Faculty of Resource Science and Technology

A MORPHOMETRIC ANALYSIS OF LONG-TONGUED NECTAR BAT (PTEROPODIDAE: *Macroglossus minimus*) IN SABAH AND SARAWAK

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A Morphometric Analysis of Long-tongued Nectar Bat (Pteropodidae: *Macroglossus minimus*) in Sabah and Sarawak

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DECLARATION

I hereby declare that no portion of the work referred to this thesis has been submitted in support of an application for another degree or qualification to this or any other university or institute of higher learning.

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(Elina W. Gom)

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List of Abbreviations

BL	bulla length
CW	cranial width
C1BW	canine tooth basal width
C1C1B	breadth across both canines outside surface
C1M5L	canine molar length or maxillary toothrow length
DBC	distance between cochleae
DL	dentary length
D2MCL	second digit metacarpal length
D3MCL	third digit metacarpal length
D3P1L	third digit first phalanx length
D3P2L	third digit second phalanx length
D4MCL	fourth digit metacarpal length
D4P1L	fourth digit first phalanx length
D4P2L	fourth digit second phalanx length
D5MCL	fifth digit metacarpal length
D5P1L	fifth digit first phalanx length
D5P2L	fifth digit second phalanx length

E	ear length
FA	forearm
GBPL	greatest basal pit length
GSL	great skull length
IOW	interorbital width
M1L	first molar tooth crown length
M2M2B	breadth across both second premolar teeth outside surfaces
M1W	first molar tooth crown width
PL	palatal length
POW	postorbital width
PPL	post palatal length
TB	tibia length
MW	mastoid length
ZW	zygomatic width

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ABSTRACT

A study on the morphometric variations of *Macroglossus minimus* was carried out to analyse the morphological variation among four populations from Sabah and Sarawak and also to determine the best character that differentiate this species between populations. *M. minimus* were morphologically analysed where 32 characters of body, skull and dental measurements were recorded. Univariate analysis, Discriminant Function Analysis (DFA) and cluster analysis were done separately on three categories of characters: external characters, internal characters and pooled external and internal characters. Univariate Analysis shows sexual dimorphism by three internal characters namely, zygomatic width (ZW), canine tooth basal width (C1BW) and breadth across both canines outside surface (C1C1B) respectively. DFA shows that the most effective way to identify this bat is by pooling both external and internal characters together and the best characters to differentiate *M. minimus* between populations were fifth digit metacarpal length (D5MCL), forearm (FA), great skull length (GSL) and dental length (DL).

Key words: *Macroglossus minimus*, morphometric analysis, Discriminant Function Analysis, Sabah and Sarawak

ABSTRAK

Satu kajian mengenai variasi morphometrik Macroglossus minimus telah dijalankan untuk menganalisis perubahan morfologi di antara empat populasi dari Sabah dan Sarawak, dan seterusnya menentukan watak yang terbaik untuk membezakan spesies ini. M. minimus secara morfologi telah dianalisis dimana 32 ciri-ciri pengukuran badan, tengkorak dan pergigian telah direkodkan. "Univariate analysis", "Discriminant Function Analysis" (DFA) dan analisa berkelompok dilakukan secara berasingan dalam tiga kategori iaitu ciri-ciri luar, ciri-ciri dalaman dan gabungan ciri-ciri luaran dan dalaman. "Univariat analysis" menunjukkan perbezaan jantina oleh tiga ciri-ciri dalaman iaitu ZW, C1BW dan C1C1B. DFA menentukan cara yang paling berkesan untuk mengenal pasti kelawar ini adalah dengan gabungan kedua-dua ciri dalaman dan luaran. Ciri-ciri yang terbaik untuk membezakan M. minimus antara populasi adalah D5MCL, FA, GSL dan DL.

