debris plays a critical conservation role, acting as a long-term reservoir for enzymatically specialized saprotrophs.

The Samin River findings support a broader recognition that fungi are foundational components of riparian ecosystem resilience through their contributions to organic matter decomposition, soil formation, and nutrient cycling (Kumar et al. 2019; Miles and Chang 2004). In particular, multi-substrate species such as *M. elegans*, *M. chlorophos*, and *P. plicatilis* signal functional redundancy and adaptive capacity within the community, traits that enhance ecosystem stability in the face of changing hydrological regimes or human disturbance (Ovaskainen et al. 2013; Bässler et al. 2015; Shigyo and Hirao 2021).

Beyond their ecological functions, several macrofungal taxa recorded here hold significant potential for food, medicinal applications, and biotechnology. Species categorized as edible (F) in Table 2-including *A. auricula-judae*, *A. nigricans*, and *Termitomyces* sp.-are widely consumed in Asia and valued for their nutritional content, antioxidant activity, and polysaccharide profiles (Boa 2004; Yusran et al. 2024). Their natural occurrence in humid wood-litter microhabitats suggests potential for community-based cultivation in semi-wild or agroforestry systems, as demonstrated in mushroom domestication efforts elsewhere in Indonesia (Kusters and Belcher 2004). The detection of *Termitomyces*, in particular, indicates the presence of well-established termite-fungus interactions in the Samin landscape, opening avenues for managed harvesting or symbiotic cultivation approaches.

Medicinally important species also feature prominently in the assemblage. *Ganoderma* sp., *P. sanguineus*, *C. unicolor*, and *Neofavolus alveolaris* have documented antimicrobial, antioxidant, and immunomodulatory properties (Le et al. 2022; Huang et al. 2023; Sondej et al. 2025). *Ganoderma* species are globally recognized for bioactive triterpenoids and polysaccharides (Karunarathna et al. 2025), while *Pycnoporus* is a source of industrially valuable laccases and secondary metabolites (Lesage-Meessen et al. 2011). The presence of these taxa within a relatively small riparian corridor highlights the biotechnological potential embedded in local fungal communities, many of which remain underutilized and understudied.

Conversely, species classified as poisonous (P), including *I. geophylla*, *T. nigripes*, and *Peziza* sp., underscore the need for caution in local utilization practices. Misidentification is a well-documented risk in tropical regions, where edible and toxic species may exhibit similar macromorphological traits (Li et al. 2025). Thus, conservation strategies should incorporate community education on mushroom identification, sustainable harvesting guidelines, and the promotion of safe, culturally informed foraging practices.

From a management perspective, maintaining and restoring riparian vegetation along the Samin River is essential for sustaining fungal diversity. Conservation measures such as limiting wood removal, retaining coarse woody debris, and reducing land-use conversion near riverbanks will preserve the substrate continuity necessary for lignicolous fungal communities (van der Linde et al. 2012). Additionally, microhabitat-specific cultivation-such as log-based cultivation of *Auricularia* or shaded-litter beds for *Marasmius* species-could offer sustainable livelihood opportunities while supporting in situ conservation. The riparian corridor of the Samin River represents both a biodiversity reservoir and a socioeconomic resource. Its fungal diversity provides ecological services, cultural value, and biotechnological potential that merit stronger integration into local conservation planning and sustainable-use frameworks.

In conclusion, this study provides a comprehensive assessment of macrofungal diversity in Java's tropical riparian Samin River, revealing it as a key refugium supporting 98 species across 38 families and 13 orders, with Basidiomycota, especially Mycenaceae, Polyporaceae, and Marasmiaceae, dominating as key decomposers. Spatial diversity patterns showed upstream zones with the highest richness (H′ = 3.03, R = 6.40) and downstream zones with lower values (H′ = 2.29, R = 3.88), reflecting gradients in humidity, light, and substrate availability. Multi-substrate species like *M. elegans* and *M. adscendens* demonstrated ecological flexibility, while edible, medicinal, and toxic taxa highlighted the community's practical relevance. Although limited by single-season, morphology-based identification, the findings underscore the need to conserve riparian vegetation and woody debris to maintain fungal-driven ecosystem functions. Future studies should integrate multi-season sampling, DNA barcoding, and functional assays to better understand temporal dynamics and species roles in this heterogeneous riparian landscape.

