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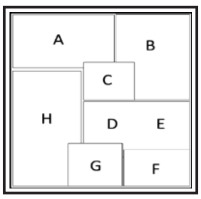

A: *Schizophyllum commune*; **B**: *Ramaria* sp.; **C**: *Filoboletus manipularis*; **D**: *Cookeina sulcipes*; **E**: *Cookeina tricholoma*; **F**: *Trametes versicolor*; **G**: *Russula* sp.; **H**: *Cantharellus* sp.

Front cover: Fungi diversity in Rainforest Discovery Centre, Sepilok. (Photos: Viviannye Paul & Clara Isah)

A preliminary checklist and notes on macrofungi from the Rainforest Discovery Centre, Sandakan, Sabah

V. Paul[1]*, P.L. Tang[2], C.I.A. Jocelyn[3], M. Ajik[1], A.Y.C. Chung[1] & N. Midin[1]

[1]*Forest Research Centre, Sabah Forestry Department, P.O. Box 1407, 90715 Sandakan, Sabah, Malaysia*
[2]*Molecular Mycology and Pathology Laboratory, Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, 84000 Jalan UMS, Kota Kinabalu, Sabah, Malaysia*
[3]*Faculty of Science and Natural Resources Complex of Science & Technology, Universiti Malaysia Sabah, 84000 Jalan UMS, Kota Kinabalu, Sabah, Malaysia*
**Author for correspondence. E-mail: Viviannye.Paul@sabah.gov.my*

Abstract. A survey on macrofungi occurring in the Rainforest Discovery Centre (RDC), Sandakan, Sabah was carried out to establish baseline data on fungal richness in the area. Surveys were conducted between 22nd May and 20th July 2018, covering a total distance of 6.7 km. Macrofungi sighted were photographed and samples were collected to serve as voucher specimens. A total of 138 specimens comprising 10 orders, 24 families and 43 genera were recorded. The order Polyporaceae was the most numerically abundant, making up almost half (47.1%) of the specimens collected. Most of the fungi sighted were on woody debris on the forest floor. Several noteworthy fungi including the bioluminescent, *Filoboletus manipularis*, the veiled *Phallus multicolor*, and the chalice-like *Cookeina* spp. were documented.

Keywords: Fungi, Rainforest Discovery Centre, Sepilok-Kabili Forest Reserve

INTRODUCTION

Fungi are not animals, nor plants. Unlike animals and plants, their cell walls are made up of chitin. Fungi cannot produce their own food, hence, they feed on dead organic matter for nutrients (saprophytic). Ascomycota and Basidiomycota are the two main classes in the fungi kingdom. Ascomycota cannot be seen with the naked eye, except for the cup fungi. Most fungi under the class Basidiomycota can be consumed, such as from the genus *Auricularia*, *Pleurotus* and *Volvariell*a (Dewi *et al*. 2019). The bolete, puffball, gilled, coral, toothed, bracket, and jelly fungi are some examples of the basidiomycetes. Each type of these fungi has its own characteristic and appearance and are useful in the identification of fungi (Branco 2011). Fungi play an important role in forest ecosystems in which they serve as the main decomposer of dead organic matter, such as dead trees, woods and leaves (Hyde *et al*. 1998). They are the food sources for certain animals, insects and even humans (Zainuddin *et al*. 2010).

RDC was chosen as the study site since it is one of the foremost environmental education centres in Sabah and is located adjacent to the Kabili Sepilok Forest Reserve, an accessible natural rainforest. Over the years, RDC has also become a popular birding and tourism site. It attracts nature photographers including those who are keen to capture close-up photographs of interesting fungi. Hence, a baseline study of the fungi diversity in RDC was carried out and the data collected were used to generate a checklist of fungi.

MATERIALS & METHODS

Study area

This study was conducted in the Rainforest Discovery Centre (RDC), located within the Taman Botanikal Sepilok Forest Reserve area (Figure 1). RDC is one of the most popular Environmental Education (EE) centres in Sabah, and its main aim is to raise awareness on the importance of forest and forest conservation through its environmental education programmes. Being classified as Class VI Virgin Forest Reserves, the Taman Botanikal Sepilok Forest Reserve area covers about 106.70 ha and acts as a shelter or home to the wildlife in that area. Sampling was conducted along nine trails in RDC (Figure 2), namely Lakeside Trail (790 m), Belian Trail (820 m), Kingfisher Trail (543 m), Woodpecker Avenue (223 m), Ridge Trail (620 m), Tarsier Crossing (700 m), Mousedeer Crossing (481 m), Sepilok Giant Pass (670 m) and Pitta Path (1.9 km).

Field surveys and collection of fungi

The fieldwork was conducted from 22nd May to 20th July 2018, covering a total distance of 6.7 km. Opportunistic sampling method was used wherein the team walked through the area and collected conspicuous specimens of fungi when sighted. The macroscopic fungi were identified in the field and photographed from the top and bottom (camera: DSLR Nikon D3200). Information on the latitude, longitude and altitude of the fungi was also recorded using the GPS (Model: Garmin GPSMAP 64S).

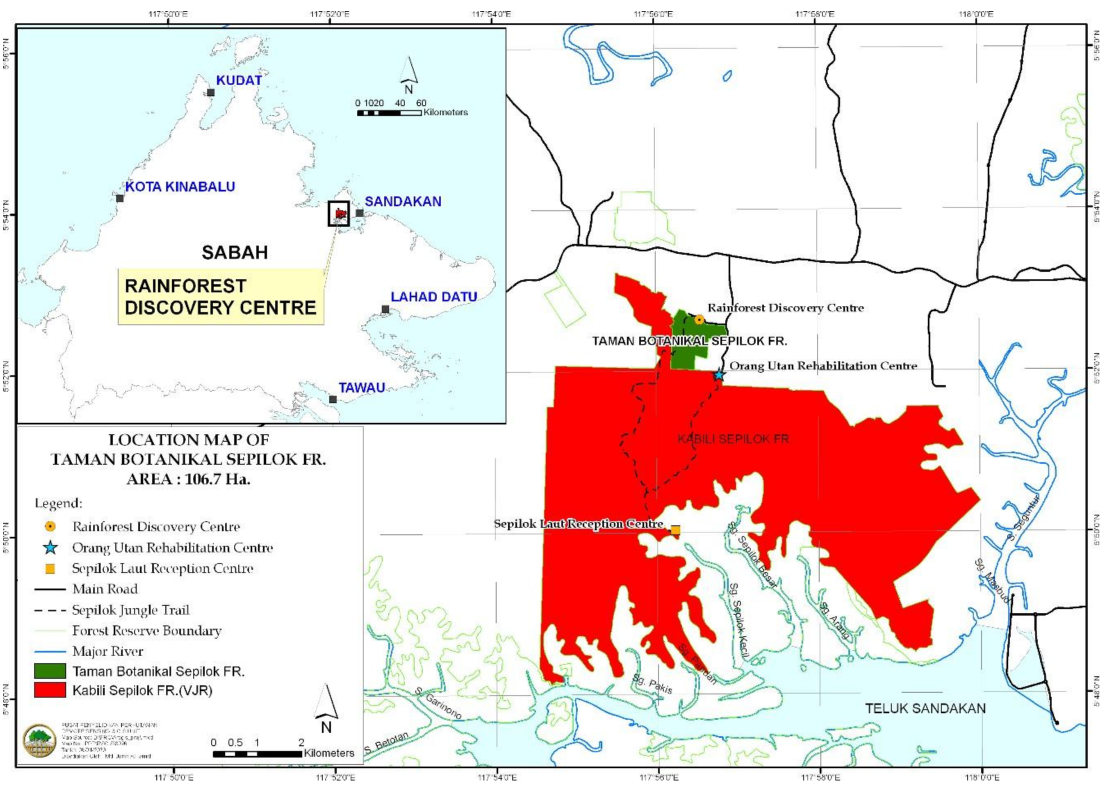

Figure 1. The RDC within Taman Botanikal Sepilok FR (dark green) and its location (inset) in Sabah.

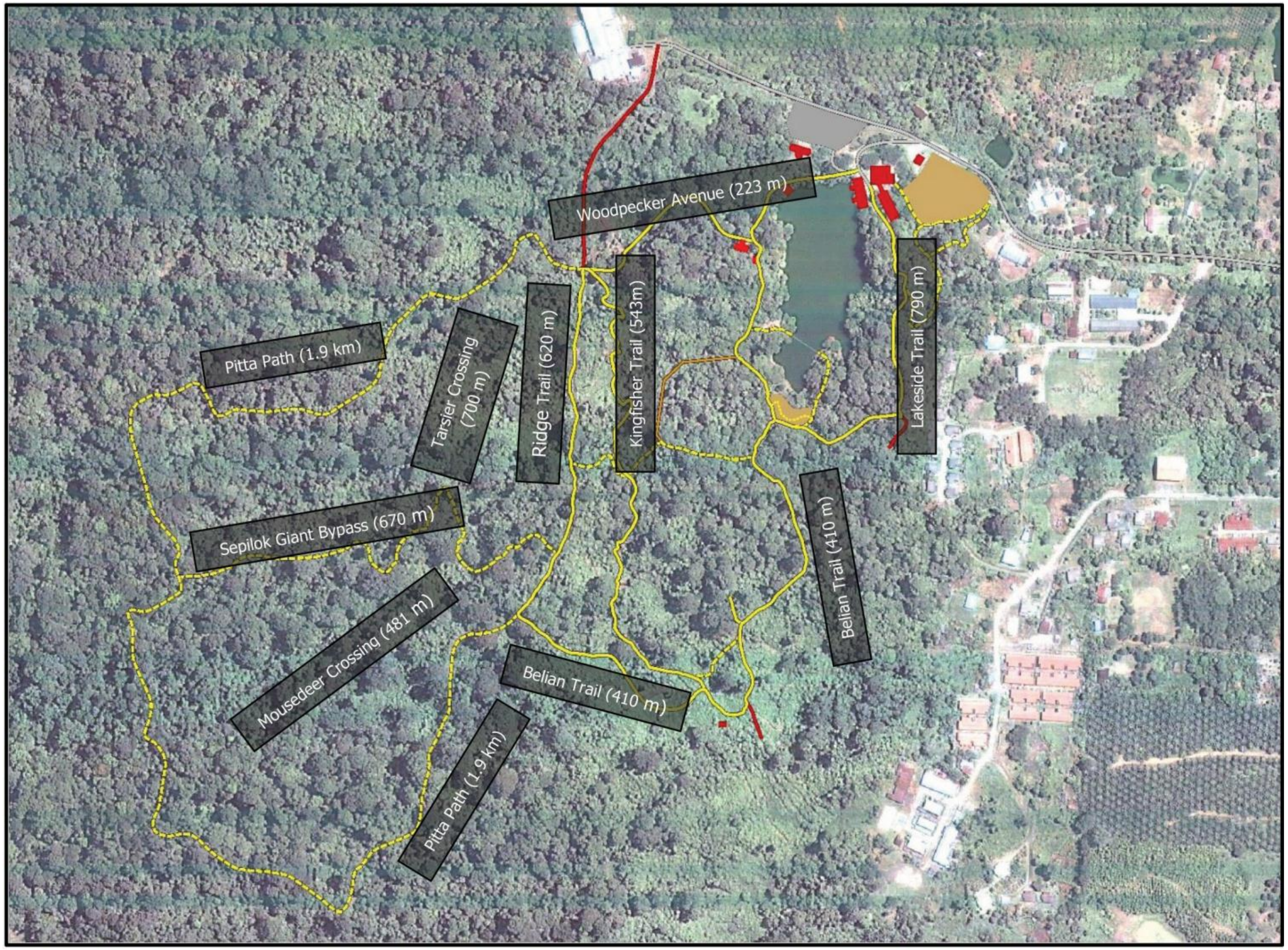

Figure 2. The nine trails in Rainforest Discovery Centre (RDC).

Taxonomic identification

The identification of macrofungi was made possible with the aid of current keys and descriptions in field guides (Singer *et al*., 1983 Pegler 1997, Zainuddin *et al*. 2010, Lee 2012). When specimens could not match to the known species descriptions, they were assigned to a genus and given a species number, for example, *Hyphodontia* sp. 1. The taxonomic status and description of these species will be examined later or when fungus specialist are available. The specimens were later brought back and dried in an incubator or oven at 45°C for 24-48 hours. The moderate temperature was set for drying in order not to kill the fungi but to keep them dormant for culture isolation in the future. The dried specimens were deposited at the Pathology Laboratory in the Forest Research Centre, Sepilok, Sandakan for further study.

RESULTS AND DISCUSSION

A total of 43 genera from 24 families belonging to 10 orders of fungi were recorded at the RDC (Appendix A). Order Polyporales (47.1%) had the highest number, followed by Agaricales (35.5%), Russulales and Xylariales, respectively, share the same percentage (3.6%), Boletales (2.9%), Pezizales (2.9%), Cantharellales and Thelephorales (1.5%), Auriculariales and Phallales (0.7%), respectively. The family Polyporaceae was the most dominant (33 individuals) whilst the least dominant were that of the Schizophyllaceae, Pleuteaceae, Nidulariaceae, Psathyrellaceae, Auriculariaceae and Phallaceae where only one individual representing each family. The genus *Ganoderma* had the highest number of individuals found in RDC, in which 23 specimens were collected, followed by *Marasmius* and *Mycena* with 12 and 10 specimens, respectively. An expanded list of macrofungi in RDC is provided in Appendix B.

The findings of this study with the Order Polyporales having the highest number recorded concurs with Yamashita *et al*. (2015) in that the species diversity of polypores in the primary forests is relatively high in the tropical region compared with that in temperate or boreal regions. The fruiting bodies of polypores is pivotal to the anthropods in which they provide food and habitat resources (Yamashita *et al*. 2015). Malaysia lack the resources and expertise in studying macrofungi (Lee *et al*. 2008, Chang & Lee 2004, Hyde 2003), with only few suitable keys and monographs available for the identification of fungi in Borneo, to date, hence there are fungi that cannot be identified up to the species level. Nevertheless, there is a marked interest to study fungi whereby a number of studies have been carried out in Sabah in recent years. Macrofungi survey was carried out from 21st to 26th of August, 2017 during the Imbak Canyon Conservation Area (ICCA) Scientific Expedition at Batu Timbang Area, Imbak Canyon, Sabah. A total of 106 species from 13 different families within Basidiomycota and Ascomycota were documented in this study (Paul *et al*. 2019). Besides that, a study on ethnomycological knowledge of wild mushrooms has been conducted within the indigenous communities of Sabah (Foo *et al*. 2018). Through this study, documentation of wild edible mushrooms in Sabah were recorded.

Photographs of selected macrofungi are shown in Plates 1 to 5. The fungi were found predominantly growing on woody debris (coarse and fine), with the exception of several specimens, such as a *Marasmius* sp. (Pl. 3b), and a *Mycena* sp. (Pl. 4a). However, our observations might be wrong due to the likely sampling bias as most of the fungi growing on leaf litter were small and relatively inconspicuous that might be overlooked during the survey. The findings, nonetheless, show the significance of woody debris and litterfall in supporting the fungal diversity in RDC.

Notes on selected species

The RDC is home to several fascinating taxa that are ecologically vital to the forest ecosystem and may be economically important. The followings are description of the fungi found in RDC.

Bioluminescent Fungus (Plate 3c&d)

The bioluminescent fungus, *Filoboletus manipularis* belongs to Mycenaceae family, was found growing in groups on dead logs at Belian Trail, Ridge Trail, Pitta Path and a trail near Keruing Café. The fungi usually grow in moist environment and decaying woods (Chew *et al*. 2015). The pileus are white in colour, are umbonate, have smooth surface and margin, and they have pores lamellae arrangement. When touched, they feel rubbery. According to Vydryakova *et al*. (2014), the pileus can be conical, rounded, plane or depressed. The colour of fungi becomes white to cream or beige when they reached maturity stage. The spore print of the *Filoboletus manipularis* is white in colour. The glowing part is only at certain part, such as stipe and underside of the cap. The light is caused by the oxygen-dependent reaction which is a chemical reaction between luciferin (a catalyst), luciferase (an enzyme), ATP (Adenosine triphosphate) and oxygen (Ilondu & Okiti 2016).

Stinkhorn fungus (Plate 5e)

Phallus multicolor, belonging to Phallaceae family, was found growing singly on the forest floor along the sidewalk of Ridge trail. This species is commonly known as Bridal Veil stinkhorn due to its orange net-like inducium hanging down from the top (Abrar *et al*. 2007). The stinking smell actually comes from the cap that contains sticky and slimy gleba. The released foul smell will attract the flies and insects to feed on the gleba (Korus *et al*. 2016, Dash *et al*. 2010). Thus, the insects act as an agent of spore dispersal for the fungi because the spores will stick on the legs and any body parts of insect (Pegler 1997, Dash *et al*. 2010). Stinkhorn prefers a cool moist with high organic matter areas (Korus *et al*. 2016). The species usually grows twice a year. The overall lifecycle takes 15 - 30 days to complete (Sitinjak 2016) while the fruiting bodies may be able to fully develop within 4 - 6 hours. However, they can last only for a few days or a maximum of one week before dying (Korus *et al*. 2016).

Coprinoid mushrooms (Plate 5c&d)

Coprinoid mushrooms are easy to recognize by their gill deliquescent characteristic upon reaching maturity stage (Roehl 2017) with the gill started to produce black spores and fruiting body turned fragile. *Parasola* sp., one of the inky caps under the family Psathyrellaceae (Szarkándi *et al*. 2017, Hussain *et al*. 2018) was found growing in small groups on the twigs at the Mousedeer Crossing trail. *Parasola* sp. is commonly known as “Pleated Inkcap” or “Little Japanese Umbrella” because of their caps which are radially grooved from the centre to the margin, looking like a parasol or an umbrella. The fruiting bodies are grey and white in colour, with a yellow dot at the cap centre. The veils are absent (Kuo 2011). They turned very fragile and inky when removed from the substrates.

Bird's nest fungus (Plate 5b)

Cyathus striatus, the bird nest's fungus of the family Nidulariaceae was found growing on a dead log at Pitta Path. The fungi are tiny and blend well with the substrate. They are called bird's nest fungi due to their fruiting bodies appearing like a nest (known as peridium) filled with eggs (spores known as peridioles) (Mahr 2014). The morphological characteristics are as the followings: a) vase-shaped or cup-shaped peridium; b) grey disc-shaped bodies peridioles; c) shiny striated internal wall; d) brown hairy external surface (Kuo 2014, Leonard 2017). The fungi depend on the force of raindrops to splash the peridioles out and this method is known as splash dispersal (Hassett *et al*. 2013).

Yellow-footed polypore (Plate 1a&b)

Microporus xanthopus is a very common fungi that can be found in all the nine trails in RDC. The "*xanthopus*" derives from two Greek words and literally means yellow foot (Lepp 2008) hence they are called yellow footed due to their yellow stipe. The fruiting bodies are funnel-shaped and sometimes the two fruiting bodies grow together to formed a bigger body. The surface is concentrically zoned with brown, yellow and black colour. The margin is wavy. Its underside is white in colour and the pores are minuscule to be seen by naked eyes. They are usually found growing on the dead branches. According to Chang & Lee (2004), *Microporus xanthopus* can be used in weaning process for babies.

Cup fungi (Plate 5f&g)

Cookeina is commonly known as cup fungi or "*Kulat mangkuk*" in Malay, belonging to the class Agaricamycota (Order: Pezizales; Family: Sarcosyphaceae). This genus is quite common and is usually found near the river in RDC. The two species found in the survey were *Cookeina tricholoma* and *C. sulcipes* and it is fairly easy to differentiate them based on their morphology. *Cookeina tricholoma* is usually red to peach colour with short stipe and white hairs covering the cup surface. The colour of *Cookeina sulcipes* is between peach to light pink or from light yellow to white and it usually has a long stipe where tiny hairs that can be seen at the edge of the cup surface (Abdulah & Rusea 2009, Denison 1967, Zainuddin *et al*. 2010). *Cookeina* sp. can be used as fish bait by rubbing it against the fish hook (Chang & Lee 2004).

The *split gill fungus (Plate 6a&b)*

The *Schizophyllum commune* or generally known as split gill fungus is a widely and commonly distributed fungi in the world hence the word "commune" means common in its Latin name (Emberger 2008). Belonging to the family Schizophyllaceae, the fruiting bodies have a flat surface and white in colour. However, the most exciting part is on their split gill which is located at the underside of the fruiting bodies (Vellinga 2013) making them extra special and fairly easy to see. The fruiting bodies are small in size, fan-shaped and lack of stem (Kuo 2003). The split gill was found growing on the dead logs at Pitta Path.

CONCLUSIONS

The order Polyporales had the highest number of fungi in RDC, with almost half (47.1%) of the specimens collected were from this order. It is recommended that further studies on fungi be carried out for a more comprehensive documentation in RDC. Research need to be further intensified to gather and document the many fungi that have yet discovered in Borneo too. It is hopeful that the findings of this study may generate further interest to work or conduct comprehensive study on fungi.

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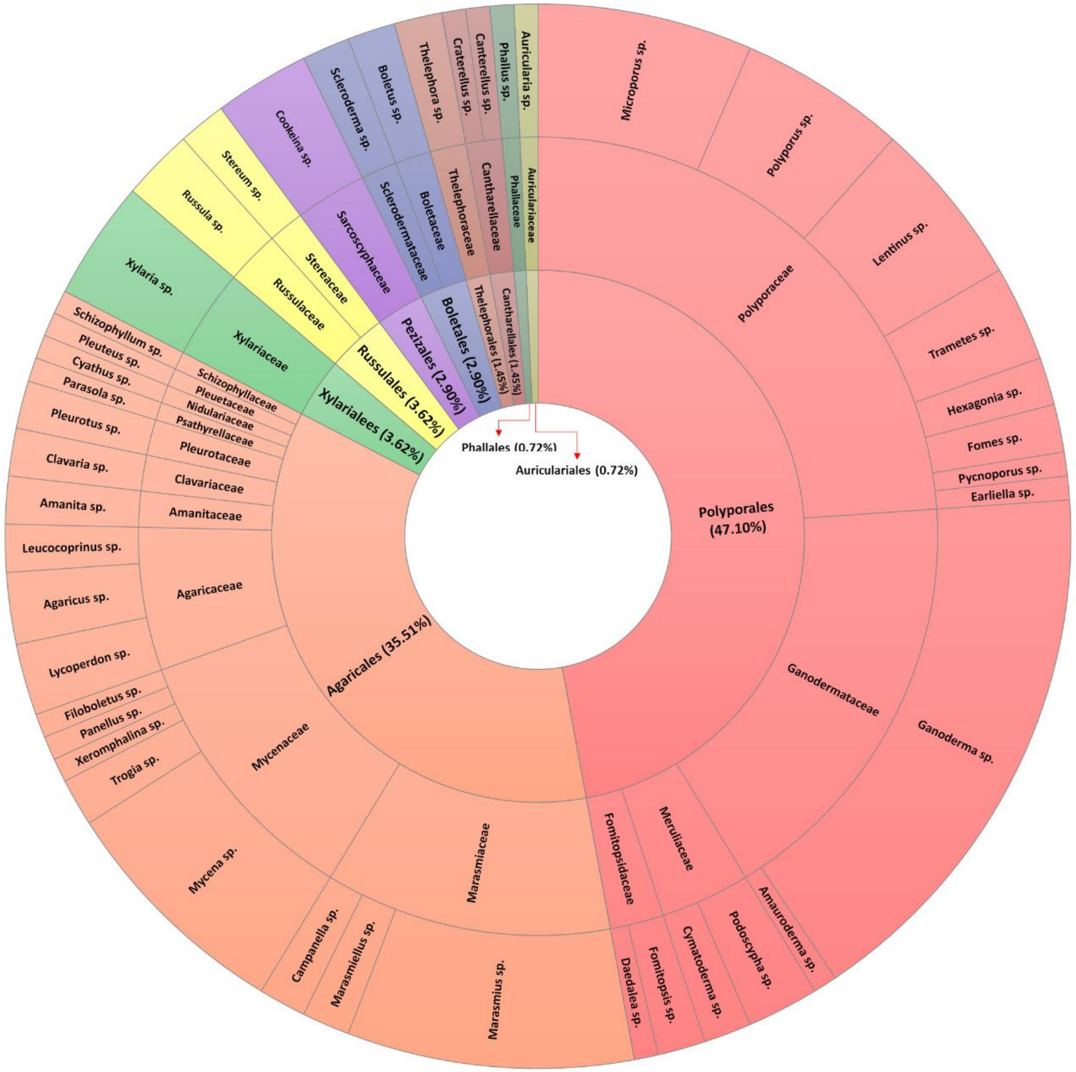
Appendix A. Percentage of families of macrofungi in Rainforest Discovery Centre, Sepilok, Sandakan.



