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Viewable Terrestrial Mammals along the Nature Trails at the Lowland Tropical Forests of Western Sabah, Malaysia Borneo

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ABSTRACT

The information related to the species of terrestrial mammals that can be detected along the nature trails established in the lowland tropical forests of Western Sabah remains scarce at this moment. The camera trapping surveys were commenced at the Tenghilan Community Forest (TCF), Kawang Forest Reserve (KFR), and the urban forest of Universiti Malaysia Sabah (UMS) to investigate the terrestrial mammal species that could be observed along the local trails. A total of 20 terrestrial mammal species belonging to 13 different families were observed in 2,077 trap nights, where most of them were validated to be non-threatened (n = 16 or 80.0%) and omnivorous (n = 13 or 65.0%) species. Twelve species were found along the nature trails in TCF (*H'* = 2.223; 1-D = 0.8650) and KFR (*H'* = 1.730; 1-D = 0.7078), whereas seven species were detected along the trails in the urban forest of UMS (*H'* = 1.217; 1-D = 0.5567). The differences in the mammalian composition, diversity richness, and distribution evenness between these three study sites were validated as significant ($p<0.05$). The present findings emphasize that these three study sites are favorable habitats for four threatened species. Hence, conservation efforts are needed to protect these terrestrial mammal species from facing extinction risks in future.

1. Introduction

The establishment of a nature trail serves to increase the accessibility of a forested area and its resources to humans (Nair *et al.* 2018; Lim *et al.* 2019), and it tends to overlap with the existing pathways of the terrestrial mammals (Scholten *et al.* 2018; Ota *et al.* 2019). In Malaysia Borneo, Sabah houses more than 200 species of terrestrial mammals, yet only certain species can be found along the nature trails that are regularly used by humans (Phillipps and Phillipps 2018; Bernard *et al.* 2019). Much research has been conducted on the terrestrial mammals that inhabit the lowland tropical forest in Sabah, particularly those which are situated in the Divisions of Sandakan and Tawau (e.g., Wearn *et al.* 2017; Kee *et al.* 2018; Hearn *et al.* 2018; Bernard *et al.* 2019; Lim and Mojiol 2022), at this moment. On the contrary, the terrestrial mammals that can be detected along the nature trails at the West Coast Division of Sabah (Western Sabah) are rarely being examined (Wells *et al.* 2014; Sompud *et al.* 2023) because the researchers focused majorly on the local bat and avian species instead (e.g., Gilbert *et al.* 2018; Lim and Mojiol 2019; Aloysius *et al.* 2021; Lok *et al.* 2021).

Humans can easily access the biological resources in the lowland tropical forests of Western Sabah through the established nature trails, the impact of human visitation concentrated on the trail regions (Nair *et al.* 2018; Lim and Mojiol 2019; Aloysius *et al.* 2021). Furthermore, the vegetation composition and structure of a forest landscape can be altered by humans, which can ultimately define the movement behaviors adopted by the local terrestrial mammals in moving within the given area (Wilting and Azlan 2010; Matsubayashi *et al.* 2011; Samejima *et al.* 2012; Scholten *et al.* 2018). Henceforth, the terrestrial mammal species that can be found along the trails are expected to be varied across the different forest landscapes at Western Sabah (Bernard *et al.* 2019; Ota *et al.* 2019; Bakri *et al.* 2020; Bookhari *et al.*

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2020). Since this particular matter has not yet been investigated scientifically, there is a need to fill up the given research gap.

Consequently, the camera trapping surveys were commenced at three lowland tropical forests, which were under three different districts in Western Sabah, to determine the terrestrial mammal species that use the nature trails established in these regions. The selected study sites included the Tenghilan Community Forest (TCF), Kawang Forest Reserve (KFR), and the urban forest of Universiti Malaysia Sabah (UMS). Then, the distribution evenness, diversity richness, and species composition of the detected terrestrial mammals were hypothesized to be differed significantly among these three study sites, as suggested by the results of several relevant past studies (e.g., Wilting and Azlan 2010; Matsubayashi *et al.* 2011; Samejima *et al.* 2012; Wearn *et al.* 2017). The present findings were expected to provide an update on the current conditions of the mammalian communities presented at the selected three study sites and also at Western Sabah of Malaysia Borneo, which subsequently filled up the above-mentioned research gap.

