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**Short Communications**

# Basidiomycota Macrofungal Communities Across Four Altitudinal Ranges in Bukit Baka Bukit Raya National Park, Indonesia

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**ABSTRACT**
The influence of elevation gradient has been investigated across different taxa. However, such studies are scarce for macrofungal communities. This study examined the community structure of Basidiomycota macrofungi across four elevations in Bukit Baka Bukit Raya National Park, Indonesia. Macrofungi were collected from randomly placed five 10 x 10 m plots at each altitude and identified at the genus level. The results showed that there were 32 genera belonging to 20 families. The NMDS ordination and ANOSIM confirmed that macrofungal composition and abundance do not differ between the studied altitudinal ranges.



Ecological and evolutionary responses to elevational gradients have been investigated across different biota around the globe. Such studies are useful for understanding the responses of biota toward changes in environmental conditions along elevational gradients, particularly temperature, atmospheric pressure, and clear-sky turbidity (Korner 2007). However, there is little published data on patterns in macrofungal communities along elevational gradients. Published works on this subject include Mt. Korbu (Malaysia), central Veracruz (Mexico), the Moldavian Plateau, Sub-Carpathians Hills, and the Eastern part of Eastern Carpathians (Romania) (Gómez-Hernández et al. 2012; Copot & Tanase 2019; Nur 'Aqilah et al. 2020). These studies suggest that macrofungal communities differ depending on elevation, and environmental factors along elevational gradients, such as vegetation structure and temperature, may be attributed to the ecological responses of macrofungal communities. However, these previous works employed different approaches and were conducted in different vegetation types and elevation ranges. For example, Nur 'Aqilah et al. (2020) investigated macrofungal communities in Mt. Korbu, Malaysia, using convenience sampling along different trails up to 1,000 masl with dipterocarp forests as the dominant vegetation type. The other two published data used plot-based sampling to study the influence of elevation on macrofungal communities. Convenience sampling may lead to collector bias and has no standardization of sampling efforts, while plot-based sampling provides standardization of sampling efforts

(O'Dell et al. 2004).

This study used quantitative data on macrofungi from four elevational ranges of Bukit Baka Bukit Raya National Park, Indonesia, to investigate macrofungal communities along four elevational gradients. We are particularly interested in confirming elevation's effects on macrofungal communities in the area having similar vegetation types to a study by Nur 'Aqilah et al. (2020) using plot-based sampling. We use Basidiomycota as a model system because it is a major phylum of Fungi with more than 40,000 fungal species (He et al. 2022), and contains several well-known macrofungal species (Tang et al. 2015). Macrofungi produce visible structures (fruiting bodies) and have parasitic, saprophytic, or symbiotic lifestyles. Macrofungi play essential roles in the ecosystem as food sources and decomposers for faunas (Tang et al. 2015).

This study was conducted in the tropical rainforest of Bukit Baka Bukit Raya National Park (Figure 1). The national park lies between 112°12' and 112°56' east longitude and 0°28' and 0°56' south latitude and consists of four ecosystems dominated by lowland and highland Dipterocarps and mossy forests at high altitudes. The elevation of the national park ranges from 150 to 2,278 m above sea level (masl) and has a type A climate with an average air temperature of 18°C and rainfall exceeding 60 mm (Abduh et al. 2018).

The macrofungal community was examined at four sites with different altitudes: 250, 500, 750, and 1000 meters above sea level (asl). We did not locate any sampling sites at higher altitudes due to high slopes and safety reasons. Five 10 x 10 m plots were randomly established at each site, with a minimum distance between plots of 10 m. Plot sizes and spacing between plots follow (Gómez-Hernández et al. 2012). Macrofungi found in each plot were collected and then identified in the field at the