Appendix B. Checklist of macrofungi in Rainforest Discovery Centre, Sepilok, Sandakan.

Division	Order	Family	Genus	*n*	Plate
Basidiomycota	Polyporales	Polyporaceae	*Microporus*	9	Pl. 1: a,b
			Lentinus	7	
			Polyporus	7	Pl. 1: c
			Trametes	4	Pl. 1: d
			Fomes	2	Pl. 1: e
			Hexagonia	2	Pl. 1: f
			Earliella	1	Pl. 1: g
			Pycnoporus	1	Pl. 2: a
		Ganodermataceae	*Ganoderma*	23	Pl. 2: b
			Amauroderma	1	Pl. 2: c
		Meruliaceae	*Podoscypha*	3	
			Cymatoderma	2	Pl. 2: d
		Fomitopsidaceae	*Fomitopsis*	2	Pl. 2: e
			Daedalea	1	
	Agaricales	Marasmiaceae	*Marasmius*	12	Pl. 3: a,b
			Campanella	2	
			Marasmiellus	2	
		Mycenaceae	*Filoboletus*	1	Pl. 3: c,d
			Panellus	1	Pl. 3: e,f
			Xeromphalina	1	
			Trogia	2	
			Mycena	10	Pl. 4: a
		Agaricaceae	*Agaricus*	3	
			Lycoperdon	3	Pl. 4: b
			Leucocoprinus	2	Pl. 4: c
		Amanitaceae	*Amanita*	2	Pl. 4: d
		Clavariaceae	*Clavaria*	2	Pl. 4: e
		Pleurotaceae	*Pleurotus*	2	
		Nidulariaceae	*Cyathus*	1	Pl. 5: a,b
		Pleuteaceae	*Pleuteus*	1	
		Psathyrellaceae	*Parasola*	1	Pl. 5: c,d
		Shizophyllaceae	*Schizophyllum*	1	Pl. 6: a,b
	Russulales	Russulaceae	*Russula*	3	
		Stereaceae	*Stereum*	2	
	Boletales	Boletaceae	*Boletus*	2	
		Sclerodermataceae	*Scleroderma*	2	
	Cantharellales	Cantharellaceae	*Cantharellus*	1	
			Craterellus	1	
	Thelephorales	Thelephoraceae	*Thelephora*	2	
	Auriculariales	Auriculariaceae	*Auricularia*	1	
	Phallales	Phallaceae	*Phallus*	1	Pl. 5: e
Ascomycota	Xylariales	Xylariaceae	*Xylaria*	5	
	Pezizales	Sarcoscyphaceae	*Cookeina*	4	Pl. 5: f,g

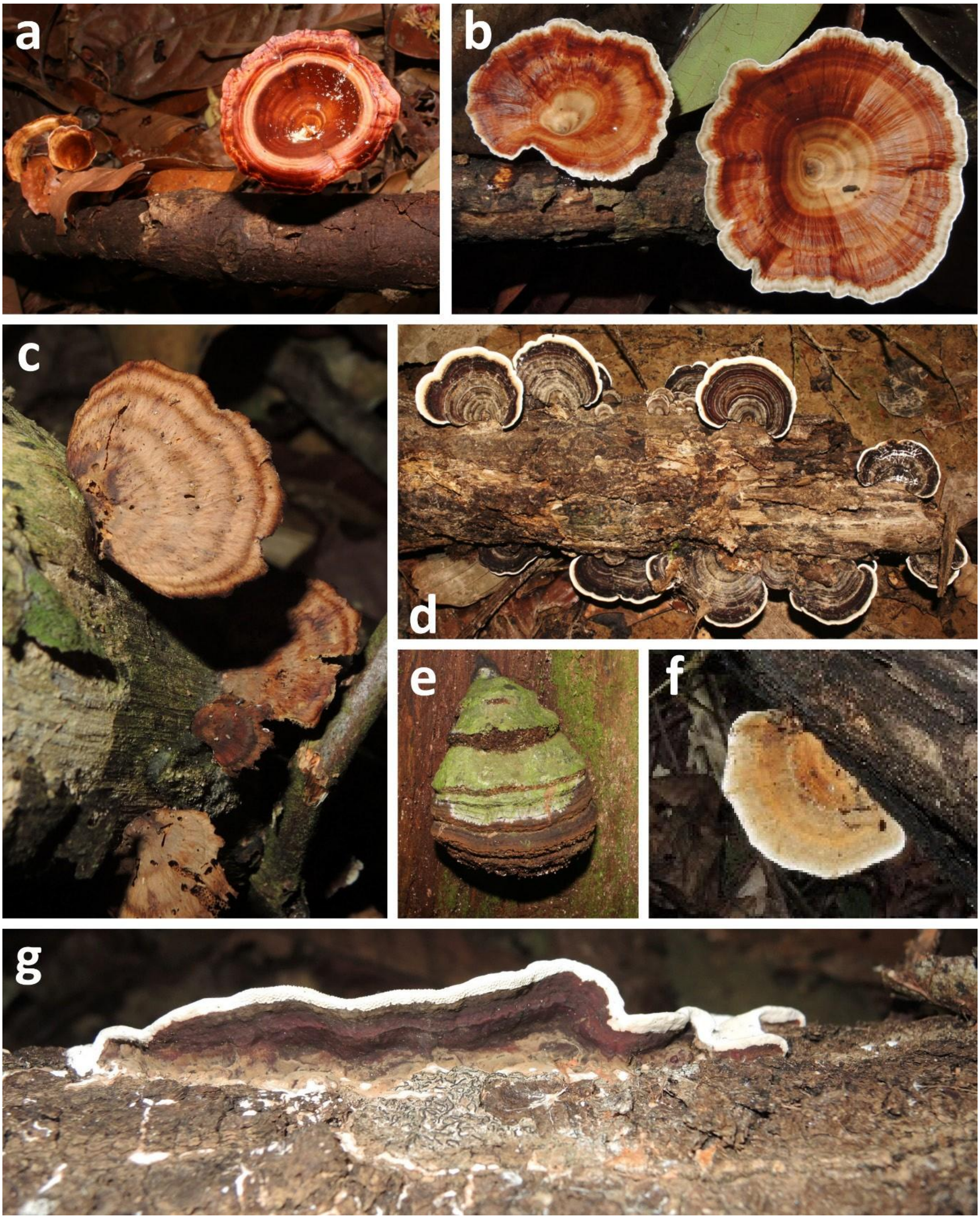


Plate 1 (a, b) *Microporus xanthopus*; (c) *Polyporus* sp.; (d) *Trametes* sp.; (e) *Fomes* sp.; (f) *Hexagonia* sp.; (g) *Earliella scabrosa*.

Plate 2 (a) *Pycnoporus* sp.; (b) *Ganoderma* sp.; (c) *Amauroderma* sp.; (d) *Cymatoderma* sp.; (e) *Fomitopsis* sp.

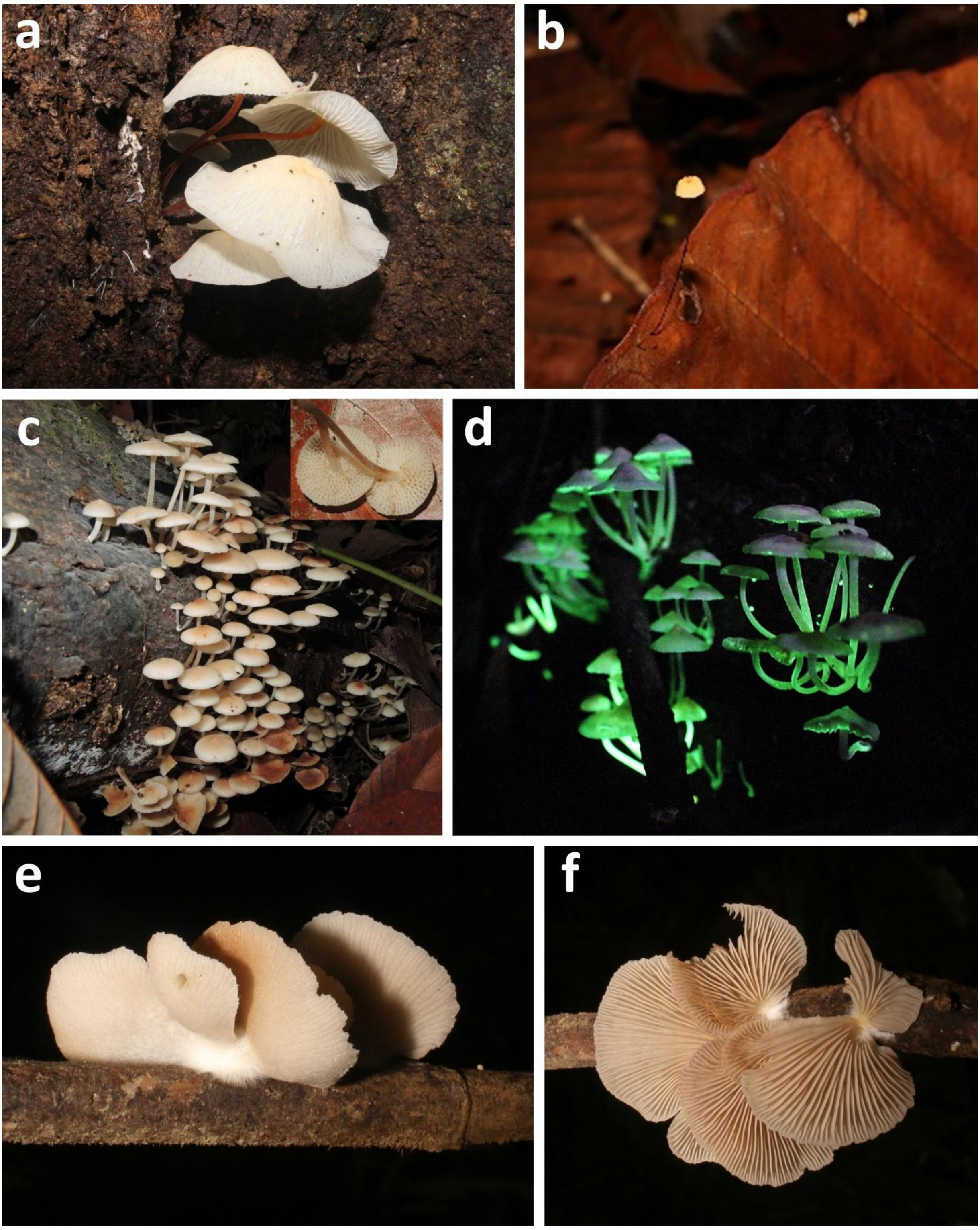


Plate 3 (a,b) *Marasmius* spp.; (c,d) *Filoboletus manipularis*; (e,f) *Panellus* sp.

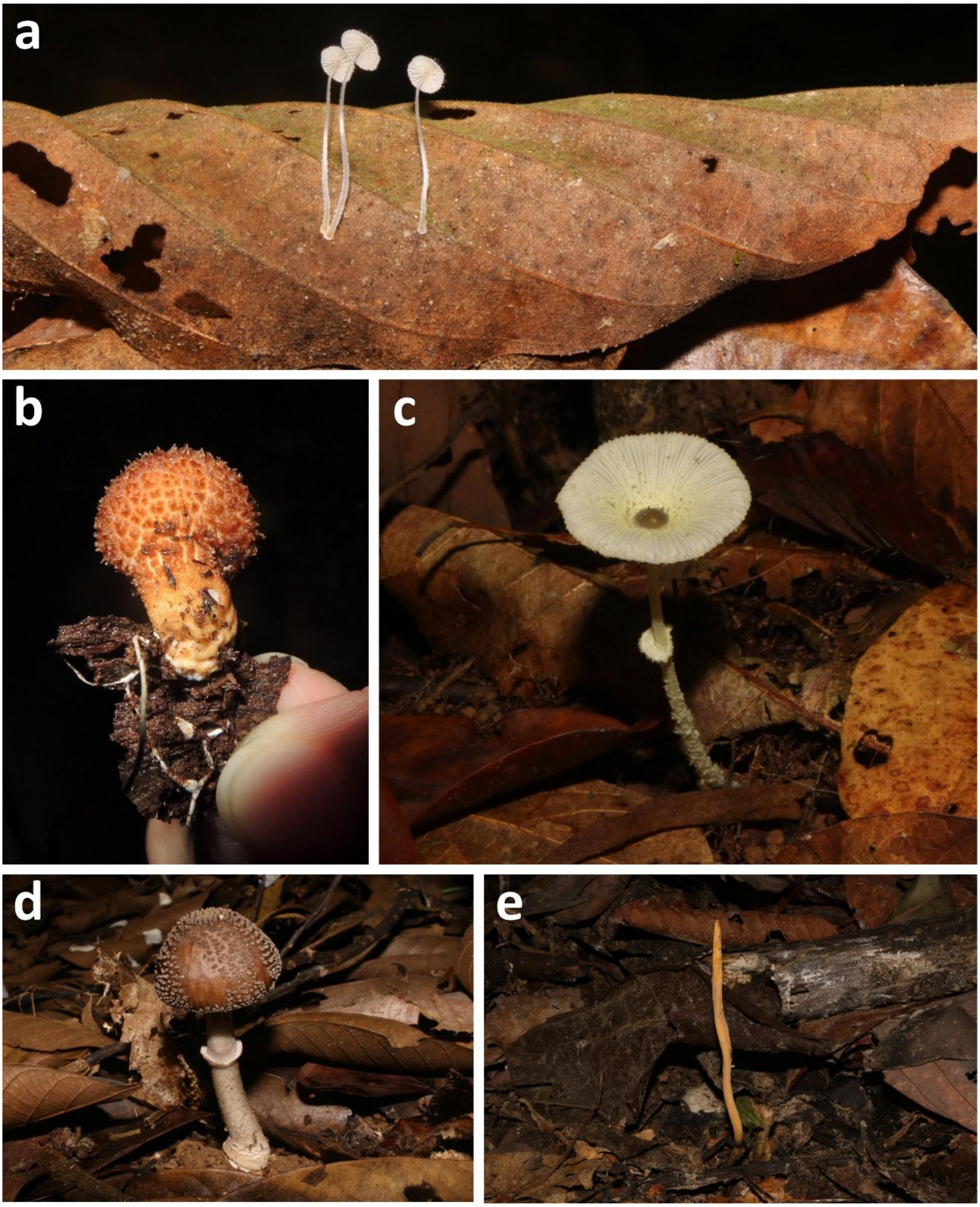


Plate 4 (a) *Mycena* sp.; (b) *Lycoperdon* sp.; (c) *Leucocoprinus* sp.; (d) *Amanita* sp.; (e) *Clavaria* sp.

Plate 5 (a,b) *Cyathus* sp.; (c,d) *Parasola* sp.; (e) *Phallus multicolor*; (f) *Cookeina tricholoma*; (g) *Cookeina sulcipes*.

Plate 6 (a,b) *Schizophyllum commune*.

Precipitation trend and heterogeneity of Sabah, North Borneo

C.K.C, Ng[12]*, J.J, Sikui[3], S.K. Nur Syafiqah[3] & R. Nilus[3]

[1]*Forever Sabah, H30, Gaya Park, Lorong Muntahan 1C, Jalan Penampang, 88300 Kota Kinabalu, Sabah, Malaysia*
[2]*Centre for Biodiversity Research, Faculty of Science, Universiti Tunku Abdul Rahman, Jalan Universiti Bandar Barat, 31900 Kampar, Malaysia*
[3]*Forest Research Centre, Sabah Forestry Department, P.O. Box 1407, 90715 Sandakan, Sabah, Malaysia*
**Author for correspondence. Email: caseywaej@gmail.com*

Abstract. Understanding the spatio-temporal pattern of precipitation is crucial when making policies to prevent disaster and support socio-economic activities in a political region. This paper represents the first attempt to investigate the spatio-temporal precipitation pattern in Sabah by employing monthly datasets from 24 weather stations across Sabah that were recorded between 2006 and 2015. Results show that precipitation distribution was not spatially uniform and six major groupings were identified based on Ward's cluster analysis. The precipitation datasets did not demonstrate a significant linkage with El Niño Southern Oscillation forcing. Temporal precipitation trends in densely populated towns showed a detectable decline, which could be a cause for alarm and precautions against potential adverse impacts may be necessary. Whilst some limitations are highlighted, this paper offers insights into micro and macro-scaled forcings that are critical to Sabah and reinforces the need to pay more attention to meteorological variability to inform forestry and other socio-economic activity planning.

Keywords: Flood, rainfall, urban planning, policy

INTRODUCTION

It is unequivocal that global warming and climate change have a direct impact on the intra-seasonal, inter-annual and inter-decadal natural and anthropogenic systems. For example, the timing, variability and intensity of seasonal precipitation are important in determining the success rate of reforestation projects and rain-fed agriculture (Hawtree *et al.* 2015, Locatelli *et al.* 2015, Sakamoto *et al.* 2015, Beyer *et al.* 2016). In contrast, heavy precipitation shocks are responsible for flooding (Hai *et al.* 2017) and their occurrence also affect the productivity of the fishery industry (Seggel *et al.* 2016). Conversely, drought periods are highly undesirable as they are commonly linked to predicaments such as forest fires, biodiversity depletion, reduced crop harvests and water shortages (Van Nieuwstadt & Sheil 2005,Wong *et al.* 2005,Yemenu & Chemeda 2010, Wooster *et al.* 2012, Busby & Smith 2014, Schyns *et al.* 2015, Zhang *et al.* 2019). As more countries are shifting towards micro-hydro and solar-driven renewable energy options (UNIDO 2016, REN21 2017), it is no surprise that a period of precipitation surplus or deficit may have an effect on energy security as well. Given such a heavy dependence on climatic knowledge to inform planning and policy-making endeavours for building resilience against the negative impacts, spatially analysing the regional precipitation pattern is the first crucial step. Moreover, since global warming and climate change is already evident (Trenberth

2011, Scalzitti *et al.* 2016, Pendergrass *et al.* 2017), this makes it more urgent to analyse the latest available data to detect any changes in the local climate for taking precautions and driving policies and legislative regulation.

Review of literature showed that previous studies on the precipitation patterns in Sabah had mainly focused on characterizing variation in small areas or districts (Walsh & Newberry 1999, Chappell *et al.* 2001, Bidin & Chappell 2003, Margrove *et al.* 2015, Suparta *et al.* 2015). These may be too small-scaled to capture larger climatic influences. On the other hand, there had been several studies for the whole of Borneo island (Wooster *et al.* 2012, Qian *et al.* 2013, Sa'adi *et al.* 2017) that conversely may be too large-scaled and coarse to recognize subtle factors that influence the climatic mechanism in Sabah's unique landscapes. To the best of our knowledge, no empirical study has analysed the precipitation patterns in Sabah in the recent decade which may reveal possible factors that could affect its precipitation trends well into the future.

Recognizing the gap in current knowledge, the objective of our work was to examine and delineate distinctive precipitation patterns based on available datasets recorded at weather stations across Sabah from 2006 to 2015 (10 years). The report herein represents the first attempt to elucidate the trend regarding temporal variability in precipitation across spatial domains in Sabah and dissimilarities between these domains using multivariate statistical approach. Particular emphasis was put on coastal regions where the most populated townships are located. Additionally, we examined the linkage between the precipitation datasets with corresponding Oceanic Niño Index (ONI) and Southern Oscillation Index (SOI) values to investigate whether El Niño Southern Oscillation (ENSO) forcings have any influence on the precipitation patterns in Sabah.

MATERIALS AND METHODS

Study area

Sabah (5° 26' 13'' N, 116° 56' 48'' E) is a Malaysian State located at north Borneo. The area occupies ~10% (73,620 km^2; DOS 2015) of the total area of the third largest island in the world. Its coastline faces the South China Sea in the northwest, Sulu Sea in the northeast and Celebes Sea in the southeast. The eastern region is mainly flat while the west and inland southern regions are predominantly a complex intersperses of hilly and mountainous terrains. Sabah is located in an active Asian-Australian monsoonal region, which may be generally characterized by an asymmetrical seasonal modulation between southwest monsoon (May - Oct.) and the northeast monsoon (Nov. - Apr.) (Bidin & Chappell 2003).

Dataset

Monthly precipitation dataset were acquired by Forest Research Centre (FRC), Sepilok, from 37 stations operated by Sabah Forestry Department, Sabah Meteorological Department, Sabah Agriculture Department, Department of Irrigation and Drainage, airports and some crop plantations. The focus was on datasets collected from the recent decadal time slice, from 2006 to 2015.

Preliminary examination was done to minimize errors and biases; datasets were analysed and filtered by using the stem-and box plot functions in SPSS® 20 software (IBM 2011) to identify irrational outliers and unrealistic values. Following World Meteorological Organization (2006), Vicente-Serrano *et al.* (2010) and Lyra *et al.* (2014), gaps from missing data (e.g. caused by faulty gauges and other inexplicable reasons) were replaced with values derived from linear regression from similar period of other years and nearby stations. However, datasets from many stations had to be discarded nonetheless due to overwhelming uncertainties and probable errors. These were mostly datasets from gauges set in the interior regions. Other researchers have also encountered similar issues in earlier studies (Walsh & Newberry 1999). Consequently, datasets from only 24 stations were employed for further analysis (Figure 1). For analysing the linkage between precipitation and ENSO, the corresponding monthly ONI and SOI time series values (2006-2015) were selected as signatures. The monthly ONI and SOI values were obtained from online datasets published by the NOAA (2017) and Australian Bureau of Meteorology (2017), respectively.

Analysis

We applied Ward's agglomerative hierarchical clustering algorithm (Ward 1963) to determine the statistical similarity, or Euclidean distance, between the datasets. The Ward's method provides a relatively stable degree of clustering or precipitation groupings and it has been frequently applied in climatic studies (Kalkstein *et al.* 1987, Gong & Richman 1995, De Gaetano 1996, Ramos 2001, Bravo *et al.* 2012, Pineda-Martínez & Carbajal 2017). The approach had been found to give better results when compared with other classification methods (Nathan & McMahon 1990, Domroes *et al.* 1998). The Ward's method detects inter-cluster minimum variances and uses its Euclidean distance as the yardstick for pairing dataset (Everitt & Dunn 1991). The mathematical equation for Ward's algorithm is expressed as:

$$d_e = \left[\sum_{j=1}^{n} (P_{p,j} - P_{k,j})^2 \right]^{0.5}$$

where d_e is the Euclidean distance, and $P_{p,j}$ and $P_{k,j}$ are the j^{th} value of variable p and k. Thus, the unit of clusters is generated by determining the level at which the within-group similarity is maximized while the between groups similarity is minimized (Gustavo *et al.* 2014). SPSS® and Instant Clue® (Nolte *et al.* 2018) were used to analyse all statistical indices and generate the required visualization plots. Geospatial mapping of station localities was managed, analysed and illustrated in QGIS® 2.18 (QGIS 2016).

