Original Article

Macrofungi of Sungai Kangkawat Research Station, Imbak Canyon Conservation Area, Sabah, Malaysia

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Abstract : The number of studies on macrofungi in Sabah remain scant despite being a biodiversity hotspot of the world. The Sungai Kangkawat Research Station, Imbak Canyon Conservation Area, Sabah (ICCA) is a large tropical rainforest area with a high potential to discover rare, endemic, and even new species. Macrofungi inventory was conducted from 29th September to 8th October 2018. Opportunistic sampling of fruiting bodies or sporocarps collections were carried out. A total of 104 species of macrofungi from 36 genera, 30 families from two major phyla, namely Basidiomycota and Ascomycota, was recorded. Sixty-two species (58.49%) of saprophytic macrofungi (mostly wood-decaying mushrooms), 22 species (20.75%) of soil macrofungi, 21 species (19.81%) of ectomycorrhizal mushrooms and two parasitic macrofungi (1.9%) were recorded. The two parasitic fungi are categorized into two distinct groups, one each of phytopathogenic and entomopathogenic fungus. The unique entomopathogenic fungus was identified as *Ophiocordyceps* sp.. Thirteen species identified from this survey were classified as edible, six species have medicinal values and two species are known to be poisonous. One species of bioluminescent mushroom, *Filoboletus manipularis*, was also collected. More studies are needed in order to generate appropriate morphological and molecular references for identification and characterization of the 106 specimens. Future studies, inventories and surveys of macrofungi in ICCA should incorporate molecular identification tools for accurate corroboration of identification and to contribute sequences to online databases.

Keywords: Macrofungi, Basidiomycota, Ascomycota, lowland dipterocarp forest, Sungai Kangkawat, Imbak Canyon Conservation Area, Sabah.

INTRODUCTION

Fungi play vital roles in the ecosystems they inhabit mainly as major decomposers of organic matter. They also exist as essential associates of many organisms, especially as phytopathogens, entomopathogens, predators and generalists or mutualists (Talbot et al., 2008). Fungi are heterotrophic organisms because they consume organic matter from their surroundings or act as pathogens by infecting living hosts for nutrition (Vincent et al., 2009). Macrofungi are generally considered fungi that form fruiting bodies that are visible to the naked eye (mushrooms, brackets, puffballs, false-truffles, cup fungi, etc.). These structures vary in size, color, texture and shape of the stalk, cap and cup, all of which are important keys in the identification (Chang and Miles, 1987; Al-Thani, 2010; Servi et al., 2010).

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Malaysia is ranked as the 12th most biologically diverse country in the world based on the estimations of the country's species richness and endemism (Rintelen et al., 2017). Lee et al. (2012) mentioned that currently around 4,000 distinct taxa of fungi from all divisions in Malaysia have been identified. Furthermore, they estimated that 70% of macrofungi in the region have yet to be described, with the current estimates of extant fungal species ranging from 600,000 to 650,000. So far, 1473 Basidiomycetes, 894 anamorphic fungi and 594 Ascomycetes have been reported for Malaysia (Jones, 2007; Zainuddin et al., 2010). Eighteen genera of Boletaceae out of 31 genera recorded worldwide are present in Malaysia (Zainuddin et al., 2010). Meanwhile, Hattori et al. (2007) suggest that more than 300 species of polypores are known to occur in Malaysia, and some of them are important plant pathogens. On a global perspective, tropical Asia have only recorded 400 mushroom species based on the minimal data available of selected agarics and boletes from Malaysia (Mueller et al., 2007).

Furthermore, there is a scarcity of knowledge on macrofungi in Malaysia, especially in Sabah and Sarawak (Lee and Chang, 2002; Chang and Lee, 2004). Historically, the knowledge of macrofungi of Borneo were mainly recorded from the studies of Corner (1966, 1972, 1996) and Chin (1981, 1988). Many studies of macrofungi in Borneo focused primarily on the order Polyporales, specifically fungi from the family Polyporaceae, Ganodermataceae, Fomitopsidaceae, Hymenochaetaceae and Meripilaceae (Seelan et al., 2015; Adebola et al., 2016; Viviannye et al., 2019). Ambiguous taxonomic placement of endemic tropical fungi has often led to misidentification when referenced with information on fungi from temperate regions (Hawksworth and Lücking, 2017). At the moment, there is still not enough evidence to confirm that fungal diversity is in fact richer in the tropics than in more temperate regions of the world (Arnold et al., 2000; Hawksworth and Lücking, 2017). An enormous knowledge gap still exists for tropical fungi from this region, with many taxa still awaiting comprehensive molecular DNA barcoding. Thus, Seelan et al. (2015) and Foo et al. (2018) have revised and updated the species information of some of the Bornean macrofungi, particularly Polyporaceae and Pleurotaceae fungi, using molecular approaches.

Imbak Canyon Conservation Area is one of the oldest pristine tropical rainforests and most prominent centres of biological diversity in the world. Approximately 27,599 ha in size, this forest consists of complex rainforest habitats ranging from lowland dipterocarp forests to montane heath forests (Yayasan Sabah, 2014). It is located in Tongod, Sabah, which is accessible by road from two major cities, namely Kota Kinabalu (266 km) and Sandakan (193 km). Imbak Canyon is home to a plethora of tree species, totalling at least 85 genera of Angiosperms and 40 families of Gymnosperms (Suratman et al., 2011). Despite previous studies and surveys conducted in ICCA, it has not been fully explored for its potentially large variety of unique and endemic fungal diversity.

The present survey was conducted to document macrofungi of Sungai Kangkawat Research Station, ICCA for the first time and to update the current checklist of macrofungi in Sabah, Northern Borneo. Information on Sabah's fungal diversity is vital to promote fungi research and cultivation in Malaysia. The knowledge gained will be used to enhance public awareness of edible and poisonous mushrooms and promote their culinary and medicinal properties.

