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ORIGINAL RESEARCH

Species and index diversity of macrofungi from two different locations in East Kalimantan

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Abstract. East Kalimantan represents the lowland rainforest ecosystem with a vast number of macrofungi species in Indonesia. This study aimed to evaluate the diversity of macrofungi within the two different locations in East Kalimantan. The study was conducted in several phases, including planning, survey, preparation, sampling, and data analysis. Sampling was carried out systematically in 20 × 20 m² plots. Collected samples were processed, photographed, and identified. Ecological indices, including the Shannon-Wiener diversity index, species evenness, and the Simpson dominance index, were calculated to provide a detailed analysis of the macrofungal community structure. This study found that location 1 recorded 24 species from 21 genera, while location 2 had 22 species from 20 genera. The Shannon-Wiener diversity index indicated moderate diversity at both sites, with values of 2.82 for location 1 and 2.65 for location 2. *Daedaleopsis confragosa* was the most frequent and dominant species in location 1, contributing 12.03% relative density, while *Marasmiellus candidus* dominated location 2 with 18.51% relative density. Species evenness was medium in both locations, and the dominance index was low, highlighting the ecological significance of these fungal species in their respective habitats. The results emphasize the importance of studying fungal ecology to support conservation and sustainable environmental management. The study revealed a wide variety of macrofungi that play vital roles in the tropical ecosystems of these two locations in East Kalimantan.

Keywords: Diversity index, East Kalimantan, ecosystem, macrofungi, species diversity.

INTRODUCTION

Macrofungi are essential in ecosystems, especially their living components [1–3]. They are critical decomposers, effectively breaking down organic material and aiding in the cycling of nutrients [4]. They significantly impact plant communities that depend on the byproducts of this decomposition process [5]. Macrofungi also control soil pH, causing it to become more acidic by releasing calcium and phosphate ions while breaking down complex compounds [6].

The broader group of macrofungi shows excellent promise as an essential element in creating pharmaceutical medications because of their abundant supply of bioactive substances [7]. Approximately 270 macrofungi species have been discovered and harnessed as essential components in medicinal formulations [7, 8]. The bioactive substances in these macrofungi offer hope for creating various medicinal products, displaying multiple effects, including anti-aging, antioxidant, anti-tumor, anti-cancer, anti-inflammatory, and other therapeutic properties [9–12]. Consequently, macrofungi have significant potential for further medical exploration and advancement.

The incredible biodiversity of the Indonesian archipelago is particularly notable in Kalimantan [13,

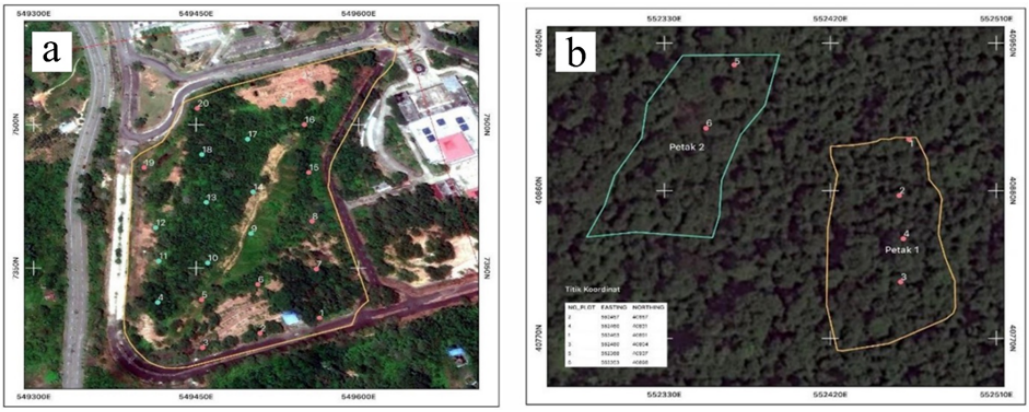

Figure 1. Sampling site for this study (a) Green open space, South Bontang District, Bontang, East Kalimantan and (b) Kutai National Park, within Sangkima Lama, South Sangatta District, East Kutai Regency, East Kalimantan.

14]. However, there is a lack of comprehensive knowledge about the diversity of macrofungi in this region, especially in East Kalimantan. This lack of information highlights the urgent need for more specific research to improve the understanding of the various and possibly distinct macrofungi species in this ecologically important area.

