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Research Article

Assemblage Structure of Palaeotropical Frugivorous Bats at Mineral Licks Sites in Deramakot and Tangkulap Forest Reserve, Sabah

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Abstract

Few studies have been done on natural mineral licks visitation on bat fauna, particularly in Borneo and Southeast Asia in general. Little is known about the assemblage of bats using mineral licks and this study was done to determine assemblage structure of Palaeotropical bats at six established mineral licks in Deramakot and Tangkulap Forest Reserve, Sabah. The main findings of the present study revealed that Palaeotropical frugivorous bats were using mineral licks, observed through their behaviour of drinking from mineral licks, supported by their high species occurrences at mineral licks and higher concentration of water insoluble soil tracer elements, Al and Si detected in their faeces in comparison with non-visitor bats. The five species of bats *Macroglos susminimus* (n=3)*, Balionycteris maculata* (n=2), *Cynopterus brachyotis* (n=1), *Megaerops ecaudatus* (n=2) and *Penthetor lucasii n=(1*) were observed drinking from mineral licks. Four species of frugivorous bats (*M. minimus, B. maculata*, *C. brachyotis* and *P. lucasii*) frequently occurred at all six sites at mineral licks. In addition, there were higher enrichment Al and Si in *M. minimus* faeces (n=5) in comparison with non-visitor bats suggesting that frugivorous bats got those elements from ingestion of mineral lick muddy water.

Keywords: Palaeotropical frugivorous bats; mineral licks; Deramakot and Tangkulap Forest Reserve; Sabah

Introduction

Mineral licks are distinct elements in the natural landscape which are present in both temperate and tropical ecosystems (Link et al., 2011; Molina et al., 2013), arctic ecosystem (Ramachandran 1995; Calef & Grant, 1975) and in montane ecosystem (Ramachandran, 1995). Mineral licks are considered keystone resources and act as limiting resources in a particular habitat for

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many wildlife species (Montenegro, 2004). Thus, they are ecologically important for various wildlife (Molina et al., 2013; Rea et al., 2004; Panichev et al., 2002). Generally, mineral licks are mineral-rich places that are long lasting and seasonally stable where animals frequently and actively visit to consume earthly minerals (Hon & Shibata, 2013; Ping et al., 2011; Link et al., 2011; Bravo et al., 2010b).

Animals do lick from clay-enriched muddy spring water or eat mineral-rich soils in order to obtain minerals such as sodium, calcium, potassium, magnesium and clay minerals (Brightsmith et al., 2008; Burger & Gochfeld, 2003; Klaus & Schmid, 1998). The most common reason for this behaviour is as strategy for mineral nutrient supplementation. Studies state that soils enriched with minerals are important for physiological processes of the body, such as pregnancy and lactation (Voigt et al., 2007). Other than that, mineral lick soil or water provide essential elements that aid in detoxification of noxious or unpalatable compounds present in the diet through absorbtion of dietary toxins and plant metabolites, aid in the digestive tract such as alleviate gastrointestinal upsets like diarrhoea, means of dealing with excess acidity in the digestive tract, and ease the digestion process of animals (Slamova et al., 2011).

Other than physiological benefits, mineral licks have conservation implications (Rea et al., 2004) since licks may affect the distribution (Panichev et al., 2002), density (Molina et al., 2003; Ping et al., 2011) and temporal structure of animal populations (Panichev et al., 2002; Rea et al., 2004; Ghanem, 2012). Furthermore, mineral licks are reported to provide a social role in inducing visitations of animals to mineral licks including a variety of terrestrial vertebrates (mammals, birds, reptiles) and also invertebrates (Blake et al., 2010; Morales, 2009; Voigt et al., 2008; Wilson, 2003).

In Neotropical regions, Neotropical frugivorous bats were reported to frequently use mineral licks (Ghanem, 2012; Bravo et al., 2012; Bravo et al., 2010a; Bravo et al., 2010b; Bravo et al., 2008; Voigt et al., 2008). Insectivorous bats were not reported to use mineral licks (Gnahem, 2013; Voigt et al., 2008). However, such information is scarce in this region. Since animal response toward licks vary seasonally and geographically (Rice et al., 2010), studies on visitation of mineral licks by bats across regions are essential to further understand its utilization.

There are a multitude of knowledge gaps in mineral lick utilization and significance, particularly in Southeast Asian bats. The presence, visitation and usage of mineral licks for bats remain unclear in Southeast Asia, particularly in Borneo. Soil of Bornean tropical rain forests tend to be nutrient-poor (Matsubayashi et al., 2007a; Klaus et al., 1998). Thus, plants that grow on such soils do not contain as much minerals such as sodium. Therefore, the mammals of tropical rain forests, especially herbivores and frugivores utilise mineral licks for mineral supplement. Matsubayashi et al. (2007b) and (2011) also state the importance of mineral licks for reproductive support of mammals. Studies on mineral licks and mammals were done in Deramakot Forest Reserve but bats were excluded (Ishige et al., 2017; Matsubayashi et al., 2011; 2007a; 2007b).

