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Research Article

Ant Community Structure in Secondary Logged Forest of Malua Forest Reserve, Sabah, Borneo

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Abstract

Ants are ecologically dominant and important in the functioning of an ecosystem. Thus, understanding their community structure has become fundamental in ecological studies. This study aims to examine the ant richness, abundance, and composition in the secondary logged forests of Sabah, Malaysia. Ground-based fogging was employed to collect canopy ants (n=38) and Winkler extraction method for leaf litter ants (n=63). A total of 12,810 ant individuals were collected, representing 389 morphospecies, 65 genera, and 11 subfamilies. The most species-rich subfamily for canopy and leaf litter ants were Formicinae (112 morphospecies, 49.34%) and Myrmicinae (116 morphospecies, 58.00%) respectively. *Polyrhachis* (56 morphospecies, 24.67%) was the most diverse genera in the canopy, while *Pheidole* (23 morphospecies, 11.50%) was the most speciose genera on the leaf litter. The most abundant species for canopy and leaf litter ants were *Dolichoderus 1* (876 individuals) and *Carebara 2* (1,215 individuals) respectively. The randomized species accumulation curves and species richness estimators reveal that additional sampling is required. We suggest that incorporating a variety of ant sampling methods and high sampling efforts are important to thoroughly sample the ant assemblage in an area.

Keywords: Formicidae, Borneo, secondary logged forest, species estimators, accumulation curve

Introduction

Logged forests are often assumed to be degraded and fragmented lands that support limited taxonomic groups (Bihn et al., 2010). Their conservation value is neglected and subsequently make them extremely vulnerable to non-forest land-use conversion (Edwards et al., 2011; Edwards et al., 2014b). For instance, constant pressure from conservationists to restrict the conversion of primary forests into agricultural lands, and changes in policy to increase agricultural profitability, have caused governments as well as plantation agencies to shift their focus to logged degraded forests (Wilcove et al., 2010).

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However, growing literature suggests that ecologists have overestimated the damage of logging to biodiversity (Ramage et al., 2012) and logged forests can have astonishing value. Logged forests are able to retain a majority of their ecological functions such as hydrological processes, carbon sequestration, thermal buffering, and climate-regulation services (Putz et al., 2012; Edwards et al., 2014a; Senior et al., 2018), provided that the logging intensity is low (i.e., less than $10m^3 ha^{-1}$, Burivalova et al., 2014); while supporting certain taxonomic groups which are vulnerable to plantation or barren land (Putz et al., 2012; Edwards et al., 2014a, b; Granados et al., 2016). For example, Edward et al. (2011) have reported that at least 75% of the dung beetle and bird species that persisted in the primary forest were also found within the twice logged tropical forests of Sabah, Borneo.

Ants are one of the ecologically diverse and ubiquitous groups among arthropods (Hölldobler & Wilson, 1990). They mediate not only a wide range of ecosystem functions (e.g., nutrient cycling, nutrient redistribution, soil turnover, and seed dispersal; Folgarait, 1998; Fayle et al., 2011), but also take part in many ecological interactions, including mutualism, predation and competition (Rico-Gray & Oliveira, 2007). Furthermore, they are known to be very responsive to their surrounding environmental changes, even at very small spatial scales (Tieda et al., 2017). Collectively, these make ants an ideal surrogate for arthropod taxa to study community structures in both degraded and natural habitats.

The ant fauna in Borneo is highly diverse (Pfeiffer et al., 2011). It is estimated at least 1,100 to 1,500 ant species exist in Borneo, with 1,000 species having been described, represented by 100 genera and 12 subfamilies (Pfeiffer et al., 2011; Fayle et al., 2014). Due to their ecological significance and contribution to community dynamics, a better understanding of ant community structure in logged forests of Borneo would greatly enhance our knowledge of the organization and dynamics of tropical ant communities in a disturbed area.