2. Materials and Methods

2.1. Study Sites

The KFR is a 1,551 ha of recovered mixed lowland dipterocarp forest located in Papar District and managed as a Class I Protection Forest Reserve by the Sabah Forestry Department (Nair *et al.* 2018). Hence, only educational, research, and non-lethal recreational activities (e.g., jungle trekking, camping, and picnicking) can be conducted at the nature trails within this fragmented forest. Moreover, the 102 ha of fragmented recovering mixed lowland acacia forest in UMS (Kota Kinabalu District), as well as its resources, are regularly accessed by humans through the existing local trails, mainly for the educational, research, and non-lethal recreational purposes (Lim and Mojiol 2019; Sompud *et al.* 2023). The forest landscape in TCF is a mixed matrix of the regenerated mixed lowland dipterocarp forest and old mixed rubber plantation forest (Aloysius *et al.* 2021), where the local dipterocarp forest is connected to the surrounding larger contiguous forests. Then, the nature trails are then established to ease the local communities in accessing various natural resources (e.g., food, water, wood, and non-timber forest products) available at the given two habitats. A total of 30 sampling points were established along the nature trails presented in these three study sites, where the UMS had the highest number of sampling points (n = 12), followed by the KFR (n = 10), and lastly the TCF (n = 8). Figure 1 displays the locations of the 30 sampling points that are established along the nature trails at the selected three study sites in the Western Sabah of Malaysia Borneo.

2.2. Camera Trapping

The camera trapping survey was commenced at the 30 sampling points for 11 months, starting with the KFR (September to November 2022), followed by the UMS (November 2022 to April 2023), and finally the TCF (April to July 2023) in this study. The sampling points were posited approximately 200 m apart from each other, to maximize the coverage of the examined trails (Bernard *et al.* 2019; Aloysius *et al.* 2021). A unit of HC-800M SunTek camera trap equipped with the passive infra-red sensor (Hong Kong Suntek International Co., Ltd.) was attached to a vertical tree (0.5 m to 1.5 m aboveground level), while facing against the trail (2.0 m to 5.0 m apart), to observe and record the frequencies of the terrestrial mammals from different sizes in using the targeted trail area (Ota *et al.* 2019; Bakri *et al.* 2020). A unit of camera trap was deployed at each sampling point for at least 60 days (TCF = 8 camera traps; KFR = 10 camera traps; UMS = 12 camera traps), to make sure that sufficient sampling efforts were obtained at the end of this research, as suggested by Si *et al.* (2014). The deployed camera traps were set to take three photographs and one 10-second video consecutively for each trigger, and also the maintenance works were applied onto them once every three weeks.

2.3. Data Analysis

This study only examined the footages with the identifiable terrestrial mammals, where a total of 1,038 photographs and videos were included in the data analysis (Matsubayashi *et al.* 2011; Lim and Mojiol 2022). The species of each detected terrestrial mammals, and also the feeding guild and conservation status of each recorded species, were determined by referring to the relevant secondary data (Phillipps and Phillipps 2018; International Union for Conservation of Nature 2023). This study used a 30-minute time gap to distinguish between two independent sightings of the same

species, based on the result of the preliminary data analysis. The relative abundance index (RAI) was measured as the visitation frequency of a mammal species to the nature trails presented in a particular study site and time period, in the number of independent sighting of the given species recorded at the given study site per 100 trap nights ($100TN^{-1}$).

This research applied the statistical software PAST ver. 3.25 (Hammer *et al.* 2001) in commencing both the descriptive and inferential analyses at the confidence level of 95.0% ($\alpha = 0.05$). Firstly, the species accumulation curve was made, by plotting the abundance (number of independent sighting) against the species number, to determine the sampling efficiency for each study site, where a sufficient sampling effort was attained when the curve approached an asymptote (Bernard *et al.* 2019). Then, the Chi-square test was used in comparing the species composition of the detected mammalian individuals among the selected three study sites. The Shannon's (*H'*) and Simpson's (1-D) diversity indices were calculated, as representations to the diversity richness and distribution evenness respectively of the terrestrial mammal species observed along the nature trails at each study site. Ultimately, the diversity t-test was used to evaluate the variability in the mammalian diversity richness and distribution evenness between the selected three study sites. This statistical analysis was proposed by Hammer *et al.* (2001), where it was applicable to both the normally distributed and non-normally distributed datasets, because it compared the 1-D and *H'* values estimated for a certain dataset with those estimated for another dataset. Henceforth, the conducting of normality test onto the camera trapping data obtained in this study was not required before running the diversity t-test.