Palaeotropical bat assemblage at mineral licks in Deramakot and Tangkulap Forest Reserve, Sabah was documented to evince the utilisation of mineral licks by bats, and to identify the bat community that visit these mineral licks. The results from this study are reported herein. In this study, frugivorous bats refer to herbivorous bats that have fruit and nectar diets.

Methodology

Nine sampling sites were identified: six representing mineral lick sites, two representing control sites and one site in the forest. The mineral lick sites were located in Deramakot Forest Reserve (five sites) and Tangkulap Forest Reserve (one site). Mineral licks in the respective sites were labelled as ML1 (5˚27'N, 117˚12'E), ML2 (5˚19'N, 117˚28'E), ML3 (5˚22'N, 117˚29'E), ML4 (5˚20'N, 117˚30'E), ML5 and ML6 (5˚29'N, 117˚34'E) (Figure 1). The control wallow site, CW1, was located approximately 800m from ML2 while CW2 was located approximately 1km away from ML5 and ML6. Both sites were surrounded by thick shrubs and yam plants with stagnant water appearing on surface.

Bats were sampled using two methods: mist net and 4-bank harp trap. At each sampling site, 2 mist-nets and 1 harp trap were established covering the pools and following the paths of bats around the sites. The mist net used in this study was the Khon Kean Fishing Net mist net, Twine number 2, measuring 2.5 x 9 x 4 with three shelves, and the mesh size was 2.5 mm. The mist nets were tied with adjustable poles for support. Meanwhile, the harp trap used consisted of four-bank, with monofilament-fishing lines (0.22 mm, 10 lb) strung vertically and spaced 2-3 cm apart. Mist nets were used to catch

Megachiroptera bats while the harp trap targeted Microchiroptera bats. Captured bats were placed inside individual bags, sexed, measured and weighed. Bat identification was done following Struebig and Sujarno (2006), Yasuma et al., (2005a), Yasuma et al., (2005b) and Payne and Francis (2007). Bats were marked on the right wing using a 3mm biopsy punch, which allow recaptures to be recognized. No sample tissues were taken during this process. Bats were released at the point of capture within a 12 hour period. For faeces collection, bats caught during the sampling session in the mineral lick and forest sites were kept inside the cloth bags for 1-3 hours to collect their faeces, one bag per individual. The faeces were collected using forceps, and each individual faeces was placed in a labelled eppendorf tube 1.5ml with 70% alcohol until further analysis.

Methods that were used to determine the captured bats using the mineral licks were behaviour observations, species occurrences and insoluble soil tracer test in bats faeces. For behaviour observation, behaviours of bats at mineral licks were recorded using the *ad. libitum* sampling method. This method aimed to determine the behaviour of bats while using the mineral licks. Any behaviour performed by bats at mineral licks was individually recorded together with time (Altman, 1974). One hour was spent per night for observations in each mineral lick site. Another observation was made after bats had been processed and released at the mineral lick.

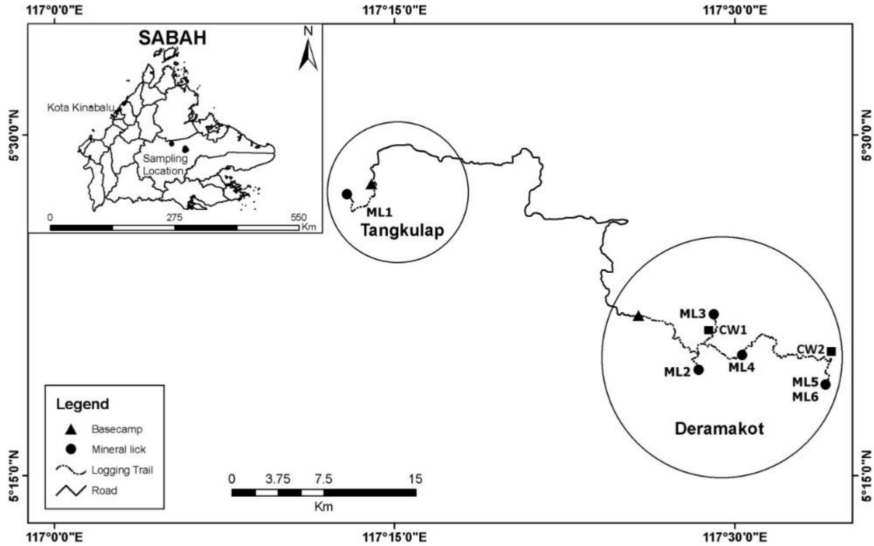

Figure 1. Location of mineral lick sampling sites in Sabah, Borneo, Malaysia.
*Mineral lick sites: ML1, ML2, ML3, ML4, ML5, and ML6; Wallow sites: CW1 and CW2.

All bats caught at mineral licks may not use mineral licks as few bats were seen drinking from mineral licks. Through this, bats that randomly flew around mineral licks and mineral licks users were distinguished. The first method was through species occurrences. Control sites were determined as a part of field sampling design in order to make a comparison between bats occurrences at mineral and non-mineral licks. In this study, wallows were chosen as the controls as their attributes are similar to wet licks. However, muddy depression of wallows created by ungulates is not made specifically for earth consumption. Common bats at mineral licks were expected to be caught more at mineral licks (as they frequently occurred mineral licks) and scored higher species occurrences similiarity in comparison with bats caught at wallow sites. This was adapted from Bravo et al. (2010) and Bravo et al. (2008) where bat-capture frequency was higher at mineral licks compared to non-mineral lick sites, hence indicating that they are mineral lick users.