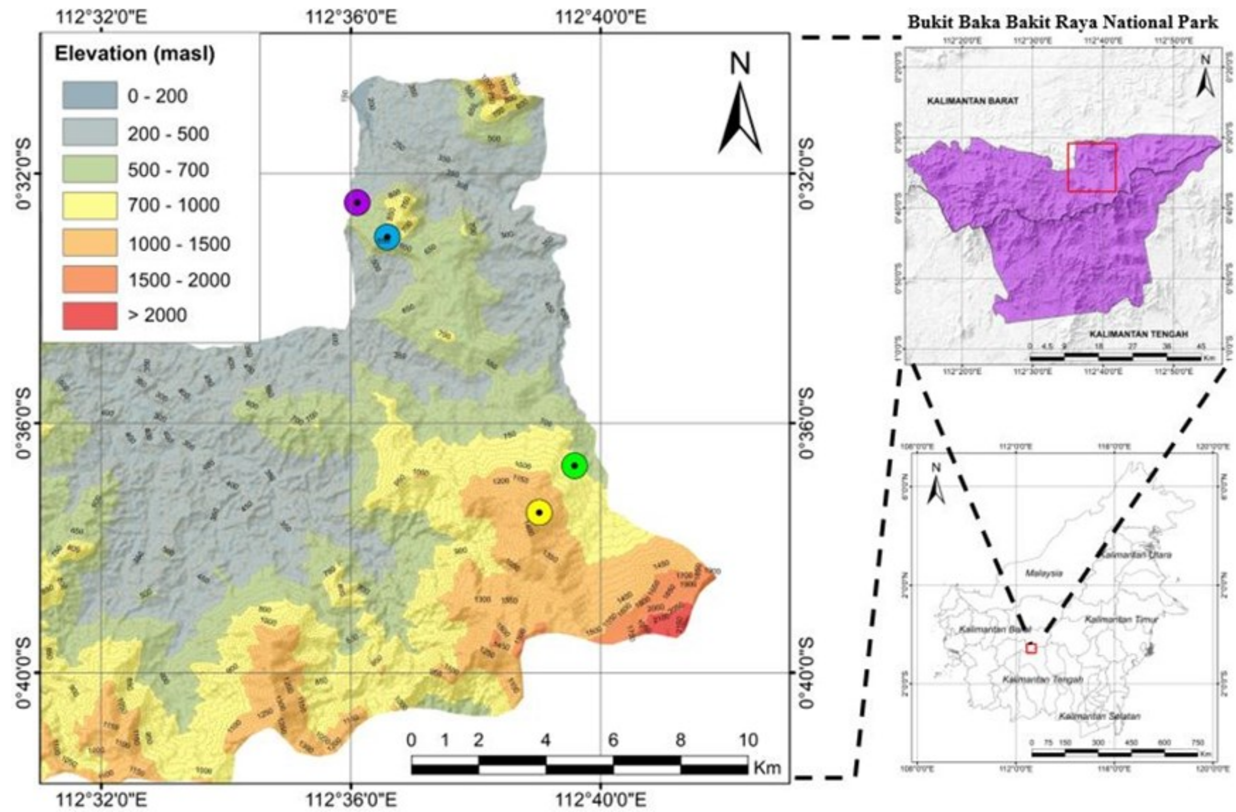


**Figure 1.** Sampling sites in the study area within Bukit Baka Bukit Raya National Park, Indonesia. Colored dots on the large map represent sampling sites at four altitudinal ranges ( 250 masl, 500 masl, 750 masl, and 1000 m).

genus level (if possible). Any unidentified samples were photographed, preserved, and transported to the Laboratory of Ecology, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Tanjungpura, for further identification. Macrofungal identification was based on macroscopic characteristics, such as cap shape, cap margin, gills, stalks, and ring, using existing literature, such as Tjiu et al. (2022) and McKnight &McKnight (1987). Macrofungal nomenclature follows the Index Fungorum (http://www.indexfungorum.org/names/Names.asp).