RESULTS

From Ward's cluster analysis of the inter-month and inter-annual precipitation variation based on data from 2006 to 2015, six groupings with dissimilar precipitation trends were identified (Figure 2). The centrality and variance of datasets for each station are illustrated in Figure 3. Each group was named after the region's most populous town: Kudat, Kota Kinabalu, Beaufort, Keningau, Sandakan and Tawau. The division into six groupings was also supported by trend line analysis that showed similar precipitation patterns amongst stations within the same regional grouping (Figure 4). The results provided confirmatory evidence that Sabah, as a whole, does not experience a homogenous pattern of precipitation.

Based on datasets analysed (2006-2015), the monthly precipitation mean of each group is provided in Table 1. A one-way ANOVA test was performed and the results showed that the differences between the means were statistically significant ($F = 71.57$, $p = 0.000$), further revalidating dissimilarities between regional groupings. The data showed that the Kudat group experienced the highest precipitation variability (CV = 0.986) followed by Sandakan group (CV = 0.667). The lowest precipitation variability was experienced by Beaufort group (CV = 0.446).

Kudat and Sandakan groups showed a "U" shaped trend line thus implying that the mid-year periods were typically drier (Figure 4). Such precipitation pattern was not observed in other groups which suggested that they received somewhat consistent amount of precipitation throughout the year. Monthly stem plots (Figure 5) showed variances were riddled by outliers (i.e. abnormal heavy precipitation episodes). In the datasets from 24 stations selected for this study, we regarded outliers as natural occurrences and they were not removed from the stem plot and linear regression computation. Extreme precipitation episodes appeared to be somewhat common throughout 2006-2015.

Although ENSO has been associated with precipitation deficit in the Southeast Asian region (Hamada *et al.* 2002, Fuller *et al.* 2004, Wooster *et al.* 2012), ONI and SOI variations surprisingly had no significant linearity with any of the grouping values based on datasets collected from 2005 to 2016 (Table 2). Due to the weak correlation between groupings and ONI values, we further performed a Residual Maximum Likelihood (REML) linear mixed-model regression to examine the overall fixed and random effects. We found weak linearity between dependent variable ONI and group values of Kudat ($F = 0.039$, $p = 0.843$), Kota Kinabalu ($F = 0.015$, $p = 0.901$), Beaufort ($F = 0.026$, $p = 0.871$) and Sandakan ($F = 1.987$, $p = 0.161$), with the exception of Tawau ($F = 4.746$, $p = 0.031$) and Keningau ($F = 6.219$, $p = 0.014$). The REML results inferred that the datasets employed may not be entirely sound for understanding ENSO influences in Sabah.

Histogram computed showed Sabah's monthly mean average precipitation was 237.96 mm (n=2880, SD=154.93) based on datasets analysed (2006–2015). We recognize, however, that there was a noticeable persistent decline in precipitation from 2006 to 2015 (Figure 6) in all heavily populated towns namely Kota Kinabalu ($y = -0.3886x + 267.65$, $R^2 = 0.009$), Keningau ($y = -0.4346x + 196.86$, $R^2 = 0.0326$) and Tawau ($y = -0.5355x + 205.85$, $R^2 = 0.0455$) with Sandakan ($y = -1.6156x + 403.46$, $R^2 = 0.0583$) experiencing the highest degree of decline. Although downtrend directions were diminutive and the resultant coefficient of correlations (R^2) was low, such noticeable decline may be a cause for concern. A more thorough investigation should be deployed using larger datasets from past decades to reconfirm and quantify the possible decline in a higher resolution manner.

DISCUSSION

Our work has successfully met the objective of delineating precipitation groupings in Sabah, analysing the decadal trends and deducing their relationships with the corresponding values of ENSO signatures. And yet, there were striking features in the results and plots that we could not entirely explain and these warranted further discussion. In the following paragraphs, we briefly discuss the sensitivity of the 2006-2015 datasets in detecting ENSO forcings. The discourse also centres on outliers detected (i.e. precipitation anomalies) and the possible factors, namely small-scale geographical and large-scale meteorological forcings. Subsequently we discuss our findings on a broader context and identify the gaps and limitations to guide future studies. Finally, we provide suggestions on how the findings of this study can be useful to inform socio-economic policymaking.

ENSO influence

ENSO climatic cycle has a variability of two to seven years' time frame (McPhaden *et al.* 2006). The ENSO cycle modulates between unusually warm (El Niño) and cold (La Niña) conditions in the area that spans between the tropical Indian and Pacific Oceans. Both the peak and periodicity of El Niño and La Niña have changed to a large extent since 1871 with considerable irregularity in time (Dore 2005). Although Sabah is located in the western Pacific Ocean and within the influences of ENSO forcing, our decadal-scale study period may not have coincided with the peak period of El Niño or La Niña. Furthermore, even if there was an occurrence of peak El Niño or La Niña, not all stations in Sabah can detect the effects due to the interplay of other meteorological cycles and the topographic localities. We recognize that more investigation and a bigger dataset that spans back to many decades are needed to decisively clarify the influences of ENSO on the precipitation patterns in Sabah.

Comparison with other studies

Comparing our work with others, we found that the precipitation trends from our investigation to be somewhat similar to trends presented by Walsh and Newbery (1999) in the areas of Kudat and Sandakan, while differing in Kota Kinabalu. Other areas of our study were not mentioned in Walsh and Newbery (1999). They also highlighted that during the 1997-98 drought in Borneo which Nakagawa *et al.* (2000) and Harrison (2001) attributed to a strong El Niño event, the precipitation decline was considerably mild in the Tawau region. Walsh (1996) and a report by the Malaysian Meteorological Department (2009) supported our findings and concluded that ENSO forcing on its own was not the primary driver of precipitation deficit in Malaysia. This was later reconfirmed by Wong *et al.* (2009), Curativo *et al.* (2012) and Wong *et al.* (2016). By analysing data collected from 1970 to 2009, Lim *et al.* (2011) opposed the notion that ENSO has an effect on the formation of cyclones in the western Pacific Ocean as they found no linearity between ENSO and the frequency and intensity of tropical cyclones in the region. This is to say that disturbances and effects from typhoons in the northern seas of Sabah are a distinct climatic force that warrant separate scrutiny. We also argue that much remains to be understood in regard to the local climatic system and urge future researchers not to rely solely on global climatic systems (e.g. ENSO, Indian Ocean Dipole and Madden-Julian Oscillation) to correlate with their data. Instead, other local determinants such as topography and diurnal sea-land wind movement should also be investigated.

Topoclimate implication

Besides external forcing such as ENSO, precipitation pattern is also influenced by a suite of local variables, which include air movement, solar radiation, surface temperature and soil temperature (Ettwein & Maslin 2011, Rajendran *et al.* 2018). They are often complex and non-linear. Each variable exhibits unique temporal and spatial sensitivity towards changes in the landscape structure. The degree of spatial variability may also differ greatly among landscape geomorphology, namely in mountainous area, forested and anthropogenic localities. For example, landscape structures that have been anthropogenically disturbed tend to experience higher day-time shortwave radiation, temperature and wind speed than undisturbed localities (Hungerford & Babbitt 1987, Han & Baik 2008, McAlpine *et al.* 2018). The increased variability is caused largely by the lack of biomass to regulate surface temperature and latent heat (Raynor 1971, Matlack 1993, Chen *et al.* 1996, Saunders *et al.* 1998, McAlpine *et al.* 2018). Precipitation can also vary from lowland to highland and from the interior to the coastal edge depending on the landscape configuration and orientation towards the sea (Ogino *et al.* 2016, Zhu *et al.* 2017). Factors mentioned would certainly have implications on the precipitation variation in Sabah as it is somewhat a projecting landmass riddled by complex terrains and surrounded by sea in its northern, eastern and western boundaries.

We offer an insight into why analysis of precipitation pattern in Sabah is problematic and thus not commonly investigated in the past. During the preliminary examination of datasets from all 37 stations, we noted that the stations located in the interior regions and at various elevations have recorded values that were wildly dissimilar to nearby stations. As mentioned earlier, we selected datasets from only 24 stations for Ward's clustering analysis. The rest was omitted as they would distort the computation process. For example, one of the stations omitted was Babagon. Although the precipitation gauges in Kota Kinabalu and Babagon were installed less than 15 km apart (Figure 7), the mean monthly precipitation values were markedly different. An independent sample t-test showed that the mean difference between Babagon ($n = 120$, mean = 413.09, SD = 212.74) and Kota Kinabalu ($n = 120$, mean = 244.14, SD = 142.82) were statistically significant, $t(119) = 10.29$, $p = 0.000$. Therefore, not surprisingly, unexpected and extreme precipitation in Babagon has been frequently causing floods in Penampang (Roslee *et al.* 2017) which is located at the downriver. It is apparent that the design of urban drainage system in Penampang should not be informed by the precipitation datasets from Kota Kinabalu but from Babagon instead. This case accentuates the importance of regional precipitation studies at a finer scale to inform urban planning and policymaking.

We have an *a priori* reason to deduce that the altitude and proximity of Babagon to the coast had caused the striking asymmetrical distribution of precipitation. Babagon had been consistently receiving more precipitation than Kota Kinabalu due to its windward slope locality. Being located near the coast, the areas of Kota Kinabalu and Babagon are subjected to the prominent effects of the diurnal land-sea breeze circulation. Air laden with moisture from the coast tends to cool down and condense at higher elevation where Babagon is located, causing a condition known as orographic induced precipitation (Gray & Seed 2000). In contrast, Tambunan recorded a much lower precipitation values due to its leeward location, or commonly termed as "rain shadow" (Ettwein & Maslin 2011) although the station is located at a higher elevation (Figure 7). Such spatial interaction on a hilly or mountainous landscape is termed as topoclimate (Littmann 2008, Slavich *et al.* 2014) and so far the discipline is underexplored in Southeast Asia, more so in Sabah. Since the interior of Sabah feature a complex assembly of rugged terrains, the lack of topoclimate studies puts the state in the dark in terms of knowledge. Concerns highlighted herein exemplify the complexity and challenges in conducting studies on the predictability and trend of precipitation in Sabah.

Episodic and sporadic forcings

To a larger extent, Sabah is located in the Maritime Continent which includes Indonesian archipelago and New Guinea. So far, the region is scientifically known to be influenced by the global intra-seasonal and inter-decadal meteorological fluctuations and interactions of the Indo-Australian monsoon system, ENSO, Indian Ocean Dipole (IOD), Madden-Julian Oscillation (MJO) and the Borneo vortex phenomenon (Walsh 1996, Manton *et al.* 2001, Tangang 2001, Lawrence & Webster 2002, Tangang & Juneng 2004, Juneng & Tangang 2005, Ihara *et al.* 2008, Tangang *et al.* 2008, Feng *et al.* 2010, Zheng *et al.* 2010, Jones & Carvalho 2011, Xavier *et al.* 2014, Raja & Aydin 2018). That is to say, the effect of each meteorological forcing may be intensified or modified by another forcing.

The incidences of Borneo vortex over the northeastern coast of Borneo island are particularly prominent. During the northeast monsoon (Nov. - Apr.), the northwestern side of Borneo island tends to develop an area of deep convection that may manifest into a cyclonic circulation, thus causing heavy precipitation (Ooi *et al.* 2011, Koseki *et al.* 2014). The frequency of the Borneo vortex has increased over the 1962-2007 period and the centroid has also shifted northwestward in recent years (Juneng & Tangang 2010). Such a sporadic forcing is expected to have an effect on the precipitation frequency and intensity in Sabah.

The climatic dynamism in Sabah is further complicated by the presence of a "typhoon belt" in the adjacent northern region. Although southwest monsoon (May-Oct.) and the northeast monsoon (Nov.-Apr.) are generally regarded as key determinants of precipitation intensity in Sabah (Bidin & Chappell 2003), extreme precipitation, storm surges and other typhoon-induced calamities may occur at any time from May through November although usually peaking in late August or early September (Fogarty *et al.* 2006). For example, on 31st May 2018, a precipitation shock struck the west coast when Ewiniar passed northern Sabah in close proximity (Figure 8). The typhoon had induced extreme precipitation that caused massive flooding in many areas in the west coast (Figure 9). The catastrophe was further exacerbated as Ewiniar also caused a storm surge which decreased the effectiveness of the urban drainage system in mitigating flood (i.e. reduced gravity flow to the coastal outlets).

At the time of this writing, four typhoons have just moved across the northern region in September 2018 alone, namely Jebi, Barijat, Mangkhut and Trami. Mangkhut was classified as a category 5 "super typhoon" and sustained a wind speed of up to 285 km/h (NOAA 2018a). From the open-source visuals captured by Himawari satellite, we observed that Trami has an effect on storm cloud pattern (Figure 10). The examples presented by Ewiniar and Trami imply that typhoon occurrences and paths, no matter near or far from north Borneo, has an effect on climate in Sabah. The physical mechanisms responsible for typhoon formation are still not fully understood (Ribera *et al.* 2005, Webster *et al.* 2005, García-Herrera 2007, Qiu *et al.* 2018) and this further renders weather forecast study as a yet-to-be precise science in Sabah.

Evidently, the climate of Sabah is naturally influenced by a mix of episodic and sporadic forcings thus we are reminded that there is a limit to the predictability of precipitation. It is a highly sensitive mix of pressures and perturbations that occur in a particular day, week, month or year. The results can vary wildly even with just slight changes of one or two factors. Consequently, outliers or extreme precipitation shocks are in fact a regular expression of the local climatic datasets (Figures 3 and 5). Taking this into consideration is essential for the understanding of any study outputs or applying the results for policymaking, planning and managing socio-economic activities.

Limitations and future researches

We recognize that our research has limitations and wish to point them out to guide future work. In terms of geographical location, stations selected were not ideally and evenly distributed. Due to the significant discrepancies in datasets recorded by stations in the interior regions as mentioned earlier, most stations selected were near coast, with the exception of stations in the Keningau group. These “discrepancies” may not reflect the actual conditions after all. As demonstrated in Babagon, linear regression among datasets recorded in nearby stations may not be entirely reliable for correlation and grouping delineation. In the rugged interior of Sabah where the topoclimate is virtually unstudied, erratic and abnormal values recorded by the stations may be the common expression of precipitation patterns. In this study, we were unable to designate precipitation groupings for the interior regions of Sabah thus, we urge future work to focus explicitly on investigating precipitation patterns in these areas to clarify our understanding of the topoclimate in Sabah.

Moreover, a large part of the interiors is still subjected to land-use changes for socio-economic activities. Many studies have found that the flux in landscape vegetation cover may shift the precipitation patterns spatially (Webb *et al.* 2005, Abis & Brovkin 2017, Bennett & Barton 2018) and quantifying the responses will further enhance our understanding of precipitation pattern in the interior regions. We know that datasets derived from stations near the coasts were relatively more stable for statistical analysis. However, there is a need to analyse and decide whether datasets from the interior regions are naturally erratic or not, and how they can be included for broad-scale analysis. Therefore, the six groupings proposed herein are tentative at best and the delineation may shift in the future as new knowledge emerges or when more inter-decadal and inter-centurial meteorological deviations set in.

Application of findings

This study is by no means comprehensive but we are certain that the results have a number of important applications. In Malaysia, the stormwater drainage design system is typically based on a 2, 5, 10, 20, 50 and 100 years average recurrence interval (ARI) precipitation intensity (DID 2012). On 1st June 2018 when a massive flood occurred in Penampang (Figure 9), the GPM-GMI data showed that Babagon and Kota Kinabalu were experiencing a precipitation rate of 8.25-9.08 mm/hr and 5.10-5.62 mm/hr, respectively. Such difference implies that engineers, urban planners and government agencies should look beyond localized precipitation data to inform urban drainage design and planning. Data in adjacent landscapes should also be evaluated to formulate the best drainage system.

As the ecotourism and fishery industry are major socio-economic activities along the coastal areas of Sabah, our findings may provide the appropriate forecast of high precipitation periods and the information may be useful for avoiding maritime mishaps. The consistently low precipitation levels observed in the Keningau and Tawau group should also be taken seriously for managing water security and to a certain extent water safety. Steps could be taken by managers of water treatment plants in these towns to mitigate impacts of water pollution as studies have shown that low precipitation levels cause physico-chemical imbalances and pollutant concentration in freshwater resources (Tornevi *et al.* 2014, Mosley 2015, Ng *et al.* 2018). Over in the rural areas, our findings may be informative for planning and policymaking initiatives related to the implementation of micro-hydro, rainwater harvesting and gravity-fed systems (GFS) initiatives which affect energy and water security.

For activities such as agriculture, forestry and environment conservation, the evidence from this study suggests that habitat enrichment, reforestation or crop planting activities in the interior regions should consider topoclimatic studies as part of the planning process. The knowledge of localized precipitation pattern is crucial for seedling survival and the success of any reforestation project. The reduced-impact logging (RIL) protocol which is largely dependent on felling timber during dry days would also benefit from our analysis. Last but not least, regional dry season periods identified in this study may assist in policymaking, planning and managing fire risks in industrial crop and forest management units.

CONCLUSION

In this study, we delineated six groupings to give better insights on the precipitation trends and heterogeneity of Sabah based on the recent 2006–2015 decadal datasets. The groupings proposed are based on historical data, and not based on predictive model, thus may reflect the reality better although we encountered some issues with data discrepancies, explicitly of those recorded in the interior regions. Additionally, we determined that the ENSO signatures, namely ONI and SOI trends, have no significant correlation with the precipitation patterns in Sabah within this period. At the spatial level, we discussed and proposed that small-scale topoclimate and large-scale meteorological forcings have a direct impact on the pattern and intensity of precipitation in Sabah. Although this research dealt mainly with the precipitation pattern of Sabah, highlights and insights unveiled herein have universal appeal and applications. We demonstrate how each region's climatic pattern was unique and deserved a closer look to reveal the nuances that can be applied for producing and enhancing policies related to socio-economic well-being. Also, a striking aspect of any weather-based study is that spatio-temporal datasets will always be fragmented. However, no matter how disjointed, historical datasets are still valuable and there is an urgent need to continuously and objectively analyse them for anticipating climatic disturbances.

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TABLES

Table 1. Summary of monthly precipitation values (mean ± SD).

Group	Sample size (n)	Mean (mm)
Beaufort	480	318.17 ± 141.93
Sandakan	600	273.34 ± 177.27
Kota Kinabalu	360	232.86 ± 139.75
Kudat	360	229.03 ± 225.81
Tawau	600	207.00 ± 92.98
Keningau	480	162.73 ± 78.71

Table 2. Summary of linear correlation values between ENSO signatures and groups.

ENSO Signature	Kudat	Kota Kinabalu	Beaufort	Keningau	Sandakan	Tawau
ONI	$R^2 = 0.035$	$R^2 = 0.0248$	$R^2 = 0.0253$	$R^2 = 0.1005$	$R^2 = 0.0423$	$R^2 = 0.0767$
	$y = -39.915x + 216.83$	$y = -24.511x + 241.68$	$y = -25.742x + 300.76$	$y = -28.969x + 167.65$	$y = -52.221x + 300.46$	$y = -26.375x + 170.8$
SOI	$R^2 = 0.0711$	$R^2 = 0.0115$	$R^2 = 0.0536$	$R^2 = 0.0984$	$R^2 = 0.0619$	$R^2 = 0.0151$
	$y = 4.8083x + 210.73$	$y = 1.4138x + 241.17$	$y = 3.1629x + 296.69$	$y = 2.4214x + 165.47$	$y = 5.337x + 294.48$	$y = 0.9877x + 171.38$

FIGURES

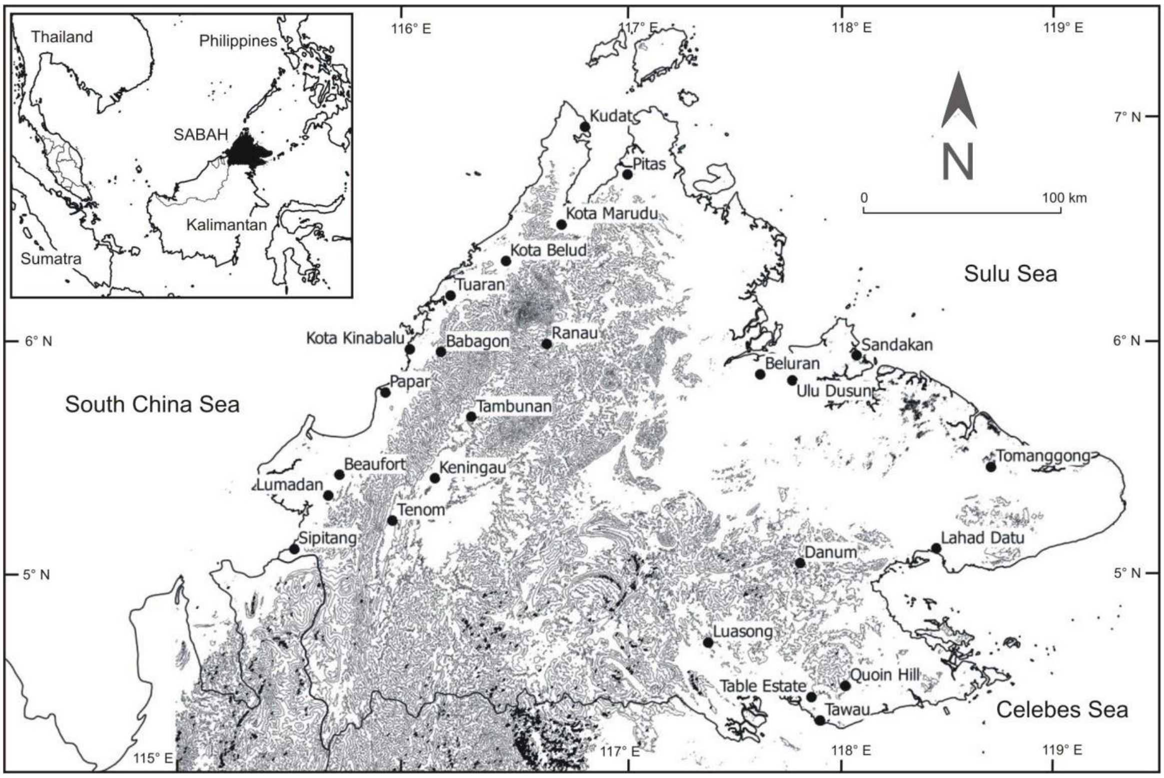

Figure 1. All stations mentioned in this paper and the location of Sabah in north Borneo (inset).

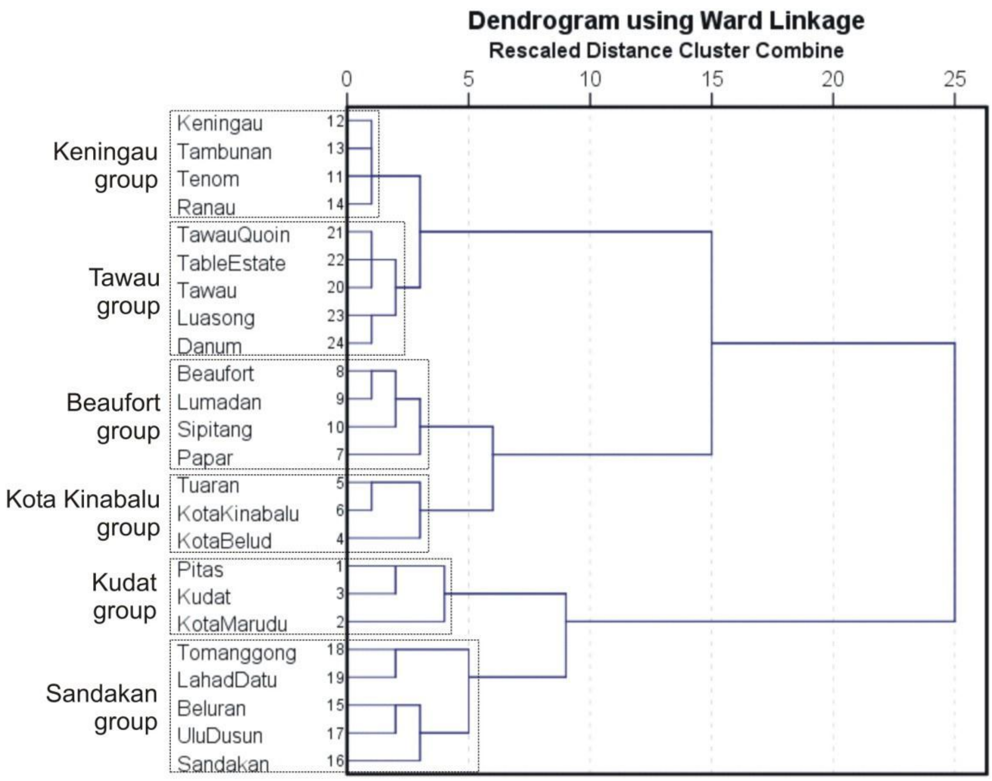

Figure 2. Dendrogram hierarchical tree based on precipitation datasets collected from 2006 to 2015. Note that there are six compound groupings with dissimilar precipitation patterns.