Here, we aim to investigate and reveal the ant community structure, specifically on species richness, ant abundance, and composition of canopy and leaf litter ants in Malua Forest Reserve (MFR), a little-known, remote secondary logged forest in Sabah, Borneo. Several past studies have been conducted to examine the ant communities in MFR. For example, in the study of the impact of climber-cutting silvicultural on arthropod groups, Dzulkifli (2014) reported that ants constituted the largest biomass in his samples. Using the Winkler method alone, Woodcock et al. (2011) recorded 196 species of leaf litter ants and found no difference in terms of species richness between unlogged and logged forests in the Ulu-Segama Malua region. We believe this study will benefit future studies by providing additional information on ant communities in MFR to the existing literature, and subsequently adding conservation value to the forest as well as contributing to future conservation planning and management.

Materials and Methods

Study site

The study was conducted between June and September 2019 at Malua Forest Reserve (MFR, between E 116˚ 28’- E 118˚ 14’ and between N 4˚ 14’ - N 5˚ 18’), located at the South-eastern part of Sabah, Borneo (Figure 1). MFR was first gazetted in 1961 and was re-gazetted in 1984 as a Commercial Class II Forest Reserve. However, in 2006, the Sabah State Government grouped several neighbouring forests, including MFR as part of the Ulu-Segama Sustainable Forest Management Area. It is now managed by Yayasan Sabah and Sabah Forestry Department (Ulu-Segama Malua SFMP, 2020).

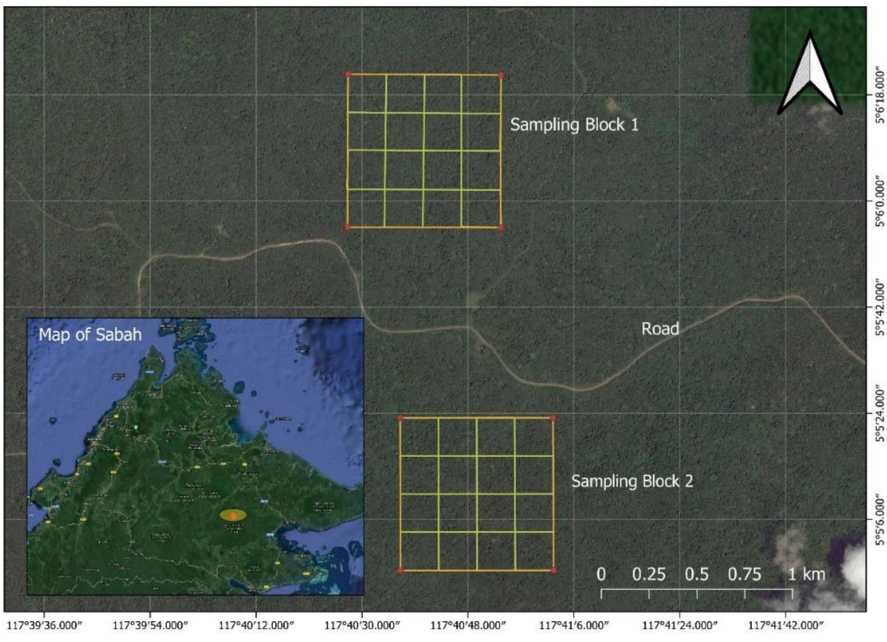

Figure 1. Map of the location of study site at Malua Forest Reserve, Sabah. The two square grids (in yellow) indicate the sampling blocks, each comprise 16 small grids or sampling plots. (Map made in QGIS 3.16)

MFR has a flat topography with elevation ranging from below 100m a.s.l. to around 800m a.s.l. and many of its vegetation types is lowland mixed dipterocarp forest. The forest is dominated by valuable timber species mainly from the family Dipterocarpaceae (Ulu-Segama Malua SFMP, 2020). MFR is a selectively logged forest that has undergone logging rotation twice (i.e., between 1987 and 1991, between 2001 and 2007).

Sampling design and sampling methods

A total of two sampling blocks were created, each sized 800m x 800m within MFR. Each of the sampling blocks was divided into 16 small plots at 200m x 200m each (Figure 1). Of the 32 plots, 13 were selected to sample leaf litter ants, while 19 were chosen to collect canopy ants. The ground-based insecticide fogging method was employed to sample canopy ants while the Winkler extraction method (Bestelmeyer et al, 2000) for leaf litter ants.

