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VARIABILITY IN THE PATTERNS OF TERRESTRIAL MAMMALS IN VISITING THE NATURAL SALT-LICKS AT A TROPICAL FOREST

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ABSTRACT

Natural salt-licks are visited frequently by various species of terrestrial mammals, but the variability in environmental conditions can modify the mammalian visitation pattern in an inland tropical forest. Given that no similar research has been conducted at Segaliud-Lokan Forest Reserve in Sabah (Malaysia), a scientific research was conducted from July 2019 to February 2020 (eight months), to investigate the effects of variability in the environmental conditions on mammalian visitation patterns to the local natural salt-licks, applying the field assessment and camera trapping techniques. Over all, a total of 12 different mammal species were recorded at four selected salt-licks, and then the visitation frequencies of certain species were confirmed to be significantly influenced by the seasonal variability in rainfall patterns, and also by the variations in onsite and surrounding conditions. Further research is required to validate the influences of variability in explanatory variables that were not included in this scientific study.

Kata kunci *(Keywords)*: Environmental Condition, Natural Salt-lick, Segaliud-Lokan Forest Reserve, Terrestrial Mammals.

INTRODUCTION

Natural salt-licks are recognized as the keystone resources with the temporal importance to the well-being of terrestrial mammals in a tropical forest ecosystem (Matsubayashi et al., 2007a & 2011). These natural features function as major sources of sodium minerals, especially for the mammalian community that have inhabited the inland tropical forest, where the local vegetation is actually sodium deficient (Jordan, 1985). Furthermore, various types of essential minerals and trace elements are available at the salt-licks in sufficient amounts (Ayotte et al., 2008; Voigt et al., 2008). Because of that, the mammal species with fiber-based diets (omnivores, herbivores, frugivores, and nectarivores) use the salt-licks regularly to replenish their body minerals by ingesting the local mineral-rich earth materials, in which this unique behavior is referred as the "Geophagy" (Hon & Shibata, 2013; Molina et al., 2014). The predator species (insectivores and carnivores), on the other hand, are attracted to visit these mineral-rich areas

for prey-hunting, thus resulting in the visitations of various species of terrestrial mammals to the tropical licks (Matsubayashi et al., 2007a; Simpson et al., 2020; Lim & Mojiol, 2022).

The tropical forest of Sabah, Malaysia Borneo, is home to about 247 species of terrestrial mammals, and 41 species have been reported detected at the local natural salt-licks (Phillipps & Phillipps, 2018; Lim & Mojiol, 2021). The herbivorous ungulates are verified as the main visitors of the local licks, although other mammal species like the fruit-eating bats, arboreal primates, rodents, and predators can also be detected visiting the given licks as well (Blake et al., 2013; Simpson et al., 2020; Lim & Mojiol, 2021). Nevertheless, the frequency of a certain mammal species in utilizing a salt-lick is dependent onto the existing environmental condition of the given lick (Matsubayashi et al., 2007a & 2011; Hon & Shibata, 2013; Matauda et al., 2015; Nin, 2017). Because of that, the variability in the environmental conditions (human disturbance, weather conditions, and bio-physiochemical properties) can result in the variation in visitation pattern of a mammal species between different salt-licks and time periods (Matsubayashi et al., 2007b; Molina et al., 2014; Ampeng et al., 2016; Lim & Mojiol, 2021).

Presently, the scientific assessment of the relationship between the salt-licks and terrestrial mammals, or recognized as the "Mammal-Lick Relationship", is seldom conducted on the natural salt-licks that are presented in Sabah (Lim & Mojiol, 2021), including the salt-licks at Segaliud-Lokan Forest Reserve (SLFR). Information on the effects of variability in environmental conditions onto the mammalian visitation pattern to a certain salt-lick and at a given time period remains uncertain for SLFR. Therefore, this study aimed to validate the given matter for the terrestrial mammals and natural salt-licks presented in SLFR, while hypothesizing that the visitation patterns of certain mammal species were affected by the changes in environmental conditions of the local licks significantly. The present findings would be beneficial in understanding the adaptive responses of each detected mammal species under different environmental conditions.

MATERIALS & METHODS

Study Site

The SLFR is currently managed as a Class II Commercial Forest Reserve by the KTS Plantation Sdn. Bhd. The given commercial forest reserve is a landscape mosaic (57,247 ha) that is comprised majorly of forest protected areas, forest plantation areas and logged natural forests. Four natural salt-licks that were located at least 1.0 km away from one another were selected as the sampling areas of the present research, as shown in Figure. 1. The selected four salt-licks were named as "SL50_A", "SL50_B", "SL56", and "SL59". Then, both the SL50_A and SL50_B were actually located in a forest plantation, while both the SL56 and SL59 were located in a forest protected area and logged natural forest respectively.

Camera Trapping Survey

A camera trapping survey was conducted for eight months (July 2019 to February 2020) at the selected four natural salt-licks in SLFR. The SunTek (Hong Kong Suntek International Co. Ltd.) passive infra-red automatic trigger camera was used in recording the frequency of a particular mammal species that visited a certain lick and at a certain time period in this research. A unit of camera trap was attached to a vertical tree at 0.5 m above ground level and aimed at

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the mineral-rich spring water at each selected salt-lick.