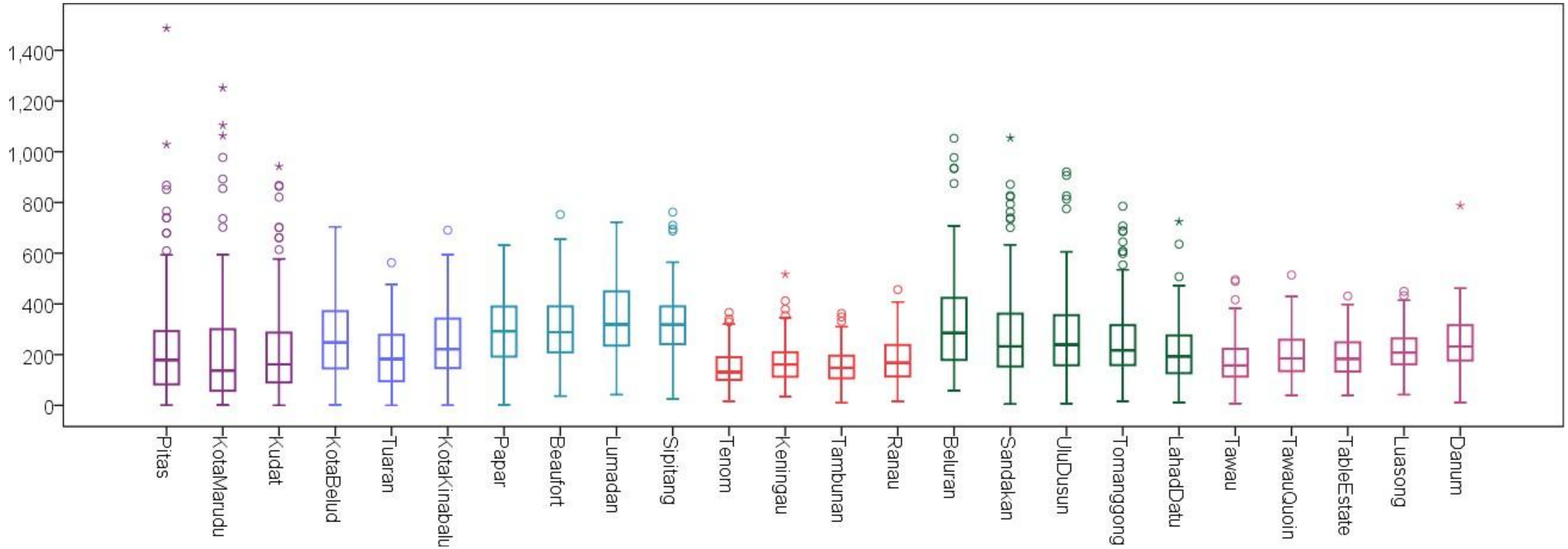

Figure 3. Stem plots of datasets (2006-2015) showing centrality, variance and outlier of precipitation values from each station. Plots of the same grouping are marked with the same colour.

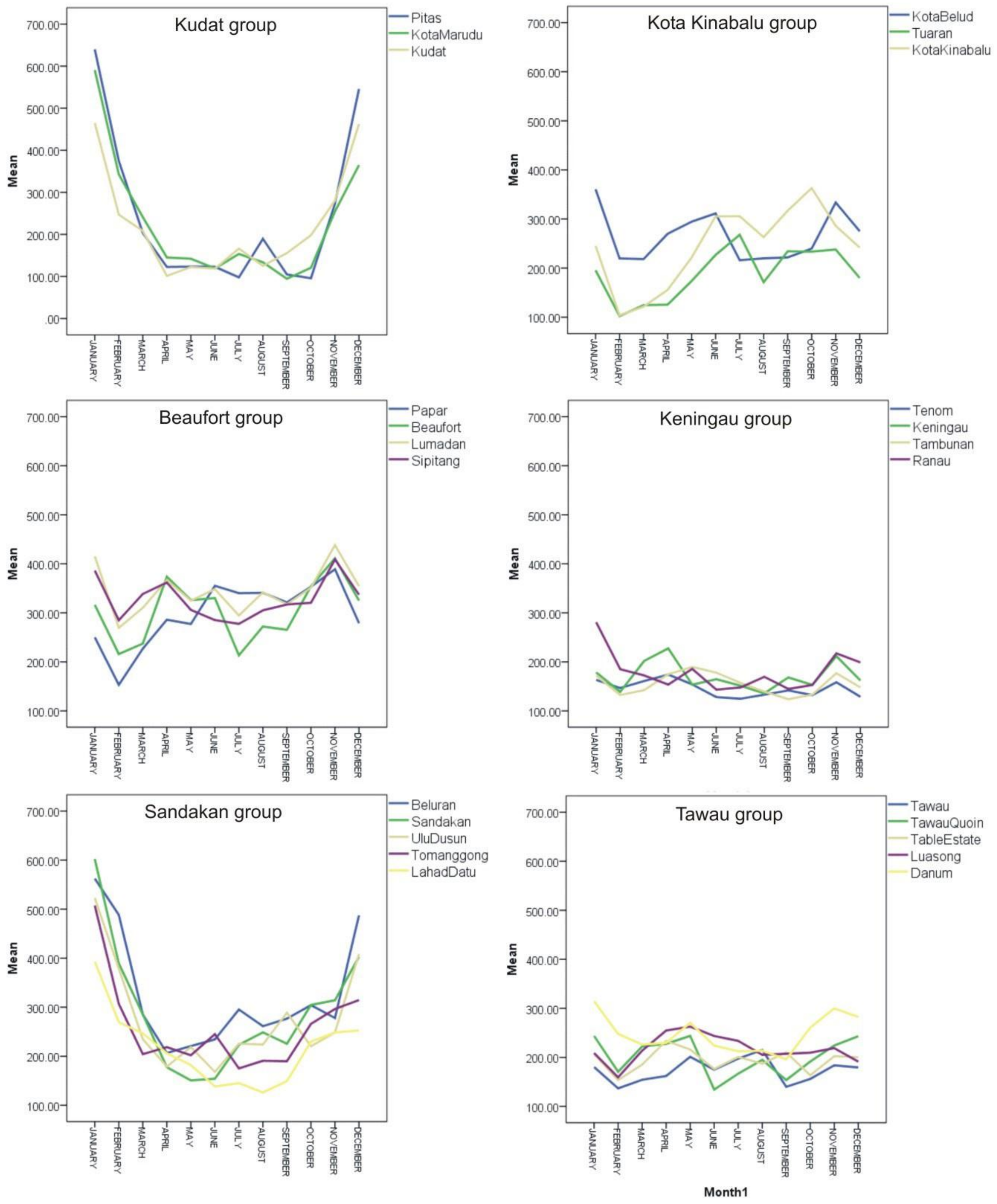

Figure 4. Monthly mean precipitation trend of each grouping.

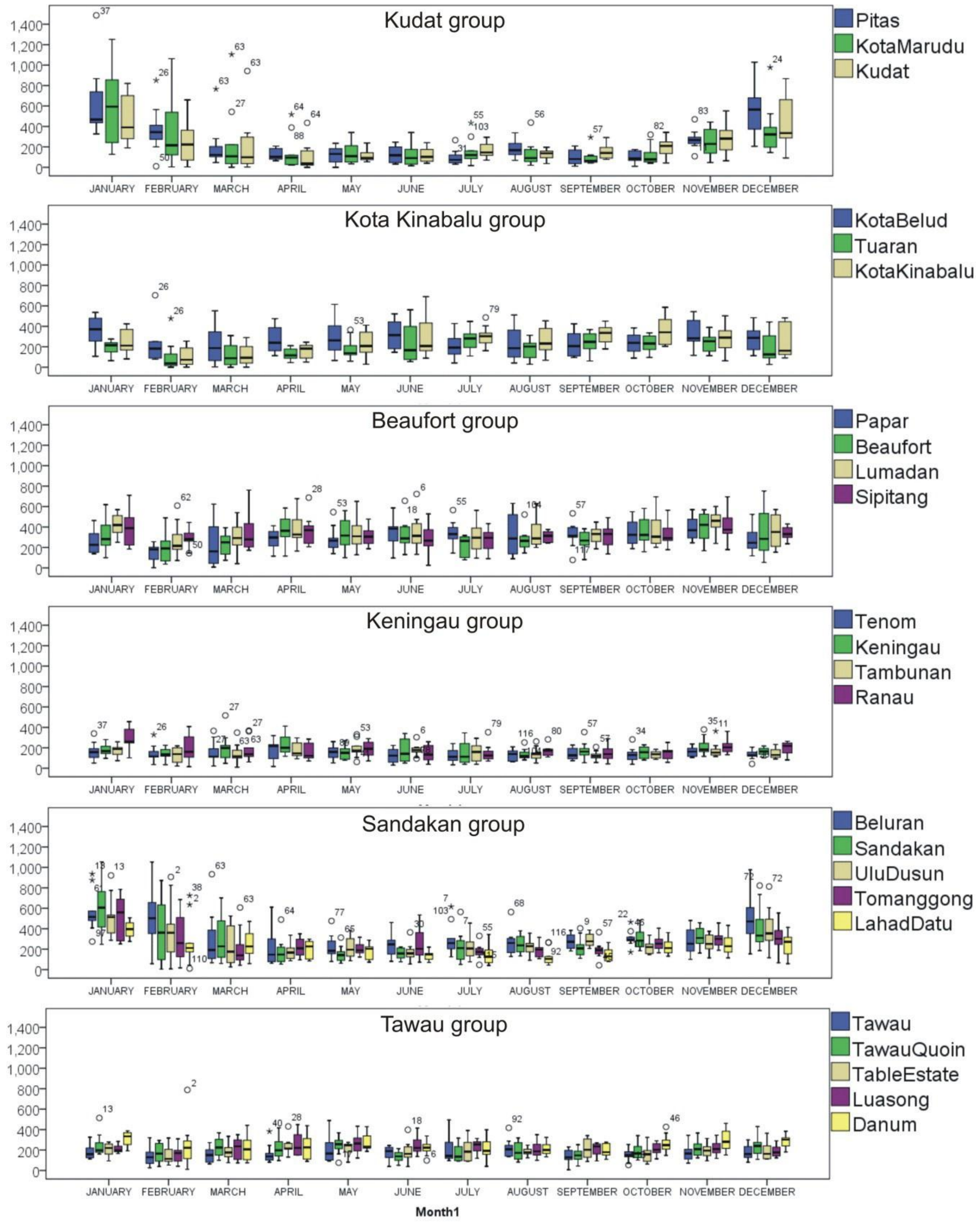

Figure 5. Stem plots for visualizing the monthly precipitation mean averages and variances. Outliers were not removed in plot computation as they represent anomaly events which are an inherent part of the local natural meteorological system.

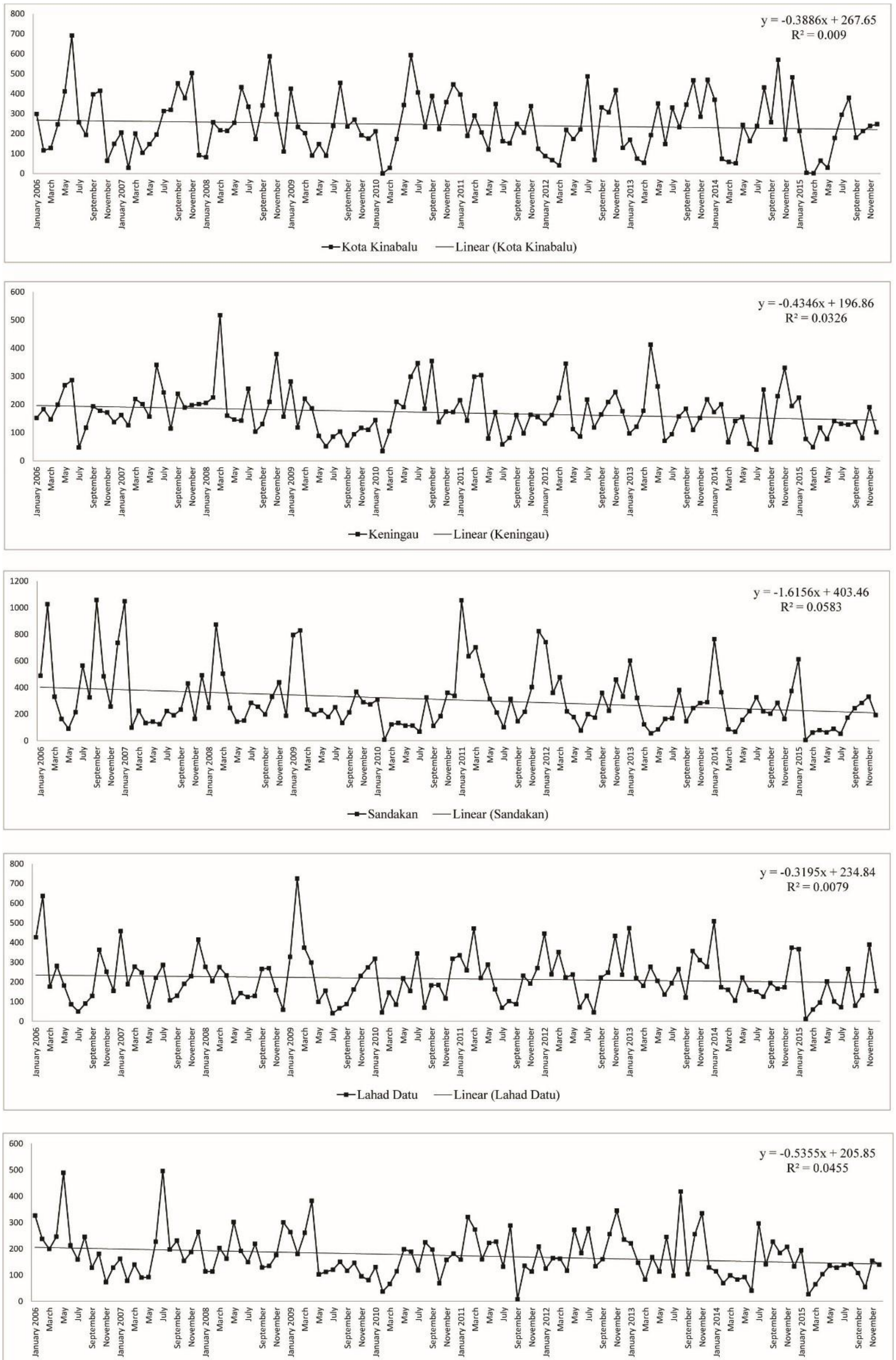

Figure 6. Negative trend lines computed from individual stations show all major towns in Sabah were experiencing noticeable reduction in precipitation from 2005 to 2016.

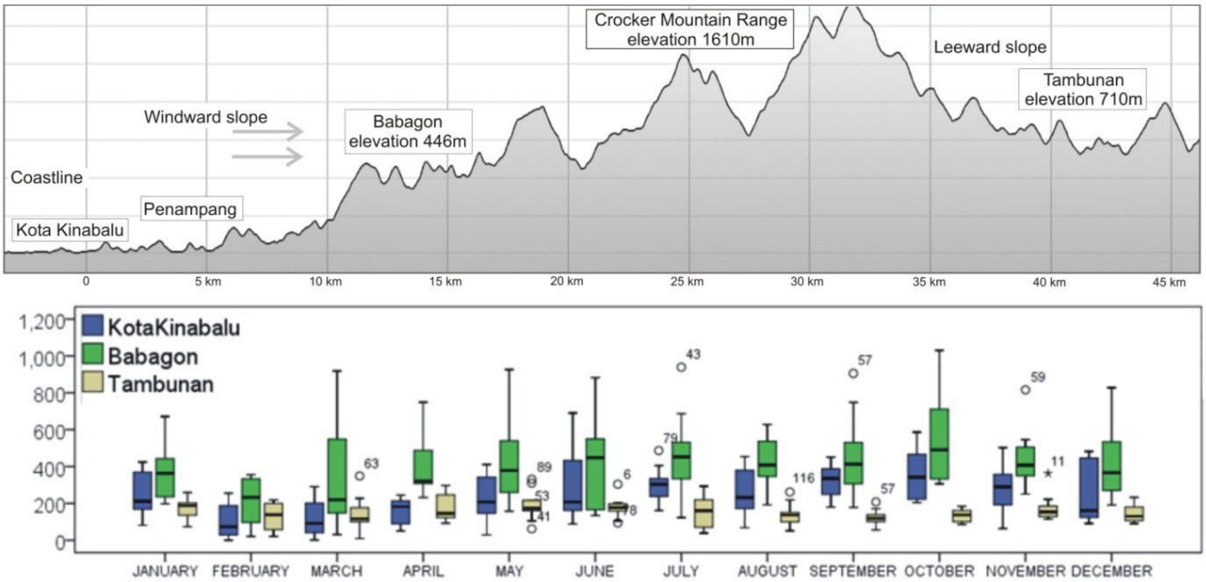

Figure 7. Elevation profile (top) of Kota Kinabalu-Babagon-Tambunan cross section and stem plot comparison (bottom) of precipitation mean values. Due to its topographic characteristic, Babagon consistently recorded higher precipitation values than Kota Kinabalu although it is barely 15 km away from the city. As expected, Tambunan which is located in the leeward position recorded lower precipitation values.

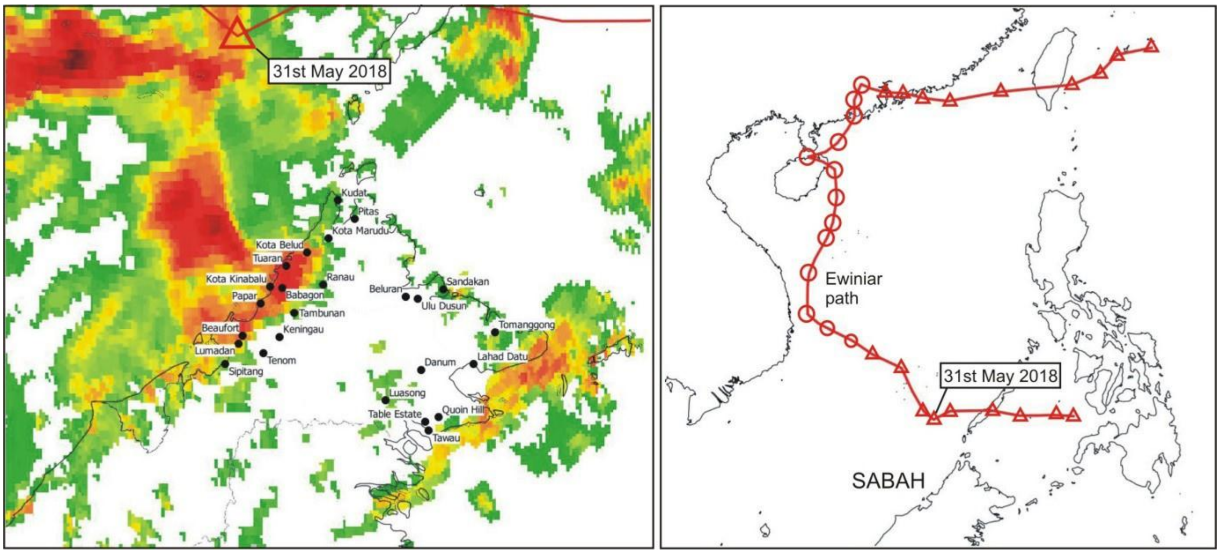

Figure 8. Visual modelled from Global Precipitation Measurement and Microwave Imager (GPM-GMI) dataset (NOAA, 2018b) showing precipitation shock (region marked red) in Sabah's west coast region on 31st May 2018 that was induced by Ewiniar typhoon.

Figure 9. The precipitation shock induced by the Ewiniar typhoon has caused flood in Donggongon, Penampang, a suburban district of Kota Kinabalu city that is located in the foothills of Babagon. This image was recorded on 1st June 2018.

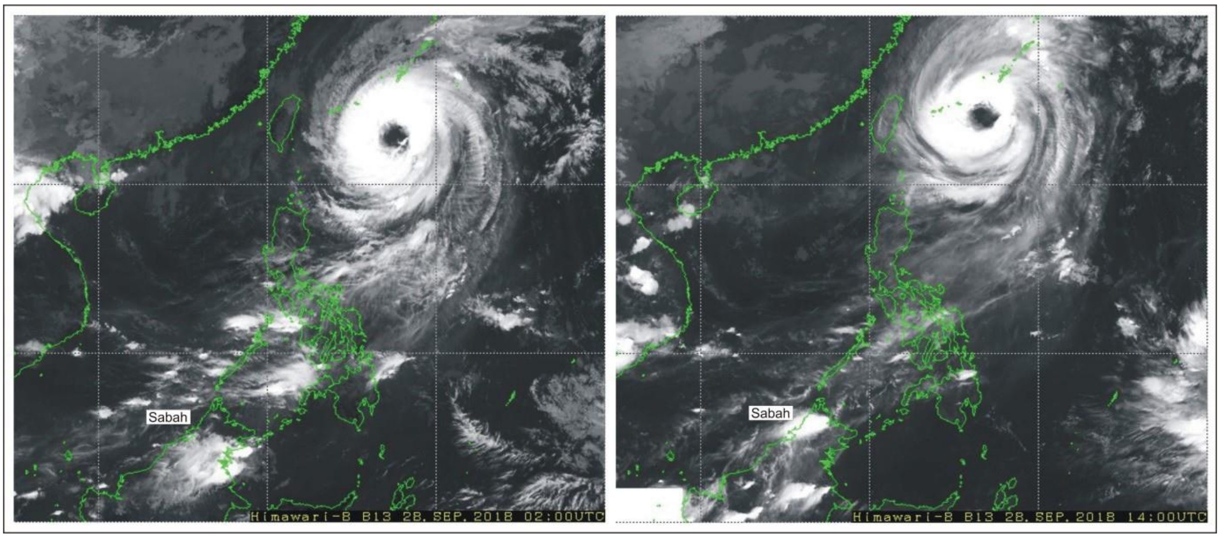

Figure 10. Visuals from Himawari satellite showing the comma-shaped Trami typhoon swirl was drawing heavy clouds into north Borneo at UTC0200 (left) and UTC1400 (right) on 28th September 2018 period (Japan Meteorological Agency, 2018). Similar episodes may have struck Sabah with precipitation shocks during the 2005-2016 period and explain some outliers in the statistical plots.

A new record of *Spodoptera litura* (Noctuidae, Hadeninae) defoliating *Begonia ruthiae* and *Begonia diwolii*

D.M. Tann[1], R. Japir[2] & A.Y.C. Chung[2]*

[1]*Faculty of Science and Natural Resources, Universiti Malaysia Sabah, UMS Road, 88400 Kota Kinabalu, Sabah, Malaysia*
[2]*Forest Research Centre, Sabah Forestry Department, P. O. Box 1407, 90715 Sandakan, Sabah, Malaysia*
**Author for correspondence. Email: Arthur.Chung@sabah.gov.my*

Begonia is one of the largest genera of flowering plants in the world (Frodin 2004). The genus is estimated to comprise more than 1,500 species worldwide, with almost 200 named species in Borneo (Kiew *et al*. 2015). *Begonia ruthiae* is one of the most beautiful Bornean begonias. The leaves are velvety on the upper surface, almost blackish green contrasting with a bright silvery margin, and deep magenta on its underneath surface. It is a Sabah endemic that is found only in Danum Valley Conservation Area in deep shade on banks, or on raised roots or wet rocks along the river in lowland dipterocarp forests (Kiew *et al*. 2015).