Kata kunci: Macroglossus minimus, morfometrik analisis, Discriminant Function Analysis, Sabah dan Sarawak

CHAPTER 1

INTRODUCTION

1.0 General Introduction

Malaysia is located on Sunda Shelf, the tectonically inactive continental shelf of East Asia (Hutchison, 2005). This includes Sabah and Sarawak, also known as East Malaysia or Malaysian Borneo, which is the part of Malaysia located on the island of Borneo. Borneo lies between latitudes 4°S and 7°N and longitudes 109° and 119°E, and is also the third largest island in the world (Yasuma and Andau, 1999). The natural vegetation of most Borneo is highly diverse tropical rainforest with high humidity and rainfall throughout the year. East Malaysia has 2,607 kilometres (1,620 mi) of coastline that is divided between coastal regions, hills and valleys, and a mountainous interior (CIA, 2006). Much of southern Sarawak consists of coastal lowlands, which shifts to a series of plateaus going north, ending in the mountainous regions of Sabah (Marshall Cavendish Corporation, 2008). This geographical barrier offers interesting opportunities to study and counter question regarding on the distribution and variation of fauna in this region.

The order Chiroptera or bats are one of the most successful and probably the most diverse mammalian order (Altringham, 1996). They can be distinguished from other mammals by having wings and their natural capability of flying (Payne *et al.*, 1985; Francis, 2008). The tropical and sub-tropical regions hold high diversity of bats (Findley, 1993) and Malaysia is the centre of Old World Bat diversity, consisting of 125 species (Simmons, 2005). In

Borneo itself, there are currently 98 species of bats recorded (Payne *et al.*, 1985; Wilson and Reeder, 2005).

Chiropterans can be divided into two suborders, namely, Megachiroptera and Microchiroptera. Megachiroptera all belong to the same family, Pteropodidae–the Old World fruit bats or flying foxes. They covers a group of frugivorous and nectarivorous bats, divided into two main subfamily which are the macroglossine bats and cynopterine bats (Payne *et al.*, 1985; Corbet and Hill, 1992; Wilson and Reeder, 2005; Francis, 2008). The nectar feeders of macroglossine which belongs to genus *Macroglossus* and *Eonycteris* has long narrow muzzle and tongue, weak jaws and reduced teeth that are specialised for nectar feeding, reflecting their ecological adaptation and behaviour (Payne *et al.*, 1985; Freeman 1995). Out of 18 Pteropodids species found in Borneo, only three are known as nectarivorous. They are *Eonycteris spelaea*, *E. major* and *Macroglossus minimus* (Payne *et al.*, 1985). *M. minimus* has a more riveting evolutionary background with the presence of its larger counterpart, *M. sobrinus*. Despite being interconnected with mainland Malaysia, only *M. minimus* ever been recorded in Borneo while *M. sobrinus* was recorded in mainland Malaysia, co-existing with *M. minimus* (Francis, 2008).

Species of Pteropodidae can be distinguished based on their visible morphological characteristics and measurements and it is necessarily to examine its skull and dentition for confirmation (Payne *et al.*, 1985; Francis, 2008). Morphological evidence shows that there are very little differences being used to distinguish both species of *Macroglossus* (Payne *et al.,* 1985; Francis, 2008). Moreover, the discovery of *M. minimus* is low as it is usually solitary (Nowak, 1999).

However, no recent and specific studies conducted on *M. minimus* on Borneo in terms of the morphological variations. This had provided an interesting basis to test whether there are any obvious morphological variations within the *M. minimus* of Malaysian Borneo. It is then hypothesised that the wide distribution of *M. minimus* in Sarawak and Sabah could provide a significant morphological variation among the *M. minimus* populations.

This research documented the morphological variation within *M. minimus* populations from Malaysian Borneo of Sarawak and Sabah. The scientific information is valuable in understanding the taxonomic status of this species in accordance to the external characters, skull and dental characters. Therefore, the objective of this study is to conduct morphological analysis on the *M. minimus* populations in Sarawak and Sabah and to determine the best character to differentiate the *M. minimus* in these populations.

CHAPTER 2

LITERATURE REVIEW

2.0 Literature Review

2.1 Study Species

M. minimus commonly known as Long-tongued Nectar Bat was first named *Pteropus minimus* which was described by Geoffroy (1810). The specimen was collected from Java, Indonesia (Corbet and Hill, 1993). This bat is appropriately named due to their long tongue for extracting nectar and pollen from flowers (Nowak, 1991).