For each elevation, we also calculated the Shannon-Wiener index (H'), Evenness index (E'), and Simpson index (D'). We used Non-metric Multidimensional Scaling (NMDS) analysis and Analysis of Similarities (ANOSIM) to examine macrofungal compositional and abundance differences. NMDS ordination was chosen because it is suitable for ecological datasets which contain a mixture of continuous metrics with varying degrees of homogeneity and normality (Walker et al. 2011), and graphically demonstrates the relationships among communities based on a distance matrix (Clarke 1993). We used ANOSIM because it is a formal hypothesis test to confirm whether the differences seen among communities in the NMDS plot were significant or not (Laaker 2018). ANOSIM is similar to one-factor analysis of variance, but it uses the Bray-Curtis dissimilarity to provide a test statistic (Clarke 1993).

Jaccard and Bray-Curtis matrices were used in the NMDS analyses for compositional and abundance data, respectively. The flexibility of dissimilarity matrices used in this study reflects one of advantages of NMDS ordination to meet a specific goal of the research. The use of Jaccard matrix, for example, is intended to analyze compositional data by transforming abundance input into binary data. However, the NMDS ordination also has disadvantages, such as failing to reach the best solution with low stress values and slow computation due to large datasets (McCune et al. 2002). In this research, the NMDS computation succeeded in reaching the best solution at low stress values (<0.2) for both compositional and abundance data (see Figure 3 & 4). The NMDS analysis and ANOSIM were done using the vegan package in R (Oksanen et al. 2022), and NMDS results were visualized using the ggplot2 package in R (Wickham 2016). Before the analysis, any rare genera (less than 1% of total macrofungal abundance) were excluded.

A total of 2344 individual macrofungi were encountered across four altitudes. All sampled macrofungi comprise 32 genera belonging to 20 families (Table 1). *Marasmius* was the most abundant macrofungal genus across four altitudes, and its highest abundance was documented at 750 masl (1.042 individual fungi/m$^2$). This finding can be attributed to the fact that *Marasmius* has a wide distribution in temperate and tropical areas, including tropical mountain forests (Singer 1976). Moreover, Polyporaceae is the largest family reported in this study. It contains eight genera, namely *Amauroderma*, *Favolus*, *Fomes*, *Ganoderma*, *Microporellus*, *Microporus*, *Polyporus* and *Trametes* (Table 1). Two out of the eight genera (i.e. *Ganoderma* and *Microporus*) had a high abundance level and were found at four different elevations. The taxonomic status of Polyporaceae as one of major families in Basidiomycota may explain this finding (Cui et al. 2019).

There are eight major genera based on abundance across four altitudinal ranges. These genera are *Campanella*, *Exidia*, *Ganoderma*¸ *Gymnopus*, *Hemimycena*, *Marasmius*, *Microporus* and *Mycena*. Figure 2 shows the eight largest macrofungal genera found at different elevations in the Bukit Baka Raya National Park.

In this research, some genera were reportedly only observed at re-

**Table 1**. Diversity and abundance of macrofungal taxa (no of individuals per square meter) found at four altitudes in Bukit Baka Bukit Raya, Kalimantan Barat, Indonesia. The top eight genera, printed in bold, are included in the NMDS ordination.

