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Macrofungal diversity in small-holder oil palm plantations on tropical peatlands

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Abstract. *Ekyastuti W, Astiani D, Ekamawanti HA, Jamiat. 2023. Macrofungal diversity in small-holder oil palm plantations on tropical peatlands. Biodiversitas 24: 3454-3461.* Mushrooms play an important role in ecosystems and human life. They can be found in various places including in oil palm plantations. The aim of this study was to survey and identify the population of macroscopic mushrooms or macrofungi in small-holder oil palm plantations on tropical peatlands in Kampung Baru Village, Kubu Raya District, West Kalimantan, Indonesia using the field survey method. In the research area, a dam has been constructed to regulate the water level at 30 cm, 40 cm, 50 cm, and 60 cm from the surface. Sampling was carried out in these four conditions. The study revealed the presence of 34 species of macrofungi belonging to the Basidiomycota. A groundwater level ranging from 40-60 cm from the surface was identified as favorable for macrofungal growth. Meanwhile, a groundwater level of 30 cm from the surface was found to be unsuitable for macrofungal growth in the peatlands. The level of macrofungal species diversity in small-holder oil palm plantations on the peatlands was determined to be moderate.

Keywords: Groundwater level, macrofungi, mushrooms, oil palm plantations, tropical peatland, West Kalimantan

INTRODUCTION

The richness of mushrooms represents a significant aspect of Indonesia's biodiversity. Mushrooms or macrofungi can be categorized into fungi, which have visible fruiting bodies that can be seen without a microscope (Suryani 2022). Macrofungi play a crucial role in forest ecosystems and human life. In forest ecosystems, macrofungi are found in various places, including the soil surface, litter, and bark of plants, as well as in dead wood (Dutta et al. 2011a, 2011b, 2012). Macrofungi serve multiple functions, encompassing not only beneficial roles such as mycorrhizal symbiosis, decomposers as saprophytes, medicinal and edible uses, but also detrimental roles as parasites (Semwal et al. 2014; Tjiu et al. 2022). Several species of macrofungi such as wood ear mushrooms (*Auricularia auricula-judae* (Bull.) Quél.) and oyster mushrooms (*Pleurotus* spp.) are examples of edible macrofungi (Nasution 2016; Das et al. 2020; Hadiyanti et al. 2020; Thu et al. 2020).

In Indonesia, the estimated number of macrofungi is around 200,000 (Tjiu et al. 2022). However, there is currently no comprehensive report on the exact count of identified or utilized macrofungi. In particular, the knowledge of macrofungi in Borneo remains limited (Tjiu et al. 2022). Macrofungi possesses visible fruiting bodies as can grow on both living trees (such as attached to wood or in the soil around the roots) and dead trees, as well as in litter. These fruiting bodies serve as an indicator to identifying macrofungi.

Macrofungi in Indonesia grow in various types of forests ranging from lowland forests to upland forests (Wahyudi et al. 2016), and even in peat swamp forests (Ekyastuti et al. 2017). In peat swamp forests, macrofungi play a crucial role as decomposers of organic matter (Ekyastuti et al. 2017; Fitriani et al. 2018). However, information regarding the specific species of macrofungi that grow in Indonesian peat swamp forests, along with their ecological functions and benefits, particularly in West Kalimantan, remains highly limited and difficult to obtain. According to the BPS Provinsi Kalimantan Barat (2022), West Kalimantan has a peat area of around 1.7 million hectares.

In peatlands, the water level of the peat has a significant impact on the life of organisms, including fungi (Astiani et al. 2018; Astiani et al. 2019). The research location chosen for this study is an area where the peat water level has been regulated (Astiani et al. 2020). Specially, the research focused on the macrofungi in small-holder oil palm plantations that are managed by the local community and planted peatland in Kampung Baru Village, Kubu Sub-district, Kubu Raya District, West Kalimantan, Indonesia. The findings of this study can contribute to understanding whether oil palm plantations on peatlands continue to support the ecological functions to macrofungal populations. Additionally, the study can identify macrofungal germplasm that has potential for consumption or use in herbal medicine.

