

Elevation influence the macrofungi diversity and composition of Gunung Korbu, Perak, Malaysia

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Abstract. Nur 'Aqilah MB, NurJannah S, Salleh S, Thi BK, Ahmad Fitri Z, Mohd Khairul Faizi M, Haja Maideen KM, Nizam MS. 2020. *Title. Biodiversitas 21: 1707-1713.* Fructification of macrofungi depends on two main factors, abiotic and biotic. In this study, the main focus is to determine the macrofungi composition and diversity as the effect of elevation and substrate. Macrofungi collection was conducted at three different elevations along the trails (Trail A, B, and C) of Gunung Korbu in July 2019. The sampling area was divided by ascent elevation from the Seroja Camp to the Rimba Gate (Trail A, 796 m above sea level[a.s.l]), the Seroja Camp to the Kijang Camp (Trail B, 1092 m a.s.l) and the Kijang Camp to the summit of Gunung Korbu (Trail C, 2183 m a.s.l). The collected macrofungi were photographed, described based on their macroscopic characters and any colour changes when bruising or chemicals reactions were recorded. In total 90 macrofungi specimens were in good condition belonging to 6 families from 13 genera, including the unidentified. About 93.33% (84 specimens) of the collections are saprotrophic fungi and six parasitic fungi. Trail B recorded the highest diversity index of 2.20 and 0.87 for Shannon Index and Simpson index, respectively. Non-metric multidimensional scaling ordinations showed a clear separation pattern of macrofungi community found in three different trails, with most of the specimens found in Trail B.

Keywords: Distinctive features, diversity, Gunung Korbu, macrofungi

INTRODUCTION

Macrofungi are known as macromycetes or larger fungi due to its visible fruiting bodies (sporocarps). The best-known examples of macrofungi are the mushrooms, puffballs, bracket fungi, and toadstools. Macrofungi are categorised under the phylum Basidiomycota and a few members under Ascomycota. The tropical region undoubtedly hosts vast biodiversity. To date, more than 93% of fungal species in the world are still unknown (Cannon et al. 2018) and in Malaysia particularly, reported about 70-80% of fungal species have yet to be discovered (Corner 1996; Lee et al. 1995). Interestingly, new species are still being identified in the tropics (Douanla-Meli et al. 2007) thus, documenting tropical macrofungi diversity is crucial to compile the information. One of the alternatives ways of documenting macrofungi diversity is via foray activities. The main objectives of a foray activity varies, for economic (e.g, food, medicinal) (Tibuhwa 2013), and education purposes (i.e. scientific study) (Donatha 2013). In Peninsular Malaysia, foray is limited where the local are hunting on selected edible macrofungi species (Chang and Lee 2004) which easily found in rubber plantation or gelam (*Melaleuca cajuputi*) forest. However, foray in generally have not been adopted as one of Malaysia culture and this is may due to the limited and scares reports in publications (Chang and Lee 2004) on edible macrofungi and taxonomic experts (Hyde 2003) in identification.

Furthermore, infrequent collection of macrofungi due to the growths pattern and their distribution are depends on several environmental factors. Among the factors, seasonality and year to year annual variation including precipitation and temperature are often show significance influence the macrofungi diversity (Lodge et al. 2004; Lee et al. 2002). For example, in Assam, India, the most collection of macrofungi is made during summer (18 species) followed by autumn (13 species), rainy season (9 species), spring (8 species) and winter (5 species) (Parveen et al. 2017). Natural castopshore in Tropical Pacific region for instance, Malaysia, faced monsoon season, where the macrofungi species grow abundantly (Zainuddin et al. 2010) compared during the El Nino strikes, the chances to find macrofungi is lesser than usual. Besides, the degree of succession can be viewed in several perspectives such as succession of sporocarps production, and changes occur in the vegetation which indirectly alter the quality of the substratum are among the major contributor in shaping the macrofungi community composition (Lodge et al. 2004). In term of succession of sporocarps production on leaf litter, after certain species of *Marasimus* decomposed leaf litter, some *Lepiota* species able to grow (Hedger 1985).

Malaysian forest classification was based on abiotic and biotic factors (Symington 1943; Wyatt-Smith 1964; Fox 1978). Forests are classified as lowland and hill dipterocarp forest with an elevation below 1200 m, while at 1200 to 1500 m, lower montane forests dominate. At 1800 m above sea level, the forest is known as upper montane forest and

mossy forest. Subalpine and alpine forests can be found at 2900 m and 3500 m, respectively (Chan et al. 2019). Studies on the diversity of macrofungi in Malaysia in the highlands/ mountains were also recorded but not as often as those conducted in the lowlands. For example, in East Malaysia, Sarawak about 54 polypore fungal genera were collected from Lambir Hills National Park (Salleh et al. 2016). Besides, diversity of macrofungi was also reported from Gunung Singai (Moi 2012) and Gunung Murud (Sepiah and Norhayati 2009), most of the macrofungi reported were belongs to poroid, agarics, and non-agarics. Meanwhile, in Peninsular Malaysia, the previous studies on mountain macrofungi were first reported by Chip (1921; as reported by Lee et al. 2012). In the Northern region of Peninsular Malaysia, especially Kedah, the microflora of four mountains have been explored (Kuthubutheen 1981; Noorlidah et al. 2005) while in the southern region, Gunung Angsi (Negeri Sembilan), Gunung Ophir (Melaka), Gunung Ledang (Johor) (Thi and Lee 2017), Gunung Pantii (Johor), Gunung Lambak (Johor), and Gunung Pulai (Johor) are among the mountains where the inventories of macrofungi were conducted (as reported by Lee et al. 2012). Additionally, the Titiwangsa Range in Pahang has several collections of macrofungi covering various types of mountain vegetation from hill to montane forests documented from Cameron Highlands (Thi and Lee 2011) and Fraser's Hills (Thi and Lee 2010a; Thi et al. 2011; Thi et al. in press); hill dipterocarps forest (Gunung Tahan), and limestone forests (Gunung Senyum (Thi and Lau 2012); Gunung Jebak Puyuh). It also reported new fungi records or new species might be found in the mountain area. For instant, five new species from mountain Oseo in Korea were recorded (Lee et al. 2014).