| Taxa | Abundance (individual fungi/m²) at four elevations (masl) | | | |
|---|---|---|---|---|
| | 250 | 500 | 750 | 1000 |
| Agaricaceae | | | | |
| *Agaricus* | 0.024 | 0 | 0 | 0 |
| *Leucocoprinus* | 0 | 0 | 0 | 0.002 |
| Amanitaceae | | | | |
| *Amanita* | 0 | 0.018 | 0 | 0 |
| Auriculariaceae | | | | |
| ***Exidia*** | 0 | 0 | 0 | 0.128 |
| Boletaceae | | | | |
| *Boletus* | 0 | 0 | 0.002 | 0 |
| Clavariaceae | | | | |
| *Clavaria* | 0 | 0.004 | 0 | 0 |
| Cortinariaceae | | | | |
| *Cortinarius* | 0 | 0.002 | 0 | 0 |
| Entolomataceae | | | | |
| *Leptonia* | 0 | 0.006 | 0 | 0 |
| Hydnaceae | | | | |
| *Clavulina* | 0 | 0 | 0.006 | 0 |
| *Craterellus* | 0.024 | 0 | 0 | 0 |
| Hyemenochaetaceae | | | | |
| *Phellinus* | 0 | 0 | 0 | 0.016 |
| Hygrophoraceae | | | | |
| *Hygrocybe* | 0 | 0.006 | 0 | 0 |
| Irpicaceae | | | | |
| *Byssomerulius* | 0 | 0 | 0.012 | 0 |
| Marasiaceae | | | | |
| ***Campanella*** | 0 | 0 | 0.050 | 0 |
| ***Marasmius*** | 0.460 | 0.932 | 1.042 | 0.716 |
| Mycenaceae | | | | |
| ***Hemimycena*** | 0 | 0.120 | 0 | 0 |
| ***Mycena*** | 0.094 | 0.034 | 0.016 | 0.008 |
| Omphalotaceae | | | | |
| ***Gymnopus*** | 0.026 | 0.096 | 0 | 0 |
| Panaceae | | | | |
| *Cymatoderma* | 0 | 0 | 0.032 | 0.012 |
| Phanerochaetaceae | | | | |
| *Inflastostereum* | 0 | 0 | 0.004 | 0 |
| Physalacriaceae | | | | |
| *Flammulina* | 0.032 | 0 | 0 | 0 |
| Polyporaceae | | | | |
| *Amauroderma* | 0.008 | 0.002 | 0.014 | 0 |
| *Favolus* | 0 | 0 | 0 | 0.018 |
| *Fomes* | 0 | 0.016 | 0.008 | 0 |
| ***Ganoderma*** | 0.030 | 0.020 | 0.082 | 0.124 |
| *Microporellus* | 0.012 | 0 | 0 | 0.004 |
| ***Microporus*** | 0.088 | 0.070 | 0.068 | 0.122 |
| *Polyporus* | 0 | 0.022 | 0.008 | 0 |
| *Trametes* | 0.008 | 0 | 0.010 | 0 |
| Russulaceae | | | | |
| *Lactarius* | 0.002 | 0 | 0 | 0 |
| *Russula* | 0 | 0.002 | 0 | 0 |
| Stereaceae | | | | |
| *Stereum* | 0 | 0 | 0 | 0.026 |


**Figure 2**. Eight major genera of macrofungi found in the study area within the montane tropical rainforest of Bukit Baka Bukit Raya National Park, Indonesia (A. *Campanella*, B. *Exidia*, C. *Ganoderma*, D. *Gymnopus*, E. *Hemimycena*, F. *Marasmius*, G. *Microporus*, H. *Mycenae*).

stricted altitudes. For example, *Agaricus*, *Craterellus*, and *Lactarius* were exclusive to 250 masl, while *Amanita*, *Clavaria*, *Cortinarius*, and *Leptonia* only occurred at 500 masl. Higher altitudes demonstrate a similar pattern. *Boletus*, *Byssomerulius*, *Clavulina, and Inflatostereum* only occur at 750 masl; *Exidia*, *Favolus*, and *Leucocoprinus* were only observed at 1000 masl (Table 1). Similar patterns were also demonstrated in a study by Nur 'Aqilah et al. (2020) on Mount Korbu, Malaysia. They reported that *Cymatoderma* and *Stereum* occur at 800 and 1030 masl, respectively. These patterns reflect different macrofungal growth requirements linked to altitudinal ranges, such as relative humidity, soil temperature, soil moisture, light intensity, slope, and litter depth (Gómez-Hernández et al. 2012).