The purpose of this study was to investigate the diversity of macrofungal in small-holder oil palm plantations in a tropical peatland. The research aimed to shed light on the macroscopic fungal ecosystem within these specific ecological settings. The findings of this study can serve various purposes, including knowledge addition to the locals regarding edible macrofungi and utilization as biofertilizer inoculums in mycorrhizal applications.

MATERIALS AND METHODS

Study area

The research was focused on Kubu Raya District, one of the districts in West Kalimantan, which is predominantly characterized by peatland. The local population in this district is primarily engaged in farming, cultivating both food crops and plantations such as rubber and oil palm. In Kubu Raya, peatlands cover a substantial portion, accounting for 523,174 hectares, or approximately 60% of the total area of the district (BPS Kabupaten Kubu Raya 2022). Krisnohadi (2011) further categorized the peatlands in Kubu Raya based on depth, indicating that the region comprises 171,376 ha of shallow peat, 38,954 ha of medium peat, 49,621 ha of deep peat, and 83,013 ha of very deep peat. The research was carried out specifically within a small-holder oil palm plantation on a tropical peatland, in Kampung Baru Village, Kubu Sub-district, Kubu Raya District, West Kalimantan, Indonesia (Figure 1). Field data collection, including the collection of macrofungi in the field, spanned a duration of one year. Subsequently, macrofungal identification and data analysis were at the Silviculture Laboratory of the Faculty of Forestry, Universitas Tanjungpura.

Data collection and analysis

The research was conducted using a survey method with a purposive sampling technique. The selection of sampling locations was based on the presence of macrofungal fruiting bodies at the research site. The study site had previously undergone adjustments in groundwater levels, as described in previous studies (Astiani et al. 2020). Specifically, there were four levels of groundwater: 30 cm, 40 cm, 50 cm, and 60 cm from the soil surface. The regulation of water levels was achieved by constructing permanent drainage canals along the boundary ditch (Figure 2). For each peat water level, a total of six observation plots were made for macrofungi. Consequently, there were 24 observation plots in total (6 plots × 4 water levels). Each observation plot had dimension of 5×5 m^2.

The data collection process for macrofungi involved explorative methods, focusing on the macrofungal fruiting bodies found in the observation plots, where they were documented, counted, and number of individuals of each species was recorded. Physical characteristics of the macrofungi, such as the cap shape and size, color, stalk, blades/pores, rings, volva, veil, and their growth location (on the ground surface, litter, tree bark, or dead wood), were also recorded. Whenever possible, identification was carried out directly in the field, using resources such as Thomas and Gary (2002) and the websites https://www.mushroomexpert.com and https://mushroomobserver.org (accessed on 19.06.2023).

Figure 2. The construction of drainage canals at the research site that has been built by Astiani et al. (2020)