Begonia diwolii has plain green leaves on the upper surface and is deep magenta underneath. It is found on vertical and horizontal rock faces from the cliff base in deep shade to light shade near the summit of limestone hills along the Segama River in Lahad Datu, (Kiew 2001). This species is also endemic to Sabah.

In May, 2019, a caterpillar was spotted feeding voraciously on the leaves of *B. diwolii* at the Forest Research Centre (FRC) nursery in Sepilok. It was collected and reared in captivity. The specimen turned out to belong to the same caterpillar species as another caterpillar caught in 2017 that fed on *B. ruthiae* (Figure 1). To confirm this, photographs of the previous caterpillar was compared with the current caterpillar, and some *B. ruthiae* leaves were given to the caterpillar as an experiment. Interestingly, the caterpillar preferred *B. ruthiae* leaves over *B. diwolii* leaves as it did not feed on *B. diwolii* leaves until all *B. ruthiae* leaves were finished.

The mature caterpillar was blackish in colour with dotted reddish lines and yellow spots running down the length of its body, and reached 40 mm in length (Figure 2). It pupated after four days in captivity. The pupa was brown, measuring 15 mm in length (Figure 3). The adult emerged 10 days after pupation, with a wingspan of 32 mm and a body length of 13 mm. It was identified as a noctuid moth, *Spodoptera litura* Fabricius (Noctuidae, Hadeninae), as shown in Figures 4 & 5. Its distribution includes Indo-Australian and Pacific tropics and subtropics. According to Holloway (1989), the caterpillar of *S. litura* is mainly light or dark brown, never green. The caterpillar caught has a different colour, which is similar to the caterpillar specimen in a research by Gupta *et al*. (2015), which also has a black appearance. Thus, it can be concluded that the caterpillars of *S. litura* have many variations.

Spodoptera litura is an important pest worldwide. The caterpillar is highly polyphagous, with over 112 host plants belonging to more than 40 plant families (Ahmad *et al*. 2008). There are also records of this caterpillar as a defoliator on *Octomeles sumatrana* and *Oxalis corniculata* in Sepilok (Chey 2005 & 2007) and on *Mangifera indica* in India (Gupta *et al*. 2015). *Begonia ruthiae* and *B. diwolii* are new host plant records for the caterpillar as there are no records in previous studies, through extensive internet search. As *S. litura* can occur in high abundance with its voracious feeding habit, it is important to monitor and control its infestation at the early stage so that it will not cause any outbreak which can completely defoliate the plants within a short period. This is particularly significant for *B. ruthiae* since it is only restricted to DVCA in its natural habitat and it is difficult to propagate and manage.

ACKNOWLEDGEMENTS

The caterpillar was spotted and collected by FRC Biotechnology Section's internship student, Ng Shi Teng, at the nursery of Forest Research Centre, Sepilok. Momin Binti, Dayang Fazrinah Ag. Damit and John L. Yukang assisted in rearing and specimen preparation. Veronica Guanih and Martin Tuyok of the Biotechnology Section provided the *B. ruthiae* leaves while the scientific names of the Begonias were provided by Eyen Khoo. The first author would like to thank Dr Maria L. Lardizabal for her support.

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Figure 1. Mature caterpillar of *Spodoptera litura* foraging on the flowers and leaves of *Begonia ruthiae*.

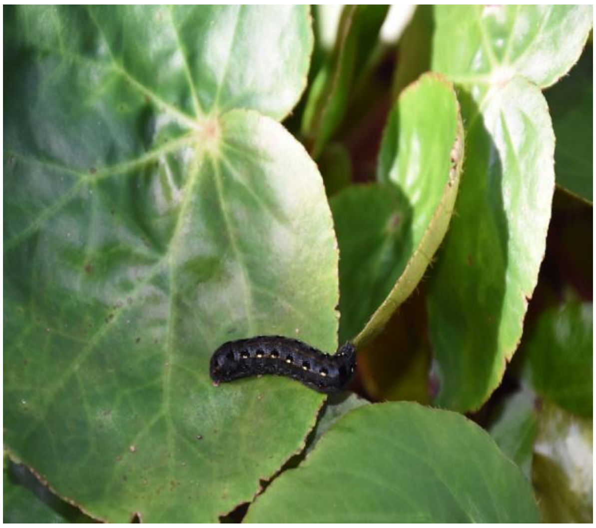

Figure 2. Close-up of the caterpillar on *Begonia diwolii* foliage.

Figure 3. Pupal case of *S. litura,* measuring 15 mm in length.

Figure 4. The adult moth of *S. litura* in natural resting position.

Figure 5. A mounted specimen of *S. litura* moth.

Inventory of terrestrial mammals and birds in Sungai Pin Conservation Area, Kinabatangan

M.A.F. Suis*, J. Miun, L. Tingkoi & R. Nilus

Forest Research Centre, Sabah Forestry Department, P.O. Box 1407, 90715 Sandakan, Sabah, Malaysia
**Author for correspondence. Email: mohdaminurfaiz.suis@sabah.gov.my*

Abstract. A rapid wildlife survey was conducted in the Sungai Pin Conservation Area, Kinabatangan from the 4th of April - 3rd of May 2019. The survey aims to update the current inventory of mammals and birds within the conservation area. These findings will serve as a baseline information for both policy makers and scientists. Camera trapping and recce transect methods were applied to record mammals and birds. A total of 17 mammal and 104 bird species were recorded throughout the survey. When merged with previous studies, the conservation area is home to at least 21 mammal and 114 bird species. Of this, 17 species were categorised as threatened species. In term of endemism, a total of six species are endemic to Borneo. At least five mammal species are found widespread in the study site, namely the pig-tailed macaque (*Macaca nemestrina*), long-tailed macaque (*Macaca fascicularis*), Bornean orang-utan (*Pongo pygmaeus morio*), bearded pig (*Sus barbatus*) and common palm civet (*Paradoxurus hermaphroditus*). The multiple habitat types in Sungai Pin Conservation Area supports many resident and migratory birds with varied feeding preferences. Additionally, this conservation area harbours seven hornbill species: white-crowned hornbill (*Berenicornis comatus*), wrinkled hornbill (*Rhabdotorrhinus corrugatus*), black hornbill (*Anthracoceros malayanus*), wreathed hornbill (*Rhyticeros undulatus*), bushy-crested hornbill (*Anorrhinus galeritus*), oriental pied hornbill (*Anthracoceros albirostris*) and rhinoceros hornbill (*Buceros rhinoceros*). A number of threats to the wildlife and their potential mitigative measures are highlighted.

Keywords: rapid wildlife survey, Sawit Kinabalu Sdn. Bhd., upper Kinabatangan River

INTRODUCTION

Borneo is home to at least 247 land mammals and 673 birds (Phillipps & Phillipps 2014, Phillipps & Phillipps 2018). These figures included a significant number of rare, threatened, endangered and endemic species. Wildlife conservation in Borneo is generally pressured by anthropogenic forces such as land-use change, habitat destruction, illegal hunting and trade, as well as over-hunting.

As of 2016, Sabah has about 1.9 million ha of totally protected areas of which 9% is designated for wildlife refugia (i.e. Wildlife Reserve, Wildlife Sanctuary and Wildlife Conservation Area) (SFD 2017). In addition to these areas, there are areas located outside of legally protected areas that are set aside as conservation areas or also internationally known as Other Effective Area-based Conservation Measures (OECM) that are privately own land (e.g. conservation area, community-used zone, steep areas, riparian reserve and municipal catchments). Target 11 of the Strategic Plan on Biodiversity referred OECMs as additional and complementary to protected areas (IUCN-WCPA 2019).

Sawit Kinabalu Sdn. Bhd. has set aside 2,632 ha of its palm oil production estate in Sungai Pin, which is located along the upper Kinabatangan River for conservation purposes. This area is called Sungai Pin Conservation Area (SPnCA). In the last two decades, the Kinabatangan floodplain landscape has been the centre of some major conservation projects, namely WWF-Malaysia's Kinabatangan-Corridor of Life, Lower Kinabatangan-Segama Wetlands Ramsar Site, Sabah EU-REDD+ and Kinabatangan 'RiLeaf'.

Furthermore, the floodplain landscape has been a focal research site for local and international scientists. However, much of the published studies have emphasized on the lower Kinabatangan areas (see Boonratana, 2003, Estes *et al*. 2012, Otani *et al*. 2012, Harun *et al*. 2015, Matsuda *et al*. 2018). A preliminary survey on mammals and birds was conducted in SPnCA (Alfred 2014). The key finding of the survey was the presence of an isolated Bornean orang-utan population with an estimated population size of 37 individuals.

This paper consolidates previous and recent surveys on mammals and birds in SPnCA that was carried out from the 4th of April – 3rd of May 2019. The surveys were part of a multidisciplinary scientific expedition undertaken by the Forest Research Centre of the Sabah Forestry Department. This study aims to update the current inventory of mammals and birds in SPnCA as well as to establish baseline information for the prescription of SPnCA's management plan and for the advancement of research. Potential and imminent threats faced by mammals and birds of the SPnCA and their conservation significant are also highlighted.

MATERIALS AND METHODS

Study site

The SPnCA lies between longitudes 117° 52' – 117° 57'E and latitudes 05° 29' – 05° 22'N (Figure 1). It is accessible from the Sandakan-Lahad Datu main road and approximately 30 km southeast from Kota Kinabatangan. The site encompasses a total of 2,632 ha of land area and at least 27 km of its boundary is alongside the Kinabatangan River. It is also in the vicinity of a few forested areas, including Pin Supu Forest Reserve (PSFR) and Sungai Kinabatangan Valley Wildlife Sanctuary.

The topographical feature of the conservation area is largely flat and the lowest elevation on the eastern part of the area is about 5 m a.s.l. There are several isolated hills and the highest elevation (127 m a.s.l.) is found at Bukit Mansuli. Major soil associations of the SPnCA are Kinabatangan and Tuaran that largely are flat and seasonally inundated during rainy seasons. Other soil associations, such as Lokan and Kretam are mostly dryland.

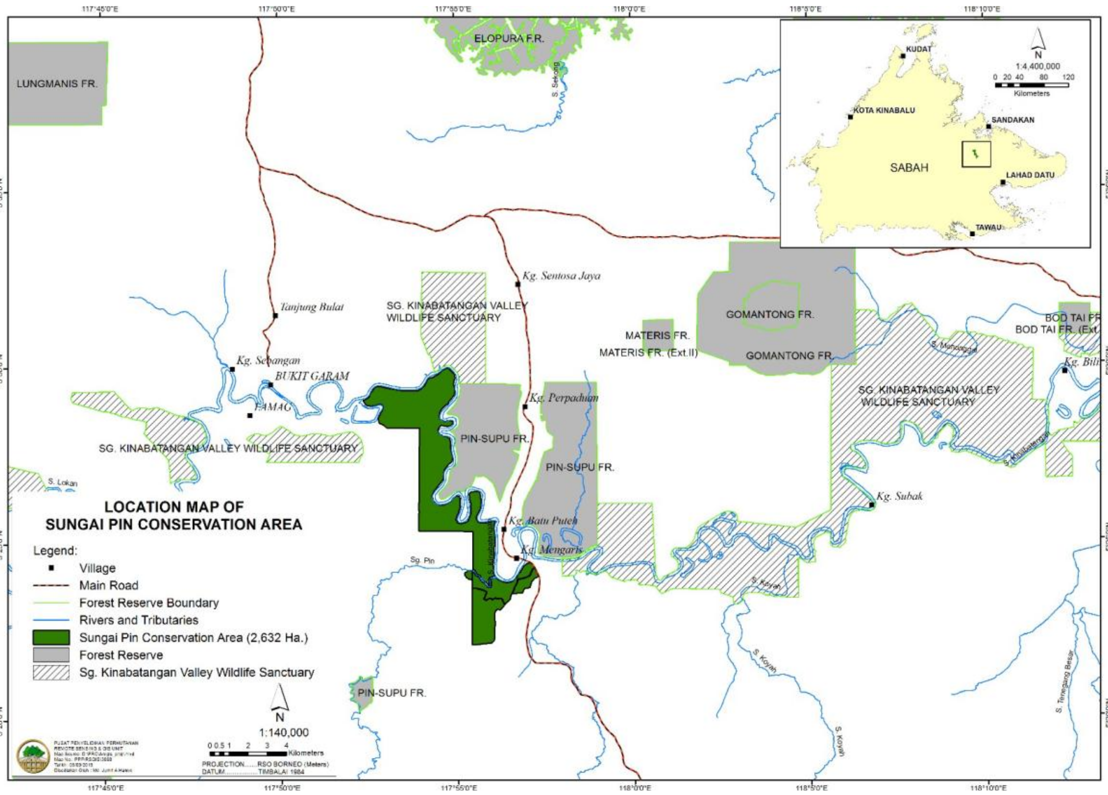

Figure 1. Location map of the Sungai Pin Conservation Area in the Kinabatangan district. Inset is a map of Sabah showing the location of the study site.

Almost the entire SPnCA has been subjected to anthropogenic disturbances, such as timber extraction activities and commercial plantation projects in the past with the exception of the upper hill of Bukit Mansuli which still has a pocket of old growth forest. Currently, there are at least four habitat types within the SPnCA: lowland mixed dipterocarp forest, lowland seasonal freshwater swamp forest, riparian forest and cultivated vegetations. The riparian forest can be found alongside the Kinabatangan River, whereas the lowland mixed dipterocarp forest is confined to Bukit Mansuli and Bukit Durian. The lowland seasonal freshwater swamp forest is the dominant forest ecosystem in this conservation area. Cultivated vegetations are scattered around the area.

Data collection on mammals

This study applied two methods to spot and record mammals and birds of the SPnCA: camera trapping and recce transect.

Camera trapping method

A total of seven cameras (Bushnell Trophy Cam HD Aggressor No Glow Model: 119776C) were deployed. Each of them was designated to seven camera-trap stations which were at least 300 m apart (Table 1). The location of camera-trap stations was pre-determined, intended to maximise the mammal detection rate. The distribution of the camera-trap stations covered Bukit Mansuli (two stations), Bukit Durian (one station), northern side near Tanjung Bulat (two stations) and forest edges in the center of the conservation area (two stations). The altitude of the stations ranged from 13 – 126 m a.s.l.

Table 1. Details of camera trapping sampling period, location and habitat type throughout the scientific expedition to the Sungai Pin Conservation Area, Kinabatangan.

Camera Label	Date of Installation	Date of Retrieval	Trap-nights	Coordinates (Datum: WGS 84)		Altitude (m)	Habitat Type
				Latitude	Longitude		
CT 01	4th April 2019	3rd May 2019	29	N 05°24′13.7″	E 117°57′10.1″	126	LMDF
CT 02	4th April 2019	3rd May 2019	29	N 05°24′06.9″	E 117°57′03.0″	115	LMDF
CT 03	5th April 2019	3rd May 2019	28	N 05°24′02.4″	E 117°55′32.1″	58	LMDF
CT 04	5th April 2019	1st May 2019	26	N 05°24′37.3″	E 117°55′35.9″	17	LSFSF
CT 05	5th April 2019	3rd May 2019	28	N 05°26′29.8″	E 117°54′01.4″	13	LSFSF
CT 06	6th April 2019	30th April 2019	24	N 05°27′56.3″	E 117°53′28.3″	17	LSFSF
CT 07	6th April 2019	30th April 2019	24	N 05°28′11.9″	E 117°53′28.2″	18	LSFSF

Note: Forest ecosystem, LMDF – lowland mixed dipterocarp forest, LSFSF – lowland seasonal freshwater swamp forest.

The camera trapping survey commenced from the 4th of April 2019 – 3rd of May 2019. All cameras were positioned at the base of trees, approximately 0.5 m above the ground to ensure good photograph of mammals. The cameras are motion-sensitive in that they are triggered to take photos and videos every time movement is detected. No baits were used and the cameras were set to operate for 24 hours, continuously.

Recce transect method

A total of seven recce or reconnaissance transects were surveyed with total distance surveyed of 20.21 km, but not carried out on consecutive days due to difficulty in finding access point from adjacent land-use (Table 2). Each survey usually took about 2 – 5 h daily and initiated before 8.30 am and ended at noon. Both direct observations (i.e. opportunistic sightings) and indirect signs (i.e. footprints, dungs or droppings, calls and nests) were applied, accordingly.

Data collection on birds

The birds of SPnCA were surveyed based on the species-list method (Mackinnon & Phillipps 1993). The survey utilized the same transects for the mammal surveys (Table 2). All observed bird species were registered through direct sightings or indirect sightings into consecutive lists of 10 species. The lists were compiled cumulatively while steadily surveying the routes and intermittently stopping to spot other bird species. New observations of birds were occasionally added by traversing slightly off the transects.

Table 2. Details of recce transect sampling period, location and habitat type throughout the scientific expedition to the Sungai Pin Conservation Area, Kinabatangan.

Transect Label	Date	Duration	Coordinates (Datum: WGS 84)		Distance Covered (km)	Habitat Type
			Starting Point	End Point		
1	8th April 2019	10.00 am – 11.30 am	N 05°24’12.7” E 117°57’19.7”	N 05°24’00.4” E 117°56’58.9”	0.75	LMDF
2	11th April 2019	9.10 am – 12.10 pm	N 05°24’07.5” E 117°55’29.0”	N 05°24’37.5” E 117°55’35.7”	1.10	LMDF
3	12th April 2019	8.30 am – 11.50 am	N 05°26’16.8” E 117°54’05.6”	N 05°26’24.7” E 117°54’05.6”	1.26	LSFSF
4	30th April 2019	9.35 am – 10.30 am	N 05°27’43.5” E 117°53’21.0”	N 05°28’11.3” E 117°53’28.3”	1.00	LSFSF
5	1st May 2019	7.40 am – 11.15 am	N 05°24’07.3” E 117°55’28.3”	N 05°24’37.3” E 117°55’35.9”	1.10	LMDF & LSFSF
6	2nd May 2019	8.00 am – 12.00 pm	N 05°24’26.5” E 117°57’02.6”	N 05°26’24.9” E 117°55’50.7”	14.00*	RF
7	3rd May 2019	7.50 am – 10.40 am	N 05°26’17.2” E 117°53’48.1”	N 05°26’29.8” E 117°54’01.3”	1.00	LSFSF

Note: Forest ecosystem, LMDF – lowland mixed dipterocarp forest, LSFSF – lowland seasonal freshwater swamp forest, RF – riparian forest. * - Transect was surveyed using a boat.

Data analysis

Identification of taxa

The species of observed mammals and birds were identified directly in the field and occasionally, by referring to field guides on mammals and birds (Phillipps & Phillipps 2014, Phillipps & Phillipps 2018). The local protection status of each species was determined by referring to the Schedules 1, 2 and 3 in the Sabah Wildlife Conservation Enactment (1997) while their extinction risks based on the IUCN Red List of Threatened Species (IUCN 2019). All mammalian and avian data obtained throughout this rapid survey were analysed separately.

Analysis of photographic data

The temporal autocorrelation of photo-capture events was minimized by following the methodology in Bernard *et al*. (2013). The camera detection rate of each mammal species and all species combined were determined based on the following equation:

$$\textit{Camera detection rate} = \frac{\textit{Number of independent photographs}}{\textit{Total trap nights}} \times 100$$

The sampling completeness ratio was calculated using EstimateS v9.1.0 (Colwell 2013). The sampling effort was presumably adequate when the ratio is equal to 1, reflecting that all species present in the area had been recorded. In order to assess the sampling efficiency, species accumulation curves were constructed based on the sample-based refraction method with 100 randomizations. Furthermore, R (R Development Core Team 2008) was used to extrapolate the sampling effort (based on the number of independent photographs) by a factor of five to estimate the sampling saturation point. The estimated species number is the average value of four different estimators (i.e. abundance-based coverage estimator (ACE), Chao1 estimator, Jack1 estimator and Bootstrap estimator).

Analysis of avian data

Since the information derived from the species-list method is an incidence data, Good-Turing theory was applied through online software SUPERDUPLICATES (Chao *et al.* 2017). Prior to the analysis, the total observed species, total number of 10-species lists, total number of uniques (birds recorded in only one list) and total number of super-duplicates (birds recorded in two or more lists) were determined.

RESULTS

Mammals and their distributions

The latest survey in SPnCA has recorded 17 mammal species. Of this, 12 species (70.6%) were detected through the camera trapping method with a calculated total of 188 camera trap-nights. In addition, 12 species were recorded while surveying the recce transects with a total distance of 20.21 km. The list of mammals compiled from both camera and recce transect observed seven overlapped species (41.2%).

The overlapped mammal species recorded in this study and in the previous study by Alfred (2014) was up to nine species. The list from this study, however, did not include proboscis monkey (*Nasalis larvatus*), Malayan porcupine (*Hystrix brachyura*), Prevost's squirrel (*Callosciurus prevostii*) and large treeshrew (*Tupaia tana*). This brings the total number of documented mammals within the SPnCA to 21 species (Table 3).

There were five species recorded in all three habitat types namely, the common palm civet, bearded pig, Bornean orang-utan, pig-tailed macaque and long-tailed macaque (Table 3). As this study was a short-term survey, the estimated mammal distribution is non-exhaustive. Mammals observed from this study belonged to five orders, 13 families and 16 genera. Almost all of these mammals have been assessed by the IUCN Red List of Threatened Species: two species were listed as Critically Endangered, one species categorised as Endangered, five species were Vulnerable and eight species were placed under Least Concern (Table 3). Only 15 species were listed either under the Schedules 1, 2, or 3 of the Sabah Wildlife Conservation Enactment 1997 (Table 3). The Bornean orang-utan, Bornean gibbon (*Hylobates muelleri*) and least pygmy squirrel (*Exilisciurus exilis*) are Bornean endemics.

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Table 3. Summary of mammals recorded throughout the rapid survey in the Sungai Pin Conservation Area, Kinabatangan.