3. Results

A total of 20 terrestrial mammals species belonged to 13 different families were found visiting the nature trails in the selected three study sites, in a total of 2,077 trap nights (KFR = 636 TN; UMS = 810 TN; TCF = 631 TN), in this research. The species accumulation curves constructed for these three study sites were found approaching an asymptote at different species numbers and number of independent sightings of terrestrial mammals, as shown in below Figure 1. This showed that sufficient sampling efforts were attained for all three study sites in this study. The Viverridae and Sciuridae families were validated to have the highest recorded species number (n =3), and then followed by the Hystricidae, Tupaiidae and Cercopithecidae families (n = 2), and finally the remaining 8 families (n = 1). Then, a majority of them were omnivores (n = 13 or 65.0 %), because only few species were validated to be the carnivores (n = 2 or 10.0 %) and herbivores-frugivores (n = 5 or 25.0 %). Moreover, only the endangered long-tailed macaque (*Macaca fascicularis*), endangered Southern pig-tailed macaque (*M. nemestrina*), vulnerable bearded pig (*Sus barbatus*), and critically-endangered Sunda pangolin (*Manis javanica*) were validated as the threatened species (n = 20.0 %), while the remaining 16 species were the non-threatened species (n = 80.0 %). Twelve terrestrial mammal species were observed at the trails in both the KFR and TCF (60.0 %), while only seven species was detected at the trails in the UMS (35.0%). Actually, the small-toothed palm civet (*Arctogalidia trivirgata*) and red giant flying Squirrel (*Petaurista petaurista*) were observed only at UMS (Figure 2).

Then, the bearded pig, collared mongoose (*Herpestes semitorquatus*), large treeshrew (*Tupaia tana*), slender treeshrew (*T. gracilis*), and the plantain squirrel (*Callosciurus notatus*) were observed only at the TCF. At the same time, the thick-spined porcupine (*Hystrix crassispinis*), Sunda stink-badger (*Mydaus javanensis*), yellow-throated marten (*Martes flavigula*), Southern pig-tailed macaque, and Malay civet (*Viverra tangalunga*) were found only at the KFR. Regarding the remaining eight species, which were the Sunda pangolin, long-tailed macaque, leopard cat (*Prionailurus bengalensis*), Prevost's squirrel (*Callosciurus prevostii*), mousedeer (*Tragulus* spp.), common palm civet (*Paradoxurus hermaphroditus*), Southern red muntjac (*Muntiacus muntjak*), and long-tailed porcupine (*Trichys fasciculate*), they were successfully observed at two or more study sites. Since distinguishing between the greater mousedeer (*T. napu*) and lesser mousedeer (*T. kanchil*) by referring to the captured footages was difficult, both species were assumed merely as mousedeer in this research. Table 1 shows the summary of the terrestrial mammal species recorded during the camera trapping survey conducted at the nature trails in the selected three study sites.

The trails at KFR were used majorly by the Southern pig-tailed macaque (n = 30; RAI = 4.717 $100TN^{-1}$), long-tailed porcupine (n = 10; RAI = 1.572 $100TN^{-1}$) and the common palm civet (n = 4; RAI = 0.6289 $100TN^{-1}$).