The second method was through faecal analysis of bats caught at mineral licks and forest control sites. In Neotropics, insectivorous bats were not reported to use mineral licks (Gnahem, 2013; Gnahem et al., 2013; Bravo et al., 2008). Faeces of insectivorous bats caught at mineral licks and forest site were used as the control. Faecal analysis was done by using insoluble soil tracer elements, aluminium, Al (Gnahem, 2013) and silica, Si (Panichev et al., 2002) to detect soil consumption by bats. Al and Si are elements that are commonly used to determine the consumption of soil in humans because these elements are not metabolized or are poorly absorbed in the gut (Abraham, 2013; Darvis & Mirick, 2006). Bats which use mineral licks were expected to ingest soils, and contain higher concentration of insoluble soil tracer elements in their faeces (Gnahem, 2013). In a study conducted by Gnahem (2013a), faecal analysis was used to measure concentrations of insoluble soil tracer in bats. In this study, faeces samples 0.07g were used, labelled and underwent a series of acid digestion and heat using hydrogen peroxide (analytical grade), nitric acid (70%), hydroflouric acid (40%), and perchloric acid (analytical grade). Next, the solutions were filtered using 0.45µm (JET BIOFIL) and then further analysed in inductively coupled plasma-optical emission spectrometer (ICP-OES).

Data analysis

The correlation between mineral lick sites and species occurrences for both frugivorous bats and insectivorous bats were determined using the non-parametric test, Spearman's Rank Order Correlation, which was generated using SPSS v.21 (Gnahem, 2013; Bravo et al., 2008). The pattern of species similiarities among all six mineral lick sites were determined by using Bray-curtis similiarity index generated using estimateS (Gnahem, 2013; Bravo et al., 2008). The capture rate index of bats was calculated after the following equation, adapted from Gnahem (2013a) and Bravo et al. (2008) to examine the overall occurrences of bats at mineral lick and wallow sites.

$$\frac{\dfrac{\text{Bats}}{\text{Capture rate = total number of traps}}}{\text{total number of sampling nights}}$$

Results and Discussion

The overall sampling effort recorded was 42 trapping nights, pooled across all sampling sites. Total bats caught was 94 bats (91 individuals at mineral lick sites and 3 individuals at wallow sites). No recaptured individuals were recorded during the sampling sessions.

Behaviour Observation

A total of nine individuals from five species of frugivorous bats were observed flying close to the ground and licking mineral lick pools. These were *Macroglossus minimus, Balionycteris maculata, Cynopterus brachyotis, Penthetor lucasii* and *Megaerops ecaudatus.* Observation was conducted in the morning upon the release of the captured bats, where they then descended to drink from the licks. Their behaviour is presented in figure 2 and figure 3. The first type of behaviour observed was when the bats were flying close to the surface of the mineral licks descending and ascending to drink from the licks (Figure 2). The other behaviour observed was that the bats were flying very low, close enough to the water pool and perched on any structure in order to drink from the mineral licks (Figure 3).

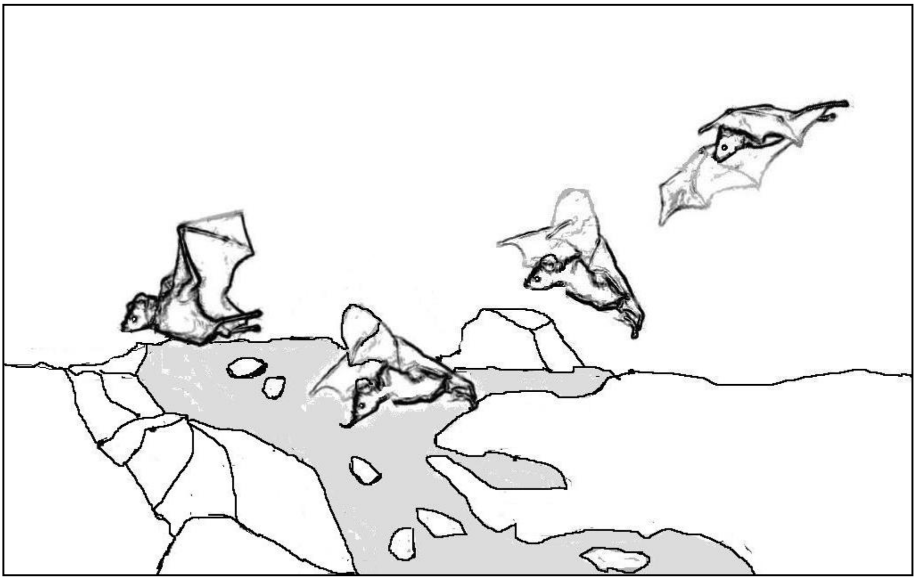

Figure 2. Behaviours of bats' drinking from mineral lick puddles: drink on wing.