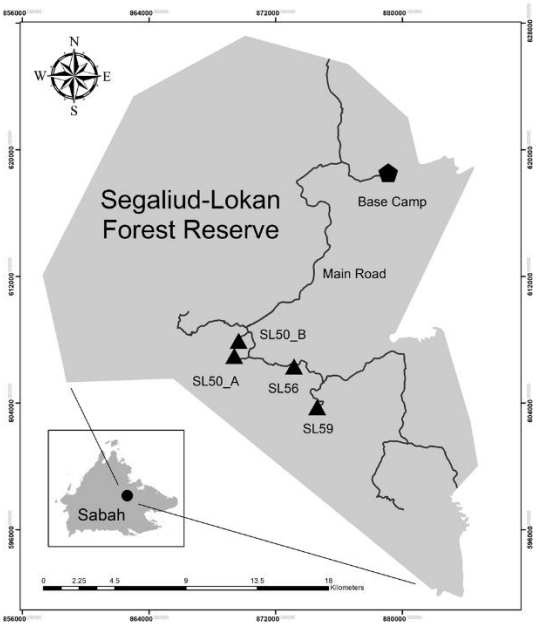

Figure 1. Locations of the four selected natural salt-licks in Segaliud-Lokan Forest Reserve, Sandakan, Sabah

The camera traps were set to capture the footage (three photographs and one video) of any medium to large-sized mammals, 24/7 a day at the given licks, using the setting of a 60-sec delay per three consecutive photographs (6-sec gap per motion trigger). The deployed camera traps were visited once every 14 days to remove any view-blocking vegetation, transfer data, and replace the batteries. The overall camera trapping effort of this research amounted to a total of 343 trap nights (SL50_A=86 TN; SL50_B=95 TN; SL56=87 TN; SL59=75 TTN).

The captured footages with no or unidentifiable mammalian individuals were excluded from this study. A 30-min time interval was used in distinguishing between two independent sightings from the successive photographing of a specific mammal species at a given time and salt-lick (Matsubayashi et al., 2007a). After that, relevant secondary data was applied in identifying the species of each detected individual (Phillipps & Phillipps, 2018), by referring to its morphological traits. Furthermore, the number of independent sightings recorded per 100 trap nights ($100TN^{-1}$) was estimated as the visitation frequency of a certain species detected at a specific salt-lick or time period (month) in the present research, as proposed by Lim and Mojiol (2022).

Field Assessment

The existing environmental conditions of each selected salt-lick was evaluated, in terms of the weather conditions (rainfall), bio-physiochemical properties (size of salt-lick and mineral concentration), and the anthropogenic disturbance (vegetation structure and close proximity of a salt-lick towards the nearest road). First of all, the concentrations of four essential minerals, namely the calcium (Ca), potassium (K), sodium (Na), and magnesium (Mg), in the spring waters of each selected natural lick were estimated. The preliminary findings of camera trapping survey and direct observation of this study revealed that the mammalian individuals at SLFR ingested the spring water mainly to obtain minerals from the given licks. Hence, three water samples were collected from the spring water of each lick, and then filtered using the sterile membrane filters, to remove the large-sized particles (size>1.0 μm). Then, the concentrations of the above-mentioned four dissolved essential minerals in the water samples were analyzed by using the inductively coupled plasma optical emission spectrometry (ICP-OES), in parts per million (ppm), at the Chemical

Section of the Forest Research Centre (FRC) in Sepilok, Sandakan (Sabah).

Next, the lick size was calculated as the total size of a salt-lick in hectares (ha), while the close proximity of a salt-lick to the nearest road was estimated as the shortest distance between a salt-lick and the nearest main logging road presented at SLFR in meters (m). The boundary and coordinate for each selected salt-lick were mapped and recorded, respectively, using a Garmin GPSmap 64s handheld global navigation satellite system receiver, with an accuracy of less than 5.0 m error. After that, this information was inputted into the software ArcMap ver 10.4 (ESRI, 2022), majorly to digitize the shape and location, and estimate the size and close proximity of each salt-lick to the nearest road, using the functions "Calculate Geometry" and "Ruler" respectively. The rainfall data, on the other hand, was collected using the manual rain gauge, 24/7 a day at the base camp of SLFR. The depth of the gathered rainwater was measured every day at 8.00 a.m., in millimeter depth (mm). Then, the rain gauge was emptied, before readied to collect rainwater in the next 24 hours. The sum of rainfall depth for a certain month was measured as the total monthly rainfall depth, whereas the total number of rainy days recorded for a particular month was estimated as the total monthly number of rainy days, in this research.

Furthermore, three fixed-width strip transects (250.0 m × 4.0 m) were established at 360°, 120° and 240° from each selected natural salt-lick, to evaluate the surrounding vegetation structures of the given four salt-licks (Wilting & Azlan, 2010), as shown in below Figure 2.

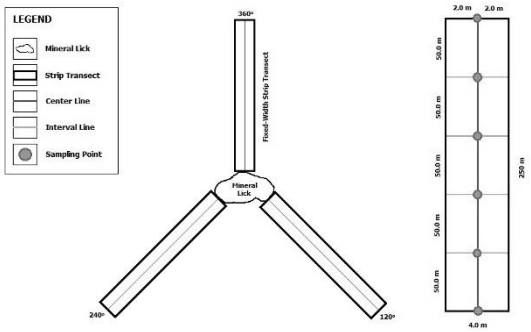

Figure 2. Design of the fixed-width strip transect applied in this study

Along the established transects, the diameter at breast height (DBH) of each tree stand was measured by using the diameter tape, at 130.0 cm aboveground level or 30.0 cm above the enlargement or buttress. Only the tree stands with a DBH of 10.0 cm and below were excluded from this study. The collected tree DBH data was employed to estimate the total aboveground biomass (TAGB), which represented the existing surrounding condition of each selected salt-lick, by using the allometric equation proposed by Basuki et al. (2009), in tonne per hectare (T/ha). The given allometric equation was used in estimating the tree AGB of the mixed-lowland dipterocarp forests in Kalimantan, therefore making it suitable for this research. Moreover, the canopy openness was measured at every 50.0 m along each transect, in percentage of openness (%), by using a spherical densiometer (Lemmon, 1956). These two parameters were used in representing the existing surrounding vegetation structure of the selected four natural salt-licks in SLFR (Matsubayashi et al., 2011; Bernard et al., 2019).

Data Analysis

The relationship between the changes in environmental conditions of the four selected natural licks and the mammalian visitation frequency was evaluated using the Spearman's Rank Correlation

analysis. This statistical analysis was carried out in the RStudio ver.1.2.5001 (R Core Team, 2022), at the confidence interval level of 95.0 % ($p<0.05$) in the present research).