Kutai National Park is of excellent scientific importance because it represents the lowland rainforest ecosystem. The park has been designated as a national park primarily because of its remarkable biodiversity, containing various ecosystems, species, and genetic diversity. The park contains various vegetation types, including freshwater swamp forests, heath forests, lowland flood forests, ironwood/meranti/limestone forests, and mixed Dipterocarpaceae forests [15]. Furthermore, certain surrounding areas of Kutai National Park have converted formerly critical, vegetation-barren lands into lush open spaces primarily overseen by a private company. About 80% of the total 5.6-hectare area has been reclaimed by vegetation, underscoring this region's restorative and ecological importance [16]. Macrofungi can contribute to ecosystems by speeding up the breakdown of organic matter where they are boosting soil fertility and improving nutrient cycling. These processes are crucial for rebuilding plant life and ecosystem functions. Their symbiotic association with plants, mainly through mycorrhizal relationships, promote plant growth and resilience in restored areas.

The deep importance of East Kalimantan emphasizes its considerable potential value in ecological contexts. However, the lack of baseline data on macrofungal diversity in these areas has partially hindered their full environmental potential value. This research offers the first macrofungal diversity in East Kalimantan. The data will help in future studies on ecology, conservation planning, and monitoring biodiversity in the region. This also can biold a basic understanding of macrofungal communities in lowland rainforests.

METHODOLOGY

Sampling site

The study was conducted from May to June 2023, confining two distinct geographical locations within the East Kalimantan region. Location 1 was in the green open space of PT Kaltim Methanol Industri, Bontang Lestari, South Bontang District, Bontang, East Kalimantan (Figure 1a) (0°5′28.71″ N, 117°26′50.44″ E). Location 2 was in the Kutai National Park, Sangkima Lama, South Sangatta District, East Kutai, East Kalimantan (Figure 1b) (0°22′19″ N, 117°28′38″ E). These selected sites served as necessary sampling points for the investigation. The two sites were chosen for their ecological and environmental factors, such as diverse vegetation, stable climates, varied soil types, and a range of host substrates. These conditions are essential for supporting diverse macrofungal communities and provide a context for assessing species richness and ecological interactions in representative tropical environments.

Sampling procedure

The study was done in several phases, including research planning, initial survey, preparation, sampling, and data analysis. The research planning phase was initiated by establishing a preparatory research framework, which yielded initial outcomes. Subsequently, an initial survey was executed to assess the prevailing geographical conditions, facilitating the preparation of necessary equipment and materials. The essential tools and materials included HVS paper, cutter, tweezers, divider container, spray bottle, glass storage container, zip lock bags, ruler, stationery, camera, lighter, work map, Avenza software, Picture Mushroom software, fungal identification book, brush, label paper, and 70% alcohol.

Sampling was conducted systematically within designated 20 × 20 m² plots, aided by using Avenza software for accurate mapping. A total of 20 plots were randomly selected at each location with careful consideration of environmental conditions such as vegetation cover, moisture levels, and substrate diversity to ensure representative sampling. Samples were

Figure 2. Macrofungi in location 1 (a) *Microporus xanthopus*, (b) *Collybiopsis subpruinosa*, (c) *Cyathus striatus* barr: 1 cm.

Figure 3. Macrofungi in location 2 (a) *Xeromphalina kauffmanii*, (b) *Clitocybula oculus*, (c) *Daedaleopsis confragosa* barr: 1 cm.

Table 1. Index of diversity, evenness, and Simpson in this study.

Index	Value		Category	
	Location 1	Location 2	Location 1	Location 2
Diversity (H')	2,82	2,65	Moderate	Moderate
Evenness (E)	0,89	0,86	Moderate	Moderate
Simpson (C)	0,07	0,09	Moderate	Low

collected under aseptic conditions and then cleaned with a brush. They were categorized by size, with smaller specimens in containers and larger ones in labeled Ziplock bags for identification.

Macrofungal specimens were documented through detailed macroscopic observations from multiple angles, such as dorsal, ventral, lateral, and sectional views. It was done to capture the key of morphological characteristics. Preliminary identification was facilitated using Picture Mushroom. These were later verified and refined by comparing them to authoritative fungal identification manuals using the identification source by H. McKnight, K. and B. McKnight 1987, and Cui et al. 2019. Additional validation was conducted by image repositories from GBIF and MycoBank. The assess the structure, diversity, and ecological indices were calculated including the Shannon–Wiener Diversity Index (H'), Evenness Index (E), and Simpson's Dominance Index (D), which provided quantitative metrics for evaluating species richness, distribution uniformity, and dominance patterns across sampling sites.

