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Macrofungal Diversity of Tingana, the Highest Flooded Forest in Peru: A Preliminary Assessment

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Abstract

This research focused on understanding the diversity of macrofungi in the "Tingana Conservation Concession" in San Martín, Peru, a unique flooded forest located at approximately 900 m a.s.l. in the Andean-Amazonian foothills. Three study areas were included: Sparse Aguajal, Semi-dense Aguajal, and Broadleaf Evergreen Forest. These were sampled using random transects; 19 macrofungi were identified to species level and 20 to genus level, distributed in 8 orders, 19 families, and 27 genera. The most diverse orders were Agaricales and Polyporales; the most representative families were Polyporaceae (11) and Psathyrellaceae (4). At a generic level, the most diverse was *Lentinus*, with a total of 5 species identified. These findings highlight the diversity and ecological importance of fungi in the decomposition of organic matter and the nutrient cycle in peatlands, which are key carbon-storing ecosystems. This study underlines the need for more research focused on inventorying fungi for the conservation of this type of ecosystem.

Keywords: Alto Mayo Valley; Amazonian; climate change; conservation; fungal; macrofungi; nutrient recycling; peatlands

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1. Introduction

In tropical ecosystems, fungi perform a variety of functions, including the decomposition of organic matter and subsequent nutrient recycling [1], conservation of genetic diversity [2], and serving as a food resource for mycophagous animals [3]. Fungi also play a role in soil restoration, with applications in agriculture [4–6]. From an ecological perspective, their participation in the carbon cycle is particularly noteworthy [7], but it is essential to understand their two contrasting functions. On one hand, fungi act as carbon sequestering agents, incorporating carbon from decomposed wood into stable fungal biomass components such as chitin and melanin, thereby functioning as mechanisms for long-term carbon storage and contributing to climate change mitigation [8,9]. On the other hand, as decomposers, they release carbon back into the atmosphere by degrading lignin and cellulose present in plant matter [10], accelerating the cycling of nutrients. Consequently,

the study of fungi assumes particular importance in ecosystems where high concentrations of greenhouse gases are stored [11], such as in the Amazonian peatlands [12,13].

In Peru, macrofungal diversity knowledge is closely linked to the heterogeneity of its ecosystems [14–16], with the Amazon region of Madre de Dios being one of the main focuses of study. In the Setapo sector of the Amarakaeri Communal Reserve, 143 species of macrofungi have been identified, distributed across 36 families and 16 orders, with a predominance of Basidiomycota [17]. The Polyporaceae family was the most dominant, with *Trametes* Fr. and *Ganoderma* P. Karst. being particularly prominent. In a separate study in Madre de Dios, Florez documented 88 species of macrofungi classified into 47 families and 52 genera, with higher species richness in forests with reduced canopy openness [15].

Peatlands are wetlands characterised by soils formed by layers of partially decomposed vegetation called 'peat' that have accumulated over millennia [18–20], due to the inhibition of organic matter decomposition in anaerobic environments generated by recurrent or permanent flooding [21,22]. These ecosystems are important carbon stores, and the rate and nature of their decomposition have significant implications for the global carbon cycle [23]. The high humidity and presence of peat create a unique and restrictive environment [11,24] for a wide range of organisms, including fungi that develop on leaves, fallen logs, stumps, and decaying remnants [25]. In peatlands, given the anoxic nature of the soil, organic matter decomposition is an inherently slow process [26]; however, the presence of fungi, with their ability to degrade complex components such as lignin and cellulose, accelerates this process [27], facilitating nutrient transformation and recycling [28,29].

Land-use change, especially due to deforestation, farming, and mining, as well as the effects of climate change, are the main threats to Amazonian peatlands [13,30] and fungi [31]. The loss of fungal diversity has serious consequences, disrupting the delicate balance of peatlands and accelerating the release of large amounts of carbon into the atmosphere [9]. Despite their ecological importance, global fungal diversity is poorly documented [31]. Fungal diversity in the Alto Mayo Valley, San Martín region, located in the Andean-Amazonian foothills, is entirely unknown. Therefore, the aim of this research is to determine the taxonomic diversity of macrofungi and their ecological role in Tingana, representing the first report for this tropical peatland ecosystem in the Andean-Amazonian foothills of Peru and a pioneering study in the Americas.

2. Materials and Methods

2.1. Study Area

The study was carried out in the territory of the Aguajales and Renacales Conservation Association of Alto Mayo (ADECARAM—Tingana), which encompasses a total area of 2867.64 hectares. The concession is located at coordinates 05°54′17.9″ S, 77°07′07.5″ W, in the district of Pueblo Libre, province of Moyobamba, department of San Martín (Figure 1). ADECARAM—Tingana manages the Tingana Conservation Concession (TCC), a unique site due to its typical plant formations of Várzea or Tahuampa forests, characterised by *Ficus trigona* L.f. (Moraceae), *Coussapoa trinervia* Spruce ex Mildbr. (Urticaceae), *Inga* Mill. sp. (Fabaceae), and *Virola* Aubl. sp. (Myristicaceae) [32,33], at an altitude of approximately 900 m a.s.l. Tingana is located in a transition zone between the low flood zone of the central Huallaga and the montane forests of the eastern Peruvian Andes [13].

Most of the TCC area constitutes flooded forest subject to recurrent flooding by the Huascayacu, Mayo, and Avisado rivers. Two distinct seasons occur throughout the year: (i) the wet season, beginning in late October, peaking in February, and ending in early April, and (ii) the dry season, beginning in the second week of April with August as its driest month [33].

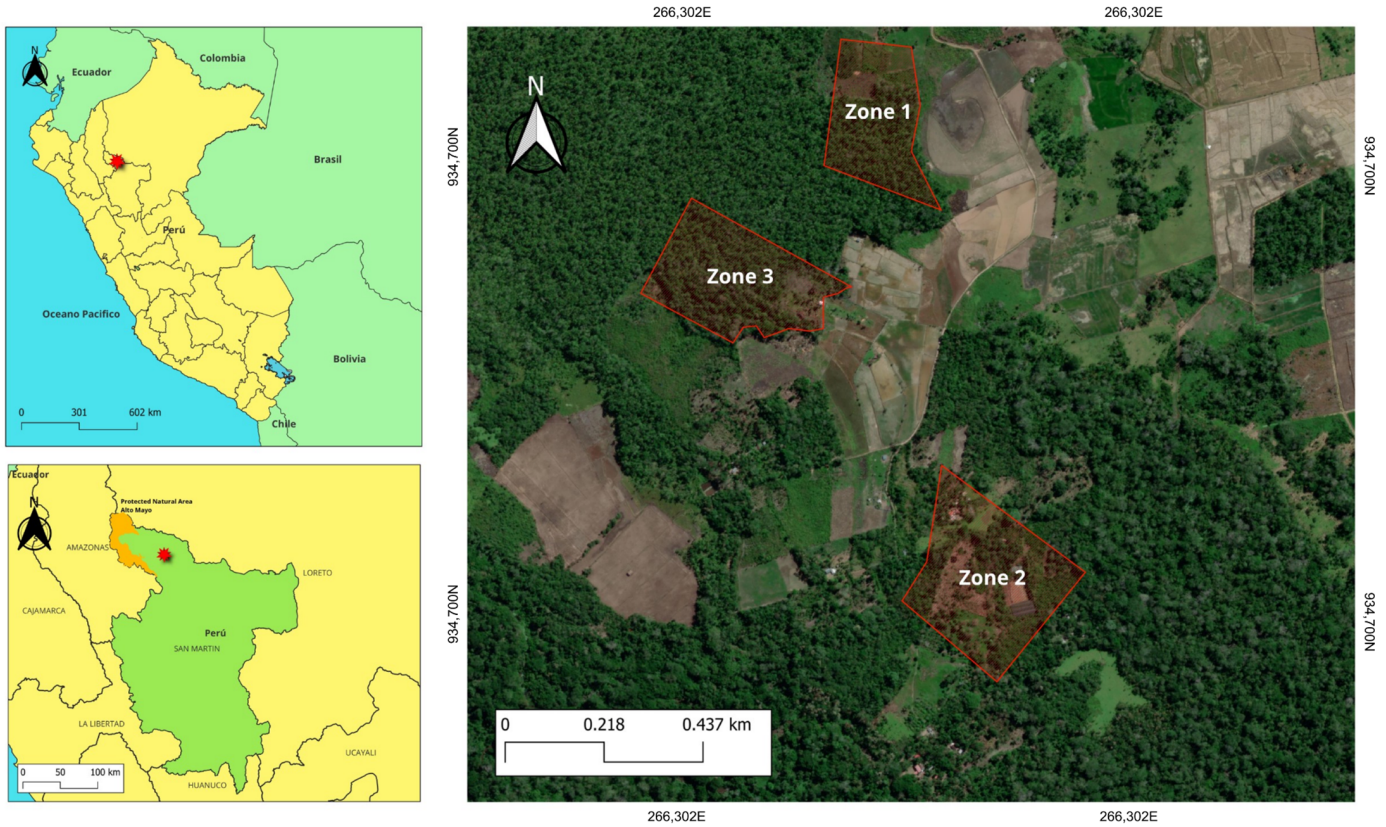

Figure 1. Location map of the Tingana Conservation Concession (TCC) and the three sampling zones. The red star indicates the study site location in Peru and in the San Martín department, where the orange area represents the Alto Mayo Protection Forest. Zone 1: Sparse Aguajal; Zone 2: Broadleaf Evergreen Forest; Zone 3: Semi-dense Aguajal.