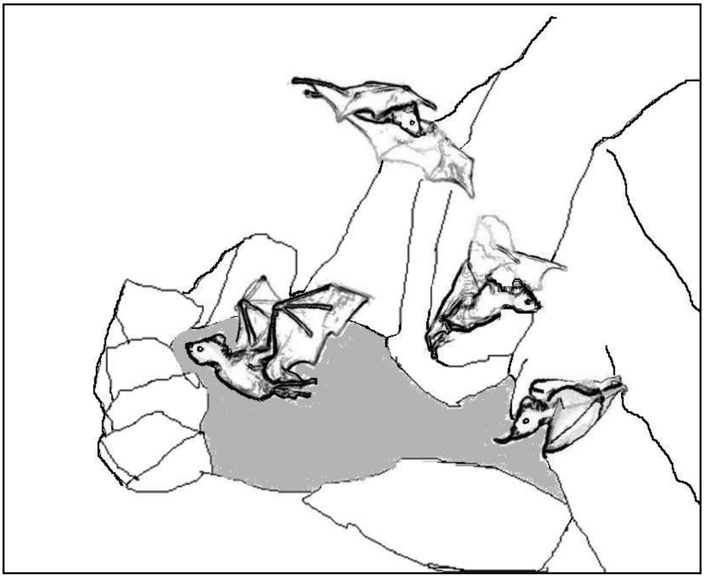

Figure 3. Behaviours of bats' drinking from mineral lick puddles: cling and drink.

Table 2. Summary of the observed behaviour of bats at mineral licks in Deramakot and Tangkulap Forest Reserve

Species of Bats	Estimated Recorded time (s) of indv.	n of indv. Observed (Σn = 9)	Mean of Estimated Time (s)±SD	Location of Observation	Behaviour Observed
Macroglossus minimus	20,21,22	3	21.67±5.77	ML5, ML6	Cling & drink
Balionycteris maculata	18,22	2	13.33±11.7	ML5	Cling & drink
Cynopterus brachyotis	18	1	6.00±10.39	ML4	Drink on wing
Penthetor lucasii	25, 23	2	16..00±13.89	ML5, ML6	Cling & drink
Megaeropse caudatus	16	1	5.33±9.24	ML3	Drink on wing

The foraging spaces for the five species of frugivorous bats were known at the upper and the middle storey (Yasuma et al., 2005a) where most fruits are more abundant in the canopy. This may explain why pteropodid bats are more readily captured in the higher forest strata than in the understorey level (Tan et al. 1998). This is also suggested by studies done in Neotropics, where mineral licks may attract species of bats that normally fly high in the forest by drawing them down and getting captured at ground levels (Bravo et al., 2008; Emmons et al., 2006). This may support the observations where bats that fly close to mineral licks intentionally visit licks for resources.

Direct observations of their behaviour was possible during the day where observations were made after releasing these bats and they flew back to drink from the mineral licks. The released methods depend on the condition of bats especially in the morning session. It was either by hanging them on the nearby tree (for the weak, vulnerable bats) or gently releasing and letting them fly away (active bats). Based on the observation of nine frugivorous bats, they flew back to drink from mineral licks after they were released.

The time duration that each bat spent utilising the licks was less than 20 seconds per individual. This starts from the time the bats approach, drink and leave the lick. Table 2 summarises the observed behaviour of bats at mineral licks.

This drinking behaviour ending in a short time was potentially due to their anti-predator strategy at mineral licks. In addition, their short drinking time at mineral licks was due to the fact that they only needed 1ml to 2ml of mineral licks water for daily consumption as suggested to be sufficient for bats by Ghanem et al. (2013). In other words, they do not need to take too much time drinking from mineral licks as they only need small amount of mineral lick water for their consumption.

Species Occurrences

A total of 91 bats were caught at mineral licks comprising of 14 species. There were 81 individuals of frugivorous bats comprising five species and 10 individuals of insectivorous bats that comprised of nine species. Bat occurrences at mineral licks were dominated by frugivorous bats (86.81%) where each frugivorous bat species can be found in at least two mineral licks.

Captured bats ranged from 1 to 7 bats per night for all sites. Sites ML6 and ML3 recorded the highest capture index score while sites ML1 and ML2 scored the lowest capture index (Table 3). There was no group of bats seen congregating to drink at mineral lick sites as noted in previous studies (Gnahem, 2013; Gnahem et al., 2013). The visitations of bats observed in this study were individual-based visitations and in small groups (<three individuals) based on the low capture index at all mineral lick sites.

Table 3. Capture rate index of bats caught in mineral licks and control sites

Site	n bats	n of traps per night	Sampling nights	Capture Rate bats/traps/night
ML1	7	3	6	2.33
ML2	6	3	6	1.99
ML3	25	3	6	7
ML4	14	3	6	4.66
ML5	16	3	4	5.67
ML6	23	3	4	7.34
CW1	1	3	6	0.33
CW2	2	3	4	0.66

This study revealed that Palaeotropical frugivorous bats in Deramakot Forest and Tangkulap Forest Reserve had different response properties toward utilisation of mineral licks. From this study, bat activities at licks were in lower intensity, less than a hundred individuals from several species. Bats were caught less than seven bats/trap/night (capture rate) and they were not observed congregating at mineral licks. In contrast with the Neotropical region, there were hundreds of individuals from several species of frugivorous bats that were reported to visit mineral licks in Peruvian and Ecuadorian Amazon, indicating higher activity of bats at mineral licks (Bravo et. al., 2008). In a study conducted by Bravo et al. (2008), bats were caught slightly more than ten bats/net/hours.