RESULTS AND DISCUSSION

This study compares the diversity and species index from 2 representative locations in East Kalimantan (Figure 1). At location 1, four orders, 12 families, 21 genera, and 24 species were identified (Figure 2). In contrast, at location 2, four orders, 12 families, 20 genera, and 22 species were documented (Figure 3). The macroscopic fungal diversity index analysis indicated that both locations had moderate diversity, with values of 2.82 and 2.65, respectively (Table 1).

The most frequently observed species in location 1 was *Daedaleopsis confragosa*, with a frequency of 0.23, typically found on wood substrates and dead plant stems. This species is crucial in breaking down organic material in these areas. In location 2, *Marasmiellus candidus* was the most abundant species, with a frequency of 0.67, thriving in damp areas such as decaying logs and leaf litter. The species with the lowest frequency in location 1 were *Collybiopsis subpruinosa*, *Phloeomana speirea*, and *Phellinus robiniae*, whereas, in location 2, *Neofavolus alveolaris*, *Cookeina tricholoma*, and *Gymnopus quercophilus* were the least frequent.

The evenness was 0.89 for location 1 and 0.86 for location 2, categorizing both areas as having medium evenness according to the Shannon-Wiener index, a measure of species evenness in a community (Table 1). The dominance index of macroscopic fungi was low, with values of 0.07 in location 1 and 0.09 in location 2 (Table 1). *Daedaleopsis confragosa* was the most dominant species in location 1, with a dominance index of 0.01, while *Marasmiellus candidus* was the most dominant in location 2, with a dominance index of 0.03

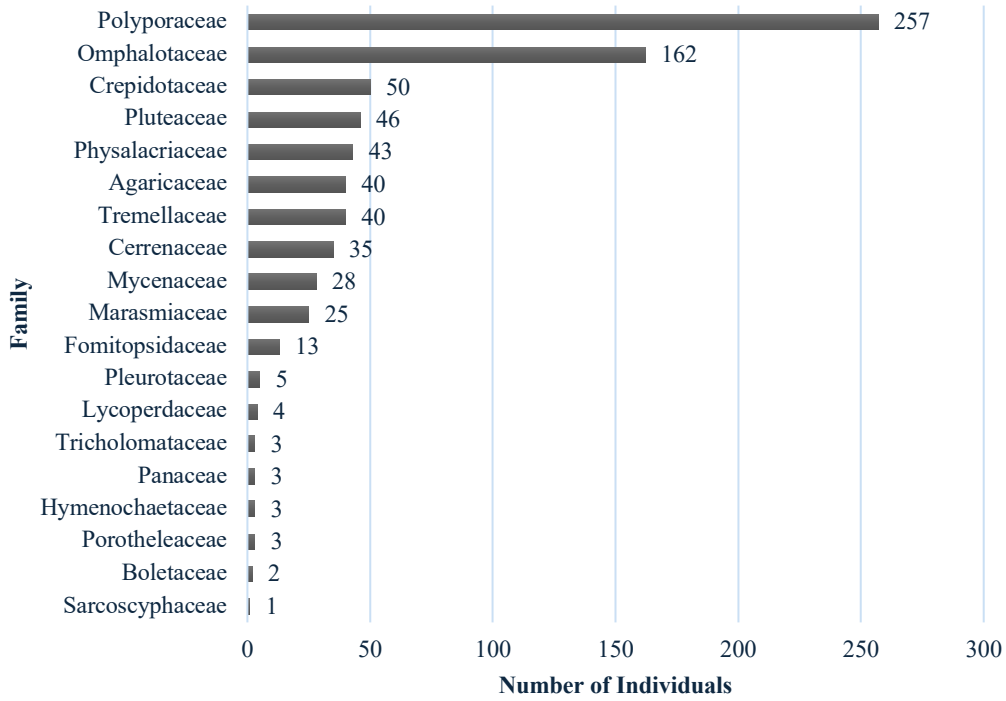

Figure 4. The number of macrofungi individual families from both locations.