Macrofungal diversity varied between elevations. This study demonstrated that the highest species richness was recorded at 500 masl (15 genera), and the lowest was observed at 750 masl (Table 2). The Shannon-Wiener (H') and Evenness Indices have the same pattern. The highest Shannon-Wiener Index was documented at 250 masl (1.55), and the lowest was observed at 750 masl (1.02). Surprisingly, the Shannon-Wiener Index increased to 1000 masl (1.33). (Table 2). This observed pattern is consistent with a study by Ping et al. (2017), which shows soil fungal diversity decreases at 699-937masl but increases at 937-1044 masl in the Pine Forest, Changbai Mountain, Korea.

To evaluate differences in macrofungal communities along studied elevational gradients, we used the Non-metric Multidimensional scaling (NMDS) technique and Analysis of Similarities (ANOSIM). Based on the NMDS plot, the composition of macrofungal genera does not differ among four altitudinal ranges. There is no clear distinction among macrofungal communities at four altitudes as shown by overlapping col-

**Table 2.** Genera richness, Shannon-Wiener Index (H'), Evenness (E), and Simpson Index (D) at different elevations in Bukit Baka Bukit Raya National Park, West Kalimantan.

| Elevation (m asl) | Genera richness | Index | | |
|---|---|---|---|---|
| | | H | E | D |
| 250 | 12 | 1,55 | 0,62 | 0,36 |
| 500 | 15 | 1,24 | 0,46 | 0,49 |
| 750 | 14 | 1,02 | 0,39 | 0,60 |
| 1000 | 11 | 1,33 | 0,56 | 0,41 |

ored dots in NMDS plot (Figure 3). The result of ANOSIM confirmed the pattern shown in NMDS ordination (*p*-value = 0.19, ANOSIM R = 0.06). This phenomenon has never been recorded for macrofungi. Research by Nur 'Aqilah et al. (2020) displayed contradicting patterns; macrofungal composition differed depending on altitudinal ranges. Nur 'Aqilah et al. (2020) investigated macrofungal composition along elevational ranges from 350 to 1040 masl. Using NMDS ordination, they detected changes in macrofungal composition along elevational gradients. The contradicting results may be due to differences in sampling methods. In this study, we employed plot-based sampling across four altitudinal ranges from 250 to 1000 masl, while Nur 'Aqilah et al. (2020) collected macrofungal samples along three trails at the elevation ranging from 350 to 1040 masl during a four-day expedition.

The abundance of macrofungal genera displays the same pattern as the compositional data. Overlapping macrofungal communities at each altitude were observed on NMDS plot (Figure 4), suggesting macrofungal abundance at each altitude was similar. ANOSIM analysis confirmed such pattern; there were no significant differences in macrofungal abundance among different elevations (*p*-value = 0.17 ANOSIM R = 0.06). Some abundance data, particularly at the elevation below 1000 masl from the present study, are consistent with Gómez-Hernández et al. (2012).