This study was carried out between August 2023 and July 2024 in three sampling areas: (i) Sparse Aguajal (SA: 5°54′08.67″ S, 77°06′55.96″ W), (ii) Broadleaf Evergreen Forest (BEF: 5°54′49.17″ S, 77°06′48.93″ W), and (iii) Semi-dense Aguajal (SDA: 5°54′19.51″ S, 77°07′05.62″ W) (Figure 2). The SA is a sparse palm swamp dominated by *Mauritia flexuosa* L.f. with alternating shrub species including *Inga* sp., *Miconia* Ruiz & Pav. sp. (Melastomataceae), and *Tococa guianensis* Aubl. (Melastomataceae); the canopy reaches 25 m and the area is subject to high anthropogenic pressure. The BEF is a sporadically flooded area dominated by *Ficus* sp., *Oxandra* A. Rich. (Annonaceae), and *Virola*, with ongoing reforestation using native species. The SDA is a permanently flooded swamp with a high alternation of *Coussapoa trinervia*, *Ficus trigona*, and *Virola elongata* Aubl., with soils rich in organic matter from *M. flexuosa* palms.

2.2. Substrate Classification

To characterize the substrate associations of the fungal records, four categories relevant to the specimens documented in this study were considered: humicolous, lignicolous, muscicolous and terricolous. Humicolous fungi were those associated with humus and decomposed organic matter; lignicolous fungi with woody substrates, including decaying logs, trunks, stumps and branches; muscicolous fungi with living mosses or moss-covered substrates; and terricolous fungi with soil substrates. Each fungal record was assigned to a single category according to the predominant substrate in direct contact with the sporocarp.

Figure 2. Sampling zones showing the predominant vegetation of each study area. (**Z1**) Sparse Aguajal: palm swamp dominated by *Mauritia flexuosa* with scattered shrubs such as *Inga* sp., *Miconia* sp., and *Tococa guianensis*; (**Z2**) Broadleaf Evergreen Forest: sporadically flooded forest dominated by *Ficus* sp., *Oxandra* sp., and *Virola* sp., with ongoing reforestation using native species; (**Z3**) Semi-dense Aguajal: permanently flooded swamp with dense cover of *Coussapoa trinervia*, *Ficus trigona*, and *Virola elongata*, and organic-rich soils derived from *Mauritia flexuosa*.

2.3. Macrofungal Sampling and Collection

In each sampling area, three transects measuring 3 × 100 m^2 (300 m^2) were established following the methodology of Pérez-López et al. [34], and the entire transect area was systematically surveyed during each sampling event. Due to the recurrent flooding and heterogeneous accessibility characteristic of the Tingana peat swamp forests, transects were positioned using a restricted random approach within the accessible portions of each sampling area. To ensure comparability among habitats, the same sampling effort was maintained across all areas, and each sampling area was separated by a minimum distance of 400 m. Transects were surveyed every three months from August 2023 to July 2024, encompassing two dry-season and two wet-season campaigns. During each survey, an intensive search for macrofungi was conducted by examining fallen leaves, woody debris, trunks, and stumps within the transects, while opportunistic collections of fruiting bodies encountered within the sampling areas were also performed to complement the inventory [35].

A Nikon D3500 camera (Nikon Corporation, Tokyo, Japan) was used to photograph every angle of the sporome. Sporomes were collected following the methodology of García-Saldaña et al. [36] and dehydrated using a solar food dehydrator for 8 h at room temperature (24–30 °C). Samples were deposited in the Herbarium of San Marcos (USM). Specimens were examined using a EUROMEX ISCOPE microscope and identified using Singer [37], Ryvarden [38–41], and Wijayawardene et al. [42]. Nomenclature followed Index Fungorum, and current names were verified to ensure taxonomic validity using the database [43].

2.4. Data Analysis

All statistical analyses were performed in R version 4.6.1 [44] using incidence (presence–absence) data to characterize macrofungal assemblages based on species occurrence. A binary incidence matrix was constructed for the three study zones. Alpha diversity was assessed using observed richness (Sobs), Shannon diversity (H′), Simpson diversity (1 − D), inverse Simpson diversity (1/D), and Pielou's evenness (J′), calculated with the vegan package [45]. Higher values of Shannon and Simpson indices indicate greater diversity, whereas Pielou's index ranges from 0 to 1, with values closer to 1 indicating a more even distribution of taxa [46–48].

Beta diversity among study zones was evaluated using Jaccard and Sørensen dissimilarity indices and partitioned into turnover (βjtu) and nestedness (βjne) components following Baselga [49] with the betapart package [50]. Species exclusivity, taxonomic composition and substrate associations were summarized descriptively, and differences in substrate use among study zones were evaluated using a chi-square test ($\alpha = 0.05$). Data visualization and manipulation were performed using packages from the tidyverse ecosystem [51] and ggplot2 [52].

3. Results

3.1. Taxonomic Diversity of Macrofungi

A total of 39 macrofungal taxa were recorded in the Tingana Conservation Concession, belonging to two phyla, three classes, eight orders, 19 families and 27 genera (Table 1). Basidiomycota overwhelmingly dominated the assemblage, accounting for 38 of the 39 recorded taxa (97.4%), whereas Ascomycota was represented by a single taxon. Of the total taxa recorded, 20 were identified to genus level and 19 were identified only to species level.

Table 1. Summary of macrofungal taxonomic diversity recorded in the Tingana Conservation Concession.

Taxonomic Level	Total	Ascomycota	Basidiomycota
Phyla	2	1	1
Classes	3	1	1
Orders	8	1	7
Families	19	1	18
Genera	27	1	26
Total taxa	39	1	38
Species-level IDs	19	1	18
Genus-level IDs	20	0	20

Values represent the number of taxa at each level. Total columns may exceed phylum-specific counts due to shared higher ranks.

A total of eight fungal orders were documented, with Agaricales (19 taxa; 48.7%) and Polyporales (14 taxa; 35.9%) comprising more than 84% of all records (Figure 3a). The remaining orders—Auriculariales, Hymenochaetales, Pezizales, Phallales, Russulales and Tremellales—were represented by a single taxon each.

At the family level, Polyporaceae exhibited the highest richness with 11 taxa, followed by Psathyrellaceae (4 taxa) and Agaricaceae (3 taxa). Marasmiaceae, Meruliaceae, Mycenaceae, Pleurotaceae and Schizophyllaceae were represented by two taxa each, whereas the remaining families contained only one recorded taxon (Figure 3b). Genus richness was strongly dominated by *Lentinus*, which represented the most diverse genus in the inventory. Other relatively species-rich genera included *Cymatoderma*, *Trametes*, *Coprinellus*, *Marasmius*, *Mycena*, *Parasola*, *Pluteus* and *Schizophyllum*, whereas most remaining genera were represented by a single taxon (Figure 4).

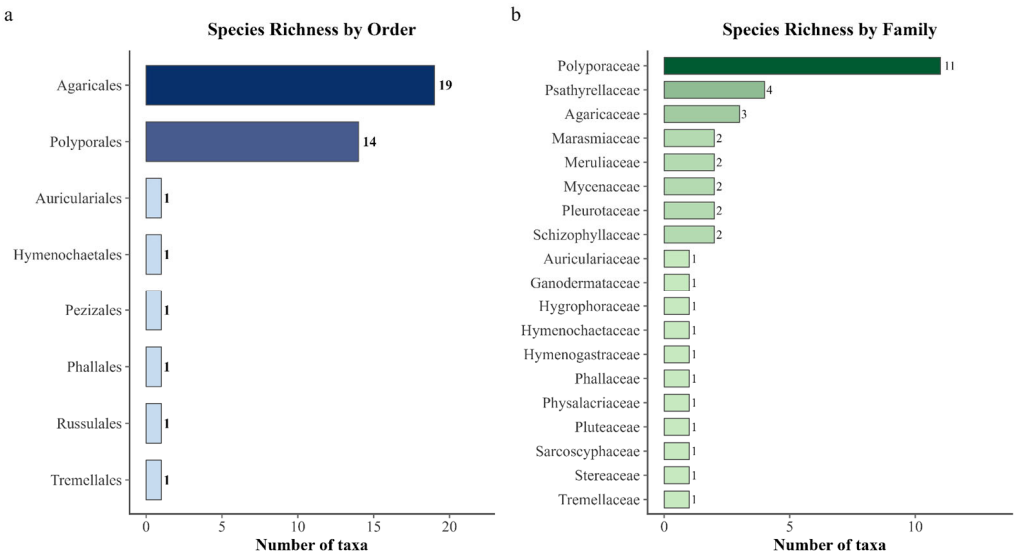

Figure 1a. Taxonomic richness per fungal order recorded in Tingana.

Figure 1b. Taxonomic richness per fungal family recorded in Tingana

Figure 3. Species richness of macrofungal taxa recorded in the Tingana Conservation Concession by (**a**) order and (**b**) family.

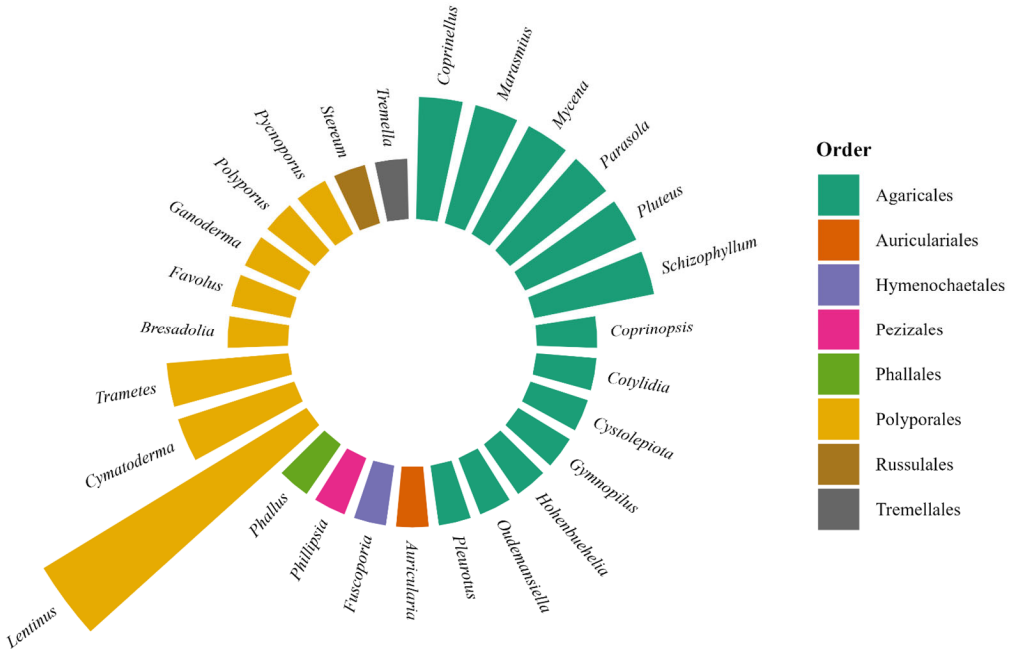

Figure 4. Genus-level richness of macrofungal taxa recorded in the Tingana Conservation Concession, colour-coded by order.