There was a modest, positive correlation between mineral lick sites and species occurrences, rho=0. 447, n=81, p<0.005. There was no bat caught at wallow sites. This indicated that most of the frugivorous bats caught at those lick sites were commonly found at mineral licks as they utilised mineral licks, and their capture was not by chance. Species *Macroglossus minimus* occurred at all sites while *Megaerops ecaudatus* were only found at ML4 and ML6. Species *Balionycteris maculata* (ML1, ML3 and ML5) and *Penthetor lucasii* (ML4, ML5, ML6) can be found at three sites each, while *Cynopterus brachyotis* can be found at two sites (ML1 and ML3). *Macroglossus minimus* occurred at all sites indicating this species is a frequent mineral lick visitor and its presence at mineral licks was not by chance.

In this study, insectivorous bat occurrences at mineral licks sites could be a random event. There was no correlation between mineral lick sites and species abundance of insectivorous bats (rho=-0.09, n=10, p>0.005). Among the nine species of insectivorous bats caught at mineral licks, none of them were recorded more than once at mineral lick sites. They were also not seen drinking from mineral licks and occurred in low occurrences in both mineral licks and wallow sites. All nine species of insectivorous bats identified in this study are species that commonly fly at the under storey level (Yasuma et al., 2005a; 2005b). This makes it easy for them to hit those traps while flying around study sites as the mineral licks and wallow sites were within their foraging range.

The similarity index (Table 4) showed 33% to 67% of bat species similarity occurred at most mineral lick sites. This is due to the fact that many frugivorous bats caught at most mineral lick sites were from the same species and this increases the percentage of species similarity among all mineral lick sites. The wallow CW1 and CW2 showed a similar pattern of species occurrence. Both sites had low species similarities in comparison to all of the mineral lick sites (<19%). This same pattern was also reported in Bravo et. al., (2008) where there were low species similarities between mineral lick and non-mineral lick forest sites.

Table 4. Bray-Curtis Similarity Index among six mineral licks and two wallow sites

Sites	ML1	ML2	ML3	ML4	ML5	ML6	CW1	CW2
ML1								
ML2	0.31							
ML3	0.38	0.39						
ML4	0.20	0.63	0.42					
ML5	0.25	0.52	0.52	0.67				
ML6	**0.13**	0.41	0.33	0.61	0.60			
CW1	0.25	**0**	**0**	**0**	**0**	**0**		
CW2	0.25	**0**	**0**	**0**	**0**	**0**	1.00	

*Notice in bold indicates low similarities (<0.2) between licks and wallows

Insolube Soil Tracer Test

In all, there were 12 faecal samples of bats collected for this laboratory test analysis. The number of insectivorous bats caught at mineral licks was limited, as one species had at the most, two individuals at mineral lick sites. Faeces of *R. borneensis* (n=2) were used for faecal analysis since the other species occurred only once at each mineral lick site (Table 6). Faecal samples of frugivorous bats *M. minimus* (n=5) were from the same species from the same site. Similarly, faecal samples for insectivorous bats, *Hipposideros cervinus* were collected at forest control (n=5). The concentration of Al and Si were higher in the faeces for frugivorous bats (bold in Table 5) compared to faeces of insectivorous bats caught at mineral lick and forest control sites.

The higher concentrations of Al and Si in their faeces suggest that frugivorous bats consume soil while they are utilising water puddles at mineral licks. Those elements were not part of their diet and thus excreted through their faeces. This makes their faeces enriched with those elements. Al and Si are elements present in high concentrations in soils but poorly absorbed through the gastrointestinal tract, thus should not be part of bat diet (Gnahem, 2013; Gnahem et al., 2013; Abraham, 2012). Meanwhile, samples of faeces from insectivorous bats, *R. borneensis* and *H. cervinus* were not enriched with Al and Si. Both species are cave dwelling bats (Yasuma et al., 2015a) and the smaller amount of concentration of insoluble soil tracer in their faeces may come from their behaviour of drinking water from small limestone caves.

Table 5. Concentration of element Al and Si in faeces of frugivorous bats and insectivorous bats caught at mineral licks and forest control

	Element concentration (Mean±SD)			
	Mineral Licks		Forest Control	
Bats (No. Of samples)	Al (ppm)	Si (ppm)	Al (ppm)	Si (ppm)
Frugivorous Bats				
Macroglossus minimus (5)	**206.05±57.50**	**156.47±25.26**	-	-
Insectivorous bats				
Rhinolophus borneensis (2)	0.27±0.21	13.71±1.81		
Hipposideros cervinus (5)			0.10±0.08	11.73±0.56

*Notice in bold, higher concentration of elements, Al and Si in faeces of *Macroglossus minimus*.