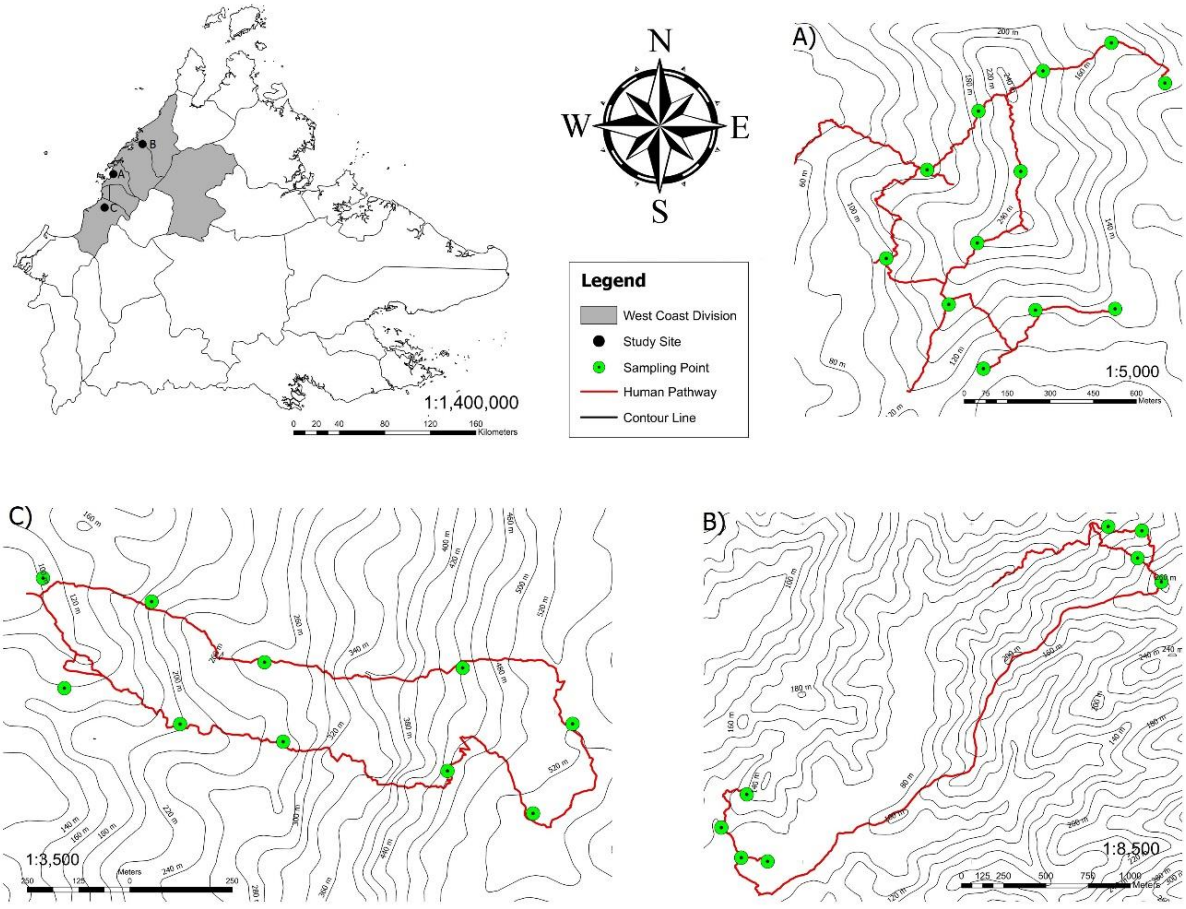

Figure 1. Locations of the 30 sampling points that are established along the nature trails at (A) Universiti Malaysia Sabah, (B) Tenghilan Community Forest, and (C) Kawang Forest Reserve, in the Western Sabah of Malaysia Borneo

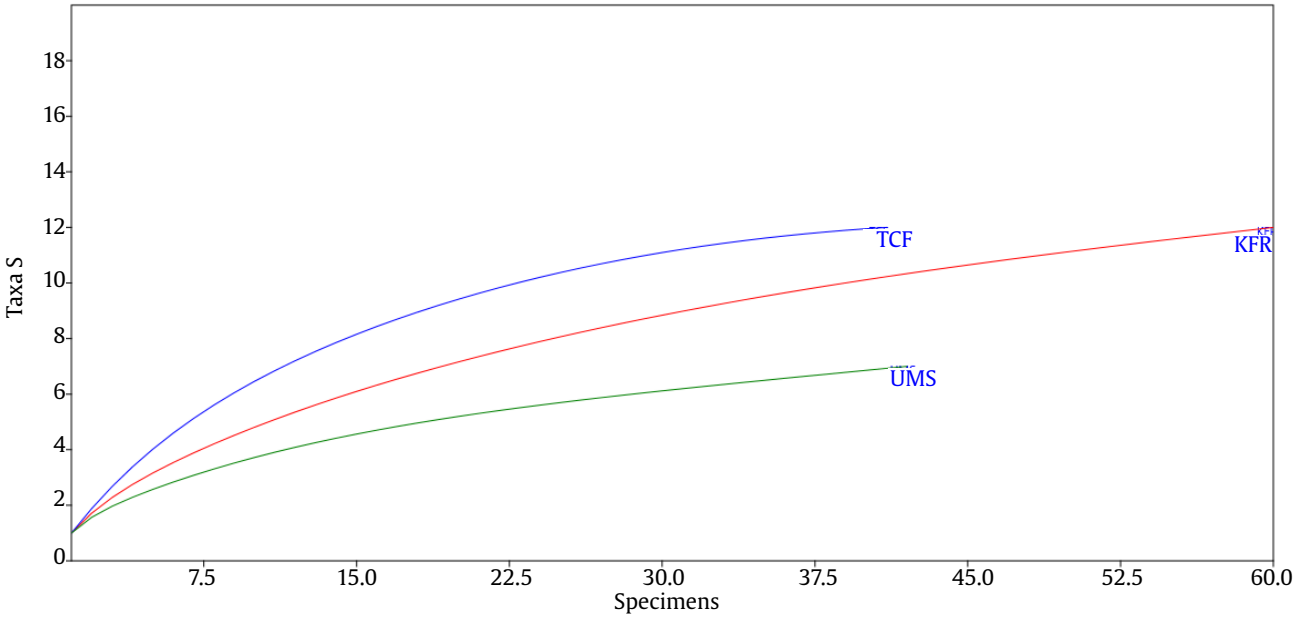

Figure 2. Species accumulation curves of the terrestrial mammals that are detected along the nature trails at the Tenghilan Community Forest (TCF), Kawang Forest Reserve (KFR) and urban forest of Universiti Malaysia Sabah (UMS) in the Western Sabah of Malaysia Borneo

Table 1. Summary on the terrestrial mammal species that are recorded during the camera trapping survey conducted at the nature trails in the selected three study sites