3.2. Alpha Diversity Among Study Zones

Macrofungal richness and diversity varied among the three study zones (Table 2). The Sparse Aguajal (SA) exhibited the highest observed richness (Sobs = 19), followed by the Broadleaf Evergreen Forest (BEF; Sobs = 13) and the Semi-dense Aguajal (SDA; Sobs = 10).

Shannon diversity values followed the same pattern, with SA showing the highest diversity ($H' = 2.944$), followed by BEF ($H' = 2.565$) and SDA ($H' = 2.303$). Similarly, Simpson diversity was greatest in SA ($1 - D = 0.947$), intermediate in BEF (0.923) and lowest in SDA (0.900).

Inverse Simpson values corresponded closely to observed richness, reaching 19 in SA, 13 in BEF and 10 in SDA. Pielou's evenness was equal to 1 in all three zones, indicating a highly even distribution of taxa when diversity metrics were calculated from incidence-based data.

Table 2. Alpha diversity metrics derived from species incidence data for macrofungal assemblages in the three study zones of the Tingana Conservation Concession.

Study Zone	S Obs	H′ Shannon	1 − D Simpson	1/D Simpson	J′ Pielou
Sparse Aguajal (SA)	19	2.944	0.947	19	1
Semi-dense Aguajal (SDA)	10	2.303	0.900	10	1
Broadleaf Evergreen Forest (BEF)	13	2.565	0.923	13	1

S obs = observed species richness; H′ = Shannon diversity index; 1 − D = Simpson diversity index; 1/D = inverse Simpson index; J′ = Pielou evenness. SA = Sparse Aguajal; SDA = Semi-dense Aguajal; BEF = Broadleaf Evergreen Forest.

3.3. Taxonomic Composition Across Study Zones

The composition of macrofungal assemblages differed among habitats (Figure 5). The Sparse Aguajal contained the highest number of taxa (n = 19) and the greatest taxonomic breadth, encompassing seven fungal orders. Agaricales dominated this zone with 10 taxa, followed by Polyporales with four taxa.

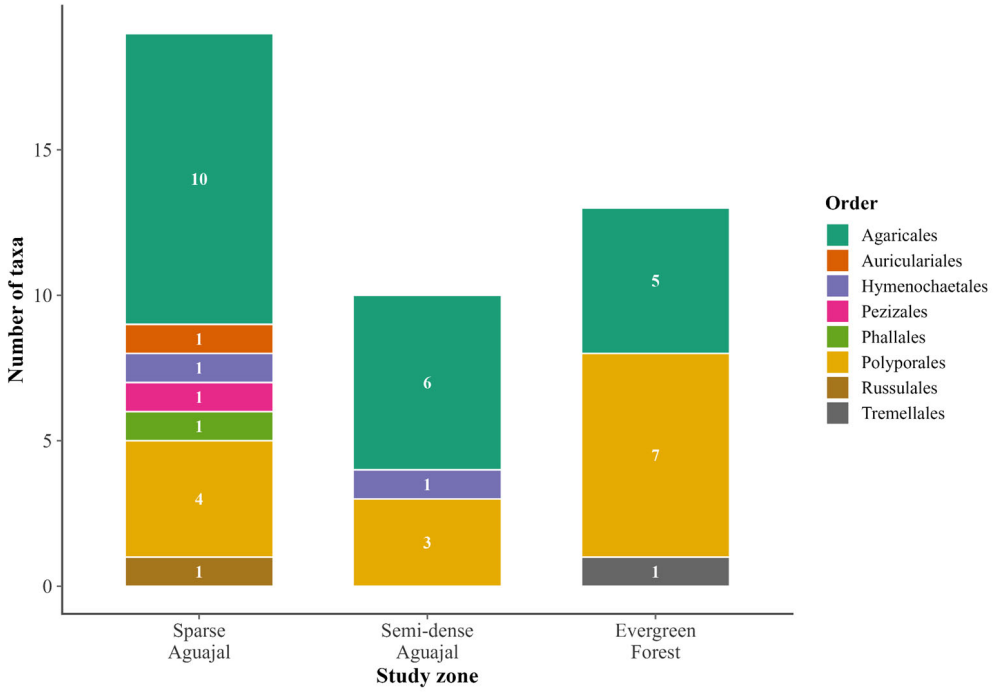

Figure 5. Taxonomic composition of macrofungal assemblages across the three study zones of the Tingana Conservation Concession, showing the number of taxa per order in each habitat.

The Semi-dense Aguajal contained 10 taxa distributed mainly between Agaricales (six taxa) and Polyporales (three taxa), with a single representative of Hymenochaetales.

The Broadleaf Evergreen Forest contained 13 taxa and showed a more balanced representation between Agaricales (five taxa) and Polyporales (seven taxa), together with one representative of Tremellales.

Although Agaricales remained the most diverse order overall, its contribution decreased from the Sparse Aguajal to the Broadleaf Evergreen Forest, whereas the relative representation of Polyporales increased in the forest habitat.

3.4. Species Distribution, Exclusivity and Beta Diversity

The presence–absence matrix revealed marked spatial segregation of taxa among study zones (Figure 6). Most taxa occurred in only one habitat type, whereas relatively few species were shared between zones.

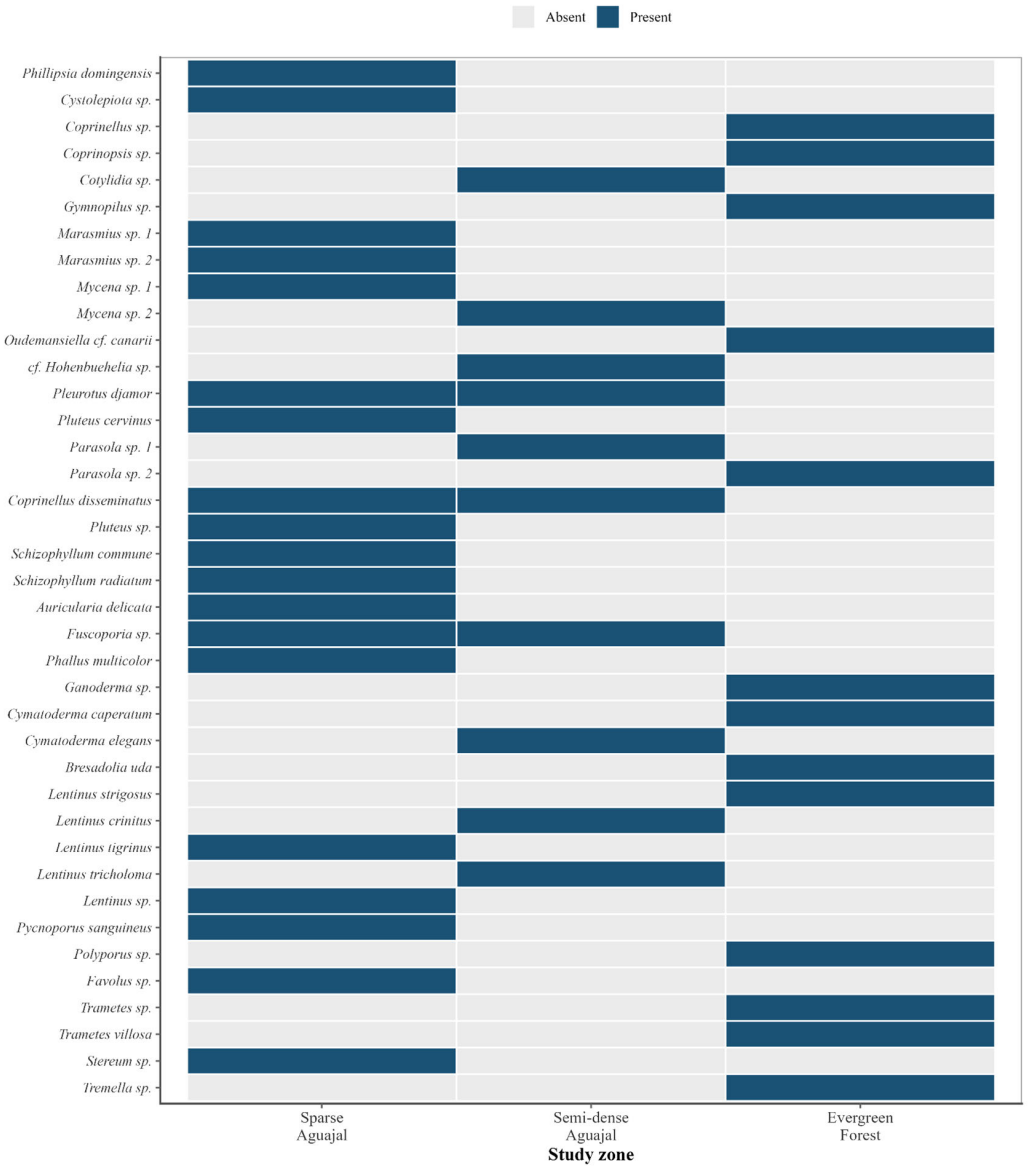

Figure 6. Presence–absence matrix of macrofungal taxa recorded across the three study zones of the Tingana Conservation Concession. Dark bars indicate presence; white bars indicate absence.