The state of Perak has about twenty mountains, and the highest mountain is Gunung Korbu, 2182 m a.s.l. located in the Hulu Kinta Forest Reserve and reported as the second highest mountain in Peninsular Malaysia behind Gunung Tahan in Pahang. The vegetation of this mountains comprises of dipterocarp forests, upper dipterocarp forests, montane forests, and ericaceous forests (Chan et al. 2019). Strategically located within the Kinta Valley Geopark, Gunung Korbu is part of prerequisite site for biodiversity and geological heritage. In Perak, fungal biodiversity has been reported at Gunung Batu Putih (Chip 1921 as reported by Lee et al. 2012), but to date, fungal biodiversity has not been studied at Gunung Korbu. Thus, Gunung Korbu has been selected as the site to study the diversity of macrofungi in the mountain areas, and this study aimed to provide a list of macrofungi diversity in Gunung Korbu. The preliminary findings on the macrofungi collected from Gunung Korbu are presented in this paper.

MATERIALS AND METHODS

Study site

A study of the macrofungi diversity had been carried out at Gunung Korbu (4° 41' N 101° 18' E) during the

Gunung Korbu Scientific Expedition on 1st July to 4th July 2019 organized by Department of Mineral and Geoscience Malaysia, Perak (Jabatan Mineral dan Geosains Malaysia, Perak, JMG Perak) in collaboration with many research institutes. During the four-day expedition, no rainfall was recorded, and the sampling areas were relatively limited as sampling was only possible along the climbing trails due to the geographic conditions of Gunung Korbu. Samples were collected along the hiking trails, which are divided into three main sections; Trail A, Seroja Camp (796 m above sea level [a.s.l]; 04°40.482'N, 101°16.788'E), Trail B, Kijang Camp (1092 m a.s.l; 04°39.415'N, 101° 16.333'E), and lastly the Trail C, Gunung Korbu (2183 m a.s.l, 04° 41' N, 101° 18' E (Figure 1).

Procedures

For the macrofungal collection, the samples were cautiously removed from the substrate with a sharp knife or soil shovel to avoid leaving any residue on the specimens/ mushrooms. To avoid any damage to the fruit bodies and to prevent specimens from dehydrating, small and medium-sized macrofungi were stored in plastic containers while large-sized specimens were wrapped using aluminum foils. The fruit bodies were photographed and information such as altitude, habitat, and substrate was recorded in the field. Macroscopic characteristics for example color, shape, size of the stipe, cap, gills, and odor were examined, described and recorded. Spore prints were prepared to determine the spore color and used in microscopic examination for identification and classification of macrofungi. Chemical reactions e.g. potassium hydroxide (KOH) was also used to observe and record any color change on macrofungi (Lodge et al. 2004). The macrofungi samples were then dried in an oven at 40°C before deposited as herbarium specimens at National University of Malaysia (Universiti Kebangsaan Malaysia, (UKMB)). Microscopic characteristics, for example, the shapes, size and ornamental of the spores, basidium, hyphae, cystidia were observed under microscope. The identification of macrofungi was based on macroscopic and microscopic characteristics using appropriate keys. A recent nomenclature of macrofungi was checked at the Index Fungorum (<http://www.indexfungorum.org>).

Data analysis

To determine the diversity within a community, the species richness and evenness were calculated according to the Shannon Diversity Index (H') and Simpson's Index (D). The analysis was conducted using macrofungi species composition and performed using Paleontological Statistics (PAST) version 2.17c (Hammer et al. 2001). To visualize and compare the composition of species community between three trails, a non-metric multidimensional scaling (NMDS) ordination of Bray-Curtis similarity matrices were drawn using PRIMER v6.1.9 (Primer-E Ltd, Plymouth, UK) with PERMANOVA+ v1 (Clarke and Gorley 2006).