Family	Scientific name	Local name	FG[1]	IUCN[2]	KFR		TCF		UMS	
					n	RAI	n	RAI	n	RAI
Felidae	*Prionailurus bengalensis*	Leopard cat	C	LC	-	-	2	0.3170	-	-
Herpestidae	*Herpestes semitorquatus*	Collared mongoose	O	NT	-	-	1	0.1585	-	-
Mephitidae	*Mydaus javanensis*	Sunda stink-badger	O	LC	4	0.6289	-	-	1	0.1235
Mustelidae	*Martes flavigula*	Yellow-throated marten	O	LC	-	-	5	0.7924	-	-
Viverridae	*Arctogalidia trivirgata*	Small-toothed palm civet	O	LC	-	-	2	0.3170	1	0.1235
	Paradoxurus hermaphroditus	Common palm civet	O	LC	3	0.4717	2	0.3170	27	3.3333
	Viverra tangalunga	Malay civet	O	LC	10	1.5720	2	0.3170	-	-
Cervidae	*Muntiacus muntjak*	Southern red muntjac	HF	LC	3	0.4717	-	-	-	-
Suidae	*Sus barbatus*	Bearded pig	O	VU	2	0.3145	3	0.4754	4	0.4938
Tragulidae	*Tragulus* spp.	Mousedeer	HF	LC	30	4.7170	-	-	-	-
Manidae	*Manis javanica*	Sunda pangolin	C	CR	-	-	9	1.4260	-	-
Cercopithecidae	*Macaca fascicularis*	Long-tailed macaque	O	EN	1	0.1572	3	0.4754	-	-
	Macaca nemestrina	Southern pig-tailed macaque	O	EN	-	-	-	-	1	0.1235
Hystricidae	*Hystrix crassispinis*	Thick-spined porcupine	HF	LC	-	-	9	1.4260	-	-
	Trichys fasciculate	Long-tailed porcupine	HF	LC	-	-	-	-	3	0.3704
Sciuridae	*Callosciurus notatus*	Plantain squirrel	O	LC	3	0.4717	1	0.1585	-	-
	Callosciurus prevostii	Prevost's squirrel	O	LC	1	0.1572	2	0.3170	5	0.6173
	Petaurista petaurista	Red giant flying squirrel	HF	LC	1	0.1572	-	-	-	-
Tupaiidae	*Tupaia gracilis*	Slender treeshrew	O	LC	1	0.1572	-	-	-	-
	Tupaia tana	Large treeshrew	O	LC	1	0.1572	-	-	-	-

[1]FG: feeding guild (O: omnivore, HF: herbivore-frugivore, and C: carnivore); [2]CS: conservation status (IUCN red list status) (LC: least concern, NT: near threatened; VU: vulnerable; EN: endangered, and CR: Critically endangered). KFR: Kawang Forest Reserve; TCF: Tenghilan Community Forest; UMS: Universiti Malaysia Sabah; n: Number of Independent Sighting, and RAI: Relative Abundance Index ($100TN^{-1}$)

Both the plantain squirrel and slender treeshrew (n = 9; RAI = 1.426 $100TN^{-1}$), plus the large treeshrew (n = 5; RAI = 0.7924 $100TN^{-1}$), were observed along the trails at TCF frequently, while the trails at UMS were used mainly by the long-tailed macaque (n = 27; RAI = 3.333 $100TN^{-1}$), Sunda pangolin (n = 5; RAI = 0.6173 $100TN^{-1}$) and the mousedeer (n = 4; RAI = 0.4938 $100TN^{-1}$). Regarding the other detected species, they were rarely sighted in this research (n < 4; RAI < 0.49 $100TN^{-1}$), and also their respective visitation frequencies to the nature trails were varied across the three study sites. Ultimately, the results of the Chi-square test indicated that the species composition of the terrestrial mammals found along the trails were varied significantly between these three study sites (TCF vs KFR: $\chi^2_{19} = 66.67$, $p < 0.001$; KFR vs UMS: $\chi^2_{19} = 36.53$, $p = 0.004$; TCF vs UMS: $\chi^2_{19} = 31.20$, $p = 0.038$).

Among the three study sites examined in this research, the highest species distribution evenness (1-D = 0.8650) and diversity richness (*H'* = 2.223) of the terrestrial mammals were attained at the nature trails in TCF, and then followed by those in the KFR (*H'* = 1.730; 1-D = 0.7078), and lastly those in the urban forest of UMS (*H'* = 1.217; 1-D = 0.5567). Furthermore, the results of diversity t-test revealed that the mammalian distribution evenness (TCF vs KFR: t = 2.554, p = 0.012; TCF vs UMS: t = -3.511, p = 0.001) and species richness (TCF vs KFR: t = -2.450, p = 0.016; KFR vs UMS: t = 2.181, p = 0.032; TCF vs UMS: t = 4.688, p < 0.001) were found varied significantly among these three study sites, except between the mammalian distribution evenness of KFR and UMS (t = -1.507, p = 0.136). This showed that the terrestrial mammal species that utilized the trails in TCF were more diverse and evenly distributed, when compared to those which used the trails at the other two study sites examined in this study.