This pattern was confirmed by species-sharing analyses (Table 3). The Sparse Aguajal contained the largest number of exclusive taxa (16; 41.0% of all records), followed by the Broadleaf Evergreen Forest (13 taxa; 33.3%) and the Semi-dense Aguajal (7 taxa; 17.9%). Only three taxa (7.7%) were shared exclusively between SA and SDA, whereas no taxa were shared exclusively between SA and BEF or between SDA and BEF. Notably, no species was recorded simultaneously in all three study zones.

The strong spatial differentiation among assemblages was further reflected in beta diversity metrics (Table 4). Jaccard and Sørensen dissimilarities were very high across all pairwise comparisons, ranging from 0.885 to 1.000 and from 0.793 to 1.000, respectively. Complete compositional dissimilarity was observed between SA and BEF and between SDA and BEF, where both Jaccard and Sørensen indices reached 1.000.

Partitioning of beta diversity indicated that turnover was the dominant component of assemblage differentiation. For SA–BEF and SDA–BEF comparisons, beta diversity was entirely explained by species replacement (βjtu = 1.000), with no contribution from nestedness (βjne = 0.000). Likewise, turnover accounted for most of the dissimilarity between SA and SDA (βjtu = 0.824), whereas nestedness contributed only marginally

(βjne = 0.061). These results indicate that differences among habitats were primarily driven by species replacement rather than by ordered species loss.

Table 3. Species sharing and exclusivity among the three study zones in the Tingana Conservation Concession.

Species Sharing	n	% of Total
Exclusive to SA	16	41.0
Exclusive to SDA	7	17.9
Exclusive to BEF	13	33.3
Shared SA & SDA (only)	3	7.7
Shared SA & BEF (only)	0	0.0
Shared SDA & BEF (only)	0	0.0
Shared all three zones	0	0.0

Percentages calculated relative to the total number of taxa recorded (n = 39). SA = Sparse Aguajal; SDA = Semi-dense Aguajal; BEF = Broadleaf Evergreen Forest.

Table 4. Pairwise beta diversity metrics and decomposition into turnover and nestedness components for macrofungal assemblages in the Tingana Conservation Concession.

Zone Pair	Jaccard (β)	Sørensen (β)	Turnover (βjtu)	Nestedness (βjne)
SA–SDA	0.885	0.793	0.824	0.061
SA–BEF	1.000	1.000	1.000	0.000
SDA–BEF	1.000	1.000	1.000	0.000

Beta diversity decomposition following [49]. Jaccard-based partitioning: βjtu = turnover component; βjne = nestedness component. SA = Sparse Aguajal; SDA = Semi-dense Aguajal; BEF = Broadleaf Evergreen Forest.

3.5. Substrate Associations

Most macrofungal taxa were associated with woody substrates (Table 5). Lignicolous fungi accounted for 28 taxa, representing 71.79% of all records. Humicolous taxa were the second most frequent group (15.38%), followed by terricolous (10.26%) and muscicolous taxa (2.56%).

Table 5. Substrate associations of macrofungal taxa recorded in each study zone of the Tingana Conservation Concession.

Substrate	SA	SDA	BEF	Total	% of Total
Humicolous	3	3	0	6	15.38
Lignicolous	14	5	11	28	71.79
Muscicolous	1	1	0	1	2.56
Terricolous	1	1	2	4	10.26

Values represent number of taxa per substrate per zone. Chi-square test (substrate × zone): $\chi^2 = 6.63$, df = 6, $p = 0.357$. SA = Sparse Aguajal; SDA = Semi-dense Aguajal; BEF = Broadleaf Evergreen Forest.

The predominance of lignicolous fungi was consistent across all study zones, with 14 taxa recorded in SA, five in SDA and 11 in BEF. Humicolous taxa were restricted to the aguajal habitats, whereas terricolous fungi occurred in all zones but were more frequent in BEF.

Despite these differences, substrate use did not vary significantly among habitats ($\chi^2 = 6.63$, df = 6, $p = 0.357$), indicating that the overall distribution of substrate guilds remained relatively similar across the three study zones.

3.6. Data Records and Photographic Evidence

A complete taxonomic inventory of the macrofungal species documented in the Tingana Conservation Concession is presented below (Table 6), including information on phylum, class, order, family, substrate association, and occurrence across the sampling zones.

To complement the taxonomic information and facilitate species recognition, representative photographs of the fruiting bodies observed in the field are provided (Figures 7–10). These images are included for reference purposes only and do not necessarily correspond to the individual specimens used for taxonomic identification or deposited as voucher material.

Table 6. Checklist of macrofungi recorded in the Tingana Conservation Concession (TCC), San Martín, Peru. SA = Sparse Aguajal; BEF = Broadleaf Evergreen Forest; SDA = Semi-dense Aguajal.

Phylum	Class	Order	Family	Species	Zone	Habitat
Ascomycota	Pezizomycetes	Pezizales	Sarcoscyphaceae	*Phillipsia domingensis* (Berk.) Berk. ex Denison	BEF	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Agaricaceae	*Cystolepiota* sp.	SA	Terricolous
Basidiomycota	Agaricomycetes	Agaricales	Agaricaceae	*Coprinellus* sp.	BEF	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Agaricaceae	*Coprinopsis* sp.	SDA	Terricolous
Basidiomycota	Agaricomycetes	Agaricales	Hygrophoraceae	*Cotylidia* sp.	BEF	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Hymenogastraceae	*Gymnopilus* sp.	SDA	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Marasmiaceae	*Marasmius* sp. 1	SA	Humicolous
Basidiomycota	Agaricomycetes	Agaricales	Marasmiaceae	*Marasmius* sp. 2	SA	Humicolous
Basidiomycota	Agaricomycetes	Agaricales	Mycenaceae	*Mycena* sp. 1	SA	Humicolous
Basidiomycota	Agaricomycetes	Agaricales	Mycenaceae	*Mycena* sp. 2	SA, SDA	Muscicolous
Basidiomycota	Agaricomycetes	Agaricales	Physalacriaceae	*Oudemansiella* cf. *canarii* (Jungh.) Höhn.	SA	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Pleurotaceae	cf. *Hohenbuehelia* sp.	SA, SDA	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Pleurotaceae	*Pleurotus djamor* (Rumph. ex Fr.) Boedijn	BEF	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Pluteaceae	*Pluteus cervinus* (Schaeff.) P. Kumm.	SDA	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Psathyrellaceae	*Parasola* sp. 1	BEF	Terricolous
Basidiomycota	Agaricomycetes	Agaricales	Psathyrellaceae	*Parasola* sp. 2	BEF	Terricolous
Basidiomycota	Agaricomycetes	Agaricales	Psathyrellaceae	*Coprinellus disseminatus* (Pers.) J.E. Lange	BEF	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Psathyrellaceae	*Pluteus* sp.	SA	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Schizophyllaceae	*Schizophyllum commune* Fr.	BEF	Lignicolous
Basidiomycota	Agaricomycetes	Agaricales	Schizophyllaceae	*Schizophyllum radiatum* Fr.	SA	Lignicolous
Basidiomycota	Agaricomycetes	Auriculariales	Auriculariaceae	*Auricularia delicata* (Mont. ex Fr.) Henn.	SA	Lignicolous
Basidiomycota	Agaricomycetes	Hymenochaetales	Hymenochaetaceae	*Fuscoporia* gilva	SDA	Lignicolous
Basidiomycota	Agaricomycetes	Phallales	Phallaceae	*Phallus multicolor* (Berk. & Broome) Cooke	SDA	Terricolous
Basidiomycota	Agaricomycetes	Polyporales	Ganodermataceae	*Ganoderma* sp.	BEF	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Meruliaceae	*Cymatoderma caperatum* (Berk. & Mont.) D.A. Reid	SA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Meruliaceae	*Cymatoderma elegans* Jungh.	SA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Bresadolia uda* (Jungh.) Audet	SA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Lentinus strigosus* Fr.	BEF	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Lentinus crinitus* (L.) Fr.	SA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Lentinus tigrinus* (Bull.) Fr.	SA, SDA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Lentinus tricholoma* (Mont.) Zmitr.	SA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Lentinus* sp.	SDA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Pycnoporus sanguineus* (L.) Murrill	SA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Polyporus* sp.	SDA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Favolus* sp.	SA	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Trametes* sp.	BEF	Lignicolous
Basidiomycota	Agaricomycetes	Polyporales	Polyporaceae	*Trametes villosa* (Sw.) Kreisel	SA	Lignicolous
Basidiomycota	Agaricomycetes	Russulales	Stereaceae	*Stereum* sp.	BEF	Lignicolous
Basidiomycota	Tremellomycetes	Tremellales	Tremellaceae	*Tremella* sp.	BEF	Lignicolous