RESULTS AND DISCUSSION

Environmental Conditions at Salt-licks

The onsite and surrounding conditions of the selected four natural salt-licks in SLFR were examined, and then the results were tabulated as shown in below Table 1. Among the given four salt-licks, the SL56 was validated as the smallest lick (0.0044 ha) and located the furthest away from the logging road (210.7 m), whereas the SL59 was the largest lick (0.036 ha) and the SL50_A was located the closest to the logging road (28.8 m) in SLFR. The given four licks were generally rich in essential minerals, however the highest availability of potassium was ascertained at the SL56 (36.33 ppm), whereas the highest sodium availability (204.55 ppm), as well as the lowest potassium (7.973 ppm) and the magnesium (5.938 ppm) availabilities, were obtained at the SL59. Moreover, the SL50_B had the highest availabilities of magnesium (16.96 ppm) and calcium (78.20 ppm), as well as the lowest sodium availability (48.87 ppm), when compared to the other three salt-licks assessed in this study. Next, the SL56 was surrounded by a forest with the highest TAGB (3.120 T/ha) and the lowest canopy openness (10.52 %), when compared to those of the other three salt-licks. On the other hand, the highest canopy openness (17.79 %) and the lowest TAGB (1.779 T/ha) were ascertained for the surrounding habitat of SL50_A in this research. In summary, the surrounding forest of SL56 was verified as the least-disturbed, followed by those of the SL59, SL50_B, and SL50_A in SLFR.

Regarding the weather conditions of the four selected natural licks at SLFR, the rainfall depth and number of rain days were investigated and determined to be fluctuating throughout the eight months of the sampling period in the present study, as shown in Figure 3. The total monthly rainfall and the number of rainy days decreased from July (279.0 mm; 10 days) to August (113.5 mm; 5 days), followed by an increase all the way until October (261.5 mm; 13 days), before decreasing again in November (205.0 mm; 12 days), and then increasing again in December (345.5 mm; 19 days) in 2019, and all the way to February (219.0 mm; 13 days) in 2020. However, the total monthly number of rainy days and total monthly rainfall were at least 10 days and 200.0 mm, respectively, from October (2019) until February (2020), highlighting that these five months were part of the wet season, whereas July, August and September were part of the dry season at SLFR.

Table 1. Onsite and surrounding habitat conditions of the four selected natural salt-licks in Segaliud-Lokan Forest Reserve

Parameters	SL50_A	Sl50_B	SL56	SL59
Lick Size[a] (ha)	0.0265	0.0299	0.0044	0.0360
Mineral Concentration[a] (ppm)				
Sodium (Na)	57.71±8.44	48.87±1.76	61.79±3.23	204.6±30.59
Potassium (K)	8.963±0.638	28.50±2.20	36.33±3.04	7.973±0.116
Magnesium (Mg)	9.879±0.534	16.96±0.32	10.52±0.27	5.938±0.444
Calcium (Ca)	67.94±5.25	78.20±1.21	62.17±1.32	52.05±4.59
TAGB[b] (T/ha)	1.779	2.251	3.120	2.612
Canopy Openness[b] (%)	17.79±3.63	13.76±5.33	10.52±2.09	16.19±4.46
Close proximity to the nearest road[b] (m)	28.80	145.96	210.70	182.74

*Note: TAGB=Total Aboveground Biomass; a=onsite habitat condition, and; b= surrounding habitat condition.

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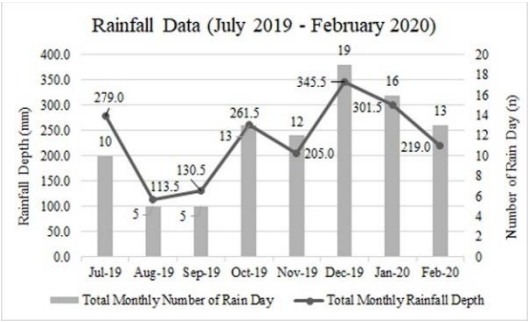

Figure 3. Monthly rainfall data at the four natural salt-licks in SLFR between July 2019 and February 2020.

The total monthly rainfall and the number of rainy days decreased from July (279.0 mm; 10 days) to August (113.5 mm; 5 days), followed by an increase all the way until October (261.5 mm; 13 days), before decreasing again in November (205.0 mm; 12 days), and then increasing again in December (345.5 mm; 19 days) in 2019, and all the way to February (219.0 mm; 13 days) in 2020. However, the total monthly number of rainy days and total monthly rainfall were at least 10 days and 200.0 mm, respectively, from October (2019) until February (2020), highlighting that these five months were part of the wet season, whereas July, August and September were part of the dry season at SLFR.

Mammal-Lick Relationship

A total of 985 independent sightings of twelve different species of terrestrial mammals were detected and recorded in 343 nights of camera trapping at the four selected natural salt-licks in this research. The visitation frequency of sambar deer (*Rusa unicolor*) was verified as positively correlated with the number of rain day, so explaining its high visitation frequency to the selected four natural salt-licks at SLFR during the months with a high number of rain day (RAI=178.57 $100TN^{-1}$), and vice versa (RAI=92.29 $100TN^{-1}$; $\rho=0.768$, $p< 0.05$). On the other hand, the visitation frequency of mousedeer (*Tragulus* spp.) was found correlated negatively with the number of rain day, in which high lick use was recorded for this species during the months with low occurrence of rain (RAI= 6.667 $100TN^{-1}$), and vice versa for the months with high rain occurrence (RAI= 1.261 $100TN^{-1}$; $\rho=-0.856$, $p<0.01$). In this research, the greater mousedeer (*T.* napu) was difficult to be differentiated from the lesser mousedeer (*T.* kanchil), when referring to the captured footages, hence both species

were identified merely as "mousedeer" in the present study.