Assemblage Structure

Species composition of bats caught at licks were dominantly frugivorous bats (86.81%). The most common species (>5% relative abundance) caught at all mineral licks in this study were *Macroglossus minimus* (58.24%), *Balionycteris maculata* (12.09%), *Cynopterus brachyotis* (9.89%), and *Penthetor lucasii* (6.59%). The frugivorous bats consisted of subfamily Cynopterinae (*Balionycteris maculata*, *Cynopterus brachyotis*, *Megaerops ecaudatus* and *Penthetor lucasii*) and subfamily Macroglossinae (*Macroglossus minimus*). In this study, the assemblage of species from subfamily Macroglossinae, *Macroglossus minimus*, was well presented at mineral licks. Meanwhile the number of insectivores bats caught at mineral licks were small at <2.2% per site, represented by three families namely, Vespertilionidae Hipposideridae and Rhinolophidae.

Table 6. Species composition and relative abundance of bats caught at mineral licks

Families	Common name	Sp. Name	Captured percentages (%)	Site
Pteropodidae	Long-tongue nectar bat	*Macroglossus minimus*	58.24	ML1, ML2, ML3, ML4, ML5, ML6
	Spotted wing fruit bat	*Balionycteris maculata*	12.09	ML1, ML3,ML5
	Short-nosed fruit bat	*Cynopterus brachyotis*	9.89	ML1,ML3
	Dusky fruit bat	*Penthetor lucasii*	6.59	ML4,ML5, ML6
	Tailless fruit bat	*Megaerops ecaudatus*	2.2	ML4, ML6
Vespertilionidae	Clear-winged woolly bat	*Kerivoula pellucida*	1.1	ML1
	Lesser woolly bat	*Kerivoula minuta*	1.1	ML4
	Lesser tube-nosed bat	*Murina suilla*	1.1	ML3
Hipposideridae	Dayak roundleaf bat	*Hipposideros dyacorum*	1.1	ML5
	Ridley's Roundleaf bat	*Hipposideros ridleyi*	2.2	ML5
Rhinolophidae	Acuminate horseshoe bat	*Rhinolophus acuminatus*	1.1	ML2
	Borneon horseshoe bat	*Rhinolophus borneensis*	2.2	ML3
	Creagh's horseshoe bat	*Rhinolophus creaghi*	1.1	ML6
	Lesser wolly horseshoe bat	*Rhinolophus seduluus*	1.1	ML4

Total individual of bats = 91 (Fruit bats = 81; Insectivorous bats = 10);
Total species =14 (Fruit bats = 5; Insectivorous bats = 9)

In Southeast Asia, Paleotropical bat assemblages are dominated by members of families Rhinolophidae, Hipposideridae and Vespertilionidae (Struebig et al. 2008). Although their assemblages are bigger than family Pteropodidae, they make up only a small percentage of bats caught in study sites especially mineral licks. In this study, there was lack of evidence to prove that bats from insectivorous families utilise mineral licks. Meanwhile frugivorous bats dominated the bat assemblages in mineral licks as they utilise mineral licks. This same pattern was also documented in studies on bats and mineral licks conducted in the Neotropics region (Ghanem, 2013a; Gnahem et al., 2013; Bravo et al., 2012; Bravo et al., 2010a; Bravo et al., 2010b; Bravo et al., 2008; Voigt et al., 2008; Voigt et al., 2007).

The underlying causes of frugivorous bats dominating bat assemblages in mineral licks still remain unclear (Gnahem, 2013). Nonetheless, there are hypotheses that have been proposed to explain their motives in consuming muddy water from licks (Gnahem, 2013; Bravo et al., 2010). Their motives are not limited to one particular hypothesis as many hypotheses can be used to explain their geophagous behaviour due to multifunction benefits of using mineral licks (Brightsmith et al., 2008). Lick water may provide minerals (Brightsmith et al., 2008), antidiarrhoeal components (Slamova et al., 2011), or clay for binding potential dietary toxins (Gilardi et al., 1999). Further studies are needed to test these hypotheses covering Paleotropical bats.

In all, this study gives a general tentative on structure of bats caught at mineral licks and can be used as a baseline for other studies. For instance, a study of bats visiting pattern to licks throughout the year. Pattern of bats visitation may relate to the reproduction season of bats, fruiting/flowering season, and climatic season such as the wet and dry seasons. More studies involving the visitation of bats across time related to the reproduction season of bat species, fruiting/flowering, wet and dry seasons in Borneo are important to reveal the underlying reasons and understanding the seasonal visiting pattern of bats visiting mineral licks in Borneo.