Around the South Pacific region, *M. minimus* is distributed throughout the countries of the Phiippines, Indonesia, Thailand, Malaysia, New Guinea, The Solomon Islands and northern Australia (Gunnell *et al.*, 1996; Winkelmann *et al.,* 2003). It is also more abundant in disturbed areas than in old growth forest (Francis, 2008). It can be found in elevations from sea-level around 1, 500 m (Mickleburgh *et al.*, 1992). The distribution of this species is due to its ability to cross narrow Pleistocene water gaps and from a plasticity of energy that permits it to retain populations on very small islands (Bonaccorso and McNab, 1997).

Although *M. minimus* shelters under the branches of trees and under roofs, the preferred daytime retreat seems to be in the rolled leaves of hemp and banana planes (Nowak, 1999). Long-tongued Nectar Bat feeds by first landing on a flower or nearby the flower, then using its long tongue to extract nectar or pollen from the flower (Mickleburgh *et al.*, 1992).

M. minimus is the smallest, weighing 16-21g, among the family Pteropodidae in the South Pacific region (Gunnell *et al.,* 1996; Winkelmann *et al.*, 2003). Payne *et al.* (1985) and Francis (2008) stated that the upperparts of *M. minimus* are buffy brown with pale bases, underparts are paler and greyer, while the wing membranes are light brown. They have long, narrow muzzle with very small teeth except for needle-like canines. Their molars are often absent as they have no need to do much chewing (Richards and Hall, 2012). Like other Pteropodids, *M. minimus* have large eyes, and they orient visually (Mijal, 2000). They also have long tongue with brush like tip called papillae for extracting nectar and pollen from flowers (Mijal, 2000; Richards and Hall, 2012).

M. minimus feeds mainly on nectar and pollen, but occasionally also drinks the juices of soft fruit (Nowak, 1991). It is reported that *M. minimus* is commonly found in the coastal mangroves in Malaysia, where the blossoms of *Sonneratia* becomes its primary food (Nowak, 1991). Other flowers that it mainly feed on are from plants of the banana tree (*Musaceae*) and the coconut tree (*Cocos nicifera*) (Gunnell *et al.*, 1996).

M. sobrinus or Greater Long-tongued Nectar Bat, which is the sister species of *M. minimus,* has upperparts of clay-brown colour and the underparts are paler as well (Francis, 2008; Payne *et al.*, 1985). Like *M. minimus*, *M. sobrinus* also shows a similar morphological characteristic by having long, narrow muzzle but with angular, slightly jutting chin (Francis, 2008). Based on Francis (2008) and Payne *et al.* (1985), the most distinctive feature that distinguish these two species was that *M. sobrinus* were slighty larger in size with a longer head, more lateral pointing nostrils and no grooves present on the upper lip.

According to the IUCN Red List of Threatened Species (2012), it is justified that *M. minimus* is listed as Least Concern species in view of its wide distribution, tolerance of broad range of habitats and large population.

2.2 Previous Study

Morphological measurements were applied earlier to discover the origin of bats before molecular techniques came broadly in resolving phylogenetic relationships among the chiropterans (Wible and Novacek, 1998). According to Fenton (1982), the studies on the morphology on bats have led to various predictions about feeding and resource partitioning, drawing on other further studies to support inferences from morphology. A few studies of bats have been revealed morphologically trends and interpreted in various ways.

Recent studies that used morphological characteristic in describing species boundaries have been well aided by the implementation of multivariate statistics (Jayaraj, 2008). The studies with implication of multivariate analysis within Chiroptera shown to be reliable in separating species which were known to have overlapping morphological characters and defining new species (Kitchener *et al.*, 1995; Kitchener and Maryanto, 1995; Maryanto and Yani, 2003). More accurate data will be obtained when high numbers of characteristics are measured to distinguish the studied species from one another and in some cases, more sample sizes are more important. The studies on the intra and the inter-specific morphometric relationship of the Indo-Malayan bats have been greatly illustrated by various authors (Dumont, 2006; Sazali *et al.*, 2008; Rahman and Abdullah, 2010; Hasan and Abdullah, 2011; Sazali *et al.*, 2012; Tingga and Abdullah, 2012).