ACKNOWLEDGEMENTS

The authors express their sincere gratitude to the local communities of Karanganyar and Sukoharjo in Central Java, Indonesia, for granting access to observation sites along the Samin River and for sharing valuable information on local environmental conditions. We thank the local governments for facilitating research permits and providing general land-use information relevant to the study area. Field assistance provided by students and volunteers during data collection in March-April 2024 is gratefully acknowledged. We also appreciate the constructive insights from colleagues in mycology and forest ecology, whose comments improved the quality of this manuscript. Finally, we acknowledge the use of taxonomic databases, including MycoBank and Index Fungorum, which supported species identification and nomenclatural validation throughout the study.

REFERENCES

Abdalla RR, Ahmed AI, Abdalla AI, Abdelmaboud OA, Khiery NTMA, Elriah NDA, Saeed MSA. 2016. Some wild edible and medicinal mushroom species at Khartoum and Sinnar States-Sudan. J Microb Biochem Technol 8 (6): 503-506.

Al-Momany AM. 2025. Identification and distribution of wild toxic *Inocybe* spp., and edible *Tricholoma* mushrooms in Jordan. Jordan J Agric Sci 21(1): 5-15. DOI: 10.35516/jjas.v21i1.2001.

Amaral-Machado L, Oliveira WN, Moreira-Oliveira SS, Pereira DT, Alencar EN, Tsapis N, Egito EST. 2020. Use of natural products in asthma treatment. Evid Based Compl Altern Med 2020: 1-35. DOI: 10.1155/2020/1021258.

Armadhan WS, Sari SP, Aji MYMB, Permatasari DP, Amalia BW, Berlin GE, Aszar AS, Indrawan M, Pradhan P, Setyawan AD. 2023. The macrofungal diversity and its potential from the karst forest of Kalipoh Village, Kebumen District, Indonesia. Asian J For 7(2): 98-105. DOI: 10.13057/asianjfor/r070204.

Bässler C, Heilmann-Clausen J, Karasch P, Brandl R, Halbwachs H. 2015. Ectomycorrhizal fungi have larger fruit bodies than saprotrophic fungi. Fungal Ecol 17: 205-212. DOI: 10.1016/j.funeco.2014.06.005.

Benjamin DR. 1995. Mushrooms: Poisons and Panaceas. A Handbook for Naturalists, Mycologists and Physicians. W.H. Freeman and Company, New York.

Beug MW, Bessette AE, Bessette AR. 2014. Ascomycete Fungi of North America: A Mushroom Reference Guide. University of Texas Press, Austin.

Bibi S, Wang ZL, Lin C, Min SH, Cheng CY. 2023. Two-stage cultivation strategies for optimal production of *Ganoderma* pellets with potential application in the vegan food industry. J Food Sci Technol 60 (6): 1793-1802. DOI: 10.1007/s13197-023-05719-x

BMKG. 2025. Prediksi Musim Kemarau Tahun 2025 di Indonesia. bmkg.go.id/iklim/prediksi-musim/prediksi-musim-kemarau-tahun-2025-di-indonesia. [Indonesian]

Boa E. 2004. Wild Edible Fungi: A Global Overview of Their Use and Importance to People. Food and Agriculture Organization, Rome.

Boddy L, Heilmann-Clausen J. 2008. Basidiomycete community development in temperate angiosperm wood. Br Mycol Soc Symp Ser 28: 211-237. DOI: 10.1016/S0275-0287(08)80014-8.

Cohen R, Persky L, Hadar Y. 2002. Biotechnological applications and potential of wood-degrading mushrooms of the genus *Pleurotus*. Appl Microbiol Biotechnol 58: 582-594. DOI: 10.1007/s00253-002-0930-y

Dai B, Rattanarithikul R, Lumyong P, Lumyong S. 2006. Ectomycorrhizal fungi in dry and wet dipterocarp forests in northern Thailand: diversity and use as food. In: Proceedings of the National Seminar on

Agriculture. Malaysian Agricultural Research and Development Institute (MARDI), Kuala Lumpur.

Dell B, Malajczuk N, Xu D. 2020. Macrofungal assemblages of tropical riparian zones in Southeast Asia. Mycoscience 61(4): 195-205. DOI: 10.1016/j.myc.2020.03.004.

Elkhateeb W, Daba GM. 2021. Fungi over fungi: Endophytic fungi associated with mushroom fruiting bodies and lichens. J Pharm Pharm Res 4: 1-4. DOI: 10.31579/2693-7247/028.