Furthermore, the Malayan porcupine (*Hystrix brachyura*) was observed at the salt-licks only during the months with low rainfall depth and rain occurrence (RAI= 1.904 $100TN^{-1}$), as its visitation frequency was negatively correlated with the number of rain day (ρ=-0.909, $p<0.01$) and rainfall depth (ρ=-0.906, $p<0.01$) in this research. Regarding the other nine mammal species, the results of this study suggested that the seasonal variability in the rainfall patterns had no significant correlations with their visitation frequencies to these four licks, throughout the entire sampling period ($p> 0.05$). However, the Bornean orang-utan, bearded pig, Bornean pygmy elephant, and thick-spined porcupine were observed at the given four salt-licks generally more frequently during the dry season (*Pongo pygmaeus morio*: RAI=17.14 $100TN^{-1}$; *Sus barbatus*: RAI=150.48 $100TN^{-1}$; *Elephas maximus borneensis*: RAI=2.857 $100TN^{-1}$; *H. crassispinis*: RAI=4.762 100 TN^{-1}), when compared to the wet season (*P. pygmaeus*: RAI=15.13 $100TN^{-1}$; *S. barbatus*: RAI=64.29 $100TN^{-1}$; *E. maximus*: RAI=2.101 $100TN^{-1}$; *H. crassispinis*: RAI=4.622 $100TN^{-1}$), and vice versa for the banteng (*Bos javanicus*) (Dry: RAI=10.48 $100TN^{-1}$; Wet: RAI= 16.81 $100TN^{-1}$). Moreover, the pig-tailed macaque was observed only at wet season (*Macaca nemestrina*: RAI=1.681 $100TN^{-1),}$ whereas the common palm civet, Malay civet and red leaf monkey were detected only during the dry season (*Paradoxurus hermaphroditus*: RAI=0.952 $100TN^{-1}$; *Viverra tangalunga*: RAI=0.952 $100TN^{-1}$; *Presbytis rubicunda*: RAI=2.857 $100TN^{-1}$), in the present research. Table 2 shows the correlation between the mammalian visitation frequency and the seasonal weather conditions at the four natural salt-licks in SLFR.

Table 2. Correlation between the mammalian visitation frequency and the seasonal weather conditions at the four selected natural salt-licks in SLFR

Species	Spearman's Rank Correlation (ρ)	
	Rainfall Depth	Number of Rain Day
Banteng (*Bos javanicus*)	-	-
Bearded Pig (*Sus barbatus*)	-	-
Bornean Pygmy Elephant (*Elephas maximus borneensis*)	-	-
Bornean Orang-utan (*Pongo Pygmaeus morio*)	-	-
Common Palm Civet (*Paradoxurus hermaphroditus*)	-	-
Malay Civet (*Viverra tangalunga*)	-	-
Malay Porcupine (*Hystrix brachyura*)	-0.906**	-0.909**
Mousedeer (*Tragulus* spp.)	-	-0.856**
Pig-tailed Macaque (*Macaca nemestrina*)	-	-
Red Leaf Monkey (*Presbytis rubicunda*)	-	-
Sambar Deer (*Rusa unicolor*)	-	0.768*
Thick-spined Porcupine (*Hystrix crassispinis*)	-	-

*Note: Spearman's Rank Correlation Analysis (Significance value: *=$p<0.05$, and; **=$p<0.01$; 2-tailed). This table only shows the ρ-values for parameters that have significant correlations ($p<0.05$) with the mammalian visitation frequency to salt-licks.

Moving on, the visitation frequencies of certain mammal species were validated to have strong and significant correlations with the surrounding habitat conditions of the selected four natural licks in SLFR, as shown in Table 3. Both the banteng and bearded pig were sighted more frequently at the SL56 (*B. javanicus*: RAI=26.44 $100TN^{-1}$; *S. barbatus*: RAI=89.66 $100TN^{-1}$) and SL59 (*B. javanicus*: RAI=21.33 100 TN^{-1}; *S. barbatus*: RAI=229.33 $100TN^{-1}$) that were surrounded by the habitats with high TAGB, when compared to both the SL50_A (*B. javanicus*: RAI=5.814 100 TN^{-1}; *S. barbatus*: RAI=25.58 $100TN^{-1}$) and the SL50_B (*B. javanicus*: RAI=7.368 $100TN^{-1}$; *S. barbatus*: RAI=41.05 $100TN^{-1}$), which were located in the forests with low TAGB. This finding supported the significantly positive correlations between their respective visitation frequencies with the TAGB (*S. barbatus*: ρ=0.590; *B. javanicus*: ρ=0.614; $p<0.05$) ascertained in this study. Then, the sambar deer visited the SL50_A, which was located near to the road, less frequently (RAI=38.37 100 TN^{-1}) than the other three salt-licks that were situated far from the road (SL50_B: RAI=249.47 $100TN^{-1}$; SL56: RAI=152.87 $100TN^{-1}$; SL59: RAI=161.33 $100TN^{-1}$). This phenomenon was supported by the positive correlation between its visitation frequency with the close proximity of a salt-lick to the nearest (ρ=0.577, $p<0.05$). The frequency of Thick-spined Porcupine in visiting the local licks was negatively correlated with the surrounding canopy openness significantly (p=-0.579, $p<0.05$), which also explained its detection only at SL56 (RAI=18.39 $100TN^{-1}$), which was surrounded by the forest habitat with the lowest canopy openness recorded in this study. The mousedeer, on the other hand, was observed only at the SL50_A that was situated in a disturbed forest (high canopy openness; low TAGB) and near to the road (RAI=11.63 $100TN^{-1}$).