Canopy ant sampling

Each small plot comprised of two replicates (n=38, 19 plots x 2 replicates) and each replicate contained four sets of funnel-shaped collection trays (Figure 2), each with a radius of 1.2m^2, that was hoisted using ropes tied on the tree trunks. A bottle that contains 70% ethanol was placed at the centre of each collection tray to collect fallen arthropods. We followed Adis et al. (1999) protocol where fogging was performed before 06:00 for four minutes, using Thermal Fogging Machine (IGEBA TF-35) with fog mixture of cypermethrin-based insecticide and diesel (ratio 15:1). After the fogging, the collection trays were left for two hours. The fallen insects in the collection trays were brushed into the bottles using a flat decorator’s brush (Floren et al., 2014).

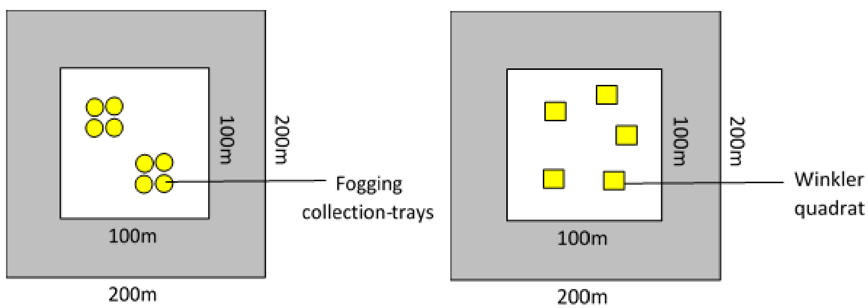

Figure 2. Diagram illustrates an example of sampling plots and the allocation of replicates for (left) canopy ant sampling and (right) leaf litter ant sampling.

Leaf litter ant sampling

A total of five 1m x 1m quadrats were placed in each plot located in the sampling blocks (n=63, 13 plots x 5 replicates; Figure 2). Leaf litter ants were sampled before ground-based fogging, using the Winkler Extraction method (Bestelmeyer et al., 2000). This was to prevent the insecticide fog from killing the litter ants, which would potentially affect the results. The leaf litter and twigs within the quadrat were collected manually and put into the Winkler sifter. The sifter was shaken thoroughly for about four minutes. Next, the contents of the sifter were transferred to a mesh inlet sack and suspended in the Winkler sack. A 50ml container that was half-filled with 70% ethanol was affixed to the metal ring located at the bottom part of the Winkler sack. Winkler sacks were then hung out to dry for three days.

Ant sorting, identification, and preservation

Sorted ant samples were counted and identified to morphospecies following Fayle et al. (2014). The major workers, queens, and male ants were excluded from this study to minimize the error caused by vagrants; Andersen, 1995), while the worker ants (which are normally found; Andersen, 1995) were then identified to morphospecies or species, depending on the availability and certainty of the ant species classification information. Labelled specimens were stored in 1.5ml filled with 70% ethanol.

Data analyses

Basic analyses using ant abundance and richness were carried out in Microsoft Excel to describe the patterns of ant samples in MFR. The relative species richness for each genera and subfamily of canopy and leaf litter ants were calculated using the formula listed below:

$$Relative\ species\ richness\ of\ genus\ A\ (\%) = \frac{Number\ of\ morphospecies\ present\ in\ genus\ A}{Total\ number\ of\ morphospecies\ from\ all\ genera} \times 100\%$$

$$Relative\ species\ richness\ of\ subfamily\ A\ (\%) = \frac{Number\ of\ morphospecies\ present\ in\ subfamily\ A}{Total\ number\ of\ morphospecies\ collected\ from\ all\ subfamiles} \times 100\%$$

The sampling effort was assessed using the rarefaction and extrapolation curve (Hill's number of q=0), with 1,000 randomization of species accumulation curves and 95% unconditional confidence intervals, based on the incidence data matrix (Colwell & Coddington, 1994). The reference sample sizes were doubled when extrapolating the curves (Chao et al., 2014).