Fawwaz DA, Warasari T, Nurhaliza Y, Sucitawati Y, Jayanti ET, Harisanti BM, Primawati SN. 2024. Diversity of fungi in the Mount Rinjani National Park Kembang Kuning Resort, Jeruk Manis Village, Sikur District, East Lombok District. Ecobios J Environ Sci 1 (1): 37-46. DOI: 10.71024/ecobios/2024/v1i1/15.

Feng T, Li ZH, Yin X, Dong ZJ, Wang GQ, Li XY, Li Y, Liu JK. 2013. New benzene derivatives from cultures of ascomycete *Daldinia concentrica*. Nat Prod Bioprospect 3: 150-153. DOI: 10.1007/s13659-013-0048-1.

Fikri AHN, Rosyid CHR, Mahajarifar RZ, Fadlun F, Noverita N. 2023. Keanekaragaman jamur makro dan potensinya di Kampung Citlahab, Balai Taman Nasional Gunung Halimun Salak. Al-Kauniyah: Jurnal Biologi 16 (1): 76-88. DOI: 10.15408/kauniyah.v16i1.20482. [Indonesian]

Fischer C, Damm C, Foeckler F, Gelhaus M, Gerstner L, Harris RMB, Hoffmann TG, Iwanowski J, Kasperidus H, Mehl D, Podschun SA, Rumm A, Stammel B, Scholz M. 2019. The "Habitat Provision" Index for assessing floodplain biodiversity and restoration potential as an ecosystem service-method and application. Front Ecol Evol 7: 483. DOI: 10.3389/fevo.2019.00483.

Ghosh S, Sett S, Saha R, Roy A, Acharya K. 2021. Comparative phytochemical screening and antioxidant properties of infusion, decoction and hydroalcoholic extracts of wood ear mushrooms *Auricularia delicata* and *Auricularia mesenterica*. Indian Phytopathol 74: 113-121. DOI: 10.1007/s42360-020-00301-3

Gilbert GS, Sousa WP. 2002. Host specialization among wood-decay polypore fungi in a Caribbean mangrove forest. Biotropica 34: 396-404. DOI: 10.1111/j.1744-7429.2002.tb00553.x.

Guerin-Laguette A, Cummings N, Butler RC, Willows A, Hesom-Williams N, Li S, Wang Y. 2014. Lactarius deliciosus and Pinus radiata in New Zealand: Towards the development of innovative gourmet mushroom orchards. Mycorrhiza 24: 511-523. DOI: 10.1007/s00572-014-0578-4.

Huang X, Shi L, Lin Y, Zhang C, Liu P, Zhang R, Chen Q, Ouyang X, Gao Y, Wang Y, Sun T. 2023. *Pycnoporus sanguineus* polysaccharides as reducing agents: Self-assembled composite nanoparticles for integrative diabetic wound therapy. Intl J Nanomed 18: 6021-6035. DOI: 10.2147/IJN.S427055.

Hyde KD, Al-Hatmi AM, Andersen B et al. 2018. The world's ten most feared fungi. Fungal Divers 93: 161-194. DOI: 10.1007/s13225-018-0413-9.

Karunarathna SC, Patabendige NM, Hapuarachchi KK, Promputtha I. 2025. Exploring the health benefits of Ganoderma: Antimicrobial properties and mechanisms of action. Front Cell Infect Microbiol 15: 1535246. DOI: 10.3389/fcimb.2025.1535246.

Kibby G. 2006. Philip's Guide to Mushrooms and Toadstools of Britain and Northern Europe. Philip's, London.

Kirk PM, Cannon PF, Minter DW, Stalpers JA. 2008. Dictionary of the Fungi. 10th ed. CAB International, Wallingford.

Kumar A, Kumar M, Ali S, Lal SB, Sinha MP. 2019. Antipathogenic efficacy of Indian edible macrofungi *Dacryopinax spathularia* (Schwein) and *Schizophyllum commune* (Fries) against some human pathogenic bacteriae. J Emerg Technol Innov Res 6: 695-704.

Kumar R, Tapwal A, Pandey S, Rishi R. 2013.Fungal diversity associated with bamboo litter from Bambusetum of Rain Forest Research Institute, Northeast India. Biodiversitas 14: 79-88. DOI: 10.13057/biodiv/d140205.

Largent DL. 1977. How to Identify Mushrooms to Genus III: Microscopic Features. Mad River Press, US.