Table 3. Correlation between the mammalian visitation frequency and the surrounding habitat conditions at the four selected natural salt-licks in SLFR

Species	Spearman's Rank Correlation (ρ)		
	Canopy Openness	TAGB	Close Proximity to the Nearest Road
Banteng (*Bos javanicus*)	-	0.614*	-
Bearded Pig (*Sus barbatus*)	-	0.590*	-
Bornean Pygmy Elephant (*Elephas maximus borneensis*)	-	-	-
Bornean Orang-utan (*Pongo Pygmaeus morio*)	-	-	-
Common Palm Civet (*Paradoxurus hermaphroditus*)	-	-	-
Malay Civet (*Viverra tangalunga*)	-	-	-
Malay Porcupine (*Hystrix brachyura*)	-	-	-
Mousedeer (*Tragulus* spp.)	0.633*	-0.825***	-0.983***
Pig-tailed Macaque (*Macaca nemestrina*)	-	-	-
Red Leaf Monkey (*Presbytis rubicunda*)	-	-	-
Sambar Deer (*Rusa unicolor*)	-	-	0.577*
Thick-spined Porcupine (*Hystrix crassispinis*)	-0.579*	-	-

*Note: TAGB=Total Aboveground Biomass (T/ha).
Spearman's Rank Correlation Analysis (Significance value: *=$p<0.05$; and; ***=$p<0.001$; 2-tailed). This table only shows the ρ-values for parameters that have significant correlations ($p<0.05$) with mammalian visitation frequency to salt-licks.

Henceforth, its visitation frequency was significantly correlated with the surrounding canopy openness positively (ρ=0.633, p<0.05) and TAGB negatively (ρ=-0.825, p<0.01), and also with the close proximity of a salt-lick to the nearest road (ρ=-0.983, p<0.001) in this study. These results highlighted that the mousedeer reacted varyingly to the surrounding habitat conditions of these licks, when compared to the other four mentioned species. Regarding the other seven species, their respective visitation frequencies were determined to share no significant correlations (p>0.05) with the given three explanatory variables that represented the surrounding forest habitat conditions of the local licks in this study.

Table 4 shows the correlation between the mammalian visitation frequency and onsite habitat conditions at the selected four natural salt-licks in SLFR. Firstly, the thick-spined porcupine visited only to the small-sized SL56, therefore resulting in a significantly negative correlation between its visitation frequency and lick size (ρ=-0.647, p<0.05). Besides that, the visitation frequencies of Bornean pygmy elephant, bearded pig and banteng were correlated significantly with the availabilities of several minerals detected at the given four salt-licks (p<0.05). These three mammal species used the calcium-poor licks more frequently than the calcium-rich licks (*E. maximus*: ρ=-0.756; *S. barbatus*: ρ=-0.713; *B. javanicus*: ρ=-0.605; p<0.05), across the eight months sampling period of this study. In fact, both the bearded pig and Bornean pygmy elephant utilized the salt-licks with high sodium (*S. barbatus*: ρ=0.687; *E. maximus*: ρ=0.827; p<0.05) and low magnesium (*S. barbatus*: ρ=-0.596; *E. maximus*: ρ=-0.715; p<0.05) availabilities more frequently, and vice versa. Coincidentally, these findings also explained the high visitation frequencies of the bearded pig, banteng and Bornean pygmy elephant to the SL56 (*E. maximus*: RAI=1.149 $100TN^{-1}$; *B. javanicus*: RAI= 26.44 $100TN^{-1}$; *S. barbatus*: RAI=89.65 $100TN^{-1}$) and SL59 (*E. maximus*: RAI= 9.333 $100TN^{-}$

Table 4. Correlation between the mammalian visitation frequency and the onsite habitat conditions at the four selected natural salt-licks in SLFR

Species	Spearman's Rank Correlation (ρ)				
	Lick Size	Mineral Concentration			
		Mg	Ca	Na	K
Banteng (*Bos javanicus*)	-	-	-0.605*	-	-
Bearded Pig (*Sus barbatus*)	-	-0.596*	-0.713**	-0.687*	-
Bornean Pygmy Elephant (*Elephas maximus borneensis*)	-	-0.715**	-0.756**	0.827***	-
Bornean Orang-utan (*Pongo Pygmaeus morio*)	-	-	-	-	-
Common Palm Civet (*Paradoxurus hermaphroditus*)	-	-	-	-	-
Malay Civet (*Viverra tangalunga*)	-	-	-	-	-
Malay Porcupine (*Hystrix brachyura*)	-	-	-	-	-
Mousedeer (*Tragulus* spp.)	-	-	-	-	-
Pig-tailed Macaque (*Macaca nemestrina*)	-	-	-	-	-
Red Leaf Monkey (*Presbytis rubicunda*)	-	-	-	-	-
Sambar Deer (*Rusa unicolor*)	-	-	-	-	-
Thick-spined Porcupine (*Hystrix crassispinis*)	-0.647*	-	-	-	-

*Note: Mineral Concentration (ppm): Mg=Magnesium; Ca=Calcium; K=Potassium, and; Na=Sodium. Spearman's Rank Correlation Analysis (Significance value: *=p<0.05; **=p<0.01, and; ***=p<0.001; 2-tailed). This table only shows the ρ-values for parameters that have significant correlations (p<0.05) with the mammalian visitation frequency to salt-licks.

[1]; *S. barbatus*: RAI=229.33 $100TN^{-1}$; *B. javanicus*: RAI=21.33 $100TN^{-1}$) in the present study. Regarding the other eight species, the correlations between their visitation frequencies and the five parameters that represented the onsite habitat conditions of the given four licks were validated to be not significant ($p>0.05$). Other than that, the influence of variability in the potassium availability to the mammalian visitation frequency was also verified as not insignificant ($p>0.05$) in this study.

In sum, the changes in environmental conditions was verified to have significant effects only onto the frequencies of certain mammal species in using the natural salt-licks presented in SLFR. Nonetheless, the Bornean orang-utan was observed at the SL59 (RAI=2.667 $100TN^{-1}$), SL56 (RAI= 45.98 $100TN^{-1}$) and SL50_A (RAI= 13.95 $100TN^{-1}$). Then, the pig-tailed macaque was observed at the SL50_B (RAI=1.053 $100TN^{-1}$) and SL56 (RAI=3.448 $100TN^{-1}$). The Malay civet was detected only at the SL59 (RAI=1.333 $100TN^{-1}$), while the common palm civet, Malayan porcupine and red leaf monkey visited only the SL56 (*P. hermaphroditus*: RAI=1.149 $100TN^{-1}$; *H. brachyura*: RAI=2.299 $100TN^{-1}$; *P. rubicunda*: RAI=3.448 $100TN^{-1}$), across the entire sampling period of this research.