(Table 2 and 3). Regarding relative density, *Daedaleopsis confragosa* had the highest value in location 1, at 12.0332%, and *Marasmiellus candidus* in location 2, at 18.50534%. These findings highlight these macroscopic fungal species' ecological significance and distribution patterns across the studied locations.

Fungi are essential for soil health and maintaining the balance of ecosystems. To promote sustainable agriculture and environmental management, it is crucial to study the mycobiome of the soil [17]. The moderate fungal diversity observed in both locations, with indices of 2.81623 at location 1 and 2.65367 at location 2, underscores the significance of these habitats in maintaining ecological balance. This finding also resonates with the theory of ecological succession, where a diverse fungal community indicates a mature ecosystem in which species coexist, each occupying specific niche [18].

The diversity of macrofungi in a specific habitat is closely linked to tree and plant species diversity, as these organisms are ecologically connected [19, 20]. Varied plant communities provide a range of organic substrates, such as leaf litter, decaying wood, and root exudates, which are essential resources for different macrofungal guilds such as saprotrophic and mycorrhizal fungi. Ectomycorrhizal fungi often form symbiotic relationships with certain tree species, determined by the fungal and plant taxa compatibility [5]. Saprotrophic species like *Daedaleopsis confragosa Daedaleopsis confragosa*are frequently found on decaying hardwoods, indicating a preference for specific tree hosts as substrates [21]

The study identified eight species of macrofungi in both locations. These species include *Marasmiellus candidus, Rhizomarasmius pyrrhocephalus, Collybiopsis subpruinosa, Daedaleopsis confragosa, Ganoderma applanatum, Microporus xanthopus, Pseudofavolus tenuis, and Collybiopsis quercophila*. These macrofungi are saprotrophic fungi that thrive on decaying woody materials [22, 23]. They have a vital function in ecosystems as they break down organic material, aid in the nutrient cycle, and help maintain the well-being of their environments [24, 25]. *Marasmiellus candidus* is recognized for its saprotrophic behavior, thriving in decaying wood [26, 27]. Likewise, *Rhizomarasmius pyrrhocephalus* and *Collybiopsis subpruinosa* are commonly found on wood substrates, often growing on small twigs or [28–30]. *Daedaleopsis confragosa* is commonly found on the trunks of injured or fallen trees [31, 32] *Ganoderma applanatum* is particularly notable for its ability to degrade lignin selectively [33, 34]. *Microporus xanthopus* is distinguished by its pharmacological potential, offering benefits beyond its ecological functions [35–37]. *Pseudofavolus tenuis* and *Collybiopsis quercophila* further also contribute to wood decomposition [27, 38].

The species composition's similarity between the two locations may be due to their shared several environmental conditions [39, 40]. Both locations consist of wooden substrates and high humidity, and historical disturbances such as forest fires have occurred. These factors influence adaptability in response to environmental changes [20, 41–43]. It also highlights the importance of the community for ecosystem restoration

Table 2. Relative density of macrofungi in location 1.

No.	Species	Family	Number of Individual	Relative Density (%)
1	*Daedaleopsis confragosa* (Bolton) J.Schröt.	Polyporaceae	58	12.03
2	*Pseudofavolus tenuis* (Fr.) G.Cunn.	Polyporaceae	48	9.96
3	*Collybiopsis quercophila* (Pouzar) R.H.Petersen	Omphalotaceae	47	9.75
4	*Phaeotremella foliacea* (Pers.) Wedin, J.C.Zamora & Millanes	Tremellaceae	40	8.30
5	*Cyathus striatus* Willd.	Agaricaceae	40	8.30
6	*Crepidotus mollis* (Schaeff.) Staude	Crepidotaceae	35	7.26
7	*Hexagonia hydnoides* (Sw.) M.Fidalgo	Cerrenaceae	35	7.26
8	*Marasmiellus candidus* (Fr.) Singer	Omphalotaceae	35	7.26
9	*Pycnoporus sanguineus* (L.) Murrill	Polyporaceae	23	4.77
10	*Ganoderma applanatum* (Pers.) Pat.	Polyporaceae	17	3.53
11	*Amauroderma rugosum* (Bl. & Nees) Imaz.	Polyporaceae	17	3.53
12	*Fomes fomentarius* (L.) Fr.	Polyporaceae	16	3.32
13	*Mycena zephirus* (Fr.) P.Kumm.	Mycenaceae	14	2.90
14	*Rhizomarasmius pyrrhocephalus* (Berk.) R.H.Petersen	Physalacriaceae	11	2.28
15	*Rhodofomes cajanderi* (P.Karst.) B.K.Cui, M.L.Han & Y.C.Dai	Fomitopsidaceae	9	1.87
16	*Gymnopus brassicolens* (Romagn.) Antonín & Noordel.	Omphalotaceae	7	1.45
17	*Pleurotus pulmonarius* (Fr.) Quél.	Pleurotaceae	5	1.04
18	*Microporus xanthopus* (Fr.) Kuntze	Polyporaceae	4	0.83
19	*Lycoperdon umbrinum* Pers.	Polyporaceae	4	0.83
20	*Lycoperdon perlatum* Pers.	Lycoperdaceae	4	0.83
21	*Fomitopsis pinicola* (Sw.) P.Karst.	Fomitopsidaceae	4	0.83
22	*Collybiopsis subpruinosa* (Murrill) R.H.Petersen	Omphalotaceae	3	0.62
23	*Phloeomana speirea* (Fr.) Redhead	Porotheleaceae	3	0.62
24	*Phellinus robiniae* (Murrill) A.Ames	Hymenochaetaceae	3	0.62
	Total		**482**	**100**