Le THY, Tran HT, Dong THA, Nguyen ML, Vu DN, Trinh TK. 2022. Antimicrobial and antioxidant activity of the polypore mushroom *Lentinus arcularius* (Agaricomycetes) isolated in Vietnam. Intl J Med Mushrooms 24 (3): 15-23. DOI: 10.1615/IntJMedMushrooms.2022042702

Lesage-Meessen L, Haon M, Uzan E, Levasseur A, Piumi F, Navarro D, Taussac S, Favel A, Lomascolo A. 2011. Phylogeographic relationships in the polypore fungus *Pycnoporus* inferred from molecular data. FEMS Microbiol Lett 325: 37-48. DOI: 10.1111/j.1574-6968.2011.02412.x.

Li H, Guo J, Karunarathna SC, Ye L, Xu J, Hyde KD, Mortimer PE. 2018. Native forests have a higher diversity of macrofungi than comparable plantation forests in the Greater Mekong Subregion. Forests 9 (7): 402. DOI: 10.3390/f9070402.

Li H, Zhang Y, Zhang H, Zhou J, Li Z, Yin Y, He Q, Jiang S, Zhang Y, Yuan Y, Lang N, Cheng B, Zhong J, Yuan M, Liu Z, Sun C. 2025. Mushroom poisoning outbreaks-China, 2024. China CDC Wkly 7: 645-649. DOI: 10.46234/ccdcw2025.106.

Lodge D, Cantrell S. 2023. The roles of macrofungi in humid tropical forests and the effects of disturbance. In: Hyde KD, Lumyong S, Xu J (eds). Fungal Diversity in the Tropics. CRC Press, Boca Raton. DOI: 10.1201/9781003429272-3.

Lodge JD, Ammirati FJ, O'Dell ET, Mueller GM. 2004. Collecting and describing macrofungi. In: Mueller GM, Bills GF, Foster MS (eds). Biodiversity of Fungi: Inventory and Monitoring Methods. Elsevier Academic Press, Burlington.

Madsen AM, Crook B. 2021. Occupational exposure to fungi on recyclable paper pots and growing media and associated health effects-A review of the literature. Sci Total Environ 788: 147-158. DOI: 10.1016/j.scitotenv.2021.147832.

Magurran AE. 1998. Ecological Diversity and Its Measurement. Princeton University Press, Princeton.

Mahardhika WA, Utami AB, Lunggani AT, Putra IP. 2022. Eksplorasi jamur di Desa Kedung Pacul, Klaten, dan potensi pemanfaatannya. Bioma: Berkala Ilmiah Biologi 24 (1): 8-23. DOI: 10.14710/bioma.24.1.8-23. [Indonesian]

Mayra MT, Siagian SLS, Putri AN, Khairani D, Santoso GZS, Abdurrahman NH, Rhama MD, Mahardhika WA, Sari OY, Putra IP. 2024. Catatan jamur di sekitar hutan Danau Situgede (Bogor) dan potensinya sebagai sumber pangan. Jurnal Jeumpa 11 (2): 226-240. DOI: 10.33059/jj.v11i2.10150. [Indonesian]

McKnight KH, McKnight VB. 1987. Peterson's Field Guide to Mushrooms. Houghton Mifflin Company, New York.

Miles PG, Chang ST. 2004. Mushrooms: Cultivation, Nutritional Value, Medicinal Effect, and Environmental Impact. 2nd ed. CRC Press, Boca Raton.

Muchane M, Terer T, Waithaka K. 2021. Macro-fungi community of Lake Ol Bolossat Basin and associated riparian ecosystems in Central, Kenya. Intl J Nat Resour Ecol Manag 6: 6-15. DOI: 10.11648/j.ijnrem.20210601.13.

Mueller GM, Bills GF, Foster MS. 2004. Biodiversity of Fungi: Inventory and Monitoring Methods. Elsevier Academic Press, Burlington.

Naiman RJ, Décamps H. 1997. The ecology of interfaces: Riparian zones. Ann Rev Ecol Syst 28: 621-658. DOI: 10.1146/annurev.ecolsys.28.1.621.

Nurzahra Vy, Muzazzinah M, Indrowati M. 2025. Diversity of macrofungi (Ascomycota and Basidiomycota) in the Banyak Mountain Forest Area, Sragen District, Indonesia. Nusantara Biosci 17 (1): 39-48. DOI: 10.13057/nusbiosci/n170105

Odum EP. 1971. Fundamental of Ecology. WE Sounders, Philadelphia.

On JO, Bassey GA, Agba MIO, Markson AA. 2021. Amino acids composition of some wild edible mushrooms from Southern Cross River State, Nigeria. Asian J Biol 12 (2): 24-32. DOI: 10.9734/ajob/2021/v12i230159.