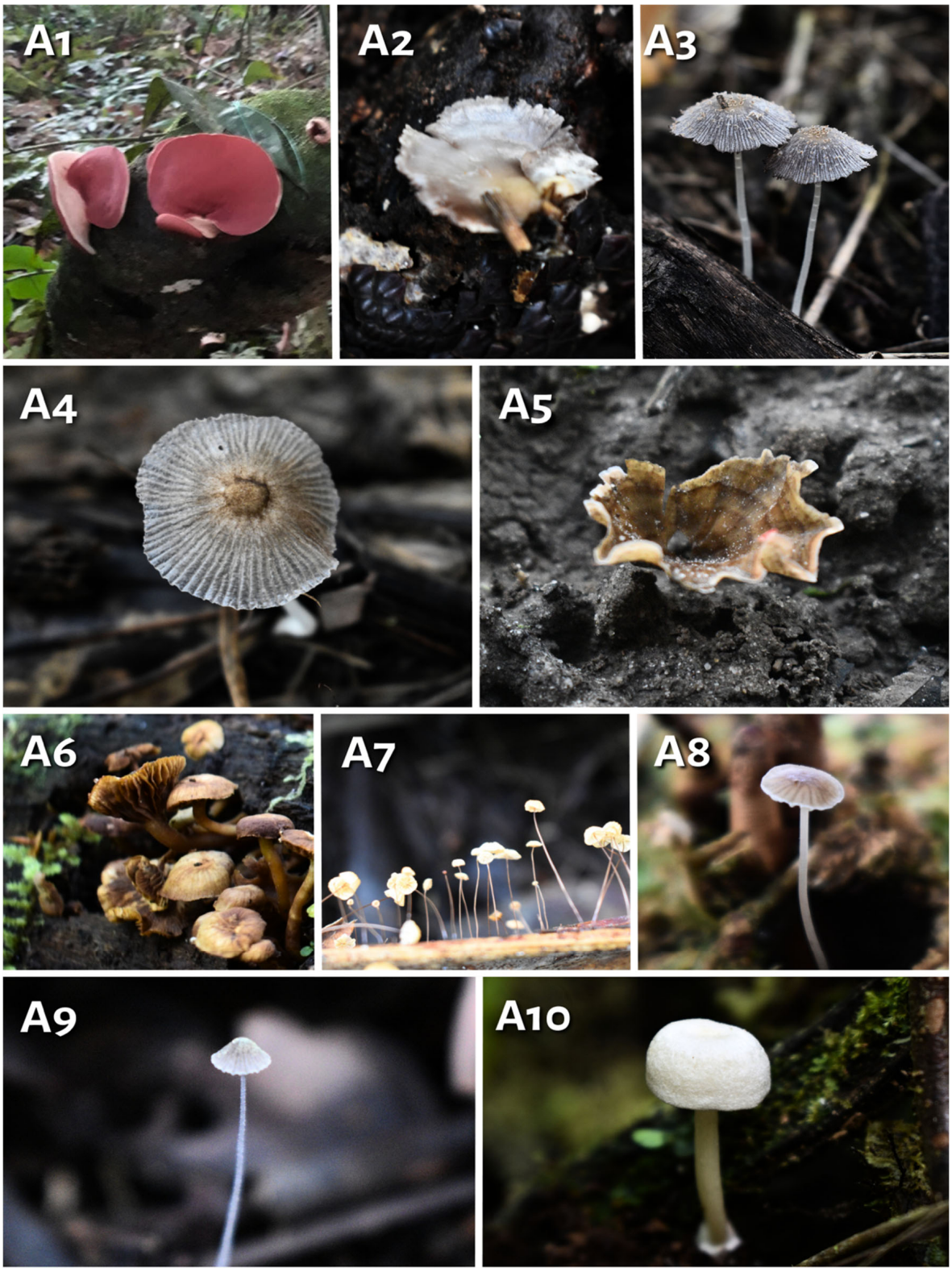

Figure 7. Representative species of macrofungi recorded in Tingana (**A1**–**A10**), presented as reference illustrations of their habit and macroscopic morphology in natural conditions: (**A1**) *Phillipsia domingensis*; (**A2**) *Cystolepiota* sp.; (**A3**) *Coprinellus* sp.; (**A4**) *Coprinopsis* sp.; (**A5**) *Cotylidia* sp.; (**A6**) *Gymnopilus* sp.; (**A7**) *Marasmius* sp. 1; (**A8**) *Marasmius* sp. 2; (**A9**) *Mycena* sp. 1; (**A10**) *Mycena* sp. 2.

Figure 8. Representative macrofungal species present in Tingana (**B1**–**B10**): (**B1**) *Oudemansiella* cf. *canarii*; (**B2**) cf. *Hohenbuehelia* sp.; (**B3**) *Pleurotus djamor*; (**B4**) *Pluteus* sp. 1; (**B5**) *Parasola* sp. 1; (**B6**) *Parasola* sp. 2; (**B7**) *Coprinellus disseminatus*; (**B8**) *Pluteus* sp. 2; (**B9**) *Schizophyllum commune*; (**B10**) *Schizophyllum radiatum*.

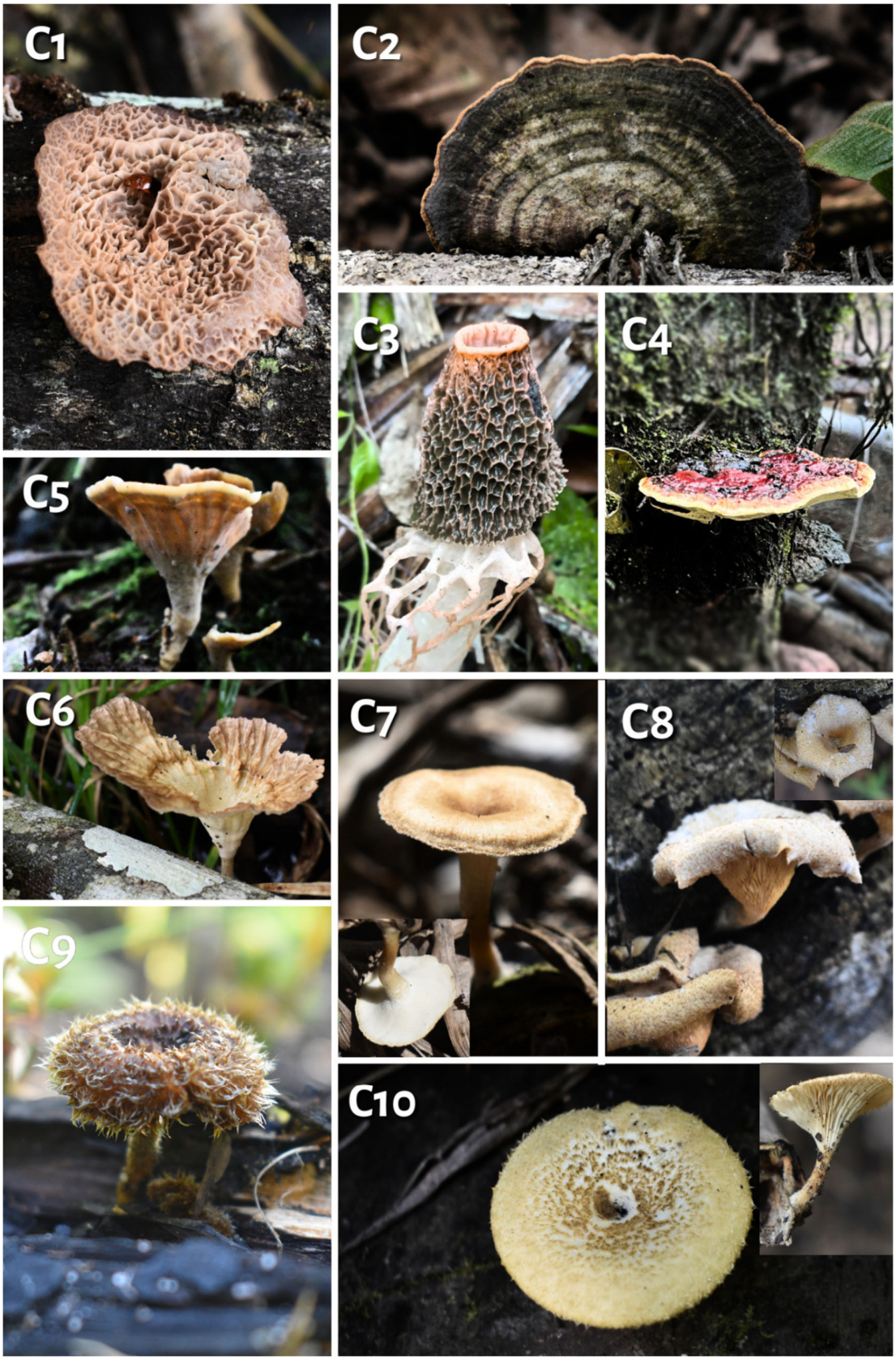

Figure 9. Representative species of macrofungi recorded in Tingana (**C1**–**C10**), presented as reference illustrations of their habit and macroscopic morphology in natural conditions: (**C1**) *Auricularia delicata*; (**C2**) *Fuscoporia gilva*; (**C3**) *Phallus multicolor*; (**C4**) *Ganoderma* sp.; (**C5**) *Cymatoderma caperatum*; (**C6**) *Cymatoderma elegans*; (**C7**) *Bresadolia uda*; (**C8**) *Lentinus strigosus*; (**C9**) *Lentinus crinitus*; (**C10**) *Lentinus tigrinus*.