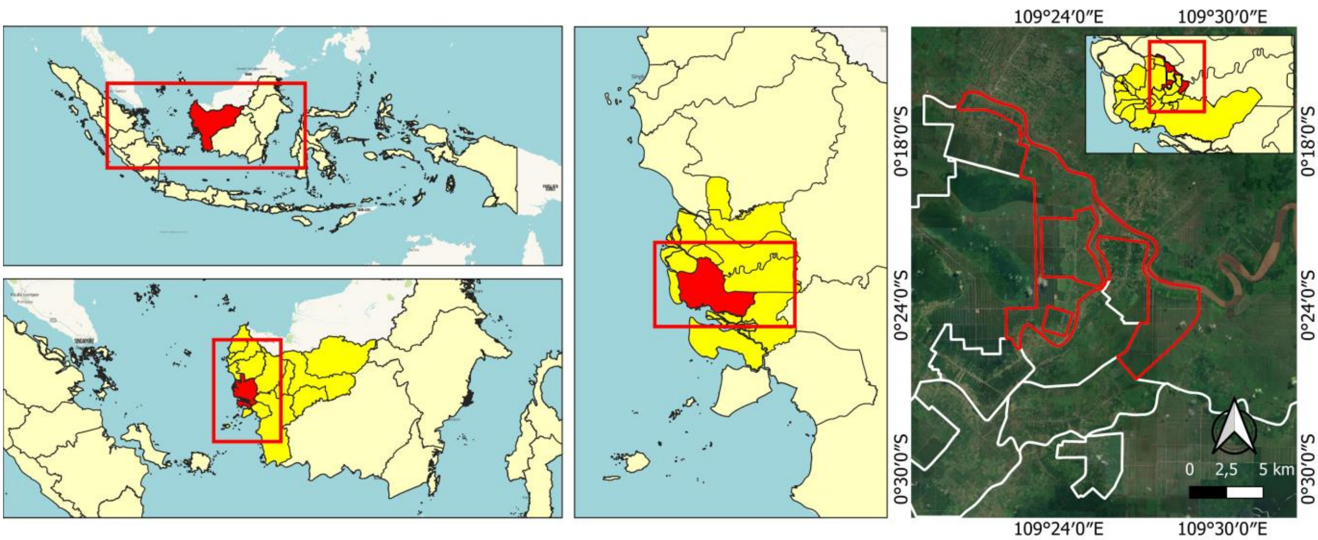

Figure 1. Map of Kubu District, West Kalimantan, Indonesia and research location (red lines)

In cases where identification couldn't be done directly in the field, a wet specimen was prepared by immersing the macrofungi in a solution of 70% alcohol and 10% glycerin with a ratio of 4:1 stored in a glass bottle (Thomas and Gary 2002) and further identification was carried out in the Silviculture Laboratory of the Forestry Faculty Universitas Tanjungpura. Species diversity index (H') was analyzed using the Shannon-Weaver (1949) formula: H' = -Σpi ln pi, where pi represents the relative abundance of species calculated as ni (number of individuals of a species) divided by N (the total number of individuals of all species) Thulasinathan et al. (2018); Pungpa et al. (2020).

RESULTS AND DISCUSSION

Diversity and characteristics of macrofungi at the research site

The study identified a total of 34 species, all belonging to Basidiomycota, specifically the class Agaricomycetes (Table 1). These species were distributed among 16 families, namely: Agaricaceae, Clavariaceae, Psathyrellaceae, Hygrophoropsidaceae, Marasmiaceae, Bolbitiaceae, Pluteaceae, Polyporaceae, Ganodermataceae, Mycenaceae, Hygrophoraceae, Strophariaceae, Schizophyllaceae, Pleurotaceae, Russulaceae, and Cortinariaceae. The dominance of the Agaricomycetes class are a group of fungal organisms with the largest number of individuals in the world (Sánchez-García et al. 2020; Tjiu et al. 2022). Members of this class exhibit a wide range of fruiting body sizes, ranging from a few millimeters to several meters, with the heaviest recorded specimen weighing 500 kg. Most Agaricomycetes fungi are terrestrial, living on land, and function as decomposers of wood and litter (saprophytes), with only a small proportion being pathogenic or parasitic. Additionally, some species in this class form mutualistic relationships with plants, particularly as ectomycorrhizal fungi (Hibbett et al. 2014). The findings of this study showed, the study site was dominated by saprophytic species (28 species), while only a small proportion are parasitic or pathogenic (4 species) and mutualistic ectomycorrhizae (3 species). Notably *Ganoderma lucidum* (Curtis) P.Karst. which is a facultative saprophyte, under favorable conditions, may shift its trophic status to parasitic mode.