MATERIALS AND METHODS

Study sites

Specimen collection was conducted from September 29 until October 8, 2018, during the Borneo Geographic Expedition 2018 at Sungai Kangkawat Research Station, ICCA (117.0596° E, 5.074774° N) (Figure 1). Sungai Kangkawat Research Station was gazetted as a Class I (Protection) Forest Reserve by the Sabah State Government in 2009, and it is situated on the eastern piece of Imbak Canyon. There are four available trails in the research station, namely the Kawang trail, South Rim trail, Pelajau trail and Nepenthes trail. The forest type in Kawang and South Rim trails are mainly of primary highland and lowland forests with the presence of dipterocarps trees, along with a variety of palm trees, lianas, epiphytes and some big non-dipterocarps trees. Nepenthes trail is located in Kerangas forest, which is a primary forest characterized by the presence of Nepenthes trees. The Pelajau trail, which is a secondary logged highland and lowland forest, is filled with logged trees and open areas consisting of grass and small herbaceous trees (Figure 2).

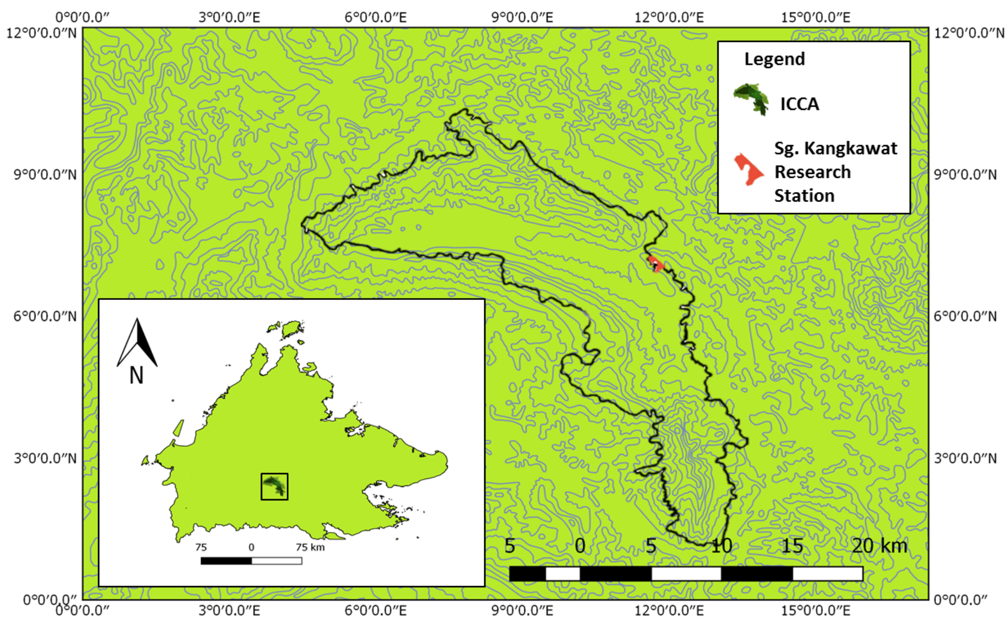

Figure 1. Map of Sg. Kangkawat Research Station, Imbak Canyon Conservation Area, Sabah

Sample collections

Mushroom sporocarps were collected by opportunistic sampling. Up to five fruiting bodies of macrofungi were collected for each specimen whenever available at a particular site. Photographs of the fresh collections were taken in the field, including the substrates on which they were found, using the Garmin GPSMAP® 64sWW and Canon DSLR EOS 80D camera (Figure 3). Bruise reactions and colour changes were observed and recorded. Samples were collected, labelled and dried in the field using an electric dehydrator at 40°C for at least 24 hours prior to and subsequently stored in paper bags or Ziploc bags. The dried specimens were brought back to the Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah for further identification. Curated specimens were placed at the BORNEENSIS Herbarium. Each specimen was given new a voucher number (i.e. BORH/F 0001).

Figure 2. Forest types of Sg. Kangkawat Research Station, ICCA. A. Forest vegetation with high canopy cover and low light penetration in Kawang Trail. B. Open canopy cover of Nepenthes Trail, the Kerangas Forest showing a dry forest floor. C. The Pelajau Trail, secondary logged forest with a logged tree covered with *Trametes* sp., a wood-decaying fungus.

Figure 3. Collection of macrofungi specimens. A. Photographs of the fresh collections were taken in the field, including the substrates on which they were found, using a DSLR camera. B. All the specimens were identified, labelled, dried and stored in labelled paper bags.

Morphological Identification

All specimens were identified using standard mycological keys and literatures (Corner, 1981; Pegler, 1983). Simple description of the habitat, substrate, physical morphology and coloration of each specimen were noted. Selected samples were only identified to the genus level because of their cryptic morphology and inadequate reference information for identification. Species level identification for unknown specimens will be inferred using molecular methods in subsequent studies. In this study, we highlighted the major groups of macrofungi that have been widely found in this site. The ecological data of all mushrooms were recorded based on their nutritional mode. Furthermore, information on the utilization of the collected mushrooms as food or medicine were gathered from the locals residing in the surroundings areas of the research station.

RESULTS

During the 10-day sampling period in Sungai Kangkawat Research Station, ICCA, 106 specimens were collected. A total of 104 species was then identified and categorized into 36 genera, 30 families, and two phyla, namely Basidiomycota (91.18%) and Ascomycota (8.82%) (Figure 4, Figure 5 and Table 1). The dominant family encountered in this expedition was Polyporaceae (21.57%) followed by Agaricaceae (7.84%), Pleurotaceae (6.86%), Russulaceae (6.86%) and Hygrophoraceae (3.92%) (Figure 4). The highest number of macrofungi specimens were collected in the South Rim trail (40.38%), followed by Kawang trail (30.77%), Pelajau trail (16.34%) and Nepenthes trail (12.5%).

Table 1. Checklist for the identified macrofungi collected in Borneo Geographic Expedition, Sg. Kangkawat Research Station, ICCA.