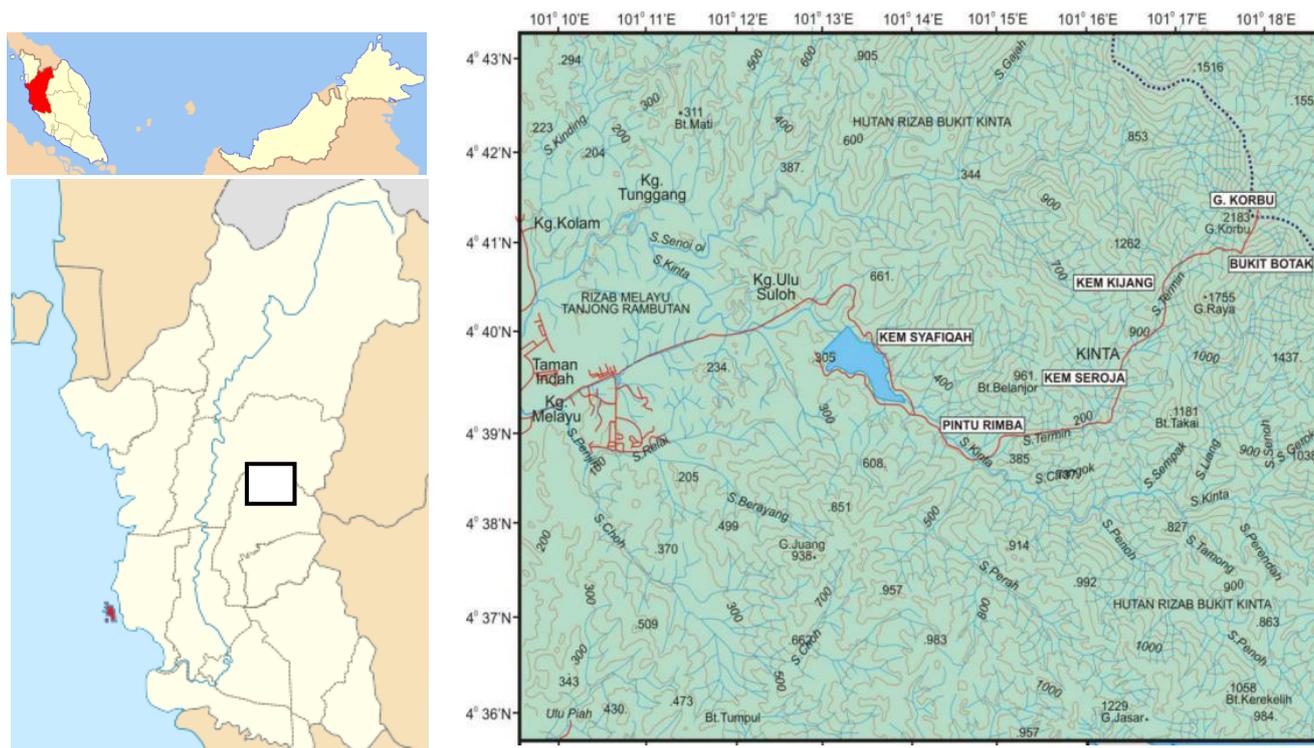


Figure 1. Location of the study area in Gunung Korbu, Perak, Malaysia. Source: RS/GIS Laboratory, SSDES, Geography Department, FSSK, UKM

RESULTS AND DISCUSSION

Collections

From this study, the collected macrofungi were listed in Table S1. From a total of 107 samples, 90 samples were in intact conditions, whereas 17 other samples were damaged/rotten possibly due to the weather condition, or eaten by an insect (Table S1). Macrofungi specimens with good conditions that identified up to the family level were included in the analysis. From 90 macrofungi specimens, only 6 families from 13 genera, including the unidentified, were identified (Table 1). In this study, the most enumerated macrofungi belong to Basidiomycota. Among the collections, member of family Polyporaceae was recorded the highest number of specimens (63 specimens) consisted of *Polyporus*, *Microsporus*, *Favolus*, *Microporus*, *Lenzites*, *Trametes*, and unidentified. The species of *Microporus* (31 specimens) were frequently recorded during this collecting trip.

Macrofungal species richness and diversity

Common diversity index, Shannon diversity index, and Simpson's diversity index were employed to analyze the samples. Shannon index showed a high diversity on Trail B with a value of 2.20. This value indicates that the study area at Gunung Korbu has a high diversity of species because the Shannon Diversity Index (H') falls between

1.5-3.5. Meanwhile, the Shannon Similarity Index (E') value range between 0-1 that showed the value of 1 represents uniformed species within the area. The three trails of Gunung Korbu showed highly-uniformed species, especially in Trail C ($E'=1.0$), followed by Trail A ($E'=0.88$), and Trail B ($E'=0.82$). This observation is due to only one macrofungi specimens belonging to Stereaceae enumerated at Trail C.

Ecologically, most terrestrial macrofungi can be classified into three feeding modes: saprophytes, parasites, and the symbiotic (ectomycorrhizal, ECM) species. Macrofungi fruiting on woody substrate is usually either saprobes or plant pathogens (Mueller et al. 2007). In this study, two feeding modes were encountered, i.e. saprophytic and parasitic, with the majority of the macrofungi specimens being classified as saprophytic fungi (93.33%) under Basidiomycota. There are a few unidentified species belonging to Ganodermataceae and Polyporaceae are considered as parasitic groups. Most of the specimens are found on decayed wood (36%) followed by living tree (32%). The family Polyporaceae, which recorded the highest number of species found in this study, recorded 6 species found on decayed trees followed by 6 species found on living trees and 4 species were also found on the twigs. The abundance of Polyporaceae in an area is due to the availability of substrates, such as decayed wood, living trees, and twigs for them to grow.