Remarkable diversity in cranial design has been exhibited by plant-visiting phyllostomids (Dumont, 2006). To explain the function basis of this diversity, Dumont (2007) had conducted a research by evaluating the correlated evolution of cranial morphology and feeding behaviour within the lineage. The inspection of reconstructed ancestor character based on morphological data available suggests that the evolution of fig-feeding bats is related with shifts to morphologies and behaviours that reflect increased masticatory stress.

In previous study done by Rahman and Abdullah (2010), it is stated that there are significant differences found in the external and craniodental characters of the Dusky Fruit Bat (*Penthetor lucasi*) from different populations within Sarawak region. These morphological differences are suggested to be driven by various environmental factors, involving relative isolation and also different selective pressures that undergo by each population (Kitchener and Maryanto, 1993). These variations in the morphological characters that occur between populations are explained by or correlated to differences in geographical distance and climate (Solick and Barclay, 2006). The differences in size may be because of the crowding effect that could lead to changes in body size due to competition for space and food resources (Rahman and Abdullah, 2010). Moreover, isolation by distance would have caused sufficient evolution of these distinct features displayed by different populations (Solick and Barclay, 2006). Ecomorphology is one of the main causes of the display of large external characters in bats (Norberg, 1981). Larger wings and body sizes are said to provide powerful flight which is required for long distance foraging activities and to protect themselves from predators, thus shows an increase in survivorship (Abdullah, 2003).

Study by Hasan and Abdullah (2011) on the morphological analysis of Malaysian *Kerivoula* in different populations separated *K. papillosa* specimens into two separate morphotypes which are *K. papillosa* type large and *K. papillose* type small. These were characterised by their differences in size. However, they suggested that each *Kerivoula* species represents an independent species even though the morphotypes occur sympatrically.

Another recent study conducted by Tingga and Abdullah (2012) on the preliminary morphometric analysis of *Aethalops aequalis* populations in Sabah and Sarawak, Malaysian Borneo stated that Northeast Sarawak groups of this species seem to possess a shorter lower jaw in order to consume harder food resources. This statement is consistent with a study by Rahman and Abdullah (2010) where it generally stated that morphological characters correlate to the dietary adaptation of organisms. However, Tingga and Abdullah (2012) concluded that the body and skull sizes were not affected by altitude or elevations with *A. aequalis* possessing a single morphotype in Malaysian Borneo.

The implementation of multivariate analysis has been successfully used in identifying the best morphological predictor in differentiating species. A study among four *Rhinolophus* species done by Sazali *et al.* (2008) were morphologically analysed where 27 linear measurements of body, skull and dental were appropriately recorded and analysed that the three characters fifth digit metacarpal length (D5MCL), forth digit metacarpal length (D4MCL) and palatal length (PL) were identified as the best morphological predictor that distinguish these species of *Rhinolophus*. In conjunction to that, Sazali *et al.* (2012) also identified three best diagnostic features which were the forearm (FA), second phalanx length (D3P2L) and palatal length (PL) for discriminating closely related species of *Hipposideros* with the aid of morphometric analysis.

Therefore, morphometric analysis approach is a valid method to establish the existence of distinct morphological variation between species from different localities that could be distinguished accordingly by morphological characters (Abdullah, 2003; Jayaraj, 2008; Rahman and Abdullah, 2010; Hassan and Abdullah, 2011; Sazali *et al.,* 2012; Tingga and Abdullah, 2012). This could also be a promising tool as an alternative to the molecular DNA analysis for the identification of Chiropteran species.

CHAPTER 3

METHODOLOGY

3.0 Methodology

3.1 Study Area

The study areas were in Sarawak and Sabah (Figure 3.1 and Table 3.1). These study areas were important as it included the maximum geographical and topographical separation in order to maximize the likelihood of finding morphological polymorphisms together with geographical local populations for comparison (Tingga and Abdullah, 2012).