Family	Scientific name	Local name	Ecology	Utilization
Agaricaceae	*Agaricus* sp. 1	n.a	Soil	Non-Edible
	Agaricus sp. 2	n.a	Soil	Non-Edible
	Lepiota sp.	n.a	Soil	Poisonous
	Lycoperdon sp. 1	Puffball	Ectomycorrhizal	Non-Edible
	Lycoperdon sp. 2	Puffball	Ectomycorrhizal	Non-Edible
	Macrolepiota sp. 1		Soil	Non-Edible
	Macrolepiota sp. 2		Soil	Non-Edible
Amanitaceae	*Amanita* sp. 1	n.a	Ectomycorrhizal	Non-Edible

	Amanita sp. 2	n.a	Ectomycorrhizal	Poisonous
Auriculariaceae	*Auricularia polytricha*	Elephant ear mushroom, Korong (Dusun)	Saprophytic	Edible, Medicinal
	Auricularia delicata	Rat ear mushroom, Korong (Dusun)	Saprophytic	Edible, Medicinal
Boletaceae	*Boletus* sp. 1	n.a	Ectomycorrhizal	Non-Edible
	Boletus sp. 2	n.a	Ectomycorrhizal	Non-Edible
	Boletus sp. 3	n.a	Ectomycorrhizal	Non-Edible
Cantharellaceae	*Cantharellus* sp. 1	n.a	Soil	Edible
	Chanterellus sp. 2	n.a	Soil	Non-Edible
Clavariaceae	*Clavulinopsis* sp.	Coral mushroom	Ectomycorrhizal	Non-Edible
Corticiaceae	*Corticium* sp. 1	n.a	Saprophytic	Non-Edible
	Corticium sp. 2	n.a	Saprophytic	Non-Edible
	Corticium sp. 3	n.a	Saprophytic	Non-Edible
	Corticium sp. 4	n.a	Saprophytic	Non-Edible
Crepidotaceae	*Crepidotus* sp.	Cracked ear mushroom	Saprophytic	Non-Edible
Dacrymycetaceae	*Dacryopinax* sp.	n.a	Saprophytic	Non-Edible
Entolomataceae	*Entoloma* sp.1	n.a	Soil	Non-Edible
	Entoloma sp. 2	n.a	Soil	Non-Edible
Fomitopsidaceae	*Fomitopsis* sp.	n.a	Saprophytic	Non-Edible
Ganodermataceae	*Amauroderma* sp. 1	n.a	Soil	Medicinal
	Amauroderma sp. 2	n..a	Soil	Medicinal

	Ganoderma sp.	n.a	Saprophytic & parasitic	Non-Edible
Gomphaceae	*Ramaria* sp. 1	Coral mushroom	Ectomycorrhizal	Non-Edible
	Ramaria sp. 2	Coral mushroom	Ectomycorrhizal	Non-Edible
	Ramariopsis sp.	Coral Mushroom	Ectomycorrhizal	Non-Edible
Hydnaceae	*Hydnum* sp.	Hedgehog	Soil	Edible
Hydnangiaceae	*Laccaria* sp. 1	n.a	Ectomycorrhizal	Non-Edible
	Laccaria sp. 2	n.a	Ectomycorrhizal	Non-Edible
Hygrophoraceae	*Hygrocybe miniata*	n.a	Ectomycorrhizal	Edible
	Hygrocybe sp. 1	n.a	Ectomycorrhizal	Non-Edible
	Hygrocybe sp. 2	n.a	Ectomycorrhizal	Non-Edible
	Hygrocybe sp. 3	n.a	Ectomycorrhizal	Non-Edible
Hymenogastraceae	*Galerina* sp.	n.a	Saprophytic	Non-Edible
Incertae sedis	*Pseudohydnum gelatinosum*	n.a	Saprophytic	Edible
Inocybaceae	*Inocybe* sp. 1	n.a	Soil	Non-Edible
Marasmiaceae	*Marasmius* sp. 1	n.a	Saprophytic	Non-Edible
	Marasmius sp. 2	n.a	Saprophytic	Non-Edible
Meruliaceae	*Podoscyphya* sp.	n.a	Saprophytic	Non-Edible
	Cymatoderma elegans	n.a	Saprophytic	Non-Edible
	Cymatoderma sp. 2	n..a	Saprophytic	Non-Edible
Mycenaceae	*Mycena* sp. 1	n.a	Saprophytic	Non-Edible
	Mycena sp. 2	n.a	Saprophytic	Non-Edible
	Filoboletus manipularis	Glowing mushroom	Saprophytic	Bioluminescence
Ophiocordycipitaceae	*Ophiocordyceps* sp.	Zombie fungi, Ant fungi	Entomopathogenic	Parasitic

Pleurotaceae	*Pleurotus* sp. 1	Oyster mushroom	Saprophytic	Edible
	Pleurotus tuberregium	Kulat ubi (Malay)	Saprophytic	Edible
	Pleurotus sp. 2	n.a	Saprophytic	Non-Edible
	Buglossoporus sp.	n.a	Saprophytic	Non-Edible
Polyporaceae	*Favolus* sp.1	Honeycomb mushroom	Saprophytic	Edible
	Favolus sp.2	Honeycomb mushroom	Saprophytic	Non-Edible
	Neofavolus sp.	n.a	Saprophytic	Non-Edible
	Lentinus squarrosulus	Kulat susu (Malay)	Saprophytic	Edible, Medicinal
	Lentinus sp.	n.a	Saprophytic	Non-Edible
	Microporus affinis	n.a	Saprophytic	Non-Edible
	Microporus xanthopus	n.a	Saprophytic	Non-Edible
	Microporellus sp. 1	n.a	Saprophytic	Non-Edible
	Microporellus sp. 2	n.a	Saprophytic	Non-Edible
	Panus lecomtei	Kulat kari-kari (Malay)	Saprophytic	Edible
	Panus sp. 2	n.a	Saprophytic	Non-Edible
	Polyporus sp. 1	n.a	Saprophytic	Non-Edible
	Polyporus sp. 2	n.a	Saprophytic	Non-Edible
	Trametes sp.	Turkey tail mushroom	Saprophytic	Medicinal
	Trametes versicolor	Turkey Tail mushroom	Saprophytic	Medicinal
Psathyrellaceae	*Parasola* sp.	Inkycap mushroom, Little Japanese Umbrella	Soil	Non-Edible
Russulaceae	*Russula* sp. 1	n.a	Ectomycorrhizal	Non-Edible
	Russula sp. 2	n.a	Ectomycorrhizal	Non-Edible