Order	Family	Scientific name	Vernacular name	Forest ecosystem	Detection method	2014 Survey (Alfred, 2014)	2019 Survey (This study)	IUCN	Sabah Wildlife Conservation Enactment 1997
Carnivora	Ursidae	*Helarctos malayanus*	Sun bear	LSFSF	CT		√	VU	Schedule 1
	Prionodontidae	*Prionodon linsang*	Banded linsang	LMDF	CT		√	LC	Schedule 2
	Viverridae	*Viverra tangalunga*	Malay civet	LMDF & LSFSF	CT		√	LC	Schedule 2
	Mephitidae	*Mydaus javanensis*	Sunda stink-badger	LMDF	CT	√	√	LC	Schedule 2
	Felidae	*Prionailurus bengalensis*	Leopard cat	LSFSF	RT		√	LC	Schedule 2
	Viverridae	*Paradoxurus hermaphroditus*	Common palm civet	LMDF, LSFSF & RF	CT & RT	√	√	LC	Schedule 2
	Mustilidae	*Aonyx cinerea*	Asian small-clawed otter	LSFSF	RT		√	VU	Schedule 2
Artiodactyla	Suidae	*Sus barbatus*	Bearded pig	LMDF, LSFSF & RF	CT & RT	√	√	VU	Schedule 3
	Cervidae	*Tragulus napu*	Greater mousedeer	LSFSF	RT		√	LC	Schedule 3
	Cervidae	*Rusa unicolor*	Sambar deer	LMDF & LSFSF	CT & RT	√	√	VU	Schedule 3
Pholidota	Manidae	*Manis javanica*	Sunda pangolin	LMDF	CT	√	√	CR	Schedule 1
Primates	Hominidae	*Pongo pygmaeus morio*	Bornean orang-utan*	LMDF, LSFSF & RF	CT & RT	√	√	CR	Schedule 1
	Cercopithecidae	*Macaca nemestrina*	Pig-tailed macaque	LMDF, LSFSF & RF	CT & RT	√	√	VU	Schedule 2
	Cercopithecidae	*Nasalis larvatus*	Proboscis monkey*	RF	RT	√		EN	Schedule 1
	Hylobatidae	*Hylobates muelleri*	Bornean gibbon*	LMDF & LSFSF	RT	√	√	EN	Schedule 2
	Cercopithecidae	*Macaca fascicularis*	Long-tailed macaque	LMDF, LSFSF & RF	CT & RT	√	√	LC	Schedule 2
Rodentia	Sciuridae	*Callosciurus notatus*	Plaintain squirrel	LMDF & LSFSF	CT & RT		√	LC	Not Listed
	Sciuridae	*Callosciurus prevostii*	Prevost's squirrel	LMDF & LSFSF	RT	√		LC	Not Listed
	Sciuridae	*Exilisciurus exilis*	Least pygmy squirrel*	LMDF & LSFSF	RT		√	DD	Not Listed
	Hystricidae	*Hystrix brachyura*	Malayan porcupine	LMDF & LSFSF	CT	√		LC	Schedule 3
Scandentia	Tupaiidae	*Tupaia tana*	Large treeshrew	LMDF & LSFSF	RT	√		LC	Not listed

Note: IUCN Red List of Threatened Species, CR – critically endangered, EN – endangered, VU – vulnerable, NT – near threatened, LC – least of concern. Sabah Wildlife Conservation Enactment 1997, Schedule 1 – totally protected animals, Schedule 2 – protected animals, Schedule 3 – game animals. Detection method, CT – detected via camera trapping method; RT – detected via recce transect method. Forest ecosystem, LMDF – lowland mixed dipterocarp forest, LSFSF – lowland seasonal freshwater swamp forest, RF – riparian forest. * - Endemic to Borneo.

Mammals recorded from the camera-trap stations

Of the 672 animal photos that were captured, 358 were treated as independent photographs (Figure 2). Camera trapping effort of each camera-trap station was 27 trap-nights, on average. The most detected mammal species was the bearded pig with 73.94 independent photographs/100 camera trap-nights, followed by the long-tailed macaque (52.66 independent photographs/100 camera trap-nights) and the pig-tailed macaque (43.62 independent photographs/100 camera trap-nights) (Table 4). These three species, including the common palm civet, were photographically-captured at least once in all camera-trap stations. Five mammal species were recorded once, namely the sun bear (*Helarctos malayanus*), banded linsang (*Prionodon linsang*), Sunda stink-badger (*Mydaus javanensis*), Sunda pangolin (*Manis javanica*) and Bornean orang-utan.

The sampling completeness ratio was 0.68. This proportion is based on the total observed mammals of 12 species and the mean estimated species number of 17.70 (ACE = 23.64; Chao1 estimate = 16.99, Jack1 estimate = 16.29; Bootstrap estimate = 13.89). Both species accumulation curve and species richness estimator implied that there were many undetected species (Figure 3). The extrapolated species accumulation curve levelled off at about 18 species (after approximately 1,800 independent photographs have been recorded) (Figure 3).

Total observed bird species

This study managed to accumulate 33 lists of 10-species lists of birds from the rapid survey. The lists comprised of 104 species, 84 genera and 43 families (Appendix 1). Of the 104 bird species, only eight were treated as threatened species, namely Storm's stork (*Ciconia stormi*), white-crowned hornbill, wrinkled hornbill, black hornbill, Javan myna (*Acridotheres javanicus*), large green-pigeon (*Treron capellei*), Wallace's hawk-eagle (*Nisaetus nanus*) and wreathed hornbill. The remaining birds were either species of Near Threatened, Least Concern or have not been evaluated. Only 28 bird species were listed as "protected animals" under the Sabah Wildlife Conservation Enactment 1997.

The total number of unique and super-duplicates were 37 and 67, respectively. The Chao2 estimated species richness of 142.7 indicated that 72.9% (104) species were observed. The species accumulation curve also progressively increased as the number of lists increases (Figure 4).

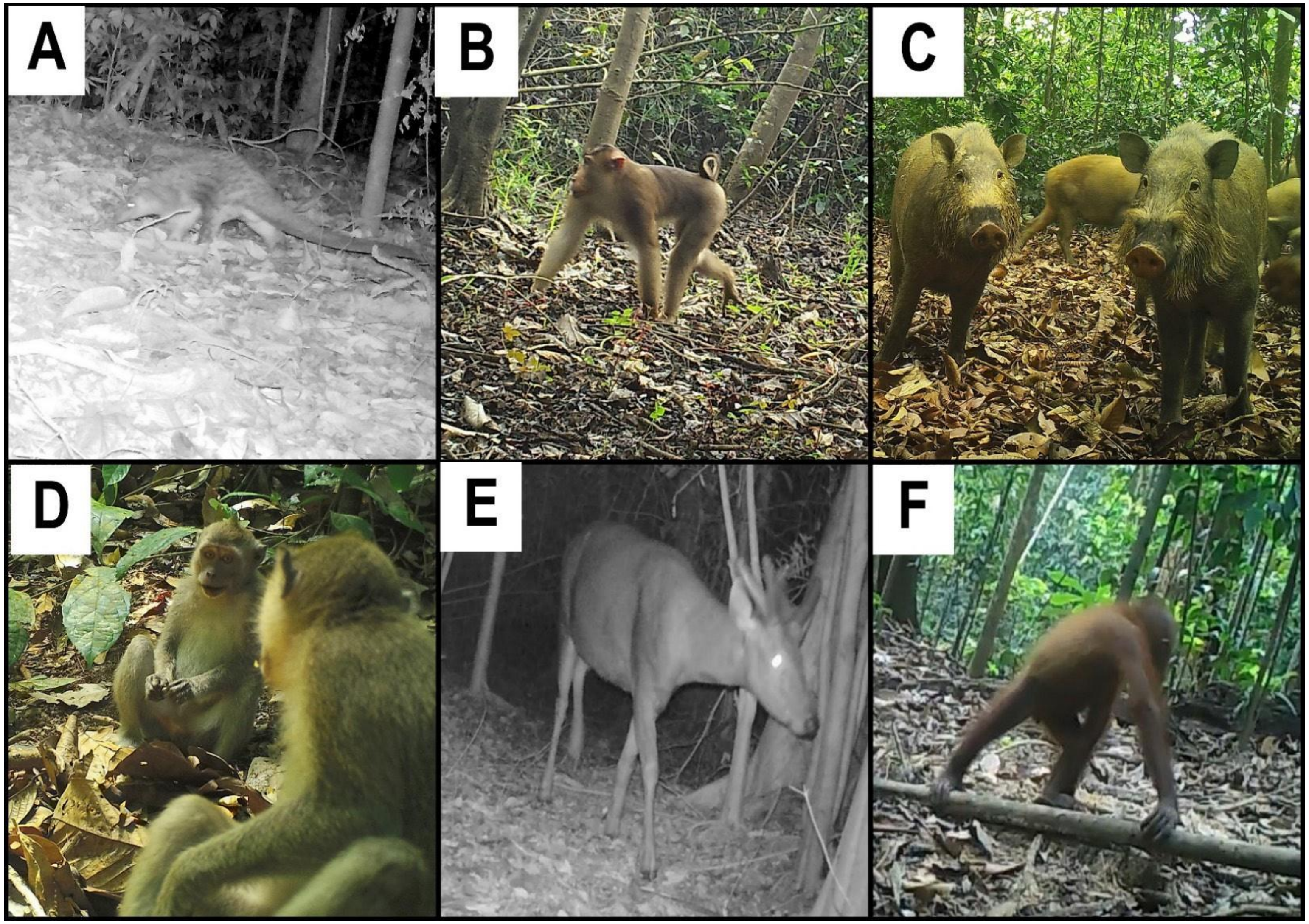

Figure 2. Some of the photographic data captured through camera trapping method in the Sungai Pin Conservation Area, Kinabatangan. **A** – Sunda pangolin; **B** – Pig-tailed macaque; **C** – Bearded pig; **D** – Long-tailed macaque; **E** – Sambar deer; **F** – Bornean orang-utan.

Table 4. Camera detection rate (number of independent photographs/100 camera trap-nights) of each mammal species recorded through camera trapping method in the Sungai Pin Conservation Area, Kinabatangan.

No.	Species	Camera Detection rate
1.	Bearded pig	73.94
2.	Long-tailed macaque	52.66
3.	Pig-tailed macaque	43.62
4.	Common palm civet	9.04
5.	Malay civet	5.32
6.	Plaintain squirrel	2.13
7.	Sambar deer	1.06
8.	Sun bear	0.53
9.	Banded linsang	0.53
10.	Sunda stink-badger	0.53
11.	Sunda pangolin	0.53
12.	Bornean orang-utan	0.53

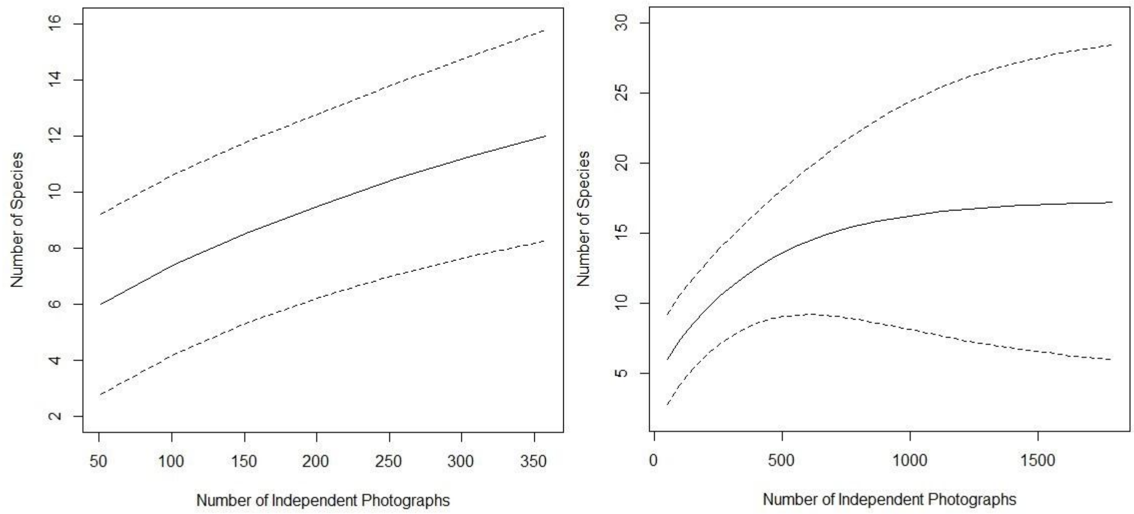

Figure 3. Species accumulation curves (solid line) of mammals and their 95% confidence intervals (dash lines) from the photographic data; (Left) based on the observed data of 358 independent photographs; and (Right) based on the extrapolated sampling efforts.

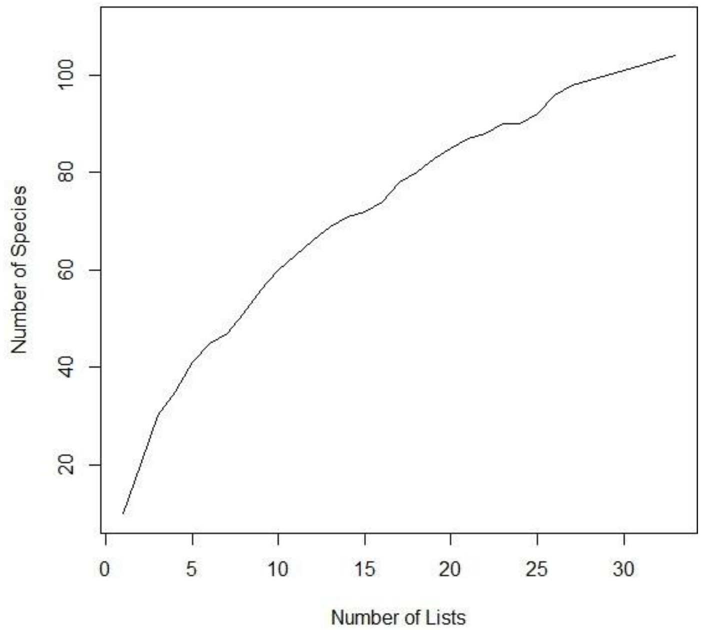

Figure 4. Species accumulation curves of birds based on the observed data of 104 species and the 33 registered 10-species lists.

DISCUSSION

Mammals of the Sungai Pin Conservation Area

By combining the findings of the present study with Alfred (2014), the total documented mammals of the SPnCA is 21 species (Table 3). The figure is however, less than the total documented mammals of the PSFR, with 36 species (SFD 2015). The high number of mammals recorded in the PSFR can be linked to a longer survey period (>12 months) and a larger total land area (4,696 ha). Therefore, future mammal surveys should be improved in several aspects (i.e. extended sampling period and wider sampling area).

Camera trapping and recce transect methods evenly contributed to the total observed mammal species of this study. Mammals recorded by the camera-traps were mostly ground-dwelling species (e.g. boars and cervids). The usage of camera-traps may not be an effective approach if the target species are canopy-dwelling mammals, for example treeshrews, squirrels, bats and primates.

The recce transect method was applied to complement the camera trapping survey. The former is suitable in detecting both terrestrial and arboreal mammals, as demonstrated in this study. For instance, only one independent photograph of Bornean orang-utan was recorded by the camera-trap as opposed to the discovery of 33 nests of the same species along the recce trails. There were four species of primates recorded in this study, three of which were registered by both approaches except for the Bornean gibbon which had only been observed during the recce transect survey.

The boat-based survey was carried out from the KOPEL jetty but there were no unequivocal signs of proboscis monkey at the SPnCA side. Many studies (e.g. Matsuda *et al*. 2018, Boonratana 2013, Stark *et al*. 2012, Sha *et al*. 2008) reported the presence of this primate species along the Kinabatangan River. Perhaps, the lack of detection of proboscis monkey is due to the narrow sampling area of this study.

The bearded pig, long-tailed macaque and pig-tailed macaque were the most detected mammals in all camera-trap stations. The high camera detection rate of the bearded pig was expected. Love *et al*. (2018) highlighted the resilience of bearded pigs in both secondary forest and oil palm plantations along the Kinabatangan River. This terrestrial mammal may also have benefitted from the mass flowering and fruiting events which were induced by the prolonged drought, supplying plentiful food for the boar.

Even in the recce transect survey, numerous signs of pig-tailed macaque and long-tailed macaque were recorded. A single individual of long-tailed macaque with an unusually large body size was spotted. This individual might be a hybrid between the two macaques. Although this claim has not been scientifically proven, hybrids between the two species had been documented in the Sepilok Orangutan Rehabilitation Centre in Sepilok (Phillipps & Phillipps 2018).

The low camera detection rate of other mammals might be a result of non-random placement of the field equipment. No camera-traps were installed at the riverbanks due to safety and theft concerns. Otherwise, relatively higher detection rate of Asian small-clawed otter (*Aonyx cinerea*) along the river could be expected (see Hussain *et al*. 2011).

Birds of the Sungai Pin Conservation Area

Due to time constraints, the species-list method was applied to rapidly survey birds of the SPnCA. Through this method, a total of 104 species were registered. The total number of recorded birds is relatively high when compared to other studies focused on the SPnCA and its adjacent areas. Both Prudente (2009) and Alfred (2014) recorded 79 species of birds in the PSFR and 34 species in the SPnCA, respectively. In the case of SPnCA, at least 10 species were not encountered in the present study including the sooty-capped babbler (*Malacopteron affine*) and the white-throated fantail (*Rhipidura albicollis*).

At least 11 species including the barn swallow (*Hirundo rustica*), common sandpiper (*Actitis hypoleucos*), long-tailed shrike (*Lanius schach*), northern boobook (*Ninox japonica*) and paddyfield pipit (*Anthus rufulus*) are considered as migratory birds. Some of these birds migrated from Australia to the north and return home according to their respective migration periods (Phillipps & Phillipps 2014). The majority of recorded birds in SPnCA are residents that breed in Borneo.

Of the eight hornbills in Borneo, seven species were encountered in the conservation area, namely the black, bushy-crested, oriental pied, rhinoceros, white-crowned, wreathed and wrinkled hornbills. Phillipps & Phillipps (2014) stated that the hornbills are indicator species of forest health because they are main seed dispersers of forest fruits (e.g. figs). The absence of this trophy species could lead to low fig tree population that subsequently affects the population of other forest frugivores, especially barbets, gibbons, binturongs and Bornean orang-utans.

The multiple forest ecosystems in SPnCA support many bird species with varied feeding preferences (e.g. frugivorous, granivorous, insectivorous, nectivorous, piscivorous and omnivorous). Japir *et al*. (2019) reported that insect diversity (85 species) of the SPnCA is moderately higher than other forest reserves in Sabah. The rivers and swamps of this conservation area are favourable to the banded kingfisher (*Lacedo pulchella*), black bittern (*Dupetor flavicollis*), blue-eared kingfisher (*Alcedo meninting*) and green-backed heron (*Butorides striata*). Additionally, the presence of six raptors from the family Acciptridae was a proof of a potentially complex food web in the SPnCA.

The species-list method is the best approach for a rapid bird survey within a limited time frame. This approach enabled the team to assess the sampling adequacy and estimate the bird species richness of the study site. It is also important to note that this method must involve an experienced bird surveyor for a robust assessment.

Managerial Implications

There were no signs of poaching activities (e.g. bullet cartridges, shelters and gunshot sounds) noticed throughout the survey. Nevertheless, prior to the gazettement of the SPnCA, illegal hunting activities and encroachment by trespassers were rampant (Charis Saliun, pers. comm). The secondary vegetations of the SPnCA are also prone to forest fires which will subsequently be detrimental to the habitat of mammals and birds. In addition, forest simplification and flood could pose a threat to these animals.

This study recommends seven measures to mitigate the impacts of the mentioned threats. First, retain the conservation status of the forests within the SPnCA. Second, collaborate with enforcement agencies to curb illegal activities in the conservation area (if any). Third, existing tree-planting projects should be continued to rehabilitate degraded areas within the SPnCA. However, the selection of trees should be based on the soil as well as land suitability and most importantly the selected trees could secure food supply for the wildlife.

In a concurrent research conducted by Sahlan *et al*. (2019), SPnCA is home to at least 18 fig trees (*Ficus* spp.) which may benefit the wildlife. The tree planting project must also be able to improve the forest contiguity in and around the surrounding areas of SPnCA. Fourth, a special wildlife research and monitoring unit should be established and trained, to carry out a long-term monitoring programmes for mammals and birds (e.g. once in every five years). Fifth, continuous re-enumeration and maintenance of the 17 permanent sample plots (PSPs) that were established by Nilus *et al*. (2019) to monitor the dynamics of forest ecosystems (habitat for wildlife). Sixth, increase the number of warning signages along the borders. Seventh, continuously hold environmental awareness campaigns which must include local communities as target participants.

This study proposes the Bornean orang-utan as a species of outstanding conservation value. This species is highly detectable (either by opportunistic sightings or indirect encounters) in the SPnCA. Bukit Durian and Bukit Mansuli are hotspots for this primate. This Bornean endemic is also a critically endangered species (IUCN 2019) and is one of the totally protected species under the Sabah Wildlife Conservation Enactment 1997.

Ancrenaz *et al*. (2004) estimated the total individuals of Bornean orang-utan in the Kinabatangan Wildlife Sanctuary is at 1,100. To date, there has been a lack of comprehensive surveys on the total population of this species in the SPnCA. Counting the nests through the aerial survey (by helicopter), though costly, is currently the most efficient option to estimate the Bornean orang-utan density (Phillipps & Phillipps 2018). Wildlife ecologists have devised several standard procedures for surveying and monitoring wide range of primates, including the Bornean orang-utan (see Kühl *et al*. 2008, Ancrenaz 2013).

CONCLUSION

This study has shed light on wildlife that was unrecorded previously, particularly mammals and birds. Findings of this study are crucial for policy makers to formulate effective management plan. Additionally, scientists could use the information as a baseline for the advancement of their studies. In the long run, this knowledge would enable us to understand better the biodiversity within the SPnCA.

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Appendix 1. List of birds recorded throughout the rapid survey in the Sungai Pin Conservation Area, Kinabatangan.

No.	Family	Species	English Name	IUCN	Sabah Wildlife Conservation Enactment 1997
1.	Pellorneidae	*Malacocincla abbotti*	Abbott's babbler	LC	Not listed
2.	Cisticolidae	*Orthotomus ruficeps*	Ashy tailorbird	LC	Not listed
3.	Sturnidae	*Aplonis panayensis*	Asian glossy starling	LC	Not listed
4.	Apodidae	*Cypsiurus balasiensis*	Asian palm-swift	LC	Not listed
5.	Cuculidae	*Cacomantis sonneratii*	Banded bay cuckoo	LC	Not listed
6.	Alcedinidae	*Lacedo pulchella*	Banded kingfisher	LC	Not listed
7.	Picidae	*Chrysophlegma miniaceum*	Banded woodpecker	LC	Not listed
8.	Hirundinidae	*Hirundo rustica*	Barn swallow	LC	Not listed
9.	Ploceidae	*Ploceus philippinus*	Baya weaver	LC	Not listed
10.	Ardeidae	*Dupetor flavicollis*	Black bittern	LC	Schedule 2
11.	Bucerotidae	*Anthracoceros malayanus*	Black hornbill	VU	Schedule 2
12.	Eurylaimidae	*Cymbirhynchus macrorhynchos*	Black-and-red broadbill	LC	Not listed
13.	Eurylaimidae	*Eurylaimus ochromalus*	Black-and-yellow broadbill	NT	Not listed
14.	Megalaimidae	*Psilopogon duvaucelii*	Black-eared barbet	LC	Not listed
15.	Pycnonotidae	*Pycnonotus atriceps*	Black-headed bulbul	NA	Not listed
16.	Accipitridae	*Elanus axillaris*	Black-shouldered kite	LC	Not listed
17.	Psittaculidae	*Loriculus galgulus*	Blue-crowned hanging-parrot	LC	Schedule 2
18.	Alcedinidae	*Alcedo meninting*	Blue-eared kingfisher	LC	Not listed
19.	Meropidae	*Merops viridis*	Blue-throated bee-eater	LC	Not listed
20.	Timaliidae	*Mixornis bornensis*	Bold-striped tit-babbler	LC	Not listed
21.	Phasianidae	*Lophura ignita*	Bornean crested fireback	NT	Schedule 2
22.	Accipitridae	*Haliastur indus*	Brahminy kite	LC	Schedule 2
23.	Strigidae	*Strix leptogrammica*	Brown wood-owl	LC	Schedule 2
24.	Nectariniidae	*Anthreptes malacensis*	Brown-throated sunbird	LC	Not listed
25.	Picidae	*Meiglyptes grammithorax*	Buff-rumped woodpecker	LC	Not listed
26.	Bucerotidae	*Anorrhinus galeritus*	Bushy-crested hornbill	NT	Schedule 2
27.	Accipitridae	*Nisaetus cirrhatus*	Changeable hawk-eagle	LC	Not listed
28.	Estrildidae	*Lonchura atricapilla*	Chestnut munia	LC	Not listed
29.	Timaliidae	*Cyanoderma erythropterum*	Chestnut-winged babbler	LC	Not listed
30.	Sturnidae	*Gracula religiosa*	Common hill myna	LC	Schedule 2
31.	Aegithinidae	*Aegithina tiphia*	Common iora	LC	Not listed
32.	Scolopacidae	*Actitis hypoleucos*	Common sandpiper	LC	Not listed
33.	Pycnonotidae	*Pycnonotus simplex*	Cream-vented bulbul	LC	Not listed
34.	Accipitridae	*Spilornis cheela*	Crested serpent-eagle	LC	Schedule 2
35.	Estrildidae	*Lonchura fuscans*	Dusky munia	LC	Not listed
36.	Columbidae	*Spilopelia chinensis*	Eastern spotted dove	LC	Not listed
37.	Apodidae	*Aerodramus fuciphagus*	Edible-nest swiftlet	LC	Schedule 2
38.	Passeridae	*Passer montanus*	Eurasian tree sparrow	LC	Not listed
39.	Pellorneidae	*Trichastoma bicolor*	Ferruginous babbler	LC	Schedule 2
40.	Timaliidae	*Macronus ptilosus*	Fluffy-backed tit-babbler	NT	Not listed
41.	Apodidae	*Collocalia esculenta*	Glossy swiftlet	LC	Not listed
42.	Ardeidae	*Ardea alba*	Great white egret	LC	Not listed
43.	Cuculidae	*Centropus sinensis*	Greater coucal	LC	Not listed
44.	Dicruridae	*Dicrurus paradiseus*	Greater racquet-tailed drongo	LC	Not listed

Appendix 1. Continued.