4. Discussion

The plotted species accumulation curves for the selected three study sites only approached an asymptote, instead of levelled, even after the sampling was completed. This indicated that the gathered data were sufficed to represent the mammalian communities that use the nature trails at these three study sites (Bernard *et al.* 2019), although various small mammal species were miss-detected in this study. Since the camera traps were set to capture footage of the terrestrial mammals from different sizes, hence clear footage of the small mammals could only be taken (for species identification), when they were close to the deployed camera traps (Matsubayashi *et al.* 2011; Samejima *et al.* 2012; Wearn *et al.* 2017). Ultimately, an increase in the sampling duration should minimize the chances of miss-detecting the local terrestrial mammal species and further improve the sampling efforts of this study (Si *et al.* 2014; Bakri *et al.* 2020).

This research managed to detect 20 terrestrial mammal species, which included four threatened species, and were more than those reported by the Wells *et al.* (2014) (n = 13). This past research utilized the cage traps to study only the small mammals, while the present study applied the camera traps in sampling the terrestrial mammals from different sizes, at different regions in Western Sabah. Then, several past studies also applied the camera traps to examine the terrestrial mammals at the Sandakan and Tawau Divisions (Wilting and Azlan 2010; Wearn *et al.* 2017; Kee *et al.* 2018; Bernard *et al.* 2019), where they had recorded similar but more species than those obtained in this study. Actually, these past studies were conducted at various forest reserves that were larger (>10,000 ha) than the study sites examined in this study. Then, these past studies evaluated both the trails and non-trail areas, thus covering large areas of the examined forest reserves, unlike this study that only focused on the accessible trail areas. The terrestrial mammals would only inhabit the habitats that are larger than their home range sizes (Phillipps and Phillipps 2018). Furthermore, the shy and elusive species, namely the threatened species with low tolerance upon the human disturbance and habitat degradation, tend to avoid visiting the trails that were regularly used by humans (Matsubayashi *et al.* 2011; Samejima *et al.* 2012; Lim and Mojiol 2022). Ultimately, this study obtained the findings that were different from those reported by the above-mentioned past studies. Table 2 displays the comparison in the recorded species of terrestrial mammals between the present study and three past research conducted in Sabah.

Moreover, the large mixed rubber plantation forest and contiguous regenerated mixed lowland dipterocarp forest have made the TCF to comprise the largest forest landscape in this study, when compared to the fragmented recovered mixed lowland dipterocarp forest in KFR (1,551 ha), plus the fragmented recovering mixed lowland acacia

Table 2. Comparison in the recorded species of terrestrial mammals between the present study and three past studies conducted in Sabah, Malaysia Borneo