	Russula sp. 3	n.a	Ectomycorrhizal	Non-Edible
	Russula sp. 4	n.a	Ectomycorrhizal	Non-Edible
	Russula sp. 5	n.a	Ectomycorrhizal	Non-Edible
	Russula sp. 6	n.a	Ectomycorrhizal	Non-Edible
	Lactarius sp.	n.a	Soil	Non-Edible
Sarcoscyphaceae	*Cookeina sulcipes*	Cendawan mangkuk (Malay)	Saprophytic	Edible
	Cooekina tricholoma	Cendawan Rambut (Malay)	Saprophytic	Edible
	Sarcoscypha sp. 1 (Yellow)	n.a	Soil	Non-Edible
	Sarcoscypha sp. 2 (red)	n.a	Soil	Non-Edible
Stereaceae	*Stereum* sp. 1	n.a	Saprophytic	Non-Edible
	Stereum sp. 2	n.a	Saprophytic	Non-Edible
Tricholomataceae	*Trogia* sp.	n.a	Saprophytic	Non-Edible
	Clitocybe sp.	n.a	Saprophytic	Non-Edible
Xylariaceae	*Xylaria* sp. 1	Dead Man Finger	Saprophytic	Non Edible
	Xylaria sp. 2	Dead Man Finger	Saprophytic	Non Edible
	Xylaria sp. 3	Dead Man Finger	Saprophytic	Non Edible
	Xylaria sp. 4	Dead Man Finger	Saprophytic	Non Edible

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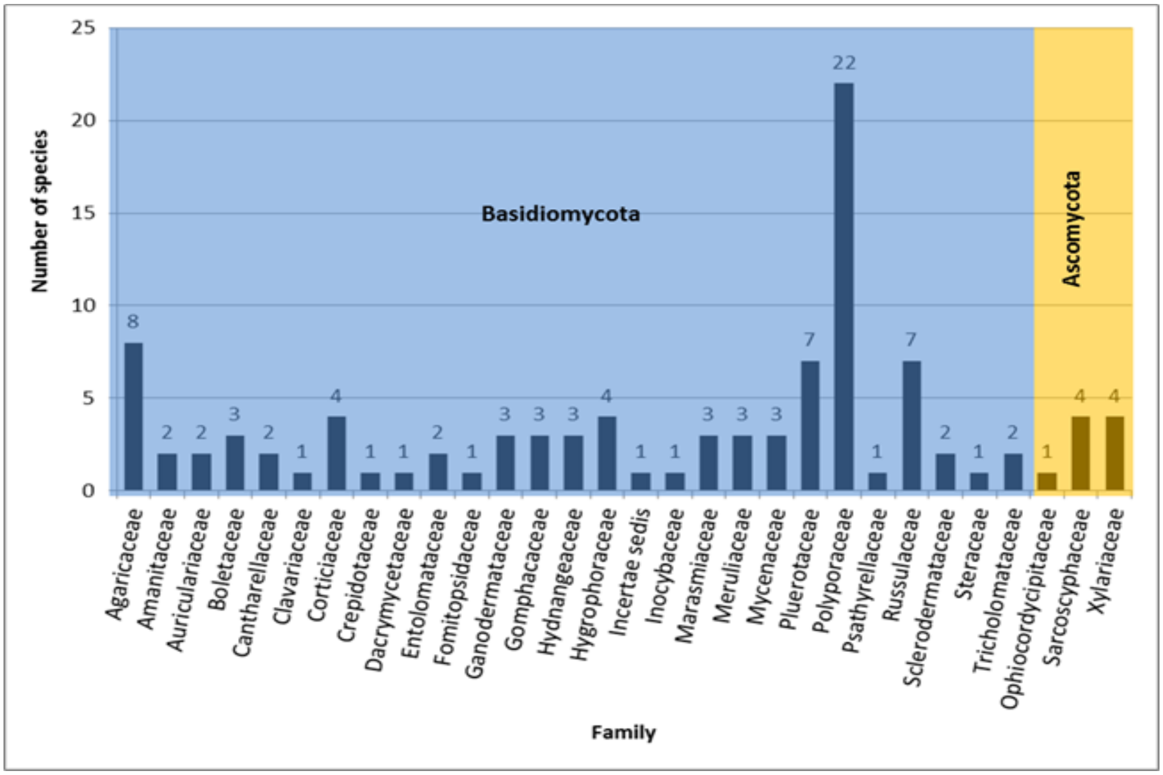

Figure 4. Macrofungi family distribution in Sg. Kangkawat Research Station, ICCA.

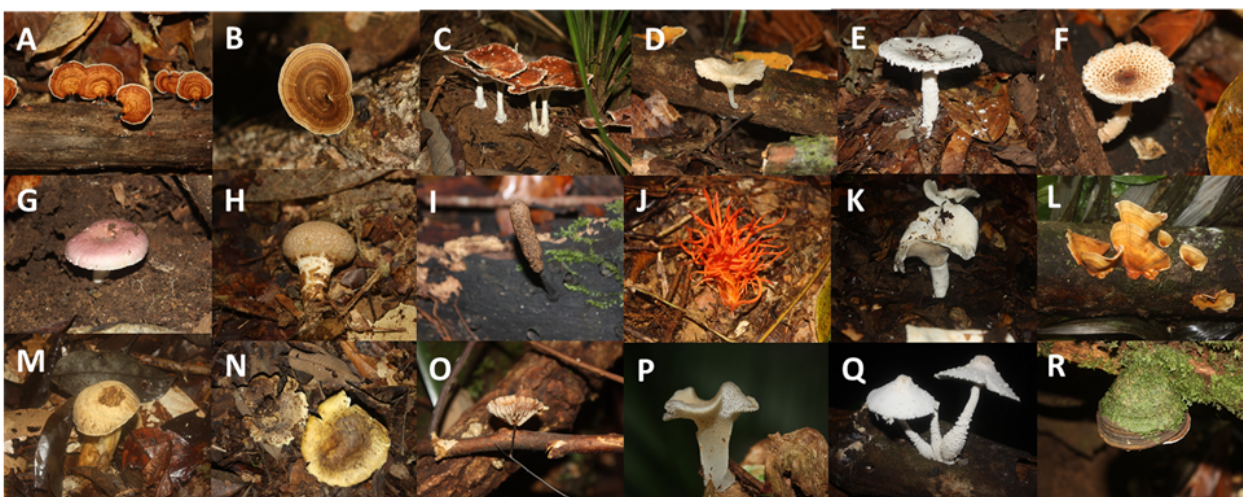

Figure 5. Macrofungi collected during the expedition. A. *Microporus affinis* B. *Microporus xanthopus*. C. *Microporellus* sp. D. *Trogia* sp. E. *Amanita* sp. F. *Lepiota* sp. G. *Russula* sp. H. *Lycoperdon* sp. I. *Xylaria* sp. J. *Clavulinopsis* sp. K. *Hygrocybe* sp. L. *Stereum hirsuta*. M. *Boletus* sp. N. *Sarcosphaera* sp. O. *Marasmius* sp. P. *Pseudohydnum gelatinosum*. Q. *Macrolepiota* sp. R. *Fomitopsis* sp.