Note:
Location 1: Green open space, Bontang Lestari, South Bontang District, Bontang, East Kalimantan, location 2: Kutai National Park, within Sangkima Lama, South Sangatta District, East Kutai Regency, East Kalimantan.

Table 3. Relative density of macrofungi in location 2.

No.	Species	Family	Number of Individual	Relative Density (%)
1	*Marasmiellus candidus* (Fr.) Singer	Omphalotaceae	52	18.51
2	*Pluteus cervinus* (Schaeff.) P.Kumm.	Pluteaceae	35	12.46
3	*Rhizomarasmius pyrrhocephalus* (Berk.) R.H.Petersen	Physalacriaceae	32	11.39
4	*Clitocybula oculus* (Peck) Singer	Marasmiaceae	22	7.83
5	*Collybiopsis subpruinosa* (Murrrill) R.H. Petersen	Omphalotaceae	17	6.05
6	*Daedaleopsis confragosa* (Bolton) J.Schröt.	Polyporaceae	16	5.69
7	*Crepidotus applanatus* (Pers.) P.Kumm.	Crepidotaceae	15	5.34
8	*Xeromphalina kauffmanii* A.H.Sm.	Mycenaceae	14	4.98
9	*Trametes ochracea* (Pers.) Gilb. & Ryvarden	Polyporaceae	14	4.98
10	*Ganoderma applanatum* (Pers.) Pat.	Polyporaceae	13	4.63
11	*Lentinus arcularius* (Batsch) Zmitr.	Polyporaceae	11	3.91
12	*Pluteus plautus* (Weinm.) Gillet	Pluteaceae	11	3.91
13	*Microporus xanthopus* (Fr.) Pat.	Polyporaceae	8	2.85
14	*Ganoderma sinense* J.D.Zhao, L.W.Hsu & X.Q.Zhang	Polyporaceae	4	1.42
15	*Pseudofavolus tenuis* (Fr.) G.Cunn.	Polyporaceae	3	1.07
16	*Cymatoderma elegans* Jungh.	Panaceae	3	1.07
17	*Tetrapyrgos nigripes* (Fr.) E.Horak	Marasmiaceae	3	1.07
18	*Delicatula integrella* (Pers.) Fayod	Tricholomataceae	3	1.07
19	*Strobilomyces confusus* Singer	Boletaceae	2	0.71
20	*Neofavolus alveolaris* (DC.) Sotome & T.Hatt.	Polyporaceae	1	0.36
21	*Cookeina tricholoma* (Mont.) Kuntze	Sarcoscyphaceae	1	0.36
22	*Collybiopsis quercophila* (Pouzar) R.H.Petersen	Omphalotaceae	1	0.36
	Total		**281**	**100**

Note:
Location 1: Green open space, Bontang Lestari, South Bontang District, Bontang, East Kalimantan, location 2: Kutai National Park, within Sangkima Lama, South Sangatta District, East Kutai Regency, East Kalimantan.

and conservation [44]. Both locations also have high water retention. This condition makes the substrate tend to be wet and suitable for the growth of certain macrofungi. Fungi prosper in environments with specific temperature, nutrient, and moisture conditions conducive to their development [45]. Abiotic factors such as light intensity and temperature significantly influence macrofungal diversity and distribution. Light affects the microclimate in forest layers, impacting moisture evaporation and substrate quality. Many macrofungi thrive in shaded conditions, which reduce desiccation stress. Temperature also plays a role which can affecting fungal metabolism and spore germination. Saprotrophic fungi showing optimal growth within specific thermal ranges [42, 45].