The incidence-based estimator (Chao2) and first-order Jackknife estimator (Jackknife1) were used to estimate the sampling completeness of this study (Colwell et al., 2004; Gotelli & Colwell, 2011). Both Chao2 and Jackknife1 species estimators have been widely used to correct or reduce the bias found in the number of observed species in a sample (e.g., rare, and undiscovered species; Gwinn et al., 2016). Chao2 operates by deriving a lower bound of undiscovered species richness with reference to the number of singletons and doubletons (Chao, 1984), while Jackknife1 uses the presence and absence of unique species in a sample to predict the undetected species (Smith & van Belle, 1984). Software EstimateS version 9.1.0 (Colwell, 2013) was employed to compute the rarefaction and extrapolation curve as well as to calculate Chao2 and Jackknife1.

Results

We identified a total of 12,810 ant individuals in MFR using the Ground-based Fogging and Winkler Extraction Method. They are represented by 389 morphospecies, 65 genera, and 11 subfamilies (Table 1). Canopy ants recorded were 5,104 individuals (227 morphospecies and 39 genera, Table 2) while leaf litter ants were documented to be 7,706 individuals (200 species, 49 genera, Table 3).

Table 1: The total number of individuals, morphospecies, genera, and subfamily of canopy and leaf litter ants collected in MFR.

	Canopy Ants	Leaf Litter Ants	Total
Individuals	5104	7706	12,810
Morphospecies	227	200	389
Genera	39	49	65
Subfamily	5	10	11

Table 2: Summary of total morphospecies and abundance of canopy ants obtained for each genus in MFR.

Subfamily	Genus	Total Morphospecies	Total Abundance
Dolichoderinae	*Dolichoderus*	10	1324
	Tapinoma	2	6
	Technomyrmex	8	212
Formicidae	*Anoplolepis*	1	1
	Camponotus	35	769
	Cladomyrma	1	2
	Dinomyrmex	1	4

	Echinopla	4	9
	Myrmoteras	1	1
	Nylanderia	5	47
	Paratrechina	1	1
	Paraparatrechina	5	34
	Polyrhachis	56	394
	Prenolepis	1	12
	Pseudolasius	1	6
Myrmicinae	*Acanthomyrmex*	1	1
	Cardiocondyla	4	14
	Carebara	6	150
	Cataulacus	1	5
	Crematogaster	23	1544
	Dilobocondyla	1	5
	Lophomyrmex	1	1
	Meranoplus	2	19
	Monomorium	4	33
	Myrmicaria	3	64
	Paratopula	1	2
	Pheidole	8	245
	Rhopalomastix	2	3
	Solenopsis	1	3
	Strumigenys	5	11
	Tetramorium	11	55
	Vollenhovia	5	30
	Vombisidris	6	25
Ponerinae	*Diacamma*	2	43
	Hypoponera	2	6
	Leptogenys	1	1
	Odontomachus	1	1
	Platythyrea	1	2
Pseudomyrmicinae	*Tetraponera*	3	19
TOTAL		**227**	**5104**

Table 3. Summary of total morphospecies and abundance of leaf litter ants obtained for each genus in MFR.

Subfamily	Genus	Total morphospecies	Total abundance
Aenictinae	*Aenictus*	3	27
Amblyoponinae	*Prionopelta*	1	51
Cerapachinae	*Cerapachys*	4	22
Dolichoderinae	*Loweriella*	1	3
	Tapinoma	2	5
	Technomyrmex	3	17
Dorylinae	*Dorylus*	1	1
Ectatomminae	*Gnamptogenys*	2	2
Formicinae	*Camponotus*	1	1

	Echinopla	1	1
	Euprenolepis	1	1
	Nylanderia	6	398
	Paratrechina	1	2
	Polyrhachis	5	18
	Pseudolasius	4	189
Myrmicinae	*Acanthomyrmex*	1	1
	Aphaenogaster	2	2
	Calyptomyrmex	3	13
	Cardiocondyla	1	3
	Carebara	12	2281
	Crematogaster	6	50
	Dacetinops	1	2
	Eurhopalothrix	3	43
	Lophomyrmex	4	1306
	Mayriella	1	2
	Monomorium	5	41
	Myrmecina	1	1
	Myrmoteras	1	27
	Pheidole	23	1381
	Pristomyrmex	1	2
	Proatta	1	26
	Pyramica	1	1
	Recurvidris	5	71
	Solenopsis	3	181
	Strumigenys	17	543
	Tetramorium	21	328
	Vollenhovia	2	4
	Vombisidris	1	2
Ponerinae	*Anochetus*	6	36
	Centromyrmex	1	2
	Crytopone	1	4
	Emeryopone	1	1
	Hypoponera	18	368
	Leptogenys	3	6
	Odontomachus	1	2
	Odontoponera	1	2
	Pachycondyla	5	113
	Ponera	8	113
Proceratiinae	*Discothyrea*	3	10
TOTAL		**200**	**7706**