Table 1. Species of macrofungi (Basidiomycota; Agaricomycetes) in small-holder oil palm plantations on the peatland in Kampung Baru Village, Kubu Raya

Species	Family	Habitat
Agaricus comtulus Fr.	Agaricaceae	Weathered oil palm stalks (saprophyte)
Agaricus dulcidulus Schulzer	Agaricaceae	Weathered oil palm stalks (saprophyte)
Leucocoprinus sp.	Agaricaceae	Litter (saprophyte)
Clavaria sp.	Clavariaceae	Weathered oil palm stalks (saprophyte)
Coprinellus angulatus Peck	Psathyrellaceae	Weathered oil palm stalks (saprophyte)
Coprinellus disseminatus (Pers.) J.E. Lange	Psathyrellaceae	Empty oil palm fruit bunches (saprophyte)
Coprinellus domesticus (Bolton) Vilgalys, Hopple & Jacq. Johnson	Psathyrellaceae	Dead oil palm stalks (saprophyte)
Coprinellus micaceus (Bull.) Vilgalys, Hopple & Jacq. Johnson	Psathyrellaceae	Litter (saprophyte)
Hygrophoropsis aurantiaca (Wulfen) Maire	Hygrophoropsidaceae	Weathered tree (saprophyte)
Marasmius oreades (Bolton) Fr.	Marasmiaceae	Empty oil palm fruit bunches (saprophyte)
Marasmius calhouniae Singer	Marasmiaceae	Weathered oil palm stalks (saprophyte)
Panaeolus acuminatus (P. Kumm.) Quél.	Bolbitiaceae	Empty oil palm fruit bunches (saprophyte)
Conocybe aurea (Jul. Schäff.) Hongo	Bolbitiaceae	Litter (saprophyte)
Conocybe tenera (Schaeff.) Kühner	Bolbitiaceae	Litter (saprophyte)
Pholiotina cyanopus (G.F. Atk.) Singer	Bolbitiaceae	Weathered oil palm stalks (saprophyte)
Pholiotina smithii (Watling) Enderle	Bolbitiaceae	Litter (saprophyte)
Pluteus cervinus (Schaeff.) P. Kumm.	Pluteaceae	Weathered oil palm stalks (saprophyte)
Trametes pubescens (Schumach.) Pilát	Polyporaceae	Shrub stems (pathogen)
Trametes hirsuta (Wulfen) Lloyd	Polyporaceae	Shrub stems (pathogen)
Trametes versicolor (L.) Lloyd	Polyporaceae	Weathered leaf midrib, weathered oil palm stalks and litter (saprophyte)
Pycnoporus sanguineus (L.) Murrill	Polyporaceae	Weathered leaf midrib (saprophyte)
Polyporus arcularius (Batsch) Fr.	Polyporaceae	Litter (saprophyte)
Ganoderma sinense J.D. Zhao, L.W. Hsu & X.Q. Zhang	Ganodermataceae	Weathered oil palm stalks (saprophyte)
Ganoderma megaloma (Lév.) Bres.	Ganodermataceae	Oil palm stalks (pathogen)
Ganoderma lucidum (Curtis) P. karst.	Ganodermataceae	Weathered oil palm stalks (pathogen/saprophyte)
Mycena leaiana (Berk.) Sacc.	Mycenaceae	Weathered tree (saprophyte)
Hygrocybe coccinea (Schaeff.) P. Kumm.	Hygrophoraceae	Ground surface (ectomycorrhiza)
Hygrocybe calyptriformis (Berk. & Broome) Fayod	Hygrophoraceae	Weathered tree (saprophyte)
Hypholoma fasciculare (Huds.) P.Kumm.	Strophariaceae	Ground surface and weathered tree (saprophyte)
Hypholoma capnoides (Fr.) P.Kumm.	Strophariaceae	Litter (saprophyte)
Schizophyllum commune Fr.	Schizophyllaceae	Litter (saprophyte)
Pleurotus djamor (Rumph. ex Fr.) Boedijn	Pleurotaceae	Weathered leaf midrib (saprophyte)
Russula sp.	Russulaceae	Ground surface (ectomycorrhiza)
Cortinarius sp.	Cortinariaceae	Ground surface (ectomycorrhiza)