No.	Family	Species	English Name	IUCN	Sabah Wildlife Conservation Enactment 1997
45.	Columbidae	*Ducula aenea*	Green imperial-pigeon	LC	Schedule 2
46.	Aegithinidae	*Aegithina viridissima*	Green iora	NT	Not listed
47.	Ardeidae	*Butorides striata*	Green-backed heron	LC	Schedule 2
48.	Columbidae	*Chalcophaps indica*	Grey-capped emerald dove	LC	Schedule 2
49.	Sturnidae	*Acridotheres javanicus*	Javan myna	VU	Not listed
50.	Columbidae	*Treron capellei*	Large green-pigeon	VU	Schedule 2
51.	Cuculidae	*Centropus bengalensis*	Lesser coucal	LC	Not listed
52.	Chloropsidae	*Chloropsis cyanopogon*	Lesser green leafbird	NT	Not listed
53.	Ardeidae	*Egretta garzetta*	Little egret	LC	Schedule 2
54.	Columbidae	*Treron olax*	Little green-pigeon	LC	Not listed
55.	Nectariniidae	*Arachnothera longirostra*	Little spiderhunter	LC	Not listed
56.	Nectariniidae	*Arachnothera robusta*	Long-billed spiderhunter	LC	Not listed
57.	Laniidae	*Lanius schach*	Long-tailed shrike	LC	Not listed
58.	Muscicapidae	*Cyornis rufigastra*	Mangrove blue-flycatcher	LC	Not listed
59.	Picidae	*Blythipicus rubiginosus*	Maroon woodpecker	LC	Not listed
60.	Strigidae	*Ninox japonica*	Northern boobook	LC	Not listed
61.	Pycnonotidae	*Pycnonotus plumosus*	Olive-winged bulbul	LC	Not listed
62.	Dicaeidae	*Dicaeum trigonostigma*	Orange-bellied flowerpecker	LC	Not listed
63.	Anhingidae	*Anhinga melanogaster*	Oriental darter	NT	Schedule 2
64.	Coraciidae	*Eurystomus orientalis*	Oriental dollarbird	LC	Not listed
65.	Alcedinidae	*Ceyx erithaca*	Oriental dwarf-kingfisher	LC	Not listed
66.	Muscicapidae	*Copsychus saularis*	Oriental magpie-robin	LC	Schedule 2
67.	Monarchidae	*Terpsiphone affinis*	Oriental paradise-flycatcher	LC	Not listed
68.	Bucerotidae	*Anthracoceros albirostris*	Oriental pied hornbill	LC	Schedule 2
69.	Motacillidae	*Anthus rufulus*	Paddyfield pipit	LC	Not listed
70.	Columbidae	*Treron vernans*	Pink-necked green-pigeon	LC	Not listed
71.	Dicaeidae	*Dicaeum minullum*	Plain flowerpecker	LC	Not listed
72.	Nectariniidae	*Anthreptes simplex*	Plain sunbird	LC	Not listed
73.	Cuculidae	*Cacomantis merulinus*	Plaintive cuckoo	LC	Not listed
74.	Ardeidae	*Ardea purpurea*	Purple heron	LC	Schedule 2
75.	Nectariniidae	*Leptocoma sperata*	Purple-throated sunbird	LC	Not listed
76.	Cuculidae	*Rhinortha chlorophaea*	Raffles's malkoha	LC	Not listed
77.	Pycnonotidae	*Pycnonotus brunneus*	Red-eyed bulbul	LC	Not listed
78.	Trogonidae	*Harpactes kasumba*	Red-naped trogon	NT	Not listed
79.	Bucerotidae	*Buceros rhinoceros*	Rhinoceros hornbill	NT	Schedule 2
80.	Nectariniidae	*Chalcoparia singalensis*	Ruby-cheeked sunbird	LC	Not listed
81.	Alcedinidae	*Actenoides concretus*	Rufous-collared kingfisher	NT	Not listed
82.	Cisticolidae	*Orthotomus sericeus*	Rufous-tailed tailorbird	LC	Not listed
83.	Apodidae	*Rhaphidura leucopygialis*	Silver-rumped spinetail	LC	Not listed
84.	Corvidae	*Corvus enca*	Slender-billed crow	LC	Not listed
85.	Cuculidae	*Surniculus lugubris*	Square-tailed drongo-cuckoo	LC	Not listed
86.	Alcedinidae	*Pelargopsis capensis*	Stork-billed kingfisher	LC	Not listed
87.	Ciconiidae	*Ciconia stormi*	Storm's stork	EN	Schedule 2
88.	Locustellidae	*Megalurus palustris*	Striated grassbird	LC	Not listed
89.	Rhipiduridae	*Rhipidura javanica*	Sunda pied fantail	LC	Not listed
90.	Hirundinidae	*Hirundo tahitica*	Tahiti swallow	LC	Not listed

Appendix 1. Continued.

No.	Family	Species	English Name	IUCN	Sabah Wildlife Conservation Enactment 1997
91.	Columbidae	*Treron curvirostra*	Thick-billed green-pigeon	LC	Not listed
92.	Accipitridae	*Nisaetus nanus*	Wallace's hawk-eagle	VU	Schedule 2
93.	Pittidae	*Pitta sordida*	Western hooded pitta	LC	Schedule 2
94.	Hemiprocnidae	*Hemiprocne comata*	Whiskered treeswift	LC	Not listed
95.	Accipitridae	*Haliaeetus leucogaster*	White-bellied sea-eagle	LC	Not listed
96.	Rallidae	*Amaurornis phoenicurus*	White-breasted waterhen	LC	Not listed
97.	Muscicapidae	*Enicurus leschenaulti*	White-crowned forktail	LC	Schedule 2
98.	Bucerotidae	*Berenicornis comatus*	White-crowned hornbill	EN	Schedule 2
99.	Muscicapidae	*Copsychus stricklandii*	White-crowned shama	NA	Not listed
100.	Bucerotidae	*Rhyticeros undulatus*	Wreathed hornbill	VU	Schedule 2
101.	Bucerotidae	*Rhabdotorrhinus corrugatus*	Wrinkled hornbill	EN	Schedule 2
102.	Cisticolidae	*Prinia flaviventris*	Yellow-bellied prinia	LC	Not listed
103.	Pycnonotidae	*Pycnonotus goiavier*	Yellow-vented bulbul	LC	Not listed
104.	Columbidae	*Geopelia striata*	Zebra dove	LC	Not listed

Avifaunal survey of Ulu Kalang Forest Reserve in the district of Tenom, Sabah, Malaysia

B.D. Joeman[1], G.H. Petol[1*] & V. Rudolf [2]

[1]*Forest Research Centre, Sabah Forestry Department, P.O. Box 1407, 90715, Sandakan, Sabah*
[2]*Lahad Datu District Forestry Office, Sabah Forestry Department, P.O. Box 61, 91107 Lahad Datu, Sabah*
**Author for correspondence. Email: hubert.petol@sabah.gov.my*

Abstract. The main objective of the Ulu Kalang Forest Reserve (UKFR) survey was to provide a brief description of the avian diversity in the area, which could be used to support future forest management initiatives. The forest reserve is situated in the district of Tenom, Sabah. The MacKinnon List method was used. The three-day survey recorded a total of 13 lists with 261 individuals detected. A total of 85 species from 36 families were recorded, with H=4.023 and E_H=0.072. Six species of Bornean endemics were observed, namely the Blue-banded Pitta, Bornean Black Magpie, Bornean Brown Barbet, Dusky Munia, White-crowned Shama and Yellow-rumped Flowerpecker. The top three most diverse families were Pycnonotidae, Pellorneidae and Megalaimidae with eight, seven and six species respectively, while Cuculidae, Muscicapidae, and Nectariidae each had five species. The Bornean Brown Barbet had the highest relative abundance index of 0.111. It was followed by the Gold-whiskered Barbet (13 individuals, 0.05) and Little Spiderhunter (12 individuals, 0.046). UKFR was dominated by insectivorous species (53.4%) and frugivores (30.2%). Approximately 88.4% of the species were forest dwellers, a majority of which were insectivorous (40 species).

Keywords: avifaunal survey, MacKinnon List method, scientific expedition, Ulu Kalang Forest Reserve, feeding guilds

INTRODUCTION

Birds are important indicators of forest health and have been included when surveying biodiversity. This report documents the outcomes of a rapid avifaunal assessment conducted during the Heart of Borneo Scientific Expedition of Ulu Kalang and Sg. Rayoh Forest Reserves in the Tenom District, held from the 5th-10th of March 2018. The expedition was organised by the Forest Research Centre, Sabah Forestry Department, with assistance from the Tenom District Forestry Office, to assess the ecological status of the forest reserves. However, only the results for Ulu Kalang Forest Reserve (UKFR) are presented in this paper.

The main objective of this survey was to evaluate the species richness and abundance of avifauna, and to identify the main feeding guilds within UKFR to support future forest management initiatives. The three-day survey, performed using the MacKinnon List (ML) method, was conducted at two sites within UKFR, with one site surveyed twice. The ML method is a rapid assessment method has been gaining popularity in the past 10 years as a cost-effective method of conducting bird surveys in the tropics. It was designed for those who have limited time, resources and personnel for surveys (MacKinnon & Phillipps 1993), such as, government agencies, non-governmental organisations, citizen scientists and forest concessionaires. It also accounts for differences in effort, observer experience and knowledge, and weather (Poulsen *et al*. 1997). Because the method relates species richness to the number of observations rather than to time, area or walking speed, this method allows for comparison of data obtained by different observers or under varying field conditions (Herzog *et al*. 2002).

MATERIALS & METHODS

Site description

The UKFR lies between latitude 05º09'43.5" - 05º09'3226.5" N and longitude 115º55'51.1" - 115º55'53.5" E in the district of Tenom. It is administered by the Tenom District Forestry Office. It was gazetted as a Class I Protection Forest Reserve on 8th December 2016 and is situated adjacent to the Crocker Range Park boundary, about 3 km north-northeast of Tenom town and is accessible by road using 4WD vehicles. The elevation of UKFR ranged from 483 to 833 m.

Although the forest had been disturbed prior to its gazettement, the forest quality was still comparable to undisturbed upland mixed dipterocarp forests found elsewhere in Sabah. Suis *et al.* (2017) found that *Vatica dulitensis* was the most dominant dipterocarp, with both *Shorea laevis* and *S. hopeifolia* as co-dominants. Seraya Bukit (*S. platyclados*), a well-known indicator species for upland dipterocarp forest, was also recorded. The Malvaceae was the second most dominant family.

The first site at Ulu Kalang FR (Hill Site) can be accessed from off the Keningau-Tenom trunk road, after which the road transitioned from tarmac to gravel and, finally, to an unsealed, earth road. The earth road, being mostly made up of clay, was extremely slippery after and during rain. The survey was conducted along a temporary trail made into the steep (~30º-45º) hills of the reserve. This site was surveyed twice (first and fourth day of the expedition).

The second site (Waterfall Site) in UKFR was accessible by road through housing estates. The survey was conducted from an abandoned forest recreation site and into the steep hills. A temporary trail was cut by other members of the expedition team.

Survey methods

For this survey, the MacKinnon List (ML) method (MacKinnon & Phillipps 1993) was employed. Both auditory and visual observations were grouped into consecutive lists of 15 species, and a species accumulation curve was generated from the addition of those species not recorded on any of the previous lists to the total species number, which is then plotted as a function of the list number. In addition, the number of individuals of the species observed was recorded.

Observation methods

The survey team comprised the authors and assisted by 4 interns of the Rainforest Discovery Centre (RDC), Sepilok. The interns were diploma-level students from Universiti Putra Malaysia, Bintulu Campus and had a three-month training in bird identification and bird survey (ML method) at the RDC prior to the expedition. Every observer had a pair of NIKON binoculars (8 x 42s). The 'Phillips' Field Guide to the Birds of Borneo', 3rd edition (Phillips & Phillips 2014) was the reference used for species identification. Audio playback equipment - consisting of an mp3 player connected to a small, battery-powered Bluetooth® loudspeaker - was used to verify the species of the bird vocalisation heard.

Surveys were conducted for 4 to 5 hours beginning 7:00 - 7:30 am, depending on weather and road conditions, and could only be conducted during the day due to the logistics of the expedition. Thus, only diurnal birds were surveyed. The surveys were conducted along narrow, temporary trails that were only established on the day of the survey. As such, trails were shared with other expedition members. A designated person recorded all visual and aural observations.

Care was taken to prevent intra-list and inter-list double-counts of individuals. As most species were detected by their calls/vocalizations, individuals were not recorded again in subsequent lists unless the observers were certain that they were different individuals, *e.g.*, when the calls originate from a different direction and/or there were more than one call heard from a similar direction of the previously recorded species.

Table 1. Schedule of surveys during the expedition.

Date	Survey site	Observation times	Number of 15-species lists
6th March	Hill Site	7:45 am – 11:45 am	5 lists
7th March	Waterfall Site	7:30 am – 11:50 am	2 lists
9th March	Hill Site	7:30 am – 12:00 pm	6 lists

Analyses

A species accumulation curve was generated from the addition of those species not recorded on any of the previous lists to the total species number, which was then plotted as a function of the list number. To estimate true species richness of the area, the authors used the SuperDuplicates® online calculator developed by Chao *et al.* (2017), which requires only the total number of species observed and the number of species observed only once (uniques/ singletons).

Analyses of feeding guilds provide information on how communities of species utilize certain forest resources (*e.g.* fruits, insects, arthropods and seeds) within UKFR and may indicate the condition or health of the forest ecosystem. Thus, the species were categorised according to six feeding guilds based on their preferred diet; carnivores (Car), frugivores (Fru), insectivores (Ins), nectarivores (Nec), granivores (Gra) and omnivores (Omn). Species are considered as omnivores if they are known to consume roughly similar amounts of animal- and plant-based food resources, such as Ins/Gra, Fru/Ins and Nec/Fru/Ins. Guild information was mainly from Phillipps & Phillipps (2014) and Wells (1999 & 2007). The feeding guilds were then described according to habitat types (forest, forest edge and open area) to examine the importance of habitats to different guilds.

RESULTS AND DISCUSSION

Species richness, H and E_H

The three-day survey yielded 13 lists and 261 detected individuals. A total of 85 species belonging to 36 families were recorded, with a Shannon-Weiner index (H) of 4.023 and Evenness (E_H) value of 0.72. The relatively low value for the total number of species may be, among others, due to the limited survey period (total of 13 observation hours). Furthermore, only diurnal birds were surveyed.

Six species of Bornean endemics were observed, namely the Blue-banded Pitta, Bornean Black Magpie, Bornean Brown Barbet, Dusky Munia, White-crowned Shama and Yellow-rumped Flowerpecker. Only the Blue-banded Pitta is listed as Vulnerable in the IUCN Red List of Threatened Species while the others are listed as Least Concern. With the exception of the Blue-banded Pitta, the other Bornean endemics are common in lowland and upland dipterocarp forests.

Table 2. Top five most diverse families (with rank 4 and 5 shared between 3 families respectively.

Rank	Family	Number of species
1	Pycnonotidae	8
2	Pellorneidae	7
3	Megalaimidae	6
4	Cuculidae	5
4	Muscicapidae	5
4	Nectariniidae	5
5	Cisticolidae	4
5	Eurylaimidae	4
5	Picidae	4

The Pycnonotidae, Pellorneidae and Megalaimidae were the top three families with the highest number of species (Table 2). Unexpectedly, for a good upper hill dipterocarp forest, the Bucerotidae was represented by only one species.

The most frequently detected family was Megalaimidae at 23%, *i.e.* almost a quarter of the individuals detected were barbets (Table 3). This high detectability was due to the presence of fruiting fig trees close to the temporary expedition trails.

Table 3. Top five families with the highest percentage of individuals detected.

Rank	Family	Number of individuals	Percentage of individuals detected (%)
1	Megalaimidae	60	23.0
2	Pycnonotidae	24	9.2
3	Pellorneidae	19	7.3
4	Muscicapidae	17	6.5
4	Nectariniidae	17	6.5
5	Cisticolidae	15	5.7

The Waterfall Site was unexpectedly poor in bird species, yielding only 2 lists, although the forest quality and terrain was very similar to the Hill Site (surveyed on Day 1 and Day 4). It cannot be verified if the detectability of birds was negatively affected by the presence of other expedition participants using the same trail. Due to logistical constraints and time limitations, the Waterfall Site was accessed only once.

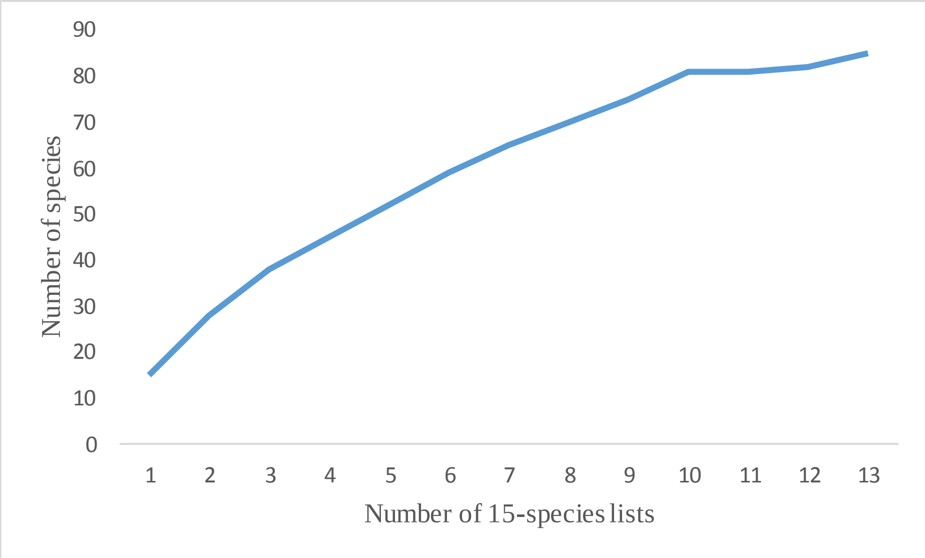

Figure 1. Species accumulation curve of bird species in UKFR.

As expected for the ML rapid assessment method, and with a 3-day duration of the survey, the species accumulation curve (Figure 1) had not achieved asymptote. To estimate the true species richness, the SuperDuplicates ® online calculator was used. The Chao1 (species richness using abundance data) was approximately 115 species, with an upper and lower threshold of approximately 138 and 130 species respectively, at 95% confidence interval. It also estimated that about 30 species were undetected, *i.e.* the survey managed to detect about 74 % of the total species in the area (Table 4).

Table 4. Results from SuperDuplicates®.

Number species detected	Number of singletons					
85	31					
Estimated number of doubletons	**Estimated species richness**	**Standard error**	**95% C.I. lower**	**95% C.I. upper**	**Number of undetected species**	**Undetected percentage (%)**
14.7	115.18	8.95	102.09	138.3	30.18	26.2

Relative abundance index

A total of 261 individuals were detected from 85 species. There were nine species with 5 highest relative abundance index (RAI), with 4 species ranked 4^{th} and 2 species ranked 5^{th} respectively. The Bornean Brown Barbet, with 29 individuals detected (see Table 5), had the highest RAI of 0.111. It is followed by the Gold-whiskered Barbet (13 individuals, RAI = 0.05) and Little Spiderhunter (12 individuals, RAI = 0.046). Out of the nine species, six species were frugivores, two were insectivores and one nectarivore.

Table 5. Top 5 relative abundances of bird species in UKFR, with species with similar values sharing ranks 4th and 5th respectively.

Rank	Species	No. of Individuals detected	Abundance Index	Feeding guild
1	Bornean Brown Barbet	29	0.111	Frugivore
2	Gold-whiskered Barbet	13	0.050	Frugivore
3	Little Spiderhunter	12	0.046	Nectarivore
4	Blue-eared Barbet	8	0.031	Frugivore
4	Dark-throated Oriole	8	0.031	Frugivore
4	White-crowned Shama	8	0.031	Insectivore
4	Yellow-vented Bulbul	8	0.031	Frugivore
5	Black-and-yellow Broadbill	7	0.027	Insectivore
5	Red-eyed Bulbul	7	0.027	Frugivore

Feeding guilds

Overall, UKFR was dominated by insectivorous species (53.4%) and frugivores (30.2%) (Figure 2). The remaining three guilds made up 16.3%. The high dominance of insectivorous and frugivorous species indicated that the forest had high insect and fruit resources to support these species, a good indication of positive forest ecosystem health. However, it has to be mentioned here that the detectability of the frugivorous species, especially barbets, were very high due to the availability of nearby fruiting fig trees at both sites.

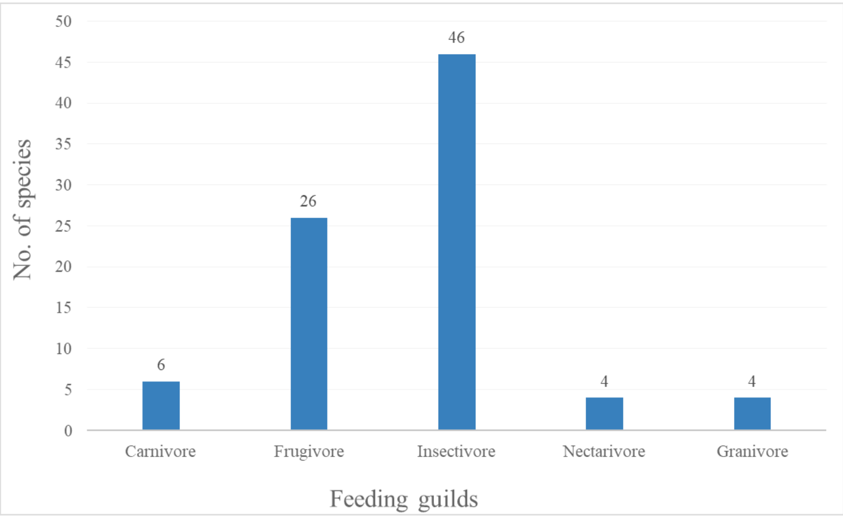

Figure 2. Number of species in feeding guilds in UKFR.

Figure 3 shows that UKFR was dominated by forest-dwelling species (88.4%), the majority of which were insectivorous (40 species). The Forest/Open Area and the Open Area species were considerably less in number and in diversity, *i.e.* 16.3% of the bird species reside in these two habitats. The adjacent, newly-established rubber plantation may support more of these species when the rubber trees begin to flower and fruit.