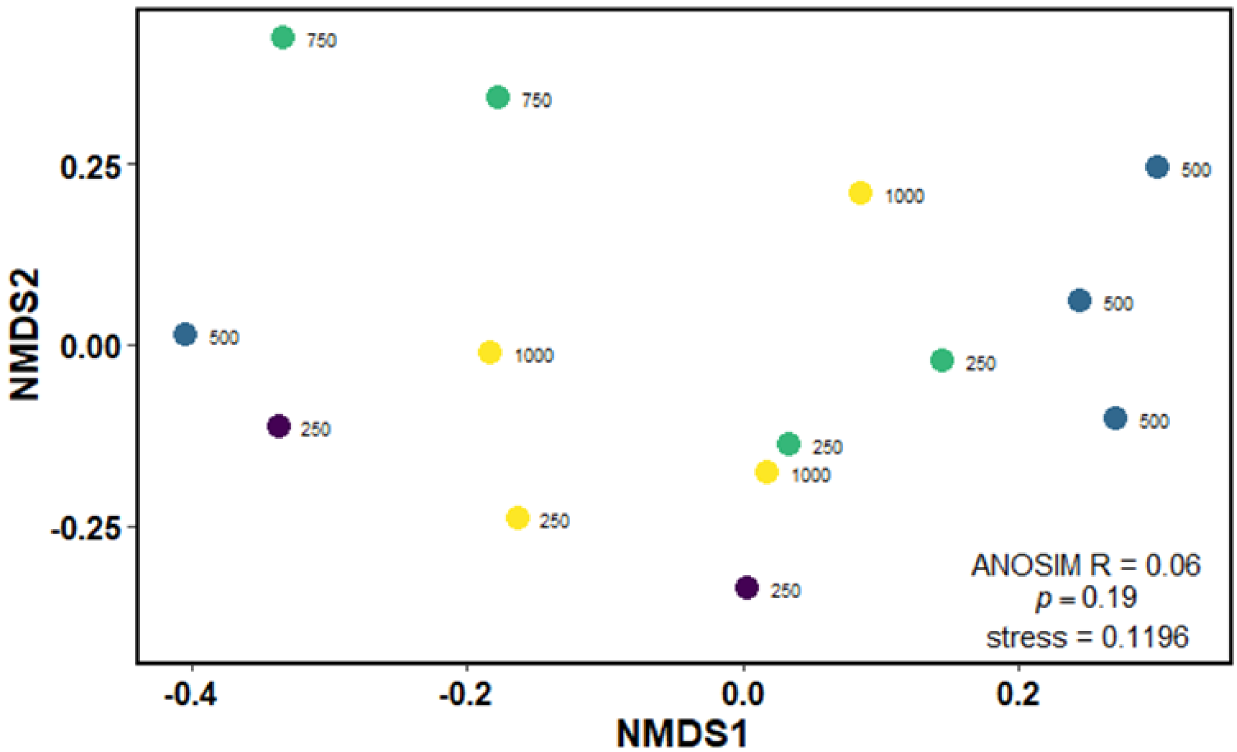


**Figure 3.** Non-metric multidimensional scaling (NMDS) ordination of macrofungal composition at four altitudinal ranges in the montane tropical rainforest of Bukit Baka Bukit Raya National Park, Indonesia. Colored dots indicate four altitudinal ranges, i.e. 250 masl, 500 masl, 750 masl, dan 1000 masl.