Figure 3. Fruit bodies of several species of decomposer macrofungi: A. *Schizophyllum commune*; B. *Polyporus arcularius*; C. *Pleurotus djamor;* D. *Leucocoprinus* sp; E. *Coprinellus disseminates*; F. *Coprinellus domesticus*

The dominance of saprophytic macrofungi may be attributed to the abundance of organic matter in the peatlands. Peat soil is composed of organic matter, which is classified into three categories: sapric (highly mature), hemic (slightly mature), and fibric (fresh). Fungi exhibit saprophytic characteristic as they play a crucial role in decomposing organic matter. Both microorganisms and macroorganisms act as vital decomposers or soil modifiers in peatlands. The decomposer function of macrofungi contributes to the availability of nutrients required for growth of vegetation. As peat matures, the nutrient availability improves (Nurhayati et al. 2014). Figure 3 presents several species of macrofungi that serve as decomposers.

In addition to being saprophytic, several species of macrofungi found at the study area are parasitic and act as pathogens to plants. These species are *G. megaloma*, *G. lucidum*, *T. hirsuta*, and *T. pubescens* (Figure 4). Among these, *Ganoderma* species are particularly notorious for causing cause stem base rot disease in oil palm plantations, which is a significant problem in Indonesia and Malaysia (Susanto et al. 2013b; Priwiratama et al. 2014). This disease is also highly prevalent in oil palm plantations on peatlands in Sumatra where *Ganoderma* infections have been reported to affect 35-63% of the total oil palm plantations. Moreover, the infection rate of *Ganoderma* on sandy soils is reported to be faster and higher than loamy soil (Susanto et al. 2013a). The impact of this disease is a significant concern for palm oil entrepreneurs. *Ganoderma* can be controlled through various cultural measures. These include constructing isolation ditches to reduce root contact, adopting a hole-in-hole planting system, sanitizing inoculum sources (especially remnants of oil palm roots), and using large planting holes. In severe cases of disease attack, the removal and disposal of diseased plant roots, as well as isolating the affected plants may be necessary (Priwiratama et al. 2014). Additionally, the application of beneficial microorganisms such as *Trichoderma* spp. and AMF (Arbuscular Mycorrhizal Fungi) has shown promising results in preventing and managing stem rot disease by *Ganoderma* (Sinthya et al. 2018).

At the study site, three species of ectomycorrhizal fungi were identified: *Hygrocybe conica*, *Russula* sp., and *Cortinarius* sp. (Figure 5). Ectomycorrhiza fungi form a mutualistic symbiosis with plants, particularly through their root systems. Several studies have demonstrated the beneficial effects of ectomycorrhizal symbiosis on growth of host plants (Gusmiaty et al. 2012; Aprillia et al. 2019; Szuba et al. 2020). In this symbiotic relationship, plants and ectomycorrhizal fungi each contribute to the mutual benefit. The plants provide carbohydrates to the fungi, while the fungi enhance nutrient uptake for the plants, especially phosphorus (P).