Conclusion

Five species of Old World frugivorous bats (*Macroglossus minimus, Balionycteris maculata*, *Cynopterus brachyotis*, *Megaerops ecaudatus* and *Penthetor lucasii*) made up the assemblages of bats visiting mineral licks in DFD. Species compositions of bats caught at licks were dominanted by frugivorous bats (86.81%), and the common visitors are *M. minimus, B.*

maculata, and *C. brachyotis.* Old World frugivorous bats were confirmed as visiting mineral licks in the Deramakot and Tangkulap Forest Reserve as these five species of frugivorous bats were observed drinking from mineral licks (*M. susminimus,* n=3; *B. maculata* n=2, *C. brachyotis,* n=1, *Megaerops ecaudatus,* n=2; *Penthetor lucasii,* n=1). These observations were supported with the species occurrences data across all mineral lick sites where four species of frugivorous bats (*M. minimus, B. maculata*, *C. brachyotis* and *P. lucasii*) were commonly found and frequently occurred at all six sites at mineral licks. Meanwhile, for species *M. ecaudatus,* this species was observed drinking at mineral licks. Frugivorous bats ingested soil from mineral licks. The concentrations of insoluble soil tracer elements, Al and Si, in frugivorous bat species (represented by species *M. minimus*) were higher compared to the concentrations of those elements in the faeces of insectivorous bats caught at mineral lick and forest sites. Indeed, Al and Si elements excreted from their faeces were not from their fruit diet, but were highly found in the soil.

References

Abraham PW. 2012. Involuntary Soil Ingestion and Geophagia: A Source of Mineral Nutrients and Potentially Harmful Elements to Consumers of Earth Materials. *Applied Geochemistry* **27:** 954-968.

Altman J. 1974. Observational study of behaviour: sampling methods. *Behaviour* **49:** 227-267.

Ayotte JB. 2004. *Ecological importance of licks to four ungulates species in North-Central British Columbia.* M.Sc. Dissertation. The University of Northern British Columbia.

Blake JG, Guerra J, Mosquera D, Torres R, Loiselle BA, Romo D. 2010. Use of mineral licks by White-Billied Spider Monkeys (*Ateles belzebuth*) and Red Howler Monkeys (*Alouatta seniculus*) in Eastern Ecuador. *International Journal of Primatology* **31:** 471-483.

Bravo A, Harms KE, Emmons LH. 2012. Keystone resource (*Ficus*) chemistry explains lick visitation by frugivorous bats.*Journal Of Mammalogy* **93(4):** 1099-1109.

Bravo A, Harms KE, Stevens DR, Emmons LH. 2008. Collpas: Activity hotspots for frugivorous bats (Phyllostomidae) in Peruvian Amazon. *Biotropica* **40:** 203-210.

Bravo A, Harms KE, Emmons LH. 2010a. Preference for collapa water by frugivorous bats (Artibeus): An Experimental Approach. *Biotropica* **42(3):** 276-280.

Bravo A, Harms KE, Emmons LH. 2010b. Puddles created by geophagus mammals are potential mineral sources for frugivorous bats (Stenodermatinae) in Peruvian Amazon. *Journal of Tropical Ecology* **26:** 173-184.

Brightsmith DJ, Taylor J, Phillips TD. 2008. Theroles of soil characteristics and toxin adsorption in avian geophagy. *Biotropica* **40(6):** 766-774.

Burger J, Gochfeld M. 2003. Parrot behaviours at a Rio Manu (Peru) clay lick temporal patterns, associations, and antipredator responses. *Acta Ethologica* **6:** 23-34.

Calef GW, Grant ML. 1975. A mineral lick of the Barrren-Ground Caribou. *Journal of Mammalogy* **56:** 240-242.

Darvis S, Mirick DK. 2006. Soil ingestion in children and adults in the same family. *Journal of Exposure Science and Environmental Epidemiology* **16(1):** 63-75.

Emmons LH, Swarner MJ, Vargas-Espinoza A, Tschapka M, Azurduy H, Kalko EKV.2006. The forest and savanna bat communities of Noel Kempff Mercado National Park (Bolivia). *Revista Boliviana de Ecolog´ıa y Conservaci´ on Ambiental* **19:** 47–57.

Ghanem SJ, Ruppert H, Kunz TH, Voigt CC. 2013. Frugivorous bats drink nutrient and clay-enriched water in the Amazon rain forest: support for a dual function of mineral-lick visits. *Journal of Tropical Ecology* **29:** 1–10.

Ghanem SJ. 2013a. Geophagy of tropical fruit-eating bats - mineral licks as a link between ecology and conservation. Ph. D. Dissertation Freie Universität Berlin.

Gilardi JD, Duffey SS, Munn CA, Tell LA. 1999. Biochemical functions of geophagy in parrotys: Detoxification of dietary toxins and cytoprotective effects. *Journal of Chemical Ecology* **25(4):** 897-922.

Hon J, Shibata S. 2013. Temporal partitioning by animals visiting salt licks. *International Journal of Environment Science and Development* **4(1):**4-48.

Ishige T, Miya M, Ushio M, Sado T, Ushioda M, Maebashi K, Yonechi R, Lagan P, Matsubayashi H. 2017. Tropical-forest mammals as detected by environmental DNA at natural saltlicks in Borneo. *Biological Conservation* **210:** 281-285.

Klaus G, Klaus-Hugi C, Schmid B. 1998. Geophagy by large mammals at natural licks in the rainforest of the Dzanga National Park, Central African Republic. *Journal of Tropical Ecology* **14:** 829-839.

Link A, Galvis N, Fleming E, Di Fiore A. 2011. Patterns of mineral lick visitation by spider monkeys and howler monkeys in Amazonia: Are licks perceived as risky areas.are licks perceived as risky areas? *American Journal of Primatology* **73:** 386-396.