Table 1. Tabulation of macrofungal taxa in Gunung Korbu, Perak, Malaysia

Phylum	Family	Genus	Number of individuals		
			Trail_A	Trail_B	Trail_C
Basidiomycota	Ganodermataceae	<i>Amauroderma</i>	0	2	0
		<i>Ganoderma</i>	0	4	0
Basidiomycota	Hymenochaetaceae	<i>Phellinus</i>	0	4	0
		Indet.	0	8	0
Basidiomycota	Meruliaceae	<i>Cymatoderma</i>	0	3	0
Basidiomycota	Mycenaceae	Indet.	3	0	0
Basidiomycota	Polyporaceae	<i>Favolus</i>	0	4	0
		<i>Lenzites</i>	5	0	0
		<i>Microporus</i>	15	16	0
		<i>Polyporus</i>	0	4	0
		<i>Trametes</i>	4	0	0
		Indet.	3	12	0
		<i>Stereum</i>	2	0	1

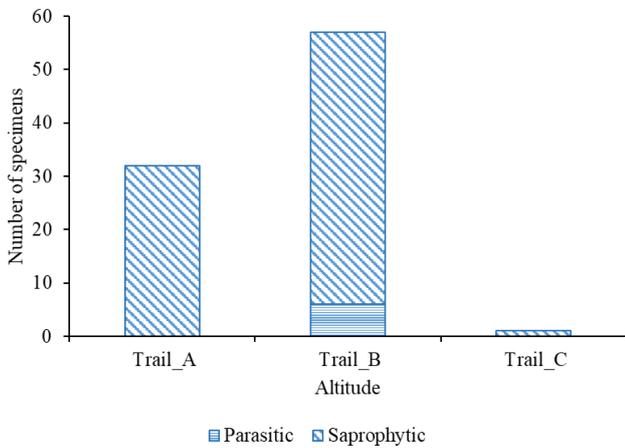


Figure 2. Number of specimens representing feeding mode of macrofungi in three different trails

Based on Figure 3, the non-metric multidimensional scaling (NMDS) ordinations of the macrofungi community at three different trails with different altitudes show a clear pattern of distribution macrofungi community. Trail A located between 300- 799 m above sea level recorded 32 specimens comprising of families Polyporaceae, Mycenaceae and Stereaceae. Sampling along the trail A also recorded the highest number of specimens from the family Polyporaceae with 27 specimens. Meanwhile, trail B with an altitude of between 800- 1200 m from sea level reported the highest number of specimens (57 specimens) consisting of families Hymenochaetaceae, Polyporaceae, Meruliaceae, and Ganodermataceae. The Polyporaceae recorded the highest number of specimens found throughout the B specimen of 36 specimens followed by Hymenochaetaceae (12 specimens), Ganodermataceae (6 specimens) and Meruliaceae (3 specimens). Trail C situated above 1040 m from sea level showed the lowest number of specimens, of which only one species was identified from the Stereaceae family, which is the species of *Stereum ostrea*.

Table 2. Diversity indices of macrofungi communities collected in three different trails at Gunung Korbu, Perak, Malaysia

Index/Value	Trail_A	Trail_B	Trail_C
Simpson_1-D	0.82	0.87	0
Shannon_H	1.82	2.20	0
Evenness_e^H/S	0.88	0.82	1

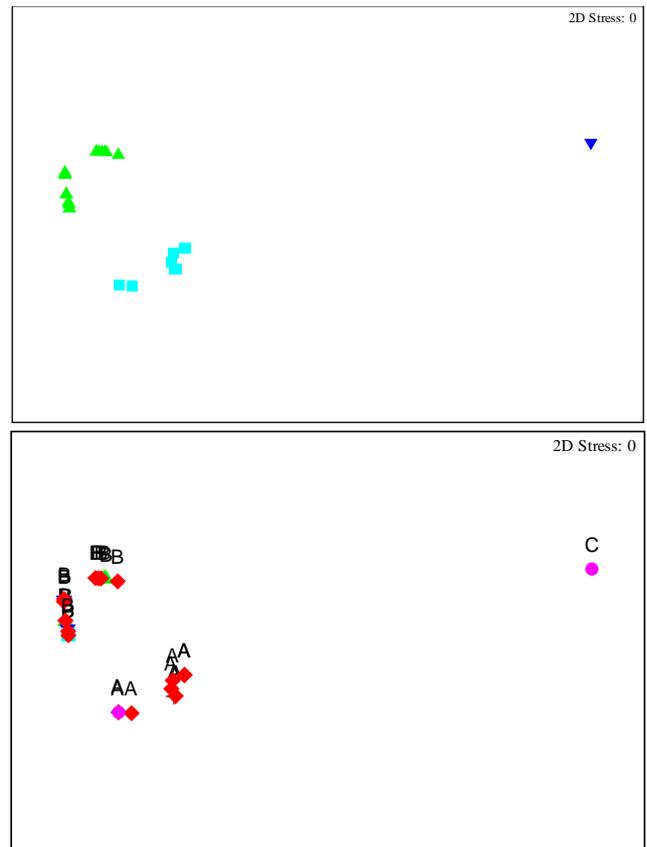


Figure 3. Non-metric multidimensional scaling (NMDS) ordinations of macrofungi community structure displaying variations among (top) trails and (bottom) family of macrofungi. Square, Trail A; Upper triangle, Trail B; Inverse triangle, Trail C. Macrofungi Family: Upper triangle, Ganodermataceae; Inverse triangle, Hymenochaetaceae; Square, Meruliaceae; Diamond, Polyporaceae; Circle, Stereaceae; Crosses, Mycenaceae