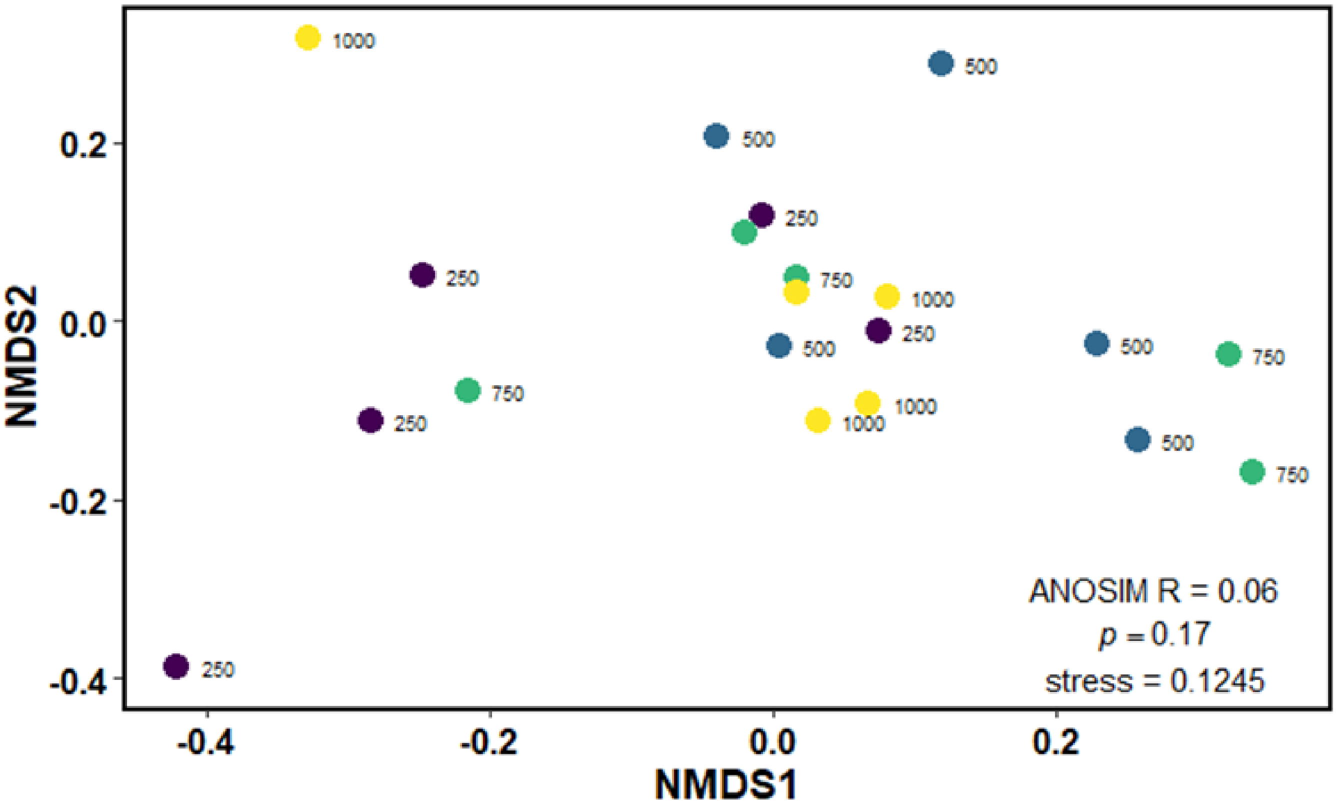


**Figure 4.** Non-metric multidimensional scaling (NMDS) ordination of macrofungal abundance at four altitudinal ranges in the montane tropical rainforest of Bukit Baka Bukit Raya National Park, Indonesia. Colored dots indicate four altitudinal ranges, i.e. ● 250 masl, ● 500 masl, ● 750 masl dan ● 1000 masl.

Their study demonstrated no clear grouping of macrofungal abundance between 100 and 500 masl using canonical correspondence analysis (CCA). However, abundance data on 1,000 masl in this study differed from Gómez-Hernández et al. (2012). This research found no significant differences in macrofungal abundance along four elevational gradients based on ANOSIM. On the contrary, Gómez-Hernández et al. (2012) suggest that macrofungal abundance differed between the altitudes below 1,000 and 1,000 masl. This contradictory pattern is probably due to differences in vegetation. Gómez-Hernández et al. (2012) conducted their study in various forest types along elevational gradients, i.e., seasonally dry tropical forest, tropical montane cloud forest, and conifer forest. In contrast, this research was conducted in a montane tropical rainforest dominated by dipterocarp forests (Abduh et al. 2018).

Our study clearly shows that elevation has no effects on macrofungal composition and abundance at low (below 1,000 masl) and mid altitudes (1,000 masl) of Bukit Baka Bukit Raya National Park, Indonesia. Our research in a mountainous area of Borneo tropical rainforests confirms that the diversity of macrofungi varied across altitudinal ranges based on diversity index. Further research is required to explain the causes of no elevation effects on macrofungal communities at low and mid altitudes.

## AUTHOR CONTRIBUTION

N.A.H. collected and analyzed data and wrote the manuscript, I.L. designed the research, analyzed data, supervised all the processes and wrote the manuscript, R.R. supervised macrofungal identification and wrote the manuscript, D.J. collected data

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## CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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