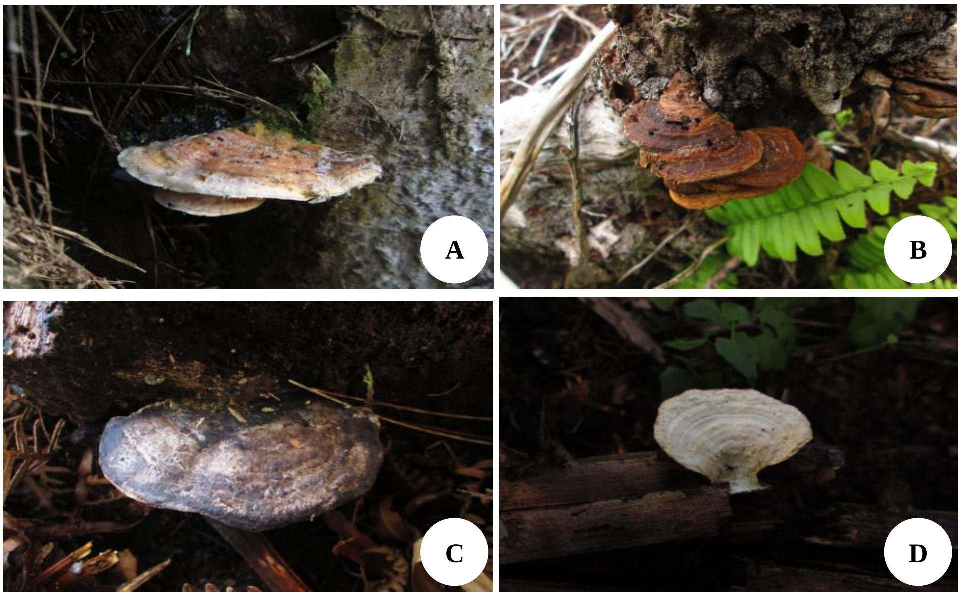

Figure 4. Fruit bodies of plant-pathogenic macrofungi: A. *Trametes hirsuta;* B. *Ganoderma lucidum;* C. *Ganoderma megaloma;* D. *Trametes pubescens*

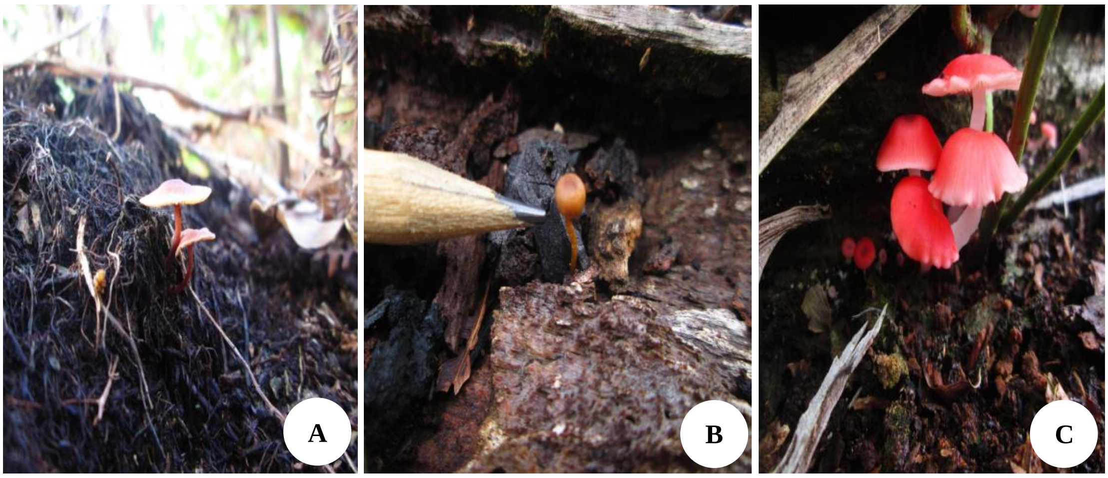

Figure 5. Fruit bodies of ectomycorrhizal fungi: A. *Hygrocybe coccinea;* B. *Cortinarius* sp.; C. *Russula* sp.