Table S1. List of macrofungi collection in Gunung Korbu, Perak, Malaysia

Family	Genus	Species	Collection	Sample condition	Trail	Altitude (m. a.s.l.)	Feeding mode
Auriculariaceae	<i>Auricularia</i>	<i>Auricularia delicata</i>	0	Poor condition	B	800	Saprophyte
Entolomataceae	<i>Entoloma</i>	<i>Entoloma</i> sp.	0	Poor condition	C	1040	Saprophyte
Ganodermataceae	<i>Amauroderma</i>	<i>Amauroderma</i> sp.	2	Good condition	B	802	Parasite
Ganodermataceae	<i>Ganoderma</i>	<i>Ganoderma</i> sp.	2	Good condition	B	800	Parasite
Ganodermataceae	<i>Ganoderma</i>	<i>Ganoderma</i> sp.	2	Good condition	B	819	Saprophyte
Hymenochaetaceae	<i>Phellinus</i>	<i>Phellinus/Inonotus</i>	4	Good condition	B	799	Saprophyte
Hymenochaetaceae	Unknown	Unknown	8	Good condition	B	799	Saprophyte
Meruliaceae	<i>Cymatoderma</i>	<i>Cymatoderma</i> sp.	3	Good condition	B	800	Saprophyte
Mycenaceae	Unknown	Unknown	3	Good condition	A	400	Saprophyte
Physalaciaceae	<i>Oudemansiella</i>	<i>Oudemansiella</i> sp.	0	Poor condition	B	799	Saprophyte
Polyporaceae	<i>Favolus</i>	<i>Favolus tenuiculus</i>	2	Good condition	B	800	Saprophyte
Polyporaceae	<i>Favolus</i>	<i>Favolus</i> sp.	0	Poor condition	B	800	Saprophyte
Polyporaceae	<i>Favolus</i>	<i>Favolus gramocephalus</i>	2	Good condition	B	860	Saprophyte
Polyporaceae	<i>Lentinus</i>	<i>Lentinus</i> sp.	0	Poor condition	A	350	Saprophyte
Polyporaceae	<i>Lentinus</i>	<i>Lentinus</i> sp.	0	Poor condition	A	480	Saprophyte
Polyporaceae	<i>Lenzites</i>	<i>Lenzites</i> sp.	2	Good condition	A	550	Saprophyte
Polyporaceae	<i>Lenzites</i>	<i>Lenzites</i> sp.	3	Good condition	A	580	Saprophyte
Polyporaceae	<i>Microporus</i>	<i>Microporus affinis</i>	5	Good condition	A	400	Saprophyte
Polyporaceae	<i>Microporus</i>	<i>Microporus affinis</i>	5	Good condition	A	480	Saprophyte
Polyporaceae	<i>Microporus</i>	<i>Microporus vernicipes</i>	5	Good condition	A	500	Saprophyte
Polyporaceae	<i>Microporus</i>	<i>Microporus affinis</i>	6	Good condition	B	799	Saprophyte
Polyporaceae	<i>Microporus</i>	<i>Microporus xanthopus</i>	5	Good condition	B	800	Saprophyte
Polyporaceae	<i>Microporus</i>	<i>Microporus affinis</i>	5	Good condition	B	819	Saprophyte
Polyporaceae	<i>Polyporus</i>	<i>Polyporus</i> sp.	4	Good condition	B	799	Saprophyte
Polyporaceae	<i>Trametes</i>	<i>Trametes menziesii</i>	4	Good condition	A	400	Saprophyte
Polyporaceae	Unknown	Unknown	3	Good condition	A	400	Saprophyte
Polyporaceae	Unknown	Unknown	5	Good condition	B	799	Saprophyte
Polyporaceae	Unknown	Unknown	2	Good condition	B	804	Parasite
Polyporaceae	Unknown	Unknown	5	Good condition	B	819	Saprophyte
Polyporaceae	Unknown	Unknown	0	Poor condition	B	890	Saprophyte
Russulaceae	Unknown	Unknown	0	Poor condition	B	819	Ectomikoriza
Stereaceae	<i>Stereum</i>	<i>Stereum ostrea</i>	2	Good condition	A	550	Saprophyte
Stereaceae	<i>Stereum</i>	<i>Stereum ostrea</i>	1	Good condition	C	1030	Saprophyte
Unknown	Unknown	Unknown	5	Good condition	A	350	Saprophyte
Unknown	Unknown	Unknown	2	Good condition	A	450	Saprophyte
Unknown	Unknown	Unknown	4	Good condition	B	840	Saprophyte
Unknown	Unknown	Unknown	1	Good condition	C	1008	Saprophyte
Unknown	Unknown	Unknown	5	Good condition	C	1040	Saprophyte
Xylariaceae	<i>Xylaria</i>	<i>Xylaria polymorpha</i>	0	Poor condition	B	804	Saprophyte

Discussions

Mycoflora of Malaysia reported two major phyla, Ascomycota and Basidiomycota consisting of 1141 species and 1820 species, respectively (Lee et al. 2012). The total number of specimens and taxa found in this study was relatively lower compared to other similar studies (Thi and Lau 2012; Sepiah and Norhayati 2009). The number of factors that contributed to this low number of macrofungi taxa and one of the factors is vegetation type. The composition and diversity of macrofungi were different may due to the difference in vegetation types along with the altitude (Moore 2008) which leads to the availability of substrates (Lodge et al. 2004; Ujang and Jones 2001). At the higher altitude, most of the vegetation was dominated by mosses, liverworts, and lichens (Moore 2008). Andrew et al. (2013) state the diversity of macrofungi is higher in areas with low and medium altitudes compared to those with high altitudes. From this study, at altitudes of above

1040 m, no samples were obtained. This finding also congruent with Sepiah and Norhayati (2009) study at Gunung Murud, Sarawak, where 73.31% of the collections and more diverse fungi taxa were found at an altitude below 1800 m above sea level. Some of the macrofungi species especially ectomycorrhizas (ECM) are host-specific (Moore et al. 2011; Roy et al. 2013; Essene et al. 2017) which associated with only 2% of woody plant (Brundrett and Tedersoo 2018). There are reports that showed ECM are highly diverse in temperate forest compared to tropical forest (Tedersoo et al. 2012; Kennedy et al. 2012) due to the temperate forest was often dominated by the ECM host such as *Alnus* (Roy et al. 2013), *Pinus* (Cullings et al. 2000) and *Quercus* (Morris et al. 2009). In this study, there is absence of ECM and this may due to lack of host, mainly Dipterocarpaceae and the soil properties which had a positive significant influence ECMs species richness and diversity (Luo et al. 2016).