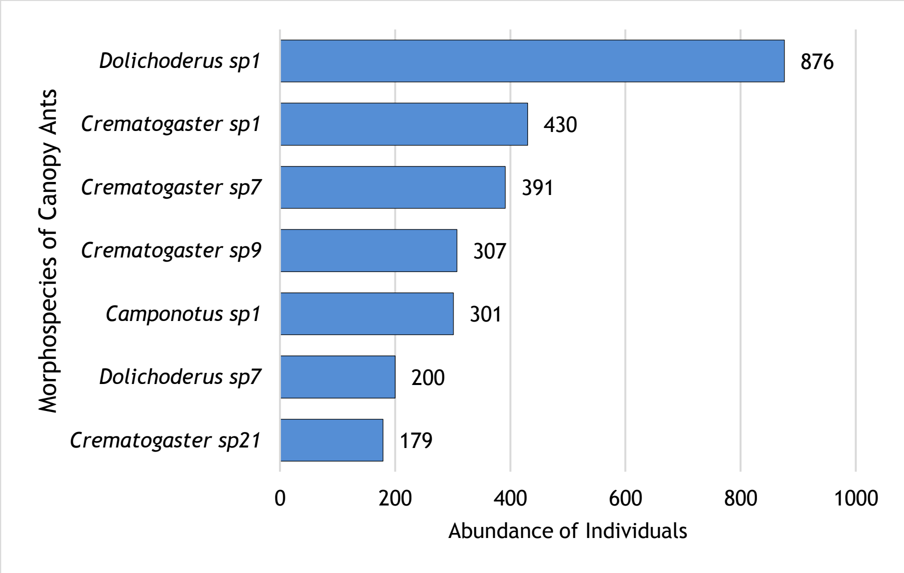

Figure 3 Top seven most abundant morphospecies of canopy ants arranged in descending order.

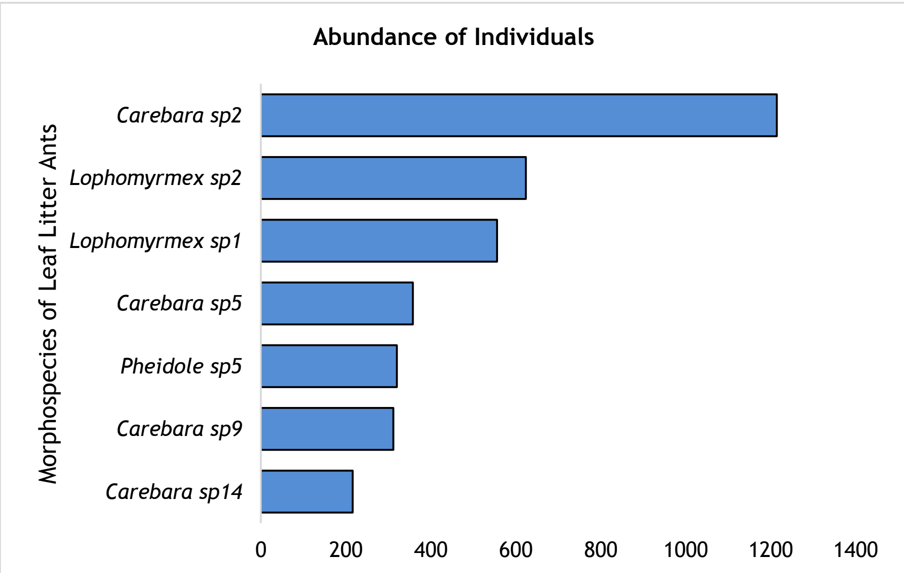

Figure 4. Top seven most abundant morphospecies of leaf litter ants arranged in descending order.