Scientific name	Common name	Present study	Wells *et al.* 2014	Wearn *et al.* 2017	Bernard *et al.* 2019
Aonyx cinerea	Asian small-clawed otter	-	-	3ab	-
Arctictis binturong	Binturong	-	-	3ab	2ac
Arctogalidia trivirgata	Small-toothed palm civet	1a	-	-	-
Bos javanicus	Banteng	-	-	3ab	-
Callosciurus adamsi	Ear-spot squirrel	-	-	3ab	-
Callosciurus notatus	Plantain squirrel	1a	1b	3ab	2c
Callosciurus prevostii	Prevost's squirrel	1a	1b	-	-
Catopuma badia	Bornean bay cat	-	-	3ab	-
Cephalopachus bancanus	Horsfield's tarsier	-	-	3ab	-
Diplogale hosei	Hose's civet	-	-	3ab	-
Echinosorex gymnura	Moonrat	-	-	3ab	2a
Elephas maximus borneensis	Bornean pygmy elephant	-	-	3ab	2ac
Exilisciurus exilis	Least pygmy squirrel	-	-	-	2c
Helarctos malayanus	Sun bear	-	-	3ab	2a
Hemigalus derbyanus	Banded civet	-	-	3ab	2a
Herpestes brachyurus	Short-tailed mongoose	-	-	3ab	2ac
Herpestes semitorquatus	Collared mongoose	1a	-	3ab	-
Hylobates muelleri	Bornean gibbon	-	-	-	2c
Hystrix brachyura	Malayan porcupine	-	-	3ab	-
Hystrix crassispinis	Thick-spined porcupine	1a	-	3ab	2a
Lariscus hosei	Four-striped ground squirrel	-	-	3ab	-
Leopoldamys sabanus	Long-tailed giant rat	-	1b	3ab	-
Lutrogale perspicillata	Smooth-coated otter	-	-	-	-
Macaca fascicularis	Long-tailed macaque	1a	-	3ab	2a
Macaca nemestrina	Southern pig-tailed macaque	1a	-	-	2a
Manis javanica	Sunda pangolin	1a	-	3ab	2c
Martes flavigula	Yellow-throated marten	1a	-	3ab	-
Maxomys baeodon	Small Bornean maxomys	-	-	3ab	-
Maxomys ochraceiventer	Chesnut-bellied spiny rat	-	-	3ab	-
Maxomys rajah	Rajah spiny rat	-	1b	3ab	-
Maxomys surifer	Indomalayan maxomys	-	1b	3ab	-
Maxomys whiteheadi	Whitehead's spiny rat	-	1b	3ab	-
Muntiacus atherodes	Bornean yellow muntjac	-	-	3ab	2c
Muntiacus muntjak	Southern red muntjac	1a	-	3ab	-
Mustela nudipes	Malay weasel	-	-	3ab	-
Mydaus javanensis	Sunda stink-badger	1a	-	3ab	2ac
Neofelis diardi borneensis	Bornean clouded leopard	-	-	3ab	2c
Niviventer cremoriventer	Sundaic arboreal niviventer	-	1b	3ab	-
Nycticebus spp.	Slow loris	-	-	-	2c
Paguma larvata	Masked palm civet	-	-	3ab	-
Paradoxurus hermaphroditus	Common palm civet	1a	-	3ab	2ac
Pardofelis marmorata	Marbled cat	-	-	3ab	2a
Petaurista petaurista	Red giant flying squirrel	1a	-	-	-
Pongo Pygmaeus morio	Bornean orang-utan	-	-	3ab	2ac
Presbytis rubicunda	Red langur	-	-	-	-
Prionailurus bengalensis	Leopard cat	1a	-	3ab	2c
Prionailurus planiceps	Flat-headed cat	-	-	-	2ac
Prionodon linsang	Banded linsang	-	-	3ab	2a
Rattus exulans	Polynesian rat	-	-	3ab	-
Rattus norvegicus	Brown rat	-	1b	-	-
Rattus rattus	House rat	-	1b	3ab	-
Rheithrosciurus macrotis	Tufted ground squirrel	-	-	3ab	-
Rusa unicolor	Sambar deer	-	-	3ab	2ac

Table 2. Comparison in the recorded species of terrestrial mammals between the present study and three past studies conducted in Sabah, Malaysia Borneo

Scientific name	Common name	Present study	Wells *et al.* 2014	Wearn *et al.* 2017	Bernard *et al.* 2019
Suncus murinus	House shrew	-	1b	-	-
Sundamys muelleri	Müller's sundamys	-	1b	3ab	-
Sundasciurus hippurus	Horse-tailed squirrel	-	-	3ab	-
Sundasciurus lowii	Low's squirrel	-	1b	-	2c
Sus barbatus	Bearded pig	1a	-	3ab	2ac
Tragulus spp.	Mousedeer	1a	-	3ab	2ac
Trichys fasciculata	Long-tailed porcupine	1a	-	3ab	2a
Tupaia dorsalis	Striped treeshrew	-	-	3ab	-
Tupaia glis	Common treeshrew	-	-	-	2c
Tupaia gracilis	Slender treeshrew	1a	-	3ab	-
Tupaia longipes	Northern long-footed treeshrew	-	-	3ab	-
Tupaia minor	Lesser treeshrew	-	-	3ab	2c
Tupaia tana	Large treeshrew	1a	1b	3ab	-
Viverra tangalunga	Malay civet	1a	-	3ab	2ac

1: West Coast Division, 2: Sandakan Division, 3: Tawau Division, a: camera trapping, b: invasive trapping, and c: transect survey

forest in UMS (102 ha) (Nair *et al.* 2018; Lim and Mojiol 2019; Sompud *et al.* 2023). Then, the local communities visit the trails in TCF majorly for travelling and resource harvesting, while the trails in KFR and UMS are used by humans mostly for the educational, research and non-lethal recreational purposes. The existing forest coverage, structure and composition, and also the type of conducted human activity, are known to shape the varieties and abundances of food and shelter, and subsequently those of the terrestrial mammals, presented in a specific habitat (Wells *et al.* 2014; Bookhari *et al.* 2020; Lok *et al.* 2021). Henceforth, the 20 species recorded in this study were generally those which could survive in different habitats, plus utilize the nature trails that were regularly by humans (Wearn *et al.* 2017; Phillipps and Phillipps 2018; Aloysius *et al.* 2021), namely the omnivorous and non-threatened species, instead of the overall species that inhabit the habitats, presented at the given three study sites.