According to Schmit et al. (2005) and Lodge et al. (2004) claimed that higher plant diversity and density generates higher diversity of substrate for macrofungi, which may, in turn, lead to higher macrofungi diversity because of the plant vigilante as habitat and source of energy for most macrofungi especially for poroid fungi. In Malaysia, Polyporaceae is the largest and most common family with 42 genera and 327 species and frequently found on a variety of substrates (Lee et al. 2012), mainly wood, available for them to grow on (Bolhassan et al. 2012). Moreover, most of the polypore fungi have tough and hard fruiting bodies that grow perennially and they can thus be found at almost any time of the year and abundantly in an area (Thi and Lee 2010b). These results correspond to the study by Li et al. (2018a) and Lee et al. (2014) where saprobic fungi, especially litter-decomposing macrofungi, are the dominant and diverse fungal group in tropical forests. Besides, according to Luo et al. (2016), no significant relationships were found between environment variables and the diversity and community composition of saprotrophic fungi in subalpine pine forest.

In higher altitude, the forest canopy gap was huge consequently prominent to higher light levels, higher temperatures and lower humidity drive to low sporocarp production (Jaya Seelan et al. 2014; Brown et al. 2006). In addition, the varied spore-producing structures which increase the degree of dispersal may contribute to the abundance of macrofungi species in an area (Aqilah et al. 2019; Raper et al. 1958). According to Li et al. (2018b) and Priyamvada et al. (2017), it is expected that more species can be recorded in different regions if the environment is optimum depending on the season, temperature and amount of rainfall. During the four days of collection on Gunung Korbu, no rainfall was recorded. Based on rainfall data from 2017 to 2019 obtained from the Malaysian Meteorological Department, it can be concluded that the rainfall from January to July in 2019 is significantly lower than in 2017 and 2018. The month of July 2019, where this study was conducted recorded only 72.2 mm of rain, which is extremely low compared to July 2018 (235.4 mm) and July 2017 (386.1 mm).

In conclusion, this is the first report on mycoflora of Gunung Korbu and further intensive studies (e.g, increase sampling period and effort) are required, as a new species or new record may be encountered in the area.