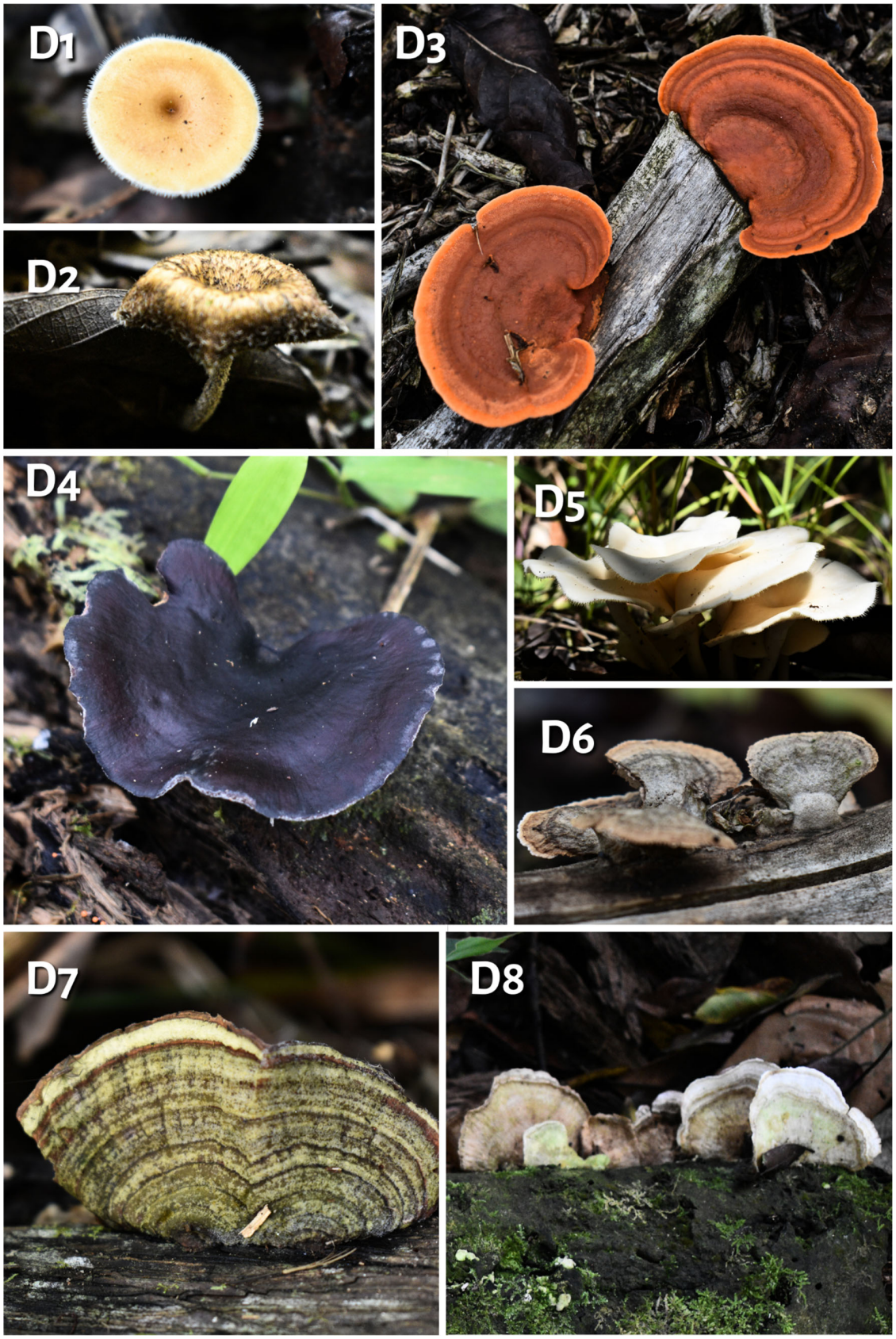

Figure 10. Representative species of macrofungi recorded in Tingana (**D1**–**D8**), presented as reference illustrations of their habit and macroscopic morphology in natural conditions: (**D1**) *Lentinus tricholoma*; (**D2**) *Lentinus* sp.; (**D3**) *Pycnoporus sanguineus*; (**D4**) *Polyporus* sp.; (**D5**) *Favolus* sp.; (**D6**) *Trametes* sp.; (**D7**) *Trametes villosa*; (**D8**) *Stereum* sp.

4. Discussion

This study revealed a remarkable diversity of macroscopic fungi in the floodplain forests of Tingana, where 20 species were identified to genus level and 19 to species level, with 38 taxa belonging to Basidiomycota and 1 to Ascomycota. The dominance of basidiomycetes is consistent with reports from other Peruvian Amazonian sites: Mori et al. documented 24 basidiomycete versus 5 ascomycete species in Puerto Almendras [53], Espinoza reported 57 basidiomycete species along the Iquitos–Nauta highway [54], and similar patterns have been confirmed elsewhere [55–58].

Despite having fewer orders than in boreal forests of the Northern Hemisphere, Agaricales and Polyporales stand out for their remarkable diversity in tropical ecosystems, where eight polyporoid orders have been recorded compared to eleven in boreal regions [59]. However, macrofungi species richness is significantly higher in the tropics, consistent with the latitudinal diversity gradient (LDG) hypothesis [60,61].

In peatlands, saprophytic fungi are crucial for the decomposition of plant debris, contributing to the formation and maintenance of peat [62]. As observed in this study, they are most abundant in lignicolous habitats. Substrate preference is a key factor determining the composition and distribution of macrofungi [63–65]. In our study, a high frequency of lignicolous fungi was observed, including *Auricularia delicata*, which grows on fallen logs and is common in tropical and subtropical regions [66]; *Schizophyllum commune*, which is widely distributed in diverse habitats colonising living trees and dead wood [62]; and species of the genus *Lentinus* [67,68]. Studies in Malaysia show a higher richness of *Lentinus* in tropical forests with more stable moisture conditions, in contrast to the water fluctuations of the Amazon flooded forest [69,70]. In addition, several recorded species are edible (see Figures 7–10): *Auricularia delicata* (Figure 9(C1)), *Oudemansiella* cf. *canarii* (Figure 8(B1)), *Phillipsia domingensis* (Figure 7(A1)), *Pleurotus djamor* (Figure 8(B3)), *Schizophyllum commune* (Figure 8(B9)), and species of the genus *Lentinus* (Figure 9(C8–C10) and Figure 10(D1,D2)) [71], representing a potential resource for local communities [72–74].

Frequent and prolonged flooding in floodplain forests creates anoxic conditions in the soil, which negatively affects terrestrial macrofungi, most of which are obligate aerobes. Excess water reduces oxygen concentration in soil pores, limiting metabolic activity, mycelial growth, and fruiting [75–77]. In contrast, lignicolous macrofungi depend more on the availability of woody substrates than on soil conditions. However, it is important to clarify that wood-decay fungi also require aerobic conditions within the woody substrate to produce fruiting bodies and secrete lignocellulolytic enzymes. Submerged or waterlogged wood becomes anoxic, inhibiting decomposition [78]. Therefore, the dominance of lignicolous macrofungi in Tingana is not due to tolerance to anoxia, but rather because the woody substrates (fallen logs, branches, stumps) remain above the water table or are periodically exposed during dry periods, providing the necessary aerobic conditions with high humidity [79].

In this study, specific morphological determinations were not possible for some specimens, mainly due to the scarcity of taxonomic information on Neotropical fungi and the existence of species complexes. Molecular tools are crucial for revealing the true extent of fungal diversity, as seen in genera such as *Gymnopilus* and *Mycena* [80,81]. These results highlight the importance of molecular techniques and the need to continue research in peatlands to gain a deeper understanding of the systematics and ecological role of these fungi [11].

One limitation of the present study is the exclusive reliance on morphological identification of specimens. Although this approach is suitable for baseline inventories in underexplored ecosystems, it does not allow for the resolution of cryptic species complexes, nor does it detect the fungal fraction that fails to fruit during seasonal sampling windows,

such as endophytes or mycorrhizal fungi. The absence of molecular data, including ITS barcode sequences or environmental metabarcoding, restricts the taxonomic verification of several groups and limits biogeographic comparisons with other Andean–Amazonian peatlands. Nevertheless, this research provides a solid and necessary foundation for understanding fungal diversity in Tingana, and the integration of molecular techniques in future studies will be essential to confirm and expand upon the ecological patterns documented here.

5. Conclusions

This study provides one of the first macrofungal inventories for tropical peatlands in the Andean-Amazonian foothills of Peru. A total of 39 taxa were recorded across three habitat types within the Tingana Conservation Concession, with Agaricales and Polyporales being the most diverse orders and lignicolous substrates accounting for 71.79% of records. These findings suggest that differences in habitat type and substrate availability are associated with variation in macrofungal richness; however, because we did not directly measure canopy structure or flooding regime, and given the short sampling period (one year), causal relationships cannot be established. The loss of fungi associated with carbon-storing ecosystems could destabilize the delicate balance of these habitats and accelerate carbon emissions, exacerbating climate change. Future studies integrating molecular tools are essential to fully characterize fungal diversity and support the conservation of these underexplored, carbon-rich ecosystems.

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Data Availability Statement: The data supporting the reported results are available from the corresponding author upon reasonable request. Voucher specimens are deposited in the Herbarium of San Marcos (USM), Lima, Peru.

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Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Heredia-Abarca, G. La importancia de los hongos (Fungi) en los servicios ecosistémicos (The importance of fungi in ecosystem services). *Bioagrociencias* **2020**, *13*, 98–108.
2. Montero-Tavera, V.; Morales-García, J.L.; González-Chavira, M.M.; Anaya-López, J.L.; Corona-Torres, T.; Gálvez-Mariscal, A. Diversidad genética, patogénica y morfológica del hongo *Colletotrichum gloeosporioides* (Penz.) de Michoacán, México. *Rev. Mex. Cienc. Agríc.* **2010**, *1*, 157–172.
3. Chuang, W.Y.; Hsieh, Y.C.; Lee, T.T. The Effects of Fungal Feed Additives in Animals: A Review. *Animals* **2020**, *10*, 805. [CrossRef] [PubMed]
4. Paredes, N. *Estudio de la Diversidad Fúngica en Turberas Compactas del sur de Tierra del Fuego*; Universidad Nacional de La Plata: La Plata, Argentina, 2015.
5. Pouris, J.; Kolyva, F.; Bratakou, S.; Vogiatzi, C.A.; Chaniotis, D.; Beloukas, A. The role of fungi in food production and processing. *Appl. Sci.* **2024**, *14*, 5046. [CrossRef]