In this collection, saprophytic macrofungi had the highest distribution of 62 species (58.49%) that comprised of 28 genera. Polyporaceae was the dominant family, followed by Pleurotaceae and Corticiaceae. Saprophytic fungi sampled included *Fomitopsis* sp., *Trametes* spp., *Ganoderma* sp., *Mycena* spp., and *Favolus* sp.. Soil macrofungi had the next highest distribution, comprising 22 species (20.75%) from 14 genera. The soil macrofungi observed included *Lactarius* sp., *Agaricus* spp., *Sarcoscyphae* spp. and *Inocybe* sp.. Next, ectomycorrhizal fungi comprised 21 species (19.81%) from nine genera, namely *Lycoperdon* spp., *Amanita* spp., *Boletus* sp., *Clavulinopsis* sp., *Ramaria* spp., *Ramariopsis* sp., *Laccaria* spp., *Hygrocybe* spp., and *Russula* spp. Only two parasitic macrofungi were collected, namely *Ophiocordyceps* sp. and *Ganoderma applanatum* (Figure 6). *Filoboletus manipularis,* a bioluminescence mushroom, was also collected in this study.

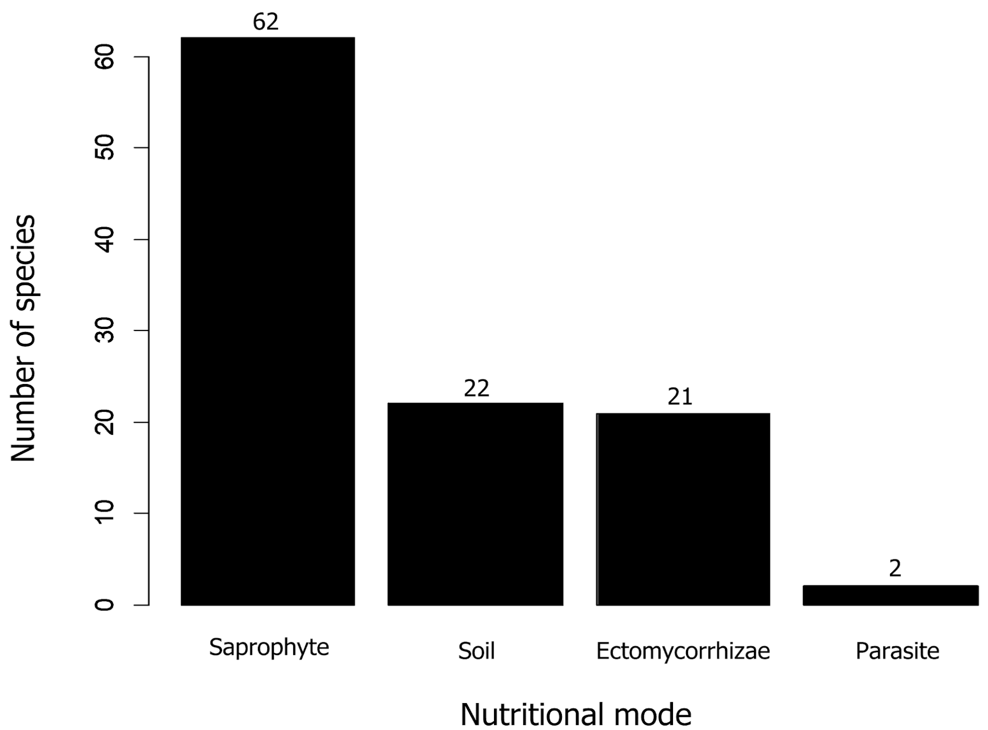

Figure 6. Macrofungi collections based on their nutritional modes

From this expedition, the proportion of edible mushroom samples (12.26%) were higher compared to poisonous mushrooms (1.89%) (Figure 7). The edible mushrooms collected were *Auricularia polytricha, Auricularia delicata, Pleurotus* sp.*, Cookeina sulcipes, Cookeina tricholoma, Panus lecomtei, Lentinus squarrosulus, Hydnum* sp.*, Favolus acervatus, Hygrocybe miniata, Pseudohydnum gelatinosum* and *Cantharellus* sp. (Figure 7, Figure 8 and Table 2). Six species are utilized for their medicinal value, namely *Auricularia polytricha, Auricularia delicata, Lentinus squarrosulus, Trametes versicolor, Amauroderma rugosum and Microporus xanthopus*. (Figure 5, Figure 8 and Table 2). Only two poisonous mushroom specimens were collected, *Amanita* sp. and *Lepiota* sp..