Genus *Polyrhachis* (56 morphospecies, 24.67%) was the most speciose genus for canopy sampling (Table 2), while *Pheidole* (23 morphospecies, 11.50%) was the most diverse in leaf litter sampling (Table 3). *Dolichoderus* sp1 (876 individuals, Figure 5) was the most abundant ant species in the canopy; *Carebara* sp2 (1,215 individuals) was most abundant in leaf litter (Figure 6). Lastly, the most species-rich subfamily for canopy and leaf litter ants were Formicinae (112 morphospecies, 49.34%) and Myrmicinae (116 morphospecies, 58.00%) respectively (Table 4).

Table 4. Number of species and relative species-abundance found in each subfamily for canopy and leaf litter ants.

Subfamily	Number of Species Represented by Canopy Ants (%)	Number of Species Represented by Leaf Litter Ants (%)
Formicinae	112 (49.34)	19 (9.50)
Myrmicinae	85 (37.44)	116 (58.00)
Ponerinae	7 (3.08)	45 (22.50)
Dolichoderinae	20 (8.81)	6 (3.00)
Pseudomyrmicinae	3 (1.32)	0 (0.00)
Cerapachinae	0 (0.00)	4 (2.00)
Proceratiinae	0 (0.00)	3 (1.50)
Aenictinae	0 (0.00)	3 (1.50)
Ectatomminae	0 (0.00)	2 (1.00)
Dorylinae	0 (0.00)	1 (0.50)
Amblyoponinae	0 (0.00)	1 (0.50)
TOTAL	**227 (100)**	**200 (100)**

Species richness estimators of Chao2 and Jackknife1 predicted that 68.17% to 68.79% of canopy ant species in MFR were collected, while 72.20% to 73.80% for leaf litter ant species (Table 5). The randomized accumulation curves and the species estimators reveal that additional sampling is required to attain a higher percentage value in the sampling completeness of ant richness in MFR. Of the 227 species of canopy ants recorded, 61 species (26.87%) were singletons, and 106 species (46.70%) were unique. On the other hand, leaf litter ants (i.e., a total of 200 species) recorded 41 (20.50%) singletons and 78 (39.00%) uniques.

Table 5. Estimated species richness calculated by Chao2 and Jackknife1 estimators. The observed species richness (S_{obs}) for both canopy and leaf litter ants were divided with each richness estimator to obtain the percentage of sampling completeness.

	S_{obs}	Chao2 ± SD	%	Jackknife1 ± SD	%
Canopy ants	227	333 ± 27	68.17	330 ± 14	68.79
Leaf litter ants	200	271 ± 21	73.80	277 ± 21	72.20

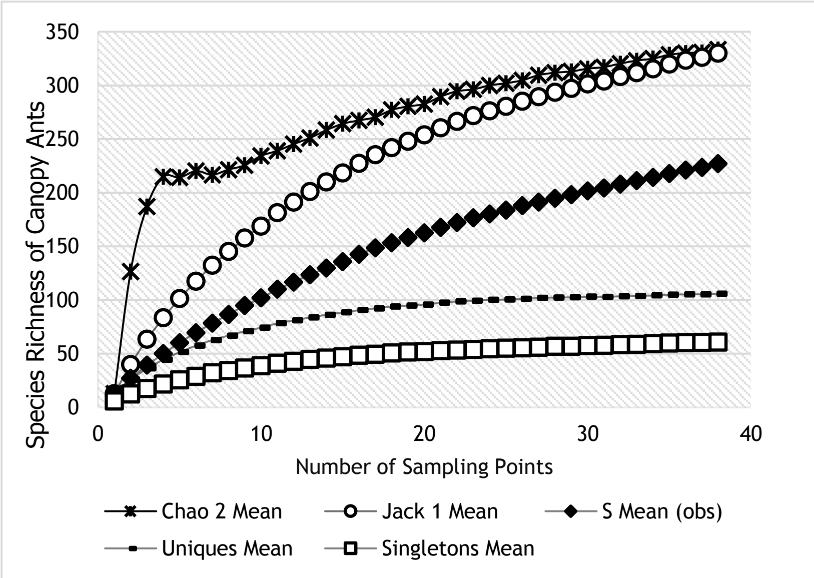

Figure 5: Randomized accumulation curves for canopy ant species richness collected (n=38) in Malua Forest Reserve. Curves are given for randomized observed species richness (S Mean), species richness estimators (Chao2 and Jackknife1), and separately for singletons and uniques.