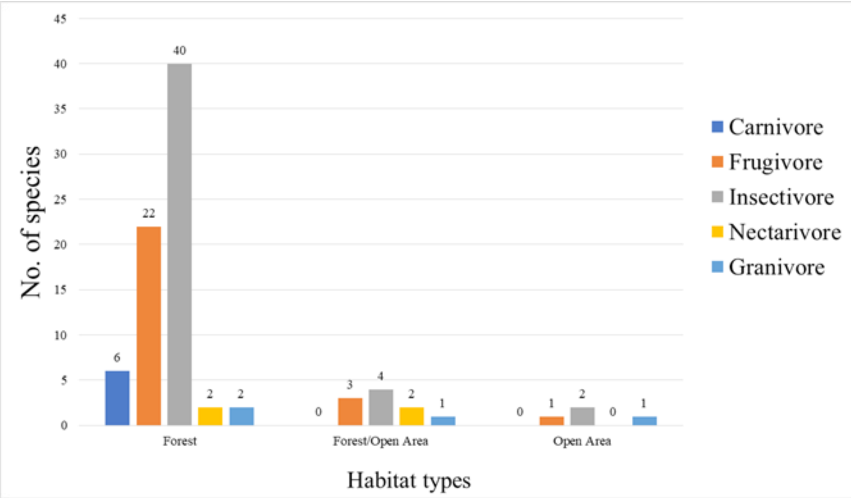

Figure 3. Number of species in their feeding guilds and habitats in UKFR.

CONCLUSION

The survey team managed to obtain a preliminary insight on the species richness and abundance of avifauna, and the main feeding guilds within UKFR. The relatively low species richness of UKFR may be a temporary consequence of the newly established rubber estate on the southern portion of the forest reserve. Disturbances by fellow expedition participants along shared trails may have also contributed to the low numbers of species. However, the species were well represented according to their feeding guilds and preferred habitats, suggesting that although the overall species richness was low, the avian community reflected that of a typical undisturbed forest. The UKFR is an excellent site for future surveys to study the impacts of the establishment of large-scale rubber plantations adjacent to forest reserves on avian ecology.

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Appendix. Common names of bird species observed in Ulu Kalang FR.

Species (Common name)	Family	Habitat	Feeding Guild
Ashy Tailorbird	Cisticolidae	Forest	Insectivore
Asian Glossy Starling	Apodidae	Open area	Insectivore
Asian Paradise Flycatcher	Monarchidae	Forest	Insectivore
Asian-fairy Bluebird	Irenidae	Forest	Frugivore
Banded Bay Cuckoo	Cuculidae	Forest	Insectivore
Banded Broadbill	Eurylaimidae	Forest	Insectivore
Barn Swallow	Hirundinidae	Open area	Insectivore
Black-and-yellow Broadbill	Eurylaimidae	Forest	Insectivore
Black-capped Babbler	Pellorneidae	Forest	Insectivore
Black-headed Bulbul	Pycnonotidae	Forest	Frugivore
Black-naped Monarch	Monarchidae	Forest	Insectivore
Black-winged Flycatcher-shrike	Tephrodornithidae	Forest	Insectivore
Blue-banded Pitta	Pittidae	Forest	Carnivore
Blue-breasted Quail	Phasianidae	Forest /Open area	Granivore
Blue-crowned Hanging Parrot	Psittacidae	Forest	Frugivore
Blue-eared Barbet	Megalaimidae	Forest	Frugivore
Blue-throated Barbet	Megalaimidae	Forest	Frugivore
Blue-throated Bee-eater	Meropidae	Forest /Open area	Insectivore
Blythe’s Hawk Eagle	Accipitridae	Forest	Carnivore
Bold-striped Tit-babbler	Timaliidae	Forest	Insectivore
Bornean Black Magpie	Corvidae	Forest	Omnivore
Bornean Brown Barbet	Megalaimidae	Forest	Frugivore
Brown Fulvetta	Pellorneidae	Forest	Insectivore
Brown Needle-tail	Apodidae	Open area	Insectivore
Brown-throated Sunbird	Nectariniidae	Open area	Nectarivore
Buff-rumped Woodpecker	Picidae	Forest	Insectivore
Changeable Hawk Eagle	Accipitridae	Forest	Carnivore
Chestnut Munia	Estrildidae	Forest	Granivore
Chestnut-backed Scimitar-babbler	Timaliidae	Forest	Insectivore
Chestnut-collared Kingfisher	Alcedinidae	Forest	Carnivore
Chestnut-winged Babbler	Timaliidae	Forest	Insectivore
Cream-vented Bulbul	Pycnonotidae	Forest /Open area	Frugivore
Crested Serpent-eagle	Accipitridae	Forest	Carnivore
Crimson-winged Woodpecker	Picidae	Forest	Insectivore
Dark-necked Tailorbird	Cisticolidae	Forest	Insectivore
Dark-throated Oriole	Oriolidae	Forest	Frugivore
Diard’s Trogon	Trogonidae	Forest	Insectivore
Dollar Bird	Coraciidae	Forest	Insectivore
Dusky Broadbill	Eurylaimidae	Forest	Insectivore
Dusky Munia	Estrildidae	Forest	Granivore
Eastern Crimson Sunbird	Nectariniidae	Forest /Open area	Nectarivore
Finch’s Bulbul	Pycnonotidae	Forest	Frugivore
Glossy Swiflet	Apodidae	Open area	Insectivore

Appendix (cont.)

Species (Common name)	Family	Habitat	Feeding Guild
Gold-Whiskered Barbet	Megalaimidae	Forest	Frugivore
Great Argus	Phasianidae	Forest	Insectivore
Greater Green Leafbird	Irenidae	Forest	Insectivore
Greater Racquet-Tailed Drongo	Dicruridae	Forest	Insectivore
Green Broadbill	Eurylaimidae	Forest	Frugivore
Green Iora	Aegithinidae	Forest	Insectivore
Grey-cheeked Bulbul	Pycnonotidae	Forest	Frugivore
Grey-chested Jungle Flycatcher	Muscicapidae	Forest	Insectivore
Grey-rumped Treeswift	Hemiprocnidae	Open area	Insectivore
Hairy-backed Bulbul	Pycnonotidae	Forest	Frugivore
Hill Myna	Sturnidae	Forest	Frugivore
Horsfield's Babbler	Pellorneidae	Forest	Insectivore
Indian Cuckoo	Cuculidae	Forest	Insectivore
Little Cuckoo Dove	Columbidae	Open area	Frugivore
Little Spiderhunter	Nectariniidae	Forest /Open area	Nectarivore
Long-billed Spiderhunter	Nectariniidae	Forest	Nectarivore
Malaysian Honey Guide	Indicatoridae	Forest/Open area	Insectivore
Olive-backed Sunbird	Nectariniidae	Open area	Nectarivore
Orange-bellied Flowerpecker	Dicaeidae	Forest /Open area	Frugivore
Oriental-dwarf Kingfisher	Alcedinidae	Forest	Carnivore
Pacific Swallow	Hirundinidae	Open area	Insectivore
Plain Sunbird	Nectariniidae	Forest /Open area	Nectarivore
Plaintive Cuckoo	Cuculidae	Forest /Open area	Insectivore
Purple-naped Sunbird	Nectariniidae	Forest	Nectarivore
Raffle's Malkoha	Cuculidae	Forest	Insectivore
Red-bearded Bee-eater	Meropidae	Forest /Open area	Insectivore
Red-crowned Barbet	Megalaimidae	Forest	Frugivore
Red-eyed Bulbul	Pycnonotidae	Forest /Open area	Frugivore
Red-throated Barbet	Megalaimidae	Forest	Frugivore
Rhinoceros Hornbill	Bucerotidae	Forest	Frugivore
Ruby-cheeked Sunbird	Nectariniidae	Forest /Open area	Nectarivore
Rufous Piculet	Picidae	Forest	Insectivore
Rufous-chested Flycatcher	Muscicapidae	Forest	Insectivore
Rufous-crowned Babbler	Pellorneidae	Forest	Insectivore
Rufous-tailed Shama	Muscicapidae	Forest	Insectivore
Rufous-tailed Tailorbird	Cisticolidae	Forest	Insectivore
Rufous-wingled Philentoma	Tephrodornithidae	Forest	Insectivore
Scaly-breasted Bulbul	Pycnonotidae	Forest	Frugivore
Scaly-crowned Babbler	Pellorneidae	Forest	Insectivore
Scarlet Minivet	Campephagidae	Forest	Insectivore
Short-tailed Babbler	Pellorneidae	Forest	Insectivore
Silver-rumped Needle-tail	Apodidae	Open area	Insectivore
Sooty-capped Babbler	Pellorneidae	Forest	Insectivore

Appendix (cont.)

Species (Common name)	Family	Habitat	Feeding Guild
Violet Cuckoo	Cuculidae	Forest /Open area	Insectivore
White-bellied Woodpecker	Picidae	Forest	Insectivore
White-breasted Waterhen	Rallidae	Open area	Omnivore
White-crowned Forktail	Muscicapidae	Forest	Insectivore
White-crowned Shama	Muscicapidae	Forest	Insectivore
Yellow-bellied Prinia	Cisticolidae	Open area	Insectivore
Yellow-crowned Barbet	Megalaimidae	Forest	Frugivore
Yellow-rumped Flowerpecker	Dicaeidae	Forest	Frugivore
Yellow-vented Bulbul	Pycnonotidae	Open area	Frugivore
Zebra Dove	Columbidae	Open area	Frugivore

Amorphophallus lambii – Some observations in the nursery and a new pest record

E. Khoo[1]*, S.T. Ng[2], D.M. Tann[2] & A.Y.C. Chung[1]

[1]*Forest Research Centre, Sabah Forestry Department, P. O. Box 1407, 90715, Sandakan, Sabah, Malaysia*
[2]*Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia*
**Author for correspondence. Email: Eyen.Khoo@sabah.gov.my*

Amorphophallus titanium was first described by Odoardo Beccari after obtaining a specimen of the plant during a trip to central Sumatra in 1878.Tubers and seeds were sent back to Europe for cultivation, and the first bloom was recorded at the Royal Botanic Gardens, Kew in 1889. To date, this species has been cultivated in many botanical gardens throughout the world, largely to display its peculiar inflorescence that can attain heights of up to 3 m. Seeing the shape of the spadix, it explains why the Dutch botanist Blume named the genus Amorphophallus in 1834, as in Ancient Greek amorphos means "mishappened, without form", whereas phallus means "penis".

Although *A. titanium* holds the record for the largest inflorescence, other species within the genus are no less interesting in terms of the stalk patterns or the inflorescence shape and texture. According to **'The Überlist of Araceae'** by Boyce & Croat (2011 onwards), the total number of published Amorphophallus is 197 at the moment, however it is estimated that there is possibly up to 219 species.

The Sandakan herbarium collection consists of 4 identifiable Amorphophallus species: *Amorphophallus lambii*, *Amorphophallus paeonifolius*, *Amorphophallus pendulus*, *Amorphophallus rugosus* and *Amorphophallus venustus*. *A. paenifolius* was likely introduced to the State through the horticultural scene, as the natural distribution of this species ranges from Madagascar, India, Southern China, Polynesia and Northern Australia. Of the other 3 species, the one that is of interest in this passage is *A. lambii* (Plate 1). In terms of inflorescence, this species shares some structural similarities with *A. titanium*, particularly with regard to the spathe and spadix overall structure (Mayo *et al.* 1982). However, this species does have its own distinguishing features as well. During the non-flowering period, the mottled shades of green of the stem makes for a particularly aesthetic appearance (Hetterscheid & Ittenbach 1996) (Plate 2). The species is found in Sabah and Central Kalimantan on rich alluvial soils. Cross checking through the collection to date, there are only a few collections in the herbarium, mainly from Keningau, Tambunan and Tenom. One of the possibilities for this low number of collections is due to the plant's evelopmental growth behaviour, as the plant's leaf and inflorescence do not exist at the same time, therefore posing a challenge when it comes to species identification when only a leaf specimen is available in the wild. Aside from that, there is the other challenge of preserving the fleshy inflorescence as a dry herbarium specimen and at the same time ensuring its structure is maintained intact post processing.

The other option would be to establish a living collection in which either seeds or whole plants are collected from the field. However as of date, the chances of the latter surviving the transplanting process is still quite low. In comparison, the success rate of raising plants from seeds collected from infructescence is much higher. In October 2018, seeds were collected for *A. lambii* from Tenom and sowed onto a mixture of top soil and saw dust. After 3 months, 80 seedlings of 6 inches (15 cm) tall were transplanted into polybags.

In February 2019，defoliation of various degrees was detected in 43 seedlings. Two caterpillars which were feeding on the leaves were collected. The degree of defoliation ranges from damaged leaflets (Plate 3) to 80% or total decimation of the whole leaf structure in which only the trunk like petiole remained. The petiole of the latter eventually wilted. Within 2 or 3 weeks, new leaves were observed emerging from 81% of the wilted plants. Height measurements taken 4 months later showed an average height of 11.5 cm, where majority of the plants' (73%) height fell within the 6 to 15 cm range (Plate 4).

The caterpillars collected were raised in captivity and fed with juvenile leaves from *Syngoniumpodophyllum* (Araceae), as a replacement due to the unavailability of Amorphophallus leaf. The only preference the caterpillars have shown was the preference to feed upon juvenile/ emerging leaves rather than the adult leaves. Post pupation, the emerged adult was identified as *Hippotion celerio* (wingspan = 65 mm; body length = 38 mm) or commonly known as Taro Hawk moth (Plates 5, 6 & 7). This species was described by Carl Linnaeus in 1758, with a reported distribution over the Palaeotropical region. Being a polyphagous species, *H. celerio* is recorded to feed on a number of plant species from a variety of families, for example the Araceae, Convovulaceae, Fabaceae, Nyctaginaceae and Vitaceae (Jeenkoed *et al*. 2016). Within the Araceae family, it was recorded to feed on young leaves of *Alocasia*, *Caladium*, *Colocasia*, Cryptocoryne, *Cyrtosperma*, *Typhonium* and *Zantedeschia* based on various research and observations (Holloway 2019). This is the first record to date, in which this polyphagous species was found feeding on *A. lambii*.

Although a large number of individuals managed to recover and produce new leaves, the potential effect of continuous defoliation by *H. celerio* could affect the survivability of *A. lambii* in the long run. The effects of defoliation stress has been greatly studied and is known to hamper a plant's physiological process. In order to survive as in this case, with the loss of photosynthetic ability, the plants have to turn to their underground reserve *i.e.* tubers for resources to initiate regrowth that is if this back up resource is available. Since *A. lambii* is known to have a tendency to subsequently die off in cultivation (Hetterscheid & Ittenbach 1996) and based on the authors' experiences, the tubers are sensitive to disturbances and generally resulting in leaf regrowth. Therefore, regular monitoring for pest attack and collection of seeds for future propagation might be the better option in conservation and maintaining the species for display.

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Plate 1. Inflorescence of *Amorphophallus lambii*.

Plate 2. Marbling effect on the stems of *Amorphophallus lambii*.

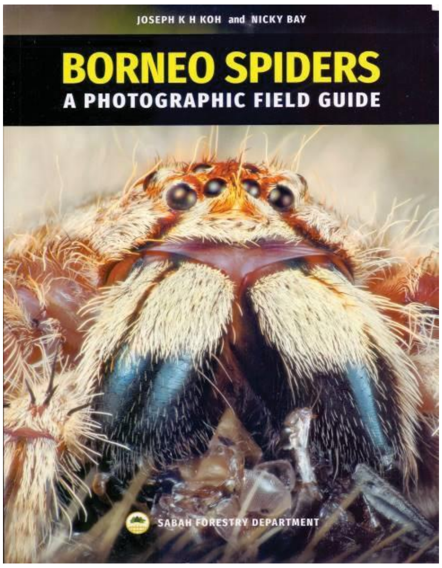
Plate 3. Defoliation on the leaflet.

Plate 4. New leaf emergent of varying heights.

Plate 5. The caterpillar of *H. celerio* where the large eyespots (false eyes) are in clear view.

Plate 6. The pupa stage.

Plate 7. The emerged female adult of *H. celerio*.



Borneo Spiders: A Photographic Field Guide by Joseph K H Koh and Nicky Bay. Published by Sabah Forestry Department, Sabah, 2019. Pp. 497. ISBN 978-967-0180-20-5.

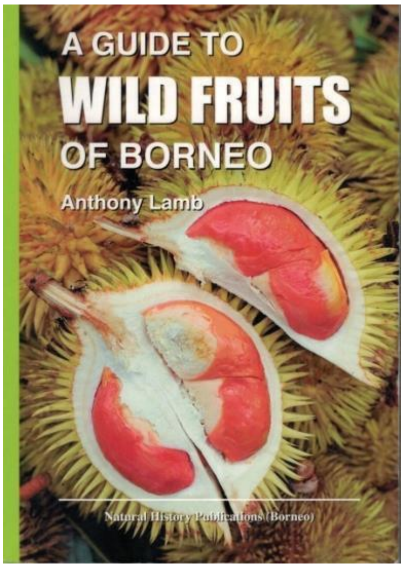
Reviewed by Razy Japir

There have not been many studies on spiders in Borneo compared to other arthropods, which is reflected in the paucity of references available for the group. Books on spiders are therefore in high demand, especially for researchers and students. Hence, this book is definitely a 'must have' for those who are working on spiders.

This photographic field guide is also suitable for public reading. The book begins with descriptions about the morphology of spiders, hence, it is useful for beginners to know more about spiders. This book comes with a useful guide listing over 150 species under 41 families that reflects the high diversity of spiders in Borneo compared to other regions. Each species is provided with scientific and vernacular names, length attributes, habitat and distribution data. Although the title is 'Borneo Spiders', it covers their distribution in Peninsular Malaysia and other Southeast Asian countries.

Readers will be excited in reading the text featuring awesome photos of each species. For certain species, the description of their morphological parts is explained thoroughly and pictorially, enabling better understanding for the readers. However, this book does not have a list of families and genera in list of the content's page, although they are listed in the index. The references at the back enable the readers to search the online database of all spider taxonomic papers from 1757 onwards.

The first author, Joseph K H Koh, has been researching spiders for more than 50 years and has authored several photographic guides of Southeast Asian spiders. He was the President of the Asian Society of Arachnology. The second author, Nicky Bay, is a well-known professional photographer and most of the amazing photos of spiders in this book were taken by him. He has conducted a lot of macrophotography workshops in Borneo and other places.



A Guide to Wild Fruits of Borneo by Anthony Lamb. Edited by Louise Neo and Kay Lyons. First published April 2019 by Natural History Publications (Borneo) Sdn. Bhd. Photographs copyright © 2019 as credited. Pp. 296. ISBN 978-983-812-191-0.

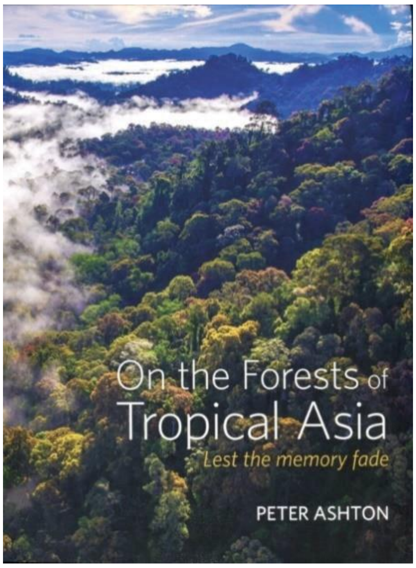
Reviewed by E.B. Johnlee

This book aims to serve as a pictorial guide to the wild fruits of Borneo with the latest botanical names of different species and their affiliation. The author is Datuk Anthony Lamb, who is well known for his work in Borneo, having written numerous books which include a two volume edition of the “Orchids of Mount Kinabalu” and “A Guide to the Gingers of Borneo”. It is my great pleasure and joy to have read this book and to write this review. When I first opened the book and flipped through the pages, it gave me a very good first impression and I believe will immediately capture the attention of the readers as it shows the beautiful and colourful pictures of various edible fruits from the front cover until the back cover.

Borneo is the third largest island in the world and one of the top five global biodiversity hotspots. The island is home to 500 different plant species, which includes a plethora of edible wild fruits, nuts and seeds found in different types of forests from coastal seashores and islands, through lowlands and hills, to montane forests, and on various types of soils. In this guide, the author started by giving the historical backdrop on how the edible fruits were consumed by local inhabitants, over many decades. These were the people who discovered the edible fruits, nuts and seeds and the toxic species that became edible after cooking or fermentation. The types of tropical rainforests in Borneo and the type of edible fruits that are available in each of the forest were also part of the introduction in the first few pages. The following pages show the main content of the guide, which is a selection of species complete with the description of each fruit, distribution and habitat, vernacular names and notes with additional information. Each species listed was also furnished with pictures of the exterior and interior parts of the fruit. As a researcher, I find the information given to be very helpful, easy to read and refer to and certainly make the process of identifying species smoother.

This guide covers only a total of 34 families, 55 genera, and 109 species of wild edible fruits throughout Borneo. There are more species of fruits, nuts and seeds that have yet to be explored and could potentially be added into the list, which was also pointed out by Mr. Tan Jiew Hoe. This book is definitely a must have especially to those who are interested to know more about the wild fruits of Borneo.

“The clearest way into the universe is through a forest wilderness.”
John Muir



On the Forests of Tropical Asia: Lest the memory fade by Peter Ashton. Published by Royal Botanical Gardens, Kew, 2014. Pp 670. ISBN 978-1-8426-475-5 Price: RM 700.00

Reviewed by E. Khoo

Professor Peter Ashton's name is no stranger to many in the field of forestry in Asia. Although he has only worked for 10 years as a forest botanist in Borneo before returning to the academia arena in the West, his passion and interest on species niche specificity and systematics and ecology of Dipterocarpaceae have become the driving force for him to continue to visit and conduct research in this region after that. This publication is a presentation of his perspective and research carried out on the forests in tropical Asia based on his field and working experience with his colleagues and students.

As expected of a botanist, the author has arranged the topics in a systematic manner through the provision of an overall background picture before providing an in-depth insight into the various essential interacting components and influencing factors in relation to the subject matter. Reading through the book is like taking a journey through time as one gains understanding on the formation of various forest forms; interesting aspects of species composition; the rise of diversity; the journey concludes with a take-home message of our role in conservation. Although there is a lot of information to be digested, the author has written it in an engaging manner that sounds like a simple conversation over a cup of tea, where theories and hypotheses were discussed, in which often enough research examples were presented to support the idea or argument.

Overall, the post reading impression is that the publication is meant to perk the interests and at the same time provoke the readers, may it be professionals or laymen to question and ponder upon the subject not just in terms of theories but also immediate actions to be undertaken in safe guarding this natural heritage. The price of the book might appear to be on the high side. However, after reading through, it is well worth the money to procure a personal copy or possibly one for the institutional level.

GUIDE TO CONTRIBUTORS

Sepilok Bulletin is a biannual peer-reviewed journal published by the Forest Research Centre of the Sabah Forestry Department. The Bulletin publishes manuscripts addressing subjects related to tropical forestry, in Borneo and elsewhere. Manuscripts may be in the form of original research papers, short communications, review articles, monographs, book reviews, and announcements.

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Tables and figures (including drawings and photographs) should be numbered and given brief self-explanatory titles. They should not be inserted in the text but prepared on separate sheets.

For abbreviations, standard chemical symbols may be used in the text, e.g. IBA, NaOH, and for scientific names, the generic name may be abbreviated to the initial, but the full term should be given at time of first mention. Measurements should preferably be in SI units with the appropriate symbols.

Acknowledgements: Acknowledgements may be included at the end of the main text preceding the references cited. It should be brief.

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Dicetak oleh Pemangku Pencetak Kerajaan,
Roland Fred Phan, A.D.K., B.S.K., Jabatan Cetak Kerajaan,
Sabah, Malaysia.
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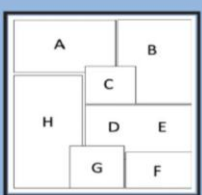

A: *Schizophyllum commune*; **B**: *Ramaria* sp.; **C**: *Filoboletus manipularis*; **D**: *Cookeina sulcipes*; **E**: *Cookeina tricholoma*; **F**: *Trametes versicolor*; **G**: *Russula* sp.; **H**: *Cantharellus* sp.

Front cover: Fungi diversity in Rainforest Discovery Centre, Sepilok. (Photos: Viviannye Paul & Clara Isah)