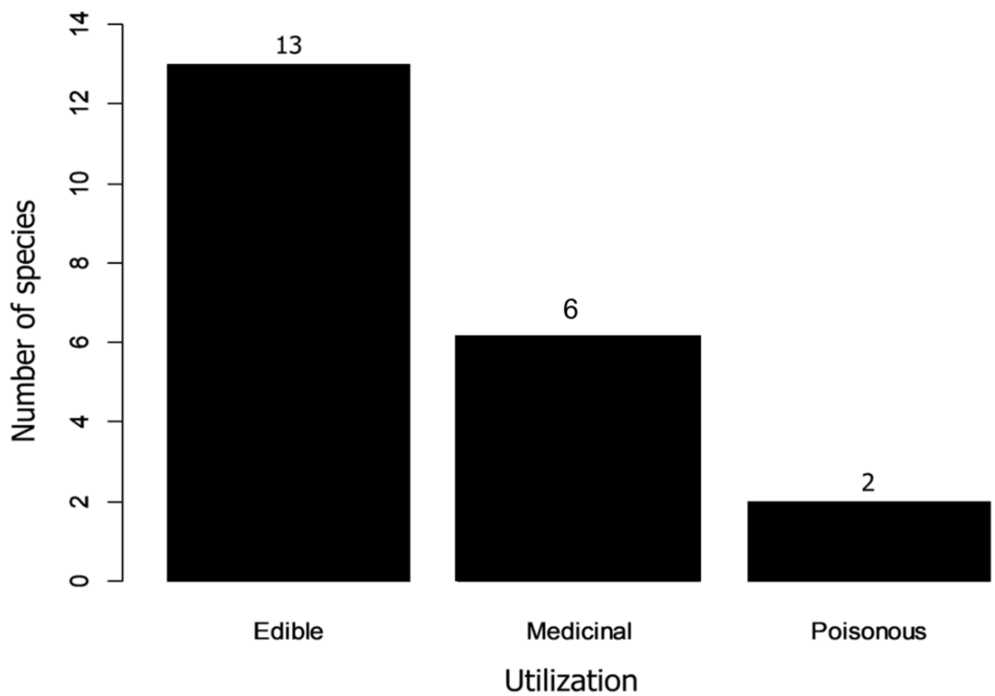

Figure 7. Macrofungi species collected based on their utilization

Table 2. List of wild edible and medicinal mushrooms collected during the expedition.

Family	Scientific name	Local name	Uses
Polyporaceae	*Lentinus squarrosulus*	Kulat susu	Edible & Medicinal (Foo et al., 2018)
	Panus lecomtei	Kulat kari-kari	Edible (Foo et al., 2018)
	Favolus sp.	Honeycomb mushroom	Edible (Grajales-Vasques et al., 2008)
	Trametes versicolor	Turkey Tail mushroom	Medicinal (Chang and Lee, 2004)
	Microporus xanthopus	Cendawan Pengering	Medicinal (Chang and Lee, 2001)
Pleurotaceae	*Pleurotus* sp.	Cendawan Tiram	Edible (Foo et al., 2018)
Auriculariaceae	*Auricularia polythrica*	Korong, Telinga gajah	Edible and Medicinal (Foo et al., 2018)
	Auricularia delicata	Korong, Telinga tikus	Edible and Medicinal (Foo et al., 2018)
Hygrophoraceae	*Hygrocybe miniata*	Kulat Topi	Edible (Foo et al., 2018)

Cantharellaceae	*Cantharellus cerinoalbus*	n.a.	Edible (Eyssartier et al., 2009)
	Cantharellus sp. 2	n.a.	Edible (Eyssartier et al., 2009)
Sarcoscyphaceae	*Cookeina sulcipes*	Cendawan Mangkuk	Edible (Foo et al., 2018)
	Cookeina tricholoma	Cendawan Rambut	Edible (Foo et al., 2018)
Hydnaceae	*Hydnum* sp.	Hedgehog mushroom	Edible (Kuo, 2007)
Incertae sedis	*Pseudohydnum gelatinosum*	Toothed Jelly fungus, Cat's tongue	Edible (Roberts and Evans ,2011)
Ganodermataceae	*Amauroderma rugosum*	Cendawan Budak Sawan	Medicinal (Fung et al., 2017)

n.a: not available

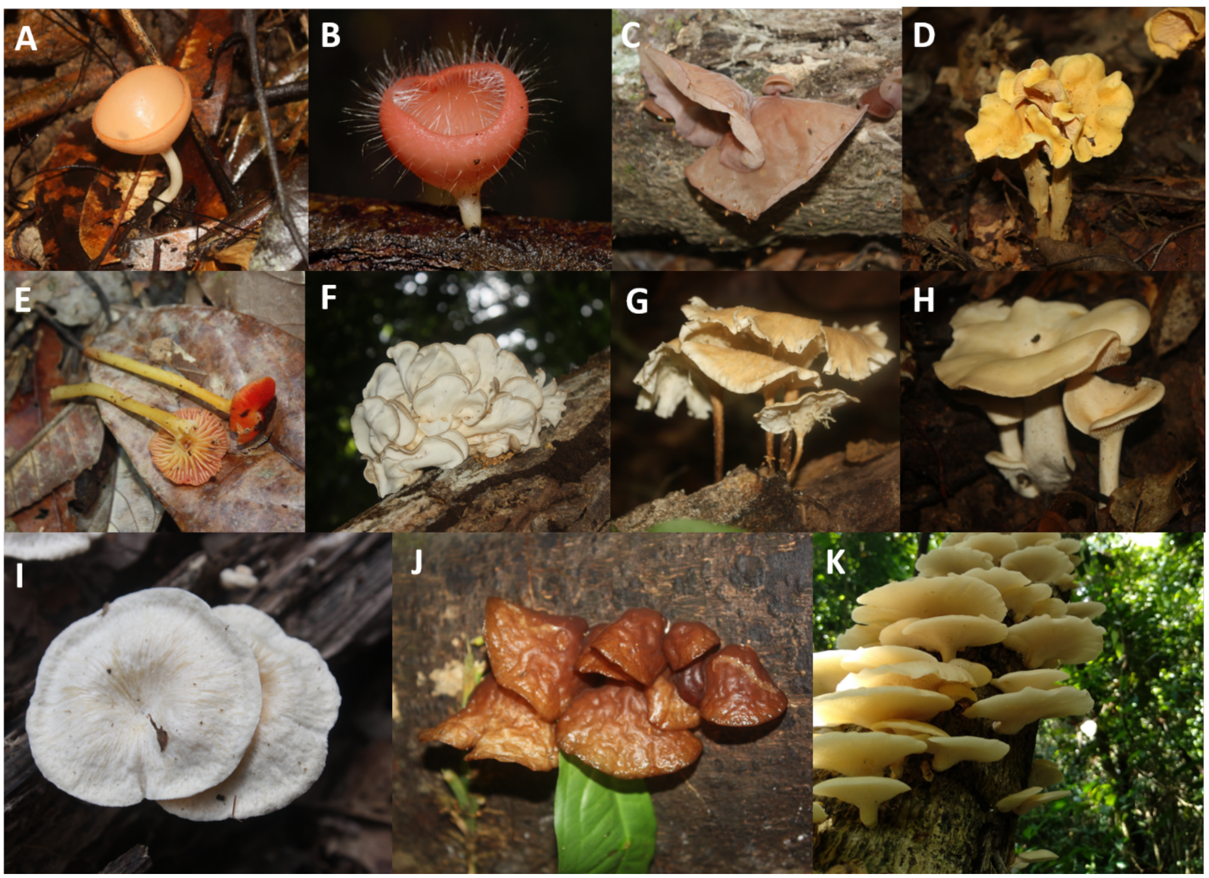

Figure 8. Wild edible mushrooms species found in ICCA. A. *Cookeina sulcipes*. B. *Cookeina tricholoma*. C. *Auricularia polytricha*. D. *Chantarellus* sp. E. *Hygrocybe miniata*. F. *Pleurotus* sp. G. *Pleurotus tuberregium* H. *Hydnum* sp. I. *Lentinus squarrosulus*. J. *Auricularia delicata*. K. *Favolus* sp.