The comparison between the number of macrofungal species found in oil palm plantations and secondary forests on peatlands highlights the significant difference in ecological conditions between these two environments. (Ekyastuti et al. 2017) observed that oil palm plantations managed by local communities had a lower number of macrofungal species (38 species) compared to secondary forests (63 species) in peatland areas. The lower species diversity in oil palm plantations can be attributed to several factors. Firstly, secondary forests typically exhibit higher levels of biodiversity due to the presence of diverse vegetation types and varying levels of growth, ranging from undergrowth to tall trees. In contrast, oil palm plantations are monocultures with a uniform growth structure, offering limited ecological niches for macrofungal species (Hasselquist et al. 2021; Huuskonen et al. 2021). Additionally, secondary forests tend to have a higher abundance of litter in the form of fallen leaves, trees, and twigs compared to oil palm plantations. The availability of ample litter in forests provides abundant food sources for macrofungi, particularly saprophytic species that thrive on decaying organic matter. The greater quantity of food resources in the forest floor contributes to a more diverse and rich macrofungal population. Similar results were also obtained from the research of Putra et al. (2017) who found more saprophytic macrofungi in litter and organic matter (such as wood) than in soil, at Ujung Kulon National Park Indonesia. These findings suggest that secondary forests offer more favorable ecological conditions for the growth and development of macrofungi in peatland areas compared to oil palm plantations. The presence of diverse vegetation, varied growth structures, and a higher abundance of litter in secondary forests contribute to a richer and more diverse macrofungal community.

Due to the multicultural vegetation species present in secondary peat forests, the microclimate in these areas is highly conducive to the growth of macrofungi. The temperature in secondary forests on the peatland typically ranges from 23-28°C, accompanied by humidity levels of 80-90% (Ekyastuti et al. 2017). These conditions align with the optimal temperature range of 20-30°C and humidity of 80-90% recommended for macrofungal growth (Tjiu et al. 2022). Meanwhile, the average temperature in small-holder oil palm plantations is 30°C with a humidity of 80%, indicating marginal microclimatic conditions for macrofungal growth. Consequently, the reduced number of macrofungal species found in small-holder oil palm plantations compared to secondary forests on peatlands can be attributed to these differing microclimatic factors.

Populations of macrofungi on the peatlands at several groundwater levels.

The macrofungal sample plots at the study site were strategically positioned at four different groundwater levels: 30 cm, 40 cm, 50 cm, and 60 cm below the ground surface. The populations of macrofungal populations observed at each water level are summarized in Figure 6. Among the 35 species of macrofungi observed in this study, several species were found across all groundwater levels. However, there was a notable variation in the composition of species between different water levels. Many species found at lower water levels were not present at high water levels, and vice versa. Interestingly, the water level ranging from 50-60 cm below the ground exhibited a higher number of macrofungal species, ranging from 16-21 species, compared to the water table 30-40 cm, which had 12-14 species. This disparity is likely influenced by differences in soil water content, which creates varying conditions for macrofungal growth. A water level of 50-60 cm below the ground provides a relatively drier and deeper growing space, as opposed to a water level of 30-40 cm.

This deeper growing space is important for the development of macrofungal mycelium, which comprises of building blocks of the macrofungal fruiting bodies (Tjiu et al. 2022). Particularly for soil macrofungi, such as ectomycorrhizal fungi, a drier and un-waterlogged soil conditions is highly favorable for the mycelial growth in the soil. Similarly, for litter-dwelling macrofungi, a less waterlogged condition offers a more suitable substrate for decomposer fungi. Consequently, the higher number of macrofungi observed at the groundwater level of 50 cm to 60 cm reflects the advantageous conditions provided by a deeper, un-waterlogged environment, as compared to the water level of 30 cm to 40 cm.

The total number of individual macrofungi in small-holder oil palm plantations on the peatlands was 782, which was less than the count in secondary forests on peatland (29,130) (Ekyastuti et al. 2017). However, it was higher than the count in the KHDTK peat swamp forest of Universitas Tanjungpura, which was 594 (Utama et al. 2019). This indicates that the microclimate in the secondary forest on peatlands is more favorable for the growth of macrofungi. This favorable condition can be attributed to the factors such as high humidity, non-flooded soil, and a greater amount of litter, compared to small-holder oil palm plantations and peat swamp forests. These findings align with the observations of Putra et al. (2017) who stated that macrofungi thrive in dry conditions and environments rich in the litter.