Relationship between the Terrestrial Mammals and Salt-licks

The present findings showed that only particular species of terrestrial mammals adopted different visitation patterns, in response towards the variability in the environmental conditions across different licks and meteorological seasons, which aligned with the findings of several past studies (Matsubayashi 2007b & 2011; Hon & Shibata, 2013; Ning, 2011; Ikeda et al., 2016; Ota et al., 2019). Among the four natural salt-licks that were examined in this study, the SL50_A was validated as more vulnerable to the human visitation and disturbance, because this salt-lick was situated the nearest to the road, and also its surrounding forest habitat was more disturbed, thus could only supply a lower variation and abundance of food to the local terrestrial mammals (Blake et al., 2013; Wearn et al., 2017), when compared to the other three salt-licks with opposite surrounding habitat conditions. Therefore, particular local terrestrial mammals may avoid in utilizing the SL50_A, despite its high calcium and sodium availabilities, indicating that the human disturbance has a much prominent impact than the mineral availabilities, in influencing the visitation patterns of the terrestrial mammals to the natural salt-licks in SLFR.

Moreover, the SL59 was confirmed to provide the highest availability of sodium, hence this salt-lick was used by the local terrestrial mammals most frequently, and then followed by the SL56, and finally the SL50_B, which agreed with the findings of Lim and Mojiol (2022). Actually, this association can be used to explain the high lick uses of terrestrial mammals with high daily sodium demands, not only in SLFR, but also at the other forest areas in Sabah, (Matsubayashi et al., 2007a & 2011; Matsuda et al., 2015). The effects of the variability in environmental conditions on each of the 12 mammal species detected in this study were discussed further in the following contexts.

Sambar Deer

As an avoidance response towards the anthropogenic disturbance, the sambar deer may adopt a permanent nocturnality, especially in visiting the salt-licks in a commercial forest reserve (Wilting & Azlan, 2010; Hon & Shibata,

2013; Ikeda et al., 2016; Ota et al., 2019). This phenomenon can be used in explaining its high visitation frequencies to the three licks surrounded by least-disturbed forests (except for the SL50_A) in SLFR (Lim & Mojiol, 2022). Besides that, this species utilized the given three licks significantly more frequently during the wet season, which agreed with Matsubayashi et al. (2007b). The high dependency of sambar deer onto salt-lick recorded in this study was associated with the high number of rainy days significantly, which most likely caused by the increasing loss of the body minerals, after ingesting a high amount of water-rich forages across the wet season (Suttle & Field, 1967). After that, both the SL56 and SL59 are situated in the middle of two different least-disturbed forests that are favorable upon the Bornean Clouded Leopard (*Neofelis diardi borneensis*) as its habitats (Phillipps & Phillipps, 2018). So, the sambar deer is posed to a higher risk of predation when visiting these two licks, when compared to the SL50_B, which is situated in a disturbed timber plantation forest (Ross et al., 2013; Cheyne et al., 2016; Hearn et al., 2018). In summary, the sambar deer mainly used the SL50_B to replenish its body minerals on a regular basis, even though its visitations to both the sodium-rich SL56 and SL59 remained high across the entire sampling period of this study. In fact, this also shows that the sambar deer may be willing to utilize the salt-licks with low sodium availability and predation risk more frequently, and vice versa, in this commercial forest reserve.

Bearded Pig

Low rainfall can raise the ambient temperature, which can subsequently stimulate the loss of body water content and, as a result, trigger the bearded pig to visit the mineral-rich spring of a salt-lick more frequently during the dry season, and vice versa for the wet season (Harris et al., 2015; Matsuda et al., 2015). Then, this species used both the SL56 and SL59 relatively more frequently than both the SL50_A and SL50_B, hence contributing to the significant correlations between its visitation frequency with the surrounding TAGB and onsite sodium availability of the four natural salt-licks examined in this study. The selective logging can partially disturb a pristine forest by creating more canopy gaps, and subsequently causing an increase in the availability of food for the local mammalian community (Wilting & Azlan, 2010; Wearn et al., 2017). At the same time, a mass fruiting event occurred at SLFR during the dry season (July to August 2019), which can further increase the availability of food in the surrounding habitats of both the sodium-rich SL56 and SL59 during this time period (Ampeng et al., 2016). The bearded pig was found travelling frequently to the locations with the high availabilities of food and sodium mineral (Matsubayashi et al., 2007a; Matsuda et al., 2015; Phillipps & Phillipps, 2018), which could ultimately result in its significantly higher visitation to both the SL56 and SL59 during the dry season than during the wet season.

Nevertheless, the variability in both the calcium and magnesium availabilities were verified to be significantly correlated with the visitation frequency of bearded pig to a natural lick at SLFR negatively. Matsuda et al. (2015) mentioned that this ungulate species preferred to utilize the salt-licks with low magnesium availability frequently, and vice versa in the riparian forest of Lower Kinabatangan River. This phenomenon

can actually be caused by the antagonistic relationships between various essential minerals that are available at a natural salt-lick, in which the high sodium availability is associated with the low calcium and magnesium availabilities, and vice versa (Sim et al., 2020). Henceforth, the significant correlations between the visitation frequency of bearded pig with the availabilities of magnesium, sodium and calcium, which were obtained in the present study, could be explained by these antagonistic relationships, instead of its daily requirements for the given elements (Ayotte et al., 2008; Phillipps & Phillipps, 2018).