Matsubayashi H, Ahmad AH, Wakamatsu N, Nakazono E, Takyu M, Majalap N, Lagan P, Sukor JRA. 2011. Natural-Licks use by Orangutans and conservation of their habitat in Bornean tropical production forest. *The Raffles Buletin of Zoology* **59(1):** 109-115.

Matsubayashi H, Lagan P, Sukor JRA, Kitayama K. 2007. Seasonal and daily use of natural licks by Sambar Deer (*Cervus unicolor*) in a Bornean tropical rain forest. *Tropics* **17(1):** 81-86.

Matsubayashi H, Lagan P, Majalap N, Tangah J, Sukor JRA, Kitayama K. 2007a. Importance of natural licks for the mammals in Borneon inland tropical rain forest. *Ecological Research* **22(5):** 742-748.

Molina E, Leon TE, Armenteras D. 2013. Characteristic of natural salt licks located in the Colombian Amazon Foothills. *Environmental Geochemistry and Health*, DOI10.1007/s10653-013-9523-1.

Montenegro O. 2004. Natural Licks as keystone resources for wildlife and people in Amazonia. Ph. D. Dissertation. University of Florida.

Morales MA. 2009. The important of natural soil licks to wildlife and humans in subtropical Paraguay, South America. Ph. D. Dissertation. University of Wisconsin Madison.

Muscallela R, Fleming TH. 2007. The role of frugivorous bats in tropical forest succession. *Biological Reviews* **82:** 573-590.

Panichev AM, Zaumyslova OYU, Aramilev VV. 2002. The importance of salt licks and other sources of sodium in the ecology of the Ussuri Moose (*Alcesalces*). *Alces Supplement* **2:** 99-103.

Payne JB, Francis CM. 2007. *A field guide to the mammals of Borneo*. The Sabah Society, Kota Kinabalu, 23-222.

Ping X, Li C, Jiang Z, Liu W, Zhu H. 2011. Sexual difference in seasonal patterns of salt lick use by South China Sika Deer *Cervus Nippon*. *Mammalian Biology* **76:** 196-200.

Purvis A, Gittleman JL, CowlishawG, Mace GM. 2000. Predicting extinction risk in declining species. *Proceedings of the Royal Society B: Biological Sciences* **267(1456):** 1947–1952.

Ramachandran KK, Balagopalan M, Nair PV. 1995. *Use pattern and chemical characterisation of the natural salt licks in Chinnar Wildlife Sanctuary*. Kerala Forest Research Institute (KFRI) Research Report 94: 18.

Rea RV, Hodder DP, Child KN. 2004. Considerations for natural mineral licks used by moose in land use planning and development. *Alces* **40:** 161-167.

Rice CG. 2010. Mineral Lick visitation by mountain goats, *Oreamnos americanus*. *Canadian Field-Naturalist* **124(3):** 225-237.

Struebig MJ, Christy L, Pio D, Meijaard E. 2010. Bats of Borneo: diversity, distributions and representation in protected area. *Biodiversity Conservation* **19:** 449-469.

Struebig MJ, Galdikas B, Suatma. 2006. Bat Diversity In Oligotrophic Forest of Southern Borneo. *Oryx* **40:** 447-445.

Struebig MJ, Kingston T, Zubaid A, Mohd-Adnan A, Rossiter SJ. 2008. Conservation value of forest fragments to Palaeotropical bats. *Biological Conservation* **141:** 2112-2126.

Tan KH, Zubaid A, Kunz TH. 1998. Food habits of *Cynopterus brachyotis* (Muller) (Chiroptera: Pteropodidae) in Peninsular Malaysia. *Journal of Tropical Ecology* **14:** 299–307.

Villalobos F, Arita HT. 2010. The diversity field of New World leaf-nosed bats (Phyllostomidae). *Global Ecology and Biogeography* **19:** 200-211.

Voigt CC, Cas KA, Dechmann DKN, Michener RH, Kunz TH. 2008. Nutrition or Detoxification: Why bats visit mineral licks of the Amazonian Rainforest. *PLos ONE* 3(4): e2011. DOI:10.1371/journal.pone.0002011.

Wilson MJ. 2003. Clay mineralogical and related characteristics of geophagic materials. *Journal of Chemical Ecology* **29(7):** 1525-1547.

Yasuma S, Henry B, Azniza M, Nakayama M. 2005a. *Pocket Guide to The Borneon Mammals Vol 2: Chiroptera Part 1-Pteropolidae, Emballonuridae, Megadermatidae, Nyctridae, Rhinolophidae, & Hipposideridae.*Research and Education Company. BBEC Programme, & Institute for Tropical Biology &Conservation, University Malaysia Sabah, 3-20.

Yasuma S, Henry B, Azniza M, Nakayama M. 2005b. *Pocket Guide to The Borneon Mammals Vol 3: Chiroptera Part 2-Vespertilionidae & Molossidae.* Research and Education Company. BBEC Programme, & Institute for Tropical Biology & Conservation, University Malaysia Sabah, 3-20.