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REFERENCES

- Andrew EE, Kinge TR, Tabi EM, Thiobal N, Mih AM. 2013. Diversity and distribution of macrofungi (mushrooms) in the Mount Cameroon Region. *J Ecol Nat Environ* 5 (10): 318-334
- Aqilah M, Lee S.Y, Ayu Kalsum K. 2019. Macrofungi of Tasik Kenyir. In: Abdullah MT, Mohammad A, Nor Zalipah M, Safiih, Lola M (eds.). *Greater Kenyir Landscapes*. Springer, Cham.
- Boddy L, Buntgen U, Egli S, Gange AC, Heegaard E, Kirk P, Mohammad AB, Kausarud H. 2014. Climate variation effects on fungal fruiting. *Fungal Ecol* 10: 20-33.
- Bolhassan MH, Abdullah N, Sabaratnam V, Tsutomu H, Abdullah S, Mohd N, Rashid N, Musa Y. 2012. Diversity and distribution of Polyporales in Peninsular Malaysia. *Sains Malaysiana* 41 (2): 155-161.
- Brown N, Bhagwat SA, Watkinson S. 2006. Macrofungal diversity in fragmented and disturbed forests of the Western Ghats of India. *J Applied Ecol* 43 (1): 11-17
- Brundrett M, Tedersoo L. 2018. Evolutionary history of mycorrhizal symbioses and global host plant diversity. *New Phytol* 220 (4): 1108-1115.
- Cannon P, Hudson B.A, Aime M.C, Ainsworth A.M, Bidartondo M.A, Gaya E, Hawksworth D, Kirk P, Leitch IJ, Lucking R. 2018. *State of the World's Fungi*. Royal Botanic Gardens, Kew.
- Chan KO, Muin MA, Anuar S, Andam J, Razak N, Aziz MA. 2019. First checklist on the amphibians and reptiles of Gunung Korbu, The Second Highest Peak in Peninsular Malaysia. *Check List* 15 (6): 1055-1069.
- Chang YS, Lee SS. 2004. Utilisation of macrofungi species in Malaysia. *Fungal Divers* 15: 15-22.
- Clarke KR, Gorley RN. 2006. *Primer-E Ltd, Plymouth Routines in Multivariate Ecological Research software*.
- Comer EJH. 1996. The agaric genera *Marasmius*, *Chaetocalathus*, *Crinipellis*, *Heimiomyces*, *Resupinatus*, *Xerula* and *Xerulina* in Malesia. *Beihefte Nova Hedwigia* 111: 1-175
- Cullings KW, Vogler DR, Parker VT, Finley SK. 2000. Ectomycorrhizal specificity patterns in a mixed *Pinus contorta* and *Picea engelmannii* Forest in Yellowstone National Park. *Appl Environ Microbiol* 66: 4988-4991.
- Donatha DT. 2013. Wild mushroom- an underutilized healthy food resource and income generator: experience from Tanzania Rural Areas. *J Ethnobiol Ethnomed* 9: 49. DOI: 10.1186/1746-4269-9-49.
- Douanla-Meli, C, Ryvarden L, Langer E. 2007. Studies of tropical African pore fungi (Basidiomycota, Aphyllophorales): Three new species from Cameroon. *Beihefte Nova Hedwigia* 84: 409-420.
- Essene AL, Shek KL, Lewis JD, Peay KG, McGuire KL. 2017. Soil type has a stronger role than dipterocarp host species in shaping the ectomycorrhizal fungal community in a Bornean Lowland Tropical Rain Forest. *Front Plant Sci* 8: 1828.
- Fox JED. 1978. Natural vegetation of Sabah, Malaysia. The physical environment and classification. *J Trop Ecol* 19 (2): 218-239.
- Hammer O, Harper DAT, Ryan PD. 2001. *PAST: Paleontological Statistics software package for education and data analysis*. *Palaeontologia Electronica* 4 (1): 9.
- Hedger J. 1985. Tropical agarics, resource relations and fruiting periodicity. In: Moore D, Casselton LA, Wood DA, Frankland JC. (eds.). *Developmental Biology of Higher Plants*. Cambridge University Press, Cambridge.
- Hyde KD. 2003. Mycology and its future in the Asia Region. *Fungal Div* 13: 59-68.
- Jaya Seelan SS, Ahmad AH, Sepiah M, Tan PE. 2014. Biodiversity Inventory of macrofungi at Sungkai Wildlife Reserve, Perak, Malaysia. *J Wildlife Parks* 27: 17-24.
- Kennedy PG, Matheny PB, Ryberg KM, Henkel TW, Uehling JK, Smith ME. 2012. Scaling up: examining the macroecology of ectomycorrhizal fungi. *Mol Ecol* 21: 4151-4154.
- Kuthubutheen AJ. 1981. Notes on the macrofungi of Langkawi. *Malayan Nat J* 34 (3): 123-130.
- Lee SS, Alias SA, Jones EGB, Zainuddin N, Chan HT. 2012. Checklist of Fungi of Malaysia. Forest Research Institute Malaysia, Kepong.
- Lee SS, Besl H, Salmiah U. 1995. Some fungi of the Sungai Halong and surrounding areas, Temenggor Forest Reserve, Hulu Perak, Malaysia. *Malayan Nat J* 48: 147-155.
- Lee SS, Watling R, Sikin YN. 2002. Ectomycorrhizal basidiomata fruiting in lowland rain forests of Peninsular Malaysia. *Bois et Forêts des Tropiques* 274: 33-43.
- Lee WD, Lee H, Fong JJ, Oh SY, Park MS, Quan Y, Jung PE, Lim YW. 2014. A checklist of the basidiomycetous macrofungi and a record of five new species from mt. Oseo in Korea. *Mycobiology* 42 (2): 132-9.
- Li H, Guo J, Goldberg S, Sreekar R, Ye L, Luo X, Sysouphanthong P, Xu J, Hyde K, Mortimer P. 2018b. Fruiting patterns of macrofungi in tropical and temperate land use types in Yunnan Province, China. *Acta Oecologica*. 91. 7-15.