6. Guo, X.; Wang, S.; Wang, C.; Lan, M.; Yang, S.; Luo, S.; Li, R.; Xia, J.; Xiao, B.; Xie, L.; et al. The changes, aggregation processes, and driving factors for soil fungal communities during tropical forest restoration. *J. Fungi* **2023**, *10*, 27. [CrossRef] [PubMed]
7. Bahram, M.; Netherway, T. Fungi as mediators linking organisms and ecosystems. *FEMS Microbiol. Rev.* **2022**, *46*, fuab058. [CrossRef] [PubMed]
8. Ali, I.; Qaiser, H.; Abdullah, R.; Kaleem, A.; Iqtedar, M.; Iqbal, I.; Chen, X. Prospective roles of extremophilic fungi in climate change mitigation strategies. *J. Fungi* **2024**, *10*, 385. [CrossRef] [PubMed]
9. Juan-Ovejero, R.; Briones, M.; Öpik, M. Fungal diversity in peatlands and its contribution to carbon cycling. *Appl. Soil Ecol.* **2020**, *146*, 103393. [CrossRef]
10. Cavalcante, F.; Costa, M.; Sales, J. New Occurrences of Macrofungi (Basidiomycota) in Southern Amazonas, Brazil. *Ciênc. Nat.* **2021**, *43*, e46. [CrossRef]
11. Filippova, N.; Zvyagina, E.; Rudykina, E.; Dobrynina, A.; Bolshakov, S. The diversity of macromycetes in peatlands: Nine years of plot-based monitoring and barcoding in the raised bog "Mukhrino", West Siberia. *Biodivers. Data J.* **2023**, *11*, e105111. [CrossRef] [PubMed]
12. Álvarez, S. La descomposición de materia orgánica en humedales: La importancia del componente microbiano. *Ecosistemas* **2005**, *14*, 17–29.
13. Quinteros-Gómez, Y.; Monroy-Vilchis, O.; Zarco-González, M. Turberas en Valle del Alto Mayo, Perú: Importancia, amenazas y perspectivas de conservación. *Cienc. Ergo-Sum.* **2021**, *28*, e116. [CrossRef]
14. Zea, F.E.; Ruiz, L. Riqueza de Macromicetos del Parque Nacional Tingo María (Huánuco-Perú). *Cienc. Desarro.* **2018**, *17*, 21–25. [CrossRef]
15. Florez, G. *Evaluación de la Biodiversidad y Composición de Macrohongos en Términos de Perturbación del Bosque Amazónico de Madre de Dios*; Universidad Nacional Amazónica de Madre de Dios: Puerto Maldonado, Peru, 2020.
16. Huamantupa-Chuquimaco, I.; Holgado, M.E.; Quispe, M.A.; García, M.; Cárdenas, A.; Quispe, W.; Poccohuanca-Aguilar, R.O.; Cuba, Z.M.; Meza, J.G.; Sanjuan, T.I. Patterns of Diversity, Structure and Local Ecology of Arthropod-Pathogenic Fungi in the Amazonian Forest of Cusco and Madre de Dios Regions, Southern Peru. *Diversity* **2023**, *15*, 1122. [CrossRef]
17. Taipe, Y.C. *Evaluación de la Biodiversidad de Macrohongos en el Sector Setapo de la Reserva Comunal Amarakaeri, Madre de Dios*; Universidad Ricardo Palma: Lima, Peru, 2023.
18. Roig, C.; Roig, F.A. Consideraciones Generales. In *Los Turbales de la Patagonia: Bases para su Inventario y la Conservación de su Biodiversidad*; Wetlands Internacional: Buenos Aires, Argentina, 2004; pp. 5–21.
19. Quinteros-Gómez, Y.; Zarco-González, M.; Gómez-Ticerán, D.; Endara-Agramont, A.; Monroy-Vilchis, O. Effects of human disturbance on above-ground carbon stocks in north-west Amazonian *Mauritia flexuosa* peat swamp forests. *Mires Peat* **2023**, *29*, 12. [CrossRef]
20. Doelman, J.C.; Verhagen, W.; Stehfest, E.; van Vuuren, D.P. The role of peatland degradation, protection and restoration for climate change mitigation in the SSP scenarios. *Environ. Res.* **2023**, *2*, 035002. [CrossRef]
21. Sahrawat, K. Organic matter accumulation in submerged soils. *Adv. Agron.* **2003**, *81*, 169–201. [CrossRef]
22. Kavanagh, K. (Ed.) *Fungi: Biology and Applications*, 3rd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2017.
23. Diaz, A.A. *Determinación del Contenido de Carbono Almacenado con Relación a la Profundidad de las Turberas (Ecosistemas de Aguajales) de la Provincia de Coronel Portillo-Ucayali-Perú*; Universidad Nacional de Ucayali: Pucallpa, Peru, 2019.
24. Tian, J.; Huang, X.; Chen, H.; Kang, X.; Wang, Y. Homogeneous selection is stronger for fungi in deeper peat than in shallow peat in the low-temperature fens of China. *Environ. Res.* **2022**, *212*, 113312. [CrossRef] [PubMed]
25. Geethanjali, P.A.; Jayashankar, P.M. A review on litter decomposition by soil fungal community. *J. Pharm. Biol. Sci.* **2016**, *11*, 1–3. [CrossRef]
26. Gerding, V. Suelos de Humedales y Trumaos Húmedos del sur de Chile. In Proceedings of the Reunión de Trabajo sobre Plantaciones forestales en Chiloé, con énfasis en suelos ñadi, Dalcahue, Chile, 28–29 May 2010.
27. Grijalva-Vallejos, N. Degradación de residuos vegetales mediante inoculación con cepas microbianas. *Enfoque UTE* **2013**, *4*, 1–13. [CrossRef]
28. Zhang, J.; Liu, G.; Fukasawa, Y. Editorial: Fungal Genetics in Plant Biomass Conversion. *Front. Microbiol.* **2022**, *13*, 875768. [CrossRef] [PubMed]
29. Gocheva, Y.; Lyudmila, D.; Venelin, D.; Hubenov, V.; Kabaivanova, L.; Angelov, P.; Simeonov, I.; Najdenski, H. Cellulolytic microorganisms: Aerobic, microaerophilic, anaerobic bacteria and microbial consortia (Part II). *Ecol. Eng. Environ. Prot.* **2023**, *1*, 36–53. [CrossRef]
30. Adesiji, A.R.; Mohammed, T.A.; Daud, N.N.; Saari, M.; Gbadebo, A.O.; Jacdonmi, I. Impacts of land use change on peatland degradation: A review. *Ethiop. J. Environ. Stud. Manag.* **2015**, *8*, 225–234. [CrossRef]
31. Antonelli, A.; Fry, C.; Smith, R.J.; Eden, J.; Govaerts, R.H.A.; Kersey, P.; Nic Lughadha, E.; Onstein, R.E.; Simmonds, M.S.J.; Zizka, A.; et al. *State of the World's Plants and Fungi 2023*; Royal Botanic Gardens, Kew: Richmond, UK, 2023.
32. Quinteros-Gómez, Y.; Macedo-Bedoya, J. Primer reporte de jardines de hormigas en renacales de Piedemonte Andino-Amazónico en Perú. *Lilloa* **2024**, *61*, 149–158. [CrossRef] [PubMed]

33. Quinteros-Gómez, Y.; Millán, B.; Gómez-Ticerán, D.; Angeles-Alvarez, F.; Salinas-Inga, A.; Macedo-Bedoya, J.; Olórtegui, S.; Balbuena-Serrano, A. Diversity and species of vascular epiphytes in Tingana, the highest flooded forest in Peru. *Mires Peat* **2024**, *31*, 05. [CrossRef]
34. Pérez-López, R.I.; Mata, G.; Aragón, A.; Jiménez, D.; Romero-Arenas, O. Diversidad de hongos silvestres comestibles del cerro El Pinal, municipio de Acajete, Puebla, México. *Ecosistemas Recur. Agropecu.* **2015**, *2*, 277–289.
35. Mueller, G.M.; Schmit, J.; Ryvarden, S.; O'Dell, T.; Lodge, D.; Leacock, P.; Mata, M.; Umania, L.; Wu, Q.; Czederpiltz, D. Recommended protocols for sampling macrofungi. In *Biodiversity of Fungi: Inventory and Monitoring Methods*; Muller, G.M., Bills, G.F., Foster, M.S., Eds.; Elsevier Academic Press: Burlington, MA, USA, 2004; pp. 168–172.
36. García-Saldaña, L.C.; Garza-Ocañas, F.; Sobal, M.; Torres-Aquino, M.; Hernández-Ríos, I. Diversidad de macromicetos en el bosque templado del Valle de Poanas, Durango. *Sci. Fungorum* **2019**, *49*, e1240. [CrossRef]
37. Singer, R. *The Agaricales in Modern Taxonomy*, 4th ed.; Koeltz Scientific Books: Koenigstein, Germany, 1986; 981p, ISBN 9783874292542. Available online: https://books.google.com/books/about/The_Agaricales_in_Modern_Taxonomy.html?id=AtlOAQAAIAAJ (accessed on 1 December 2025).
38. Ryvarden, L. *Neotropical Polypores. Part 1: Introduction, Ganodermataceae and Hymenochaetaceae. Synopsis Fungorum 19*; Fungiflora: Oslo, Norway, 2004; 238p. Available online: https://www.fungiflora.no/synopsis-19 (accessed on 1 December 2025).
39. Ryvarden, L. *Neotropical Polypores. Part 2: Polyporaceae: Abortiporus–Nigroporus. Synopsis Fungorum 34*; Fungiflora: Oslo, Norway, 2015.
40. Ryvarden, L. *Neotropical Polypores. Part 3: Polyporaceae: Obba–Wrightoporia. Synopsis Fungorum 36*; Fungiflora: Oslo, Norway, 2016.
41. Ryvarden, L.; Iturriaga, T. Studies in neotropical polypores 10. New polypores from Venezuela. *Mycologia* **2003**, *95*, 1066–1077. [CrossRef] [PubMed]
42. Wijayawardene, N.N.; Hyde, K.D.; Al-Ani, L.K.T.; Tedersoo, L.; Haelewaters, D.; Rajeshkumar, K.C.; Zhao, R.L.; Aptroot, A.; Leontyev, D.V.; Castañeda-Ruiz, R.F.; et al. Outline of Fungi and fungus-like taxa. *Mycosphere Online J. Fungal Biol.* **2020**, *11*, 1060–1456. [CrossRef]
43. Index Fungorum. *Index Fungorum*; The Royal Botanic Gardens: Kew, UK. Available online: https://www.indexfungorum.org (accessed on 15 June 2026).
44. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2026.
45. Oksanen, J.; Simpson, G.L.; Blanchet, F.G.; Kindt, R.; Legendre, P.; Minchin, P.R.; O'Hara, R.B.; Solymos, P.; Stevens, M.H.H.; Szoecs, E.; et al. *vegan: Community Ecology Package*, R package version 2.6-10; R Foundation for Statistical Computing: Vienna, Austria, 2024.
46. Shannon, C.E. A mathematical theory of communication. *Bell Syst. Tech. J.* **1948**, *27*, 379–423, 623–656. [CrossRef]
47. Simpson, E.H. Measurement of diversity. *Nature* **1949**, *163*, 688. [CrossRef]
48. Pielou, E.C. The measurement of diversity in different types of biological collections. *J. Theor. Biol.* **1966**, *13*, 131–144. [CrossRef]
49. Baselga, A. Partitioning the turnover and nestedness components of beta diversity. *Glob. Ecol. Biogeogr.* **2010**, *19*, 134–143. [CrossRef]
50. Baselga, A.; Orme, C.D.L. Betapart: An R package for the study of beta diversity. *Methods Ecol. Evol.* **2012**, *3*, 808–812. [CrossRef]
51. Wickham, H.; Averick, M.; Bryan, J.; Chang, W.; McGowan, L.D.A.; François, R.; Grolemund, G.; Hayes, A.; Henry, L.; Hester, J.; et al. Welcome to the Tidyverse. *J. Open Source Softw.* **2019**, *4*, 1686. [CrossRef]
52. Wickham, H. *Ggplot2: Elegant Graphics for Data Analysis*, 2nd ed.; Springer: Cham, Switzerland, 2016.
53. Mori, T.; Bendayan, M.; Tresierra, A.; García, M.; Ruiz, E.; Bardales, J. Ascomycetes y Basidiomycetes macroscópicos en bosques de Puerto Almendras (Loreto, Perú). *Folia Amaz.* **2011**, *20*, 7–14. [CrossRef]
54. Espinoza, M. *Determinación de Hongos de la Clase Basidiomycetes en el Centro de Investigación Allpahuayo Loreto—Perú*; Universidad Nacional de la Amazonía Peruana: Iquitos, Peru, 2004.
55. Pavlich, M. Ascomycetes y Basidiomycetes del Perú I. Con énfasis en especies de la Ceja de Montaña y Selva Tropical. *Mem. Mus. Hist. Nat. Javier Prado* **1976**, *17*, 1–45.
56. Gazis, R. *Evaluación Preliminar de la Micoflora Localizada en los Alrededores del Centro de Investigación "Rio Los Amigos", Manu*; Universidad Ricardo Palma: Lima, Peru, 2004.
57. Vasco, A.; Franco, A.; López, C.; Boekhout, T. Macromycetes (Ascomycota, Basidiomycota) de la región del medio Caquetá departamentos de Caquetá y Amazonas (Colombia). *Biota Colomb.* **2005**, *6*, 127–140.
58. Barrios, R.; Quezada, M.; López, R.; Fuentes, A. *Fortalecimiento en el Conocimiento Taxonómico de Macrohongos Tropicales de Guatemala*; Universidad de San Carlos de Guatemala: Ciudad de Guatemala, Guatemala, 2007.
59. Wu, F.; Zhou, L.W.; Vlasák, J.; Dai, Y.-C. Global diversity and systematics of Hymenochaetaceae with poroid hymenophore. *Fungal Divers.* **2022**, *113*, 1–192. [CrossRef]
60. Mittelbach, G.G.; Schemske, D.W.; Cornell, H.V.; Allen, A.P.; Brown, J.M.; Bush, M.B.; Harrison, S.P.; Hurlbert, A.H.; Knowlton, N.; Lessios, H.A.; et al. Evolution and the latitudinal diversity gradient: Speciation, extinction and biogeography. *Ecol. Lett.* **2007**, *10*, 315–331. [CrossRef] [PubMed]