Bornean Orang-utan

The Bornean orang-utan was detected at the SL50_A, SL56, and SL59, but not at the SL50_B. Furthermore, the seasonal changes in the rainfall patterns shared no significant correlations with its lick use frequency throughout the entire sampling period of this study. The absence of this species at the SL50_B, and also its low detection frequency at the SL59, can be explained by its avoidance response to the interspecific competition with the other species of terrestrial mammals. The usage of SL50_B was dominated by both the sambar deer (n=237 or 83.5%) and the bearded pig (n=172 or 53.9%), while the usages of SL50_A and SL56 were not dominated by one particular species (Lim & Mojiol, 2022). Although the SL50_A was located only 1.0 km away from the SL50_B, yet it was seldom visited by the sambar deer (n=33 or 40.2 %) and other species. Since the Bornean orang-utan has a wide home range (3.0 km2 to 8.5 km2) (Phillipps & Phillipps, 2018), thus it may choose to utilize the other three licks, instead of the SL50_B, mainly to avoid in competing with the other mammal species for mineral intake on a regular basis (Hon & Shibata, 2013; Ikeda et al., 2016).

Furthermore, this primate species may modify its seasonal activity pattern and lick dependency level, in response to the breeding season, which is associated with the occurrence of the mass fruiting event (high availability of food) (Ampeng et al., 2016). Although the Bornean orang-utan can survive across different habitat types, irrespective of the level of disturbance (Cheyne et al., 2016), yet still it prefers to inhabit the undisturbed forests and use the licks that are located far from the roads (Matsubayashi et al., 2011; Seaman et al., 2019), since the availabilities of food and shelter are higher in the undisturbed forest than in the disturbed forest (Wilting & Azlan, 2010; Wearn et al., 2017; Bernard et al., 2019). Because of that, its relatively higher visitation frequencies to the local salt-licks during the dry season could be caused by the occurrence of mass fruiting event, which also increased its need for replenishing its body minerals regularly (Ampeng et al., 2016). The SL56 was the main preferred lick for the Bornean orang-utan, because this salt-lick was located the furthest from the logging road and within a least-disturbed forest (Matsubayashi et al., 2011). Still, its visitation frequency was determined to have no significant correlation with any of the explanatory variables examined in this study, therefore emphasizing the need to conduct further research, especially onto the impacts of breeding season and surrounding food and shelter availabilities, towards its visitation frequencies to the natural salt-licks at this commercial forest reserve in future.

Banteng

The open environment of a tropical salt-lick serves as a focal point for the herd species to forage and conduct social

activities, aside from the mineral intake (Clayton & MacDonald, 1999; Gardner et al., 2016). Likewise, the seasonal changes in the rainfall patterns may not necessarily have detrimental impacts to the frequency of the banteng in visiting a given salt-lick (Journeaux et al., 2018). Henceforth, the banteng was found visiting the selected natural salt-licks in SLFR for replenishing body minerals, foraging and socializing, regardless of the local weather conditions. Nonetheless, the banteng individuals may prefer to visit the open area that is located in an undisturbed or least-disturbed forest more than the open area of the disturbed forest, especially in a commercial forest reserve (Gardner et al., 2016; Bernard et al., 2019). Because of that, this ungulate species was found mainly using the SL56 with a least-disturbed surrounding forest, and subsequently resulting in its visitation frequency significantly correlated with the surrounding TAGB of the salt-licks in this reearch, which agreed with Gardner et al. (2016) and Journeaux et al. (2018). Other than that, the banteng was found utilizing both the sodium-rich and calcium-poor SL56 and SL59 frequently, thus indicating its high dependency onto these two licks for sodium mineral intake on a regular basis (Matsubayashi et al., 2007a; Bernard et al., 2019; Lim & Mojiol 2022). This phenomenon can also be triggered by the antagonistic relationship between calcium and sodium minerals in the spring waters of SL56 and SL59 (Sim et al., 2020). Due to that, it is possible that its frequency in utilizing a salt-lick at SLFR is dependent onto the sodium availability of the given salt-lick, which is also being negatively correlated to the local calcium availability, instead of its daily requirements for these two minerals.

Mousedeer

The frequency of the mousedeer in visiting to a specific salt-lick at SLFR was dependent onto the existing surrounding TAGB and canopy openness of the given salt-lick in this research. Matsubayashi et al. (2003) revealed that this small ungulate species mainly foraged for the soft leaves and fruits of pioneer plant species, which were highly abundant in the crown-gap regions. As a result, the mousedeer only visited the SL50_A, which was located in a disturbed forest habitat (high canopy openness; low vegetation diversity; low TAGB), not only in this commercial forest reserve, but also in the other forested areas of Sabah (Matsubayashi et al., 2007a; Hon & Shibata, 2013). Moreover, the SL50_A was located the closest to the road, hence emphasizing that the mousedeer adapted to use the salt-licks that were surrounded by the human-disturbed environments and were easily accessible to humans (Blake et al., 2013; Ota et al., 2019). The high fruit availability is associated with the high rain occurrence (Dunham et al., 2018), which can cause the mousedeer to shift its diet to fruits (Klaus et al., 1998; Lim & Mojiol, 2021). This diet shifting could also be the primary factor that led to the significantly negative correlation between its lick use frequency and the number of rainy days obtained in this study. Hence, this shows that the high occurrence of rain can reduce its lick dependency level for neutralizing its body toxicity, especially during the wet season in SLFR (Klaus et al., 1998; Ayotte et al., 2008; Voigt et al., 2008).

Bornean Pygmy Elephant

The Bornean pygmy elephant visited only the SL56 and SL59, in which it used

the SL59 relatively more frequently than the SL59, in this research. This is because this species shows a higher preference in utilizing the sodium-rich licks than the sodium-poor licks (Matsubayashi et al., 2007a), therefore resulting in its visitation frequency being positively correlated with the sodium availability significantly in the present study. Then, the Bornean pygmy elephant avoids in visiting to the habitats that are highly disturbed and accessible by the humans (Ning, 2017; Bernard et al., 2019), which explained its zero detection frequency recorded at both the SL50_A and SL50_B, which were situated in the same timber plantation forest, and also the similarity in its lick use frequency across the two seasons, in this study. Since this herd species migrates from one location to another at a daily basis, while following a similar migratory route annually (Phillipps & Phillipps, 2018), the seasonal changes in rainfall patterns may have less impacts to its lick use frequency, when compared to human disturbance (Ning, 2017; Lim & Mojiol, 2021), though it is crucial to carry out further study for verifying this matter in future. The variations in the magnesium and calcium availabilities, on the contrary, were verified to have negative correlations with its lick use frequency, mostly caused by the antagonistic relationships between the sodium mineral with the given two minerals as well (Sim et al., 2020).