Further analysis revealed a trend at the study site, where a higher number of individual macrofungi (148-160 individuals) was found in dry conditions at the root area (specifically at depths of 40-60 cm) compared to wet conditions where the soil was flooded up to 30 cm from the soil surface (55 individuals). However, a slightly different pattern was observed in terms of species diversity. Although the groundwater level of 40cm had a low number of species (only 12 species), it had a relatively high number of individuals (148). This count was almost comparable to the number of individuals at groundwater levels of 50-60 cm (155-160). On the other hand, at a groundwater level of 30 cm, both the species count and individual count were low. This indicates that a groundwater level of 30 cm from the surface is not conducive for macroscopic fungal growth in the peatlands.

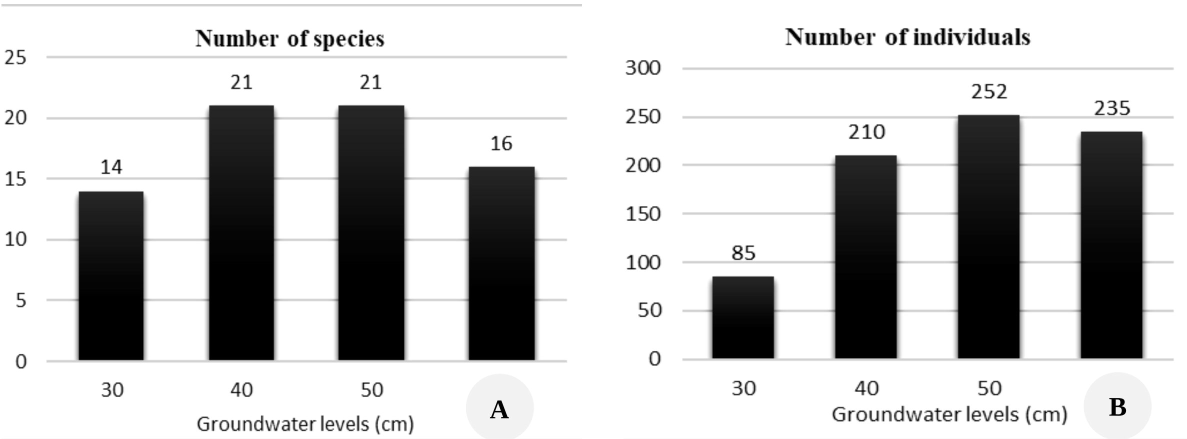

Figure 6. A. Number of species and; B. Number of individual of macrofungi at the study site

The value of Shannon-Weaver (1949) species diversity index (H') for macrofungi in small-holder oil palm plantations on peatlands was 2.97, which falls within the medium category (Pungpa et al. 2020). Medium species diversity values indicated the absence of macrofungal species dominance at the study site. This suggests ongoing competition among species of macrofungi for resource utilization and environmental conditions. This observation is supported by the average temperature and humidity at the research location, which is a small-holder oil palm plantation on the peatland which is under pressure of marginal availability of temperature (30°C) and humidity (80%) requirements. Additionally, during data collection, rainfall was infrequent, thereby failing to support the growth of macrofungal fruiting bodies. Similar findings were reported by Wati et al. (2019), emphasizing the strong influence of environmental factors, particularly water availability, temperature, humidity, and vegetation density, on macrofungal populations. The higher the vegetation density and diversity, the greater the diversity of macrofungi (Pradhan et al. 2011). In the study area, the vegetation is solely monoculture of oil palm. These conditions explain why the level of macrofungal diversity in the study site is only medium.

In conclusion, the population of macrofungi in small-holder oil palm plantations on a tropical peatland comprises of 34 species belonging to 16 families, all of which belong to Basidiomycota. The number of species and individual fungi illustrated that a water level of 40-60 cm from the peat's surface (dry condition) is favorable for macrofungi. On the other hand, a water level of 30 cm from the soil surface (wet/flooded condition) is unfavorable for macrofungal growth in peatlands. The level of macrofungal species diversity in small-holder oil palm plantations on the peatlands was classified as medium.

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