Since the UMS generally possessed the smallest and most disturbed forested habitats, only seven mammal species with small home range sizes and/or high tolerance to human disturbance and habitat degradation were found along the local trails in this research. Both the red giant flying squirrel and small-toothed palm civet were found only at UMS, mainly because the given two arboreal species coincidentally descended to the understorey and ground layers, respectively, near the deployed camera traps (Wilting and Azlan 2010; Kee *et al.* 2018). The food abundance and variety for the mousedeer, critically endangered Sunda pangolin, and the endangered long-tailed macaque were higher at the trail area of a disturbed forest than that of a less-disturbed forest, and vice versa for both the leopard cat and common palm civet (Azlan *et al.* 2017; Hearn *et al.* 2018; Phillipps and Phillipps 2018; Sompud *et al.* 2023). Hence, these three disturbance-tolerant species utilized the trails at UMS more frequently than those at KFR and TCF, while the leopard cat and common palm civet visited the trails at the TCF and KFR respectively more frequently than those at the UMS in this study. Consequently, the terrestrial mammals that utilized the trails at UMS were verified to be the least diverse (H' = 1.217) and evenly distributed (1-D = 0.5567) since the usages of the local trails were dominated by those three disturbance-tolerant species (Gilbert *et al.* 2018; Lim and Mojiol 2019).

Similarly, the usage of the trails at KFR was dominated by the endangered Southern pig-tailed macaque. At the same time, those at the TCF were used similarly frequently by the recorded 12 species, which resulted in the higher mammalian diversity richness and distribution evenness recorded at TCF (H' = 2.223; 1-D = 0.8650) than at those in KFR (H' = 1.730; 1-D = 0.7078), in this study. The low visitation frequencies of both the thick-spined porcupine and long-tailed macaque to the trails at KFR could be their avoidance responses to the competition with the long-tailed porcupine and Southern pig-tailed macaque respectively (Azlan *et al.* 2017; Hearn *et al.* 2018). However, the detections of the Southern pig-tailed macaque, Malay civet, yellow-throated marten,

thick-spined porcupine, and Sunda stink-badger only at the trails in KFR, and also the higher detection frequency of the Southern red muntjac at KFR than at TCF, indicated that these terrestrial mammal species avoided visiting the trails surrounded by disturbed forests with low availabilities of food and shelter, and/or with high risks of getting hunted by humans (Wearn *et al.* 2017; Scholten *et al.* 2018; Lim and Mojiol 2022). On the other hand, the species that could thrive in the old plantation forest were observed only at the trails in TCF, including the large treeshrew, plantain squirrel, slender treeshrew, and the Prevost's squirrel (Phillipps and Phillipps 2018). Finally, the collared mongoose and vulnerable bearded pig were known to forage regularly at the trail region within a large contiguous forest, and vice versa for the small fragmented forest (Wilting and Azlan 2010; Samejima *et al.* 2012; Bernard *et al.* 2019; Ota *et al.* 2019), which explained their detections only at TCF, but not at KFR, in this research.

In conclusion, different terrestrial mammal species can be found utilizing the nature trails established in the three lowland tropical forests at Western Sabah. The abundance and varieties of the terrestrial mammals found along the trails vary significantly, likely due to the variability in the habitat size and connectivity, type of conducted human activity, and vegetation structure and composition between these three study sites. Therefore, the terrestrial mammals that visit the trails in TCF are the most diverse and evenly distributed, followed by those that visit the trails in KFR and those that use the trails in the urban forest of UMS. The dominance of the endangered long-tailed macaque and Southern pig-tailed macaque on the usages of the nature trails in KFR and UMS, respectively, can result in the attainment of this outcome as well. In summary, the present findings indicate that the variability in these five factors may dictate the species composition, distribution evenness, and diversity richness of terrestrial mammals found along a nature trail established in a certain forested area at Western Sabah.

However, the miss-detections of various small mammal species, as well as the species that can be found only in the non-trail regions, remain the main limitation of this research. Therefore, increasing the camera trapping nights, the number of independent sightings for each recorded species, and the applications of various sampling techniques can minimize the chances of miss-detections. The non-trail regions should also be included in the survey so that the collected data can represent the overall mammalian community, not only the species that visit the local trails at the study site. These suggestions can improve the sampling efforts by helping level the plotted species accumulation curves and improving the data accuracy and precision. Additionally, this can allow the researchers to examine the actual influences of those five factors towards the presence/absence and visitation frequency of each recorded mammal species, and ultimately onto the shaping of the mammalian composition, distribution evenness, and diversity richness recorded for the nature trails presented within a particular forest landscape. Likewise, the detections of the critically endangered Sunda pangolin, vulnerable bearded pig, and two endangered macaque species emphasize that these three study sites provide favorable habitats for them to survive in Western Sabah. Henceforth, conservation efforts are required to protect these four threatened species from facing future extinction risks.

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