Malayan Porcupine and Thick-Spined Porcupine

The Malayan porcupine was observed in this study only at the SL56 and during the dry season. Low rainfall is associated with the high ambient temperature, which is indirectly related to the low supply of water, particularly during the dry season (Harris et al., 2015). Because of that, this porcupine species may visit the salt-licks with spring water more frequently during the dry season, majorly for drinking water, and vice versa for the wet season (Clayton & MacDonald, 1999; Matsuda et al., 2015). Other than that, the least-disturbed surrounding habitat of SL56 (high TAGB) is known to possess a high availability of food (Wearn et al., 2017). Since the given species is able to adapt and survive across different habitats (Phillipps & Phillipps, 2018), its visitation only to the SL56 is more likely to be related to the availability of food, though further research should be conducted to validate this matter in future. On the contrary, the visitation frequency of the thick-spined porcupine was verified to be significantly correlated with the size and surrounding canopy openness of the salt-lick in a negative manner, since it was sighted only at the SL56, mostly due to its preference in inhabiting the pristine forest with minimal disturbed crown-gap regions (Samejima et al., 2012; Wearn et al., 2017). Additionally, its higher visitation to this salt-lick during the dry season than the wet season can also be resulted from the variability in its lick dependency level to replenish its body water content across these two meteorological seasons in this forest reserve (Harris et al., 2015).

Pig-tailed Macaque and Red Leaf Monkey

The variability in the environmental conditions of the selected four salt-licks at SLFR were verified to show no significant correlations with the lick use frequencies of both the red leaf monkey and pig-tailed macaque ($p>0.05$) in this study. However, the pig-tailed macaque was detected only during the wet season at both the SL50_B and SL56, while the red leaf monkey was observed only during the dry season at the SL56. These two primate species require high

potassium intake on a daily basis, so they may visit the potassium-rich SL50_B and SL56 mainly to ascertain this essential mineral (Molina et al., 2014; Phillipps & Phillipps, 2018). However, the vegetation in Sabah is potassium-rich, hence they can obtain this mineral in a sufficient amount solely from their daily diets (Jordan, 1985; Matsubayashi et al., 2007a; Matsuda et al., 2015). Henceforth, their lick dependency for regular potassium intake can be low, which can also explain their low lick use frequencies, which were not significantly correlated with the potassium availability at the local licks, in this study.

Moreover, the red leaf monkey mainly inhabits the undisturbed forests and least-disturbed forests, since it depends onto tall trees for survival (Phillipps & Phillipps, 2018; Cheyne et al., 2020). This supported its detection only at the SL56, which also highlighted its presence at the surrounding least-disturbed forest of the SL56 in this research. The detections of the pig-tailed macaque and red leaf monkey only during the wet and dry seasons respectively can be due to the increasing need to replenish their body minerals and water contents respectively (Harris et al., 2015; Ampeng et al., 2016). Nonetheless, it is essential to conduct future research for verifying these matters, for their sample sizes were small (n<5), which could negatively impact the quality of results produced in this research (Fan et al., 2011).

Common Palm Covet and Malay Civet

Both the Malay civet and common palm civet were observed only once at the SL56 and SL59, respectively during the dry season in this study. Their presences at the local licks during the dry season can be explained by their needs to drink water from the mineral-rich spring, aside from both the prey-hunting and mineral intake (Matsubayashi et al., 2007a; Harris et al., 2015). Then, these two species are known to forage for fruits and hunt for the small invertebrates and vertebrates on the forest floor (Phillipps & Phillipps, 2018), hence they can be attracted to travel to the least-disturbed forests with high availability of food (Wearn et al., 2017), and ultimately resulting in their presences at the natural salt-licks in SLFR being associated with the surrounding food availability (Klaus et al., 1998). Then again, the given visitation patterns of these two species were based entirely on their sole detections recorded in this study, thus there is a need conduct an in-depth assessment onto these matters at SLFR in future as well

CONCLUSIONS

The changes in certain environmental conditions have detrimental impacts only upon the frequencies of certain species of terrestrial mammals in visiting the natural salt-licks presented in SLFR, including the sambar deer, banteng, mousedeer, bearded Pig, Malayan porcupine, Bornean pygmy elephant, and thick-spined porcupine. This emphasizes that different mammal species exhibit different responses to the seasonal changes in the weather conditions, as well as the variability in both the surrounding and onsite habitat conditions, of the salt-licks in the inland tropical forest of Sabah. However, this research only examined the effects of the variability in ten explanatory variables, while the other relevant factors were excluded, majorly because of a lack of appropriate instruments and sampling techniques for collecting the data of these

excluded variables. The exclusion of these independent variables may subsequently result in certain mammal species showing no detrimental changes in their visitation patterns across different natural salt-licks and seasons at SLFR in this study.

Furthermore, the lick use frequency of the Bornean orang-utan was determined to exhibit no significant correlation with the close proximity of a salt-lick to the nearest road in this research, which contradicted the findings of Matsubayashi et al. (2011). Then, only the sample sizes for the sambar deer, bearded pig, banteng, and Bornean orang-utan were large (n>50), hence the overall accuracies and precisions of the present findings could be impacted by the small sample sizes of the remaining eight species negatively (Fan et al., 2011). The influences of the antagonistic relationships between different essential minerals over the lick use patterns of particular mammal species at SLFR and other forested areas of Sabah remained uncertain (Matsuda et al., 2015). Therefore, further study should be conducted to address all the highlighted matters in the present study in future.

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