Ovaskainen O, Schigel D, Ali-Kovero H, Auvinen P, Paulin L, Norden B, Norden J. 2013. Combining high-throughput sequencing with fruit body surveys reveals contrasting life-history strategies in fungi. ISME J 7 (9): 1696-1709. DOI: 10.1038/ismej.2013.61.

Patocka J, Wu R, Nepovimova E, Valis M, Wu W, Kuca K. 2021. Chemistry and toxicology of major bioactive substances in Inocybe mushrooms. Intl J Mol Sci 22(4): 1-13. DOI: 10.3390/ijms22042218.

Pielou EC. 1966. The measurement of diversity in different types of biological collections. J Theor Biol 13: 131-144.

Putra IP. 2020. Record on macroscopic fungi at IPB University Campus Forest: description and potential utilization. Indones J Sci Educ 4(1): 1-11. DOI: 10.31003/ijose.v4i1.2180.

Rahmi NA, Hutami AT, Hasrida HM, Syahidah RN, Nurazizah S, Radiastuti N, Fifendy M. 2021. Inventarisasi keragaman dan potensi jamur makro di Taman Margasatwa Ragunan, Jakarta Selatan. Prosiding Seminar Nasional Biologi 1 (2): 554-562. DOI: 10.24036/prosemnasbio/vol1/333. [Indonesian]

Ryoo R, Lee H. 2024. In vitro anti-influenza virus (H1N1) activity of eleven species of Korean medicinal mushrooms. Res Square 2024: 1-16. DOI: 10.21203/rs.3.rs-3848264/v1.

Shannon CE, Weaver W. 1963. The Mathematical Theory of Communication. University of Illinois Press, Urbana.

Shigyo N, Hirao T. 2021. Saprotrophic and ectomycorrhizal fungi exhibit contrasting richness patterns along elevational gradients in cool-temperate montane forests. Fungal Ecol 50: 101036. DOI: 10.1016/j.funeco.2020.101036.

Simpson EH. 1949. Measurement of diversity. Nature 163 (4148): 688. DOI: 10.1038/163688a0.

Sitotaw R, Lulekal E, Abate D. 2020. Ethnomycological study of edible and medicinal mushrooms in Menge District, Asossa Zone, Benshangul Gumuz Region, Ethiopia. J Ethnobiol Ethnomed 16: 1-14. DOI: 10.1186/s13002-020-00361-9.

Sondej D, Pigoń-Zając D, Jaszek M, Stefaniuk D, Matuszewska A, Bielak K, Opielak G, Małecka-Massalska T, Rahnama-Hezavah M, Prendecka-Wróbel M. 2025. Is laccase from medicinal mushroom *Cerrena unicolor* cytotoxic to colon cancer cell line CT-26? PLoS One 20(5): e0322211. DOI: 10.1371/journal.pone.0322211.

Srivastava M, Kumari M, Karn SK, Bhambri A, Mahale VG, Mahale S. 2024. Submerged cultivation and phytochemical analysis of medicinal mushrooms (*Trametes* sp.). Front Fungal Biol 5: 1-16. DOI: 10.3389/ffunb.2024.1414349.

Staita K, Khmaissa M, Akrout I, Greff S, Ghariani B, Turbé-Doan A, Lomascolo A, Albert Q, Faulds CB, Sciara G, Mechichi HZ, Record E, Mechichi T. 2024. Biotransformation of the fluoroquinolone antibiotic levofloxacin by the free and immobilized secretome of *Coriolopsis gallica*. J Fungi 10 (12): 1-19. DOI: 10.3390/jof10120861.

Stamets P. 2005. Mycelium Running: How Mushrooms Can Help Save the World. Ten Speed Press, Berkeley.

Teixeira-Silva M, Silva C, Santos G, Carvalho C, Cortez V, Silveira M. 2024. Macrofungal species richness and composition of Acre State, Amazon, Brazil: State of the art. Bot Rev 90: 1-25. DOI: 10.1007/s12229-024-09302-7.

van der Linde S, Holden E, Parkin PI, Alexander IJ, Anderson IC. 2012. Now you see it, now you don't: The challenge of detecting, monitoring and conserving ectomycorrhizal fungi. Fungal Ecol 5: 633-640. DOI: 10.1016/j.funeco.2012.04.002.

Yusran Y, Erniwati E, Rukmi R. 2024. Ethnomycology of wild edible mushrooms by the Bunggu Tribe in West Sulawesi, Indonesia. Intl J Des Nat Ecodyn 19 (6): 2097-2107. DOI: 10.18280/ijdne.190626.