61. Tedersoo, L.; Suvi, T.; Beaver, K.; Kõljalg, U. Ectomycorrhizal fungi of the Seychelles: Diversity patterns and host shifts from the native *Vateriopsis seychellarum* (Dipterocarpaceae) and *Intsia bijuga* (Caesalpiniaceae) to the introduced *Eucalyptus robusta* (Myrtaceae), but not *Pinus caribea* (Pinaceae). *New Phytol.* **2007**, *175*, 321–333. [CrossRef] [PubMed]
62. Marian, I.M.; Valdes, I.D.; Hayes, R.D.; LaButti, K.; Duffy, K.; Chovatia, M.; Johnson, J.; Ng, V.; Lugones, L.G.; Wösten, H.A.B.; et al. High phenotypic and genotypic plasticity among strains of the mushroom-forming fungus *Schizophyllum commune*. *Fungal Genet. Biol.* **2024**, *173*, 103913. [CrossRef] [PubMed]
63. Ye, L.; Li, H.; Mortimer, P.; Xu, J.; Gui, H.; Karunarathna, S.; Kumar, A.; Hyde, K.; Shi, L. Substrate Preference Determines Macrofungal Biogeography in the Greater Mekong Sub-Region. *Forest* **2019**, *10*, 824. [CrossRef]
64. Ma, Z.; Guo, D.; Xu, X.; Lu, M.; Bardgett, R.; Eissenstat, D.; Luke, M.; Hedin, L.O. Evolutionary history resolves global organization of root functional traits. *Nature* **2018**, *555*, 94–97. [CrossRef] [PubMed]
65. Avila-Salem, M.E.; Montesdeoca, F.; Orellana, M.; Pacheco, K.; Alvarado, S.; Becerra, N.; Marín, C.; Borie, F.; Aguilera, P.; Cornejo, P. Soil Biological Properties and Arbuscular Mycorrhizal Fungal Communities of Representative Crops Established in the Andean Region from Ecuadorian Highlands. *J. Soil Sci. Plant Nutr.* **2020**, *20*, 2156–2163. [CrossRef]
66. Wu, F.; Tohtirjap, A.; Fan, L.-F.; Zhou, L.-W.; Alvarenga, R.L.M.; Gibertoni, T.B.; Dai, Y.-C. Global diversity and updated phylogeny of *Auricularia* (Auriculariales, Basidiomycota). *J. Fungi* **2021**, *7*, 933. [CrossRef] [PubMed]
67. Gui, H.; Purahong, W.; Hyde, K.D.; Xu, J.; Mortimer, P.E. The Arbuscular Mycorrhizal Fungus *Funneliformis mosseae* Alters Bacterial Communities in Subtropical Forest Soils during Litter Decomposition. *Front. Microbiol.* **2017**, *8*, 1120. [CrossRef] [PubMed]
68. Díaz-Ariza, L.A.; Rivera, E.L.; Sánchez, N. Occurrence of arbuscular mycorrhizal fungi in leaf litter and roots of shaded coffee plantations under organic and conventional management. *Rev. Bras. Cienc. Solo* **2021**, *45*, e0200110. [CrossRef]
69. Pegler, D.N. *Agaric Flora of the Lesser Antilles*; Kew Bulletin Additional Series; Kew Bulletin: London, UK, 1983.
70. Bolhassan, M.H.; Abdullah, N.; Sabaratnam, V.; Tsutomu, H.; Abdullah, S.; Noor, N.M.; Musa, M.Y. Diversity and Distribution of Polyporales in Peninsular Malaysia. *Sains Malays.* **2012**, *41*, 155–161.
71. Boa, E. *Non-Timber Forest Products 17: Edible Wild Mushrooms: A Global Perspective on Their Use and Importance to the Population*; FAO: Rome, Italy, 2005.
72. García, M. *Macrohongos Más Comunes del Tambopata*; Juan Gtemberg Editores: Puerto Maldonado, Peru, 2020; p. 130, ISBN 976-612-00-5143-6.
73. Aguilar, F. *Caracterización del Hongo Silvestre Pleurotus sp. de la Comunidad Nativa de Korimani del Centro Poblado de Kiteni-Echarate-la Convención*; Seminario de Investigación, Universidad Nacional de San Antonio Abad del Cusco: Cusco, Peru, 2015.
74. Dávila-Arenas, C.; Sulca-Quispe, L.; Pavlich-Herrera, M. Estudio etnomicológico de la micobiota comestible en dos comunidades nativas de la cuenca Alto Madre de Dios, Reserva de Biosfera del Manu. *Sagasteguiana* **2013**, *1*, 121–130.
75. Shuhada, S.; Salim, S.; Nobilly, F.; Lechner, A.; Azhar, B. Conversion of peat swamp forest to oil palm cultivation reduces the diversity and abundance of macrofungi. *Glob. Ecol. Conserv.* **2020**, *23*, e01122. [CrossRef]
76. Qiqige, B.; Liu, J.; Li, M.; Hu, X.; Guo, W.; Wang, P.; Ding, Y.; Zhi, Q.; Wu, Y.; Guan, X.; et al. Different flooding conditions affected microbial diversity in riparian zone of Huihe Wetland. *Microorganisms* **2025**, *13*, 154. [CrossRef] [PubMed]
77. Hartman, K.; Tringe, S. Interactions between plants and soil shaping the root microbiome under abiotic stress. *Biochem. J.* **2019**, *476*, 2705–2724. [CrossRef] [PubMed]
78. Farias, V.; Vilhena, M.; Gondim-Vieira, A.; Mendes-Freire, R.; Pacheco, R.; Da Silva, B.; Soares, A. Distribution patterns of wood-decay macrofungi (Agaricomycetes) in floodplain forest islands of the eastern Amazon. *J. Fungi* **2025**, *11*, 288. [CrossRef] [PubMed]
79. Brinkmann, N.; Schneider, D.; Sahner, J.; Ballauff, J.; Edy, N.; Barus, H.; Irawan, B.; Budi, S.; Qaim, M.; Daniel, R.; et al. Intensive tropical land use massively shifts soil fungal communities. *Sci. Rep.* **2019**, *9*, 3403. [CrossRef] [PubMed]
80. Ke, H.M.; Lee, H.H.; Lin, C.I.; Liu, Y.C.; Lu, M.R.; Hsieh, J.A.; Chang, C.C.; Wu, P.H.; Lu, M.J.; Li, J.Y.; et al. *Mycena* genomes resolve the evolution of fungal bioluminescence. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 31267–31277. [CrossRef] [PubMed]
81. Yang, W.Q.; Li, J.X.; He, M.Q.; Wang, S.H.; Zhu, X.Y.; Phurbu, D.; Yun, J.M.; Zhao, R.L. Five New Species of *Gymnopilus* from Xizang Autonomous Region of China and Surrounding Areas. *J. Fungi* **2024**, *10*, 220. [CrossRef] [PubMed]