The most abundant macrofungi identified in both locations are *D. confragosa* and *M. candidus*. Literature suggests that *D. confragosa* has been recorded in Russia, Serbia, Poland, and Bangladesh [19, 32, 46, 47]. *D. confragosa* exhibiting optimal lignolytic potential, particularly on wheat straw substrates [48]. Additionally, *D. confragosa* can interact with *Irpex lacteus*, enhancing the production of ligninolytic enzymes contributing to lignin degradation [49]. This species is known to cause white rot on broad-leaved plants and can also function as a saprotroph with significant medical benefits, including anticancer, antiviral, antifungal, antibacterial, cytotoxic, and analgesic effects [50]. In Indonesia, *M. candidus* has been found in West Java and Banten [26, 51]. This fungus is also prevalent in other Asian regions such as Iran, Bangladesh, India, and Russia [52–55]. This fungus also is noted for its antibacterial potential [56].

The macrofungi most commonly found individually belong to the families Polyporaceae and Omphalotaceae (Figure 4). In this study, members of the Polyporaceae family were prevalent in location 1, while the Omphalotaceae family dominated location 2. The most abundant Polyporaceae species included *D. confragosa* and *Pseudofavolus tenuis*, whereas *Marasmiellus candidus* was the most common species in the Omphalotaceae family. Polyporaceae are characterized by poroid fungi with shelf-like fruiting bodies that initially are soft but harden into a woody texture, becoming decay-resistant as they mature [57]. Family Omphalotaceae are distinguished by their unique sesquiterpene content and ability to cause white rot [58]. The differences in species dominance between the two locations can be attributed to environmental factors. Location 1 features acidic karst soil with clay deposits near a peat area, sloping terrain with rainwater run-off, and increased sunlight penetration due to sparse tree cover. In contrast, location 2 is a humid rainforest with dusty clay loam soil and dense tree canopies that limit sunlight from reaching the forest floor.

The medium evenness values indicate a balanced distribution of species within the fungal communities that were studied. Understanding the evenness and dominance is crucial to comprehending the overall species distribution in a community [59, 60]. When the distribution is spread evenly, the index value will get closer to one but will decrease gradually if there are species that deviate from the uniformity [61]. The Simpson Index approaches zero when no dominant species indicates a stable community [62]. This study's results suggest that the macrofungal community's structure in both locations is stable and does not experience ecological stress. The presence of dominant species, such as *D. confragosa* and *M. candidus*, indicates their competitive advantage in resource acquisition, possibly due to their adaptability and efficient utilization of available resources. The dominance of these species can have ecological consequences. These fungi can accelerate decomposition rates and make contribution to nutrient cycling and the breakdown of coarse woody debris, and benefit the restoration of ecosystems [50, 52, 58]. Their activity improves soil organic matter and supports the establishment of other organisms, including plants and microbes. However, prolonged or excessive dominance may also reduce fungal diversity because these competitive species can monopolize available resources and inhibit establishing more specialized or less competitive fungi [3, 63]. In the context of ecosystem management and restoration, this could limit the ecological functions that a more diverse fungal community provides, such as niche differentiation and symbiotic interactions with various plant species [63].

CONCLUSION

This study found that both locations in East Kalimantan contain moderately diverse macrofungal communities. Location 1 shows slightly higher species richness, with 24 species from 21 genera, compared to Location 2, which has 22 species from 20 genera. Diversity indices indicate relatively balanced and stable fungal communities in both ecosystems. *Daedaleopsis confragosa* was most abundant in location 1, while *Marasmiellus candidus* dominated location 2, reflecting potential site-specific ecological adaptations and substrate preferences. This research provides insight into the study of macrofungi ecology, especially in tropical environments such as in the East Kalimantan region. Fungi contribute to the decomposition process and nutrient cycle as a part of the ecosystem. In addition, this macrofungi's diversity, evenness, and dominance provide preliminary knowledge of the dynamics of macrofungi populations and communities in tropical regions such as East Kalimantan, Indonesia.

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