- Li H, Guo J, Samantha CK, Ye L, Xu J, Hyde KD, Mortimer PE. 2018a. Native forests have a higher diversity of macrofungi than comparable plantation forests in the Greater Mekong Subregion. *Forests* 9 (7): 402. DOI: 10.3390/f9070402.
- Lodge DJ, Ammirati JF, O'Dell TE, Mueller GM. 2004. *Collecting and Describing Macrofungi*. Biodiversity of Fungi: Inventory and Monitoring Methods. Elsevier Academic Press, Amsterdam.
- Luo X, Karunarathna SC, Luo YH, Xu K, Xu JC, Chamyuang S, Mortimer PE. 2016. Drivers of macrofungal composition and distribution in Yulong Snow Mountain, southwest China. *Mycosphere* 7 (6): 727-740.
- Moi LG 2012. Macrofungi from Gunung Singai, Sarawak, Malaysia. In: Malaysia International Biological Symposium: Sustainable Management of Bioresources, 11th - 12th July 2012, Residence Hotel, Selangor, Malaysia.
- Moore D, Robson GD, Trinci APJ. 2011. 21st Century Guidebook to Fungi. Cambridge University Press, Cambridge.
- Moore PD. 2008 *Ecosystem Series: Tropical Forest*. Infobase Publishing, New York.
- Morris MH, Perez-Perez MA, Smith ME, Bledsoe CS. 2009. Influence of host species on ectomycorrhizal communities associated with two co-occurring oaks (*Quercus* spp.) in a tropical cloud forest. *FEMS Microbiol Ecol* 69: 274-287.
- Mueller GM, Schmit JP, Leacock PR, Buyck B. 2007. Global diversity and distribution of macrofungi. *Biodiv Conserv* 16 (1): 37-48.
- Noorlidah A, Vikineswary S, Yusoff M, Desjardin DE. 2005. Higher Fungi of Northeast Langkawi. *Malaysian J Sci* 24: 95-102.
- Parveen A, Khataniar L, Goswami G, Hazarika DJ, Das P, Gautom T, Barooah M, Boro RC. 2017. A study on the diversity and habitat specificity of macrofungi of Assam, India. *Intl J Curr Microbiol Appl Sci* 6 (12): 275-297.
- Pegler DN. 1997. *The larger fungi of Borneo*. Natural History Publications, Kota Kinabalu, Malaysia.
- Priyamvada H, Akila M, Singh RK, Ravikrishna R, Verma RS, Philip L, Marathe RR, Sahu LK, Sudheer KP, Gunthe SS. 2017. Terrestrial macrofungal diversity from the tropical dry evergreen biome of Southern India and its potential role in aerobiology. *PLoS ONE* 12 (1): e0169333. DOI: 10.1371/journal.pone.0169333.
- Raper JR, Krongelb GS, Baxter MG. 1958. The number and distribution of incompatibility factors in *Schizophyllum commune*. *Amer Nat* 92: 221-232.
- Roy M, Rochet J, Manzi S, Jargeat P, Gryta H, Moreau PA, Gardes M. 2013. What determines *Alnus*-associated ectomycorrhizal community diversity and specificity? a comparison of host and habitat effects at a regional scale. *New Phytol* 198: 1228-1238.
- Salleh H, Ghani Y, Nelson S, Haryanie, Mohamad S, Yamashita S. 2016. Fungi in Sarawak: practical use of historical samples in the fungarium of the Forest Department Sarawak. Proceedings of the symposium "Frontier in tropical forest research: progress in joint projects between the Forest Department Sarawak and the Japan Research Consortium for Tropical Forests in Sarawak", 2016: 160-164
- Schmit JP, Mueller GM, Leacock PR, Mata JL, Wu Q, Huang Y. 2005. Assessment of tree species richness as a surrogate for macrofungal species richness. *Biol Conserv* 121: 99-110
- Sepiah M, Norhayati S. 2009. Macrofungi of Gunung Murud, Sarawak. In: UNIMAS Special Focus on Biodiversity Research Update 5 (2): 17.
- Symington CF. 1943. *Foresters' Manual of Dipterocarps*. Malayan Forest Record No. 16. University of Malaya Press, Kuala Lumpur.
- Tedersoo L, Bahram M, Toots M, Diédhiou AG, Henkel TW, Kjoller R, Morris MH, Nara K, Nouhra E, Peay KG, Pölme S, Ryberg M, Smith ME, Kõljalg U. 2012. Towards global patterns in the diversity and community structure of ectomycorrhizal fungi. *Mol Ecol* 21: 4160-4170.
- Thi BK, Lee SS. 2011. Macrofungal diversity of Cameron Highlands: A preliminary survey. In: Abd Rahman A R, Koh HL, Mohd Paiz K, Muhamad A, Latiff A. (eds.). *Hutan Pergunungan Cameron Highlands: Pengurusan hutan, persekitaran fizikal dan kepelbagaian biologi*. Siri Kepelebagaian Biologi Hutan 14. Jabatan Perhutanan Semenanjung Malaysia, Kepong.
- Thi BK, Lau SS. 2012. Macrofungi of Gunung Senyum. *Bulletin Supporting Plant and Animal Conservation in Malaysia*, No. 15. Forest Research Institute Malaysia, Kepong.
- Thi BK, Lee SS. 2010a. Macrofungi of Fraser's Hill: Part 1. Conservation Malaysia. *Bulletin Supporting Plant and Animal Conservation in Malaysia*, No. 11. Forest Research Institute Malaysia, Kepong.
- Thi BK, Lee SS. 2010b. Some Macrofungi of Pulau Pangkor. *Proceeding of Seminar Ekspedisi Saintifik Kepelebagaian Biologi Hutan Pulau Pangkor*. *Kertas* 28: 1-7. Jabatan Perhutanan Semenanjung Malaysia, Kepong.
- Thi BK, Lee SS. 2017. Diversity of macrofungi at Gunung Ledang Johor National Park. In Ahmad Naqiyuddin B, Abdul Rauf A, Farida Zuraina M.Y, Singh HR, Tokiman L (eds.) *Gunung Ledang: Geology, Biodiversity and Socio-economic Environment*. Penerbit Press Universiti Teknologi Mara, Shah Alam.
- Thi BK, Lee SS, Zainuddin N, Chan HT. 2011. *A Guidebook to the Macrofungi of Fraser's Hill*. Forest Research Institute Malaysia, Kepong.
- Tibuhwa DD. 2013. Wild Mushroom—An Underutilized Healthy Food Resource and Income Generator: Experience from Tanzania Rural Areas. *J J Ethnobiol Ethnomed* 9: 49. DOI: 10.1186/1746-4269-9-49.
- Tsia MK, Aqilah M. 2019. Macrofungi of Pulau Bidong. *Universiti Malaysia Terengganu J Undergrad Res* 1 (2): 26-35
- Ujang S, Jones EBG. 2001. Occurrence of wood inhabiting fungi in forests of Peninsular Malaysia. *J Trop For Sci* 13 (2): 237-245.
- Whitmore TC. 1984. *Tropical Rain Forests of the Far East*. Clarendon Press, Oxford.
- Wyatt-Smith J. 1964. A preliminary vegetation map of Malaysia with description of vegetation types. *J Trop Geogr* 18: 200-213.
- Zainuddin N, Alias SA, Kin TB, See LS, Twu CH. 2010. Macrofungi of Pulau Redang, Terengganu and Pulau Aur, Johor in the South China Sea. *J Sci Technol Tropics* 6: 120-125.
- Zhang Y, Zhou DQ, Zhao Q, Zhou TX, Hyde KD. 2010. Diversity and ecological distribution of macrofungi in the Laojun Mountain Region, Southwestern China. *Biodiv Conserv* 19: 3545-3563.