DISCUSSION

A total of 106 macrofungi samples from 30 families was collected at the Sungai Kangkawat Research Station, ICCA. As reported in previous studies, the number of samples collected is considered normal for a ten-day sampling period during the rainy season. Tibuhwa (2011) and Andrew et al. (2013) reported that higher fungi occurrences are obtained during the rainy seasons. This might be due to the adequate moisture content, relative humidity and temperature from the heavy rain that trigger the accumulated mycelium to fruit (Gates et al., 2011). Of the total 106 samples, 104 were identified to the species level. The remaining two unidentified specimens remains so because of cryptic morphology and the lack of information on key morphological traits, especially for tropical macrofungi. These unidentified samples will be subjected for DNA analysis for further identification.

Saprophytic fungi accounted for most of the samples collected (58.49%), and Polyporaceae fungi (21.57%) was the family with the highest distribution. Polyporaceae fungi tend to have a higher distribution when an increased number of plant species as substrates, an increased number substrate types (i.e. branch, log, suspended log, snag, stump, and living-tree) and increased substrate sizes (diameter class) are available (Brazee et al., 2012). Generally, polypores play an important role in the biogeochemical cycles as saprophytes and are relatively common in tropical forest regions (Zhou et al., 2011; Bolhassan et al., 2012). Otherwise, the accumulation of undecayed lignocellulosic wood will have a negative impact on the essential nutrient cycling and forest regeneration that should happen (Sanchez et al., 2009).

The physical and ecological conditions of each trail seemed to affect its fungal distribution and diversity. The South Rim trail, made up mainly of primary highland dipterocarp forest, recorded the highest fungal diversity (40.38%) compared to the other three trails sampled. The tree canopy in the South Rim trail was much better developed, with many shaded regions from the forest canopy. Further, the high fungal diversity recorded in the South Rim trail is likely due to higher humidity levels because of the greater amount of canopy cover. Canopy cover is a factor that leads to increased humidity, which in turn enhances the fungal growth (Santos-Silva et al., 2011). The Kawang trail had the next highest diversity (30.77%). It not only has a similar forest type as the South Rim trail, but it also includes lowland dipterocarp forest. Pelajau Trail had the third highest diversity (16.34%), and it is a disturbed secondary forest with a variety of vegetation types such as highland forest, lowland forest and open areas consisting of grass and small herbaceous trees. The soil consisted of nutrients such as dead wood and dead logs because of the on-going logging activity for the past five years. These factors all contributed to the increased macrofungi growth. The common saprophytic macrofungi recorded in the trail, namely in the genera *Microporus*, *Trametes*, *Ganoderma*, *Fomitopsis*, and also *Marasmius* spp.. The diversity of macrofungi was the lowest (12.5%) in Nepenthes trail likely because Kerangas forest has relatively poor canopy cover leading to dry surroundings.

The weather and environmental conditions of Sungai Kangkawat Research Station was optimal for macrofungal growth. The recorded average temperature during the expedition was 25°C with 86% relative humidity, and the average rainfall during the expedition period was 436 mm per month (World Weather and Climate Information 2019). Among all collected macrofungi, saprophytic macrofungi had the highest distribution (58.49%), followed by soil fungi (20.75%), ectomycorrhizal fungi (19.81%) and parasitic fungi (1.89%). The high variety of fungal taxa obtained from this study is likely due to the high diversity of the forest flora. Besides dipterocarp trees, a variety of palm trees, lianas and epiphytes were clearly visible in the forest of Sungai Kangkawat Research Station, indicating the complexity of forest structure in this area.

There are also a number of large non-dipterocarp trees such as Fagaceae and Chrysobalanaceae in the forest. The high level of plant species diversity in this forest provides increased biomass variety, which in turn enhances the growth of a larger variety of fungal species in the forest (Perring et al. 2015). The various nutritional modes of the macrofungi collected in this study signify their ecological roles. Saprophytic macrofungi and many soil macrofungi act as decomposers which break down dead wood into nutrients and minerals. The main difference between these fungi is that the fruiting bodies of saprophytic fungi can be found on dead wood while the fruiting bodies of soil fungi can be found in or on the soil itself (Ritz, 2005). In this study, one specimen of a bioluminescent mushroom, *Filoboletus manipularis*, was encountered on dead wood substrates along Kawang trail. Bioluminescent mushrooms are visually fascinating in the terrestrial environment. It is a saprophytic basidiomycete fungus is mostly found in tropical forests, which are always associated with hydrated substrates (Deheyn and Latz, 2007). So far, there have been only two species of bioluminescent mushrooms recorded in Sabah, namely *Mycena silvaelucens* from Sandakan (Sepilok) (Desjardin et al., 2010) and *F. manipularis* from Mount Kinabalu (Kundasang) (Lee et al., 2012). Thus, the collection of *F. manipularis* from Kangkawat (Imbak Canyon) is considered to be a new record for this area (lowland dipterocarp forest) since the previous specimens were found in montane forest areas (Kinabalu Park).

Ectomycorrhizal fungi form symbiotic relationships with the surrounding flora. Many of the fungi collected were mutualistic fungi with mycorrhizal association. Mycorrhizal fungi play important roles in plant nutrition, soil biology, and chemistry, all of which affect the growth rate of the trees and plants (Reblova and Svrcek, 1997). Dipterocarp trees have mutual relationships with various ectomycorrhizal fungi, such as the *Boletus*, *Russula*, *Amanita* and *Ramaria* (Dokmai et al., 2015), samples of which were collected during this expedition.