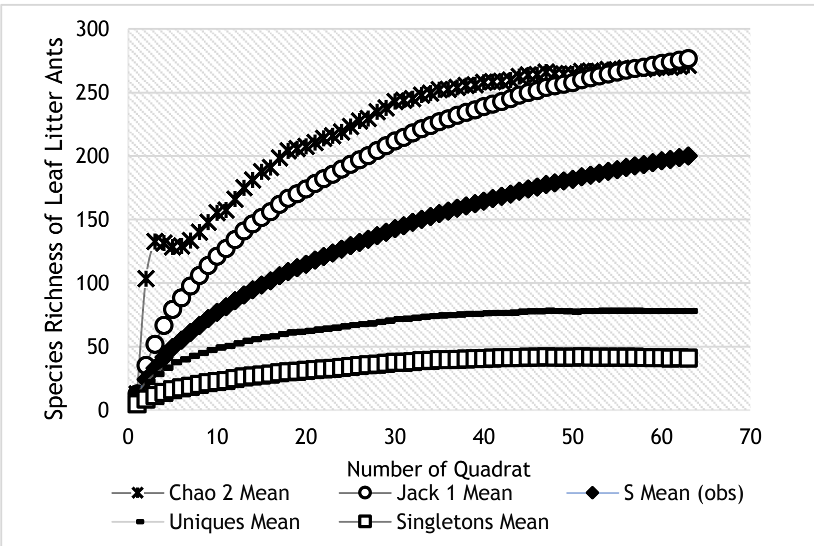

Figure 6. Randomized accumulation curves for leaf litter ant species richness collected (n=63) in Malua Forest Reserve. Curves are given for randomized observed species richness (S Mean), species richness estimators (Chao2 and Jackknife1), and separately for singletons and uniques.

Discussion

Borneo ant fauna comprises 12 subfamilies with a minimum of 97 genera (Pfeiffer et al., 2011). In this study, a total of 11 ant subfamilies were recorded, except the family Leptanillinae that was represented by 65 genera. Two thirds of the species collected were in subfamily Myrmicinae and Formicinae for both canopy and leaf litter ants. This is consistent with previous studies done in Borneo, where approximately 70% of the ant species collected belonged to these subfamilies (Sukimin et al., 2010; Yusah et al., 2012; Pfeiffer et al. 2011; Klimes et al., 2015). With about 6,500 described species in the world, Myrmicinae is the most diverse and largest subfamily of ants; followed by Formicinae, the second largest, comprising nearly 3,030 described species (Boudinot, 2015). Not surprisingly, two groups of subfamilies were dominant in this study.

Moreover, we found that *Polyrhachis* was the most genera-rich genus for canopy ants in this study and this is supported by Yusah et al. (2012) and Klimes et al. (2015), where they also found similar results in the tropical forests of Borneo. On the contrary, *Pheidole* was the most speciose genera for leaf litter ants. Not only ecologically dominant, Economo et al. (2014) also noted that the genus is one of the most hyper-diverse species of all the ants in the world and can be found in most of the tropical biomes.

Randomized accumulation curves and species estimators indicate that the sampling completeness of both canopy and leaf litter ants are far from complete. Houadria and Menzel (2021) also detected similar pattern in the subterranean ants of MFR. Although sampling completeness of ant communities can be improved by extensive sampling efforts and incorporating multiple sampling methods (Agosti et al., 2000; King & Porter, 2005), Pfeiffer et al. (2011) argued that in the tropics, many ant species are rare with cryptic behaviour. Thus, it is usual that the accumulation curves of tropical ants do not reach 85% (e.g., Floren & Linsenmair, 2000; Pfeiffer & Mezger, 2012).

By using Winkler extraction and ground-based fogging, our study offers an overview of the pattern of assemblage structure of canopy and leaf litter ants in MFR. We believe this study will form a foundation for future research on ant diversity and abundance, particularly in the secondary forest of Sabah, Borneo. Finally, to thoroughly sample ant assemblage in an area, higher sampling efforts combined with multiple sampling methods are recommended for future ant research.

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