Two parasitic fungi were collected in this study. One was entomopathogenic fungus, Ophiocordyceps sp., while the other was a *Ganoderma* sp. a phytopathogenic fungus. The *Ganoderma applanatum* collected in this study grows living trees as its host and can cause severe diseases attacking stem, butt, and root (Kues et al., 2015). The entomopathogenic fungus, *Ophiocordyceps* sp., is a specialized fungus that has evolved to exploit and kill insects, usually ants (Arouja and Hughes, 2016). This unique fungus invades their host through the hosts' integument and cause death by depletion of host metabolites, production of toxic products or by-products, destruction of vital tissues or a combination of all three (Hanel et al., 1981; Rath, 2000). The transmission of this entomopathogen is dependent on a number of processes which are conidia production, discharge, dispersal, survival and germination (Scholte et al., 2004). *Ophiocordyceps* can be easily identified by its clavate asci with gradually thickening apices and elongate, fusiform ascospores that do not disarticulate into part-spores (Sanjuan et al., 2015).

Thirteen species (12.26%) of wild edible mushroom were identified in this study, and all of them are consumed by the indigenous community in Sabah. The identification of the edible mushrooms by indigenous communities was mainly based on their experience and traditional knowledge (Foo et al., 2018). *Pleurotus* is one of the most widely consumed and cultivated in the world (Rosmiza et al., 2016). Indigenous communities from Malaysia and Mexico consume *Cookeina sulcipes* as a food source (Sánchez et al., 1995; Abdullah and Rusea, 2009, Lee et al., 2009). *Cantharellus* sp. is a popular cuisine in Europe but little is known on its edibility in Malaysia (Chang and Lee, 2004; Eyssartier et al., 2009). However, Lee et al. (2006) reported that *Cantharellus* species resembles fungi in the subgenus *Afrocantharellus*, and they are consumed and appreciated by several communities of local tribes in Peninsular Malaysia.

Indigenous communities believe that fungi in the genus *Auricularia* (jelly fungi) has the ability to heal sickness (Foo et al., 2018). This was supported by previous research that stated *A. polytricha* and *A. delicata* provide medicinal properties (Abdullah and Rusea, 2009; Foo et al., 2018). *Auricularia polytricha* was reported to have antioxidant, antimicrobial properties and stimulate fibrinolytic activities (Sabaratnam et al., 2014; Avcı et al., 2016). *Lentinus squarrosulus* is an edible mushroom with medicinal properties, and it is served as food mainly in Africa and Asia (Lau and Abdullah, 2017). In Peninsular Malaysia, the *Microporus xanthopus* is traditionally used by the indigenous community to wean off breastfeeding (Chang and Lee, 2004). *Amauroderma rugosum* is used by indigenous people in Peninsular Malaysia as a type of medicine to prevent fits and incessant crying in babies by wearing it as a necklace (Chan et al., 2013). In some countries like Japan, Korea, China and Russia, *Trametes versicolor*, or commonly known as turkey-tail mushroom, is used as a remedy against cancer or are sold as a polysaccharide anticancer drug with the brand name PSK (Krestin) (Zjawiony, 2003). There are no ethnomycological records available for *M. xanthopus*, *A. rugosum* and *T. versicolor*, in Sabah. The genus *Amanita* may exist as either edible or deadly poisonous species. Local practices and knowledge is one of the most useful sources of information to differentiate the edible and non-edible mushrooms (Boa, 2004).

Pseudohydnum gelatinosum, an enigmatic toothed jelly fungus, is a rare mushroom species that was collected in this study. It is also known as a false hedgehog mushroom, cat's tongue and white jelly mushroom (Roberts and Evans, 2011). *Pseudohydnum gelatinosum* is a jelly-like basidiomycete with translucent and gelatinous flesh. It is a saprophytic mushroom that grows on dead wood or woody debris. Like other jelly fungi, this fungus is considered to be an edible mushroom (Roberts and Evans, 2011; Stoyneva-Gartner et al., 2017). In Bulgaria, this fungus is reported to be consumed as a kind of comfort food in its fresh state, included as supplement to green salads, and is locally known as Pig's ears (in Bulgarian – Svinski ushi) (Stoyneva-Gartner et al., 2017). The species was recorded in Sarawak for the first time on rotten trees in a riparian forest (Chin, 1981, 1988; Lee et al., 2012). However, this is another new record for Sabah. Perhaps it can contribute to the information on mushroom edibility and can be utilized as a food source in the future.

There were limitations to the methodology applied in this study. Primarily, it was impossible to select sites with identical surroundings with identical tree diversity and canopy cover due to the specific selection of ready-made trails. Also, the nutrient availability in the different soil types likely would not have been identical between the different sites. Furthermore, because opportunistic sampling was conducted, and only fungi along the trail paths were collected, the collection of specimens may not provide a fully representative distribution of the macrofungal diversity of the Sungai Kangkawat Research Station. While this method of sampling is warranted for regular surveys, especially for the collection of preliminary or checklist data, plot sampling between various sites or over time generally provides a more accurate representation of fungal diversity and distribution of any specific taxon (O'Dell et al., 2004).

Nonetheless, the collected data remains vital to mycological studies in Borneo as it supplements any existing checklist of macrofungal diversity for Sabah and Malaysia. Also, this study provides baseline information for future studies and surveys conducted on fungi in ICCA in the near future. Future studies on macrofungi in ICCA should focus on plot sampling rather than opportunistic sampling. Although this would require more resources and time, it would reduce collector bias by standardizing the sampling area, and it would allow for the proper quantification of the results. The data accumulated from plot sampling will allow for better comparison between sites or suitable to compare the same sites between seasons. Also, this would provide more information on what proportion of macrofungi in ICCA are edible or poisonous.

CONCLUSION

A total of 106 macrofungi specimens was collected in this study, which accounted for 104 species in 36 genera, 30 families, and 2 phyla, Basidiomycota and Ascomycota. Of these samples, there were 62 saprophytic species, 22 soil fungi, 21 ectomycorrhizal species, 13 edible wild mushrooms, six medicinal mushrooms, two poisonous mushroom species, two parasitic fungi and one bioluminescent mushroom species. The South Rim trail recorded the most diverse collection of fungi, followed is an exigent need for more morphological and molecular taxonomic studies on macrofungi in this region that would provide a more accurate identification and characterization references, especially for Sabah. Publications regarding the medicinal and chemical properties of the macrofungi in Sabah are still very much lacking. We hope that the findings of this study will contribute to the Borneensis-Agaricomycetes project especially to accurately identify species and better taxonomic, phylogenetic and evolutionary relationship information for all macrofungi encountered in Sabah.

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