The study areas were divided into Southwest Sarawak region, Central Sarawak region, Northeast Sarawak region and Sabah regions. The selected sites were at various forest areas such as in mangrove forest, beach forest, peat swamp forest, kerangas forest, mixed dipterocarp forest, secondary forest as well as plantation forest around Sarawak region; and lowland forest and lower dipterocarp forest for the Sabah region.

3.2 Field Sampling

In general, this research was based on the available museum specimens for this species; however fieldworks were conducted to include new localities of *M. minimus* that were not collected. Fieldworks (refer Table 3.2) had been conducted to add up the collection of this species as wet specimens and the rest of the specimens were obtained from the Zoological Museum UNIMAS. The vegetation of the chosen sites provides suitable habitat for both foraging and roosting sites for *M. minimus*.

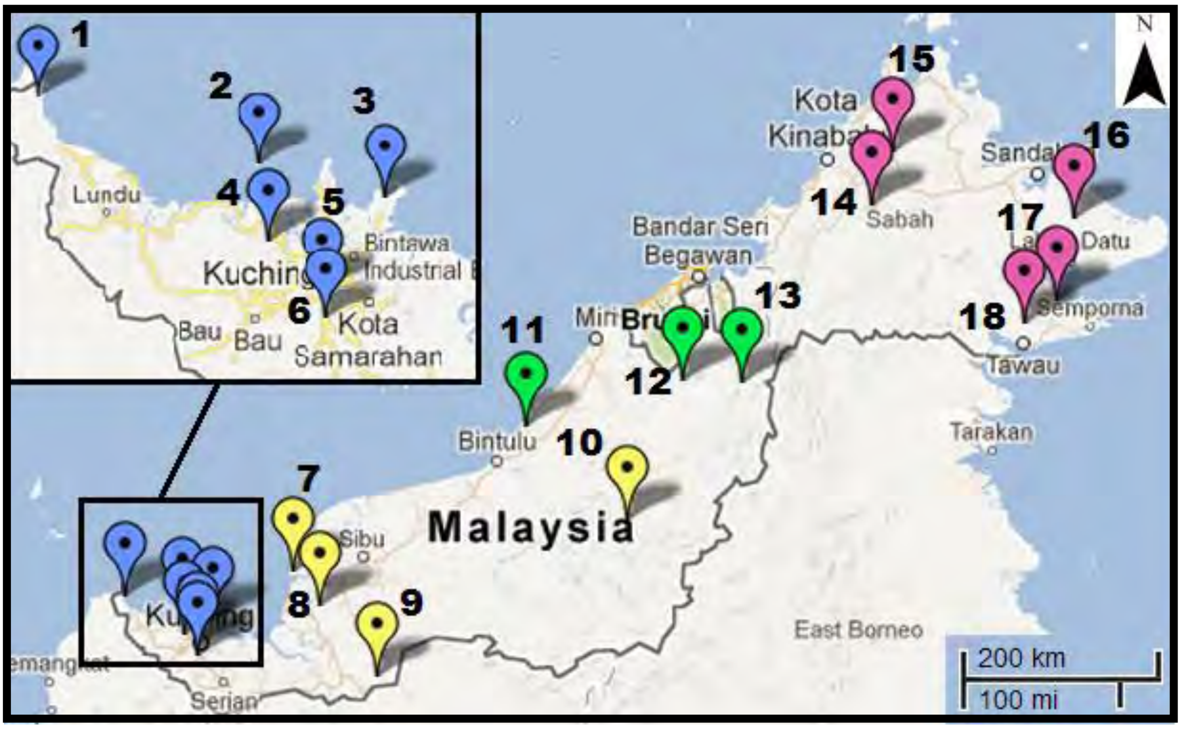

Figure 3.1 Locations of the specimens of *M. minimus* populations that is examined in Sarawak and Sabah from four regions as: Southwest Sarawak Region (1= Samunsam Wildlife Sanctuary; 2= Pulau Satang Besar; 3= Bako National Park; 4= Kubah National Park; 5= Kg. Tembirat Asajaya; 6= Mount Penrissen Borneo Heights), Central Sarawak Region (7= Tanjung Manis Sarikei; 8= Sebangkoi Recreational Park; 9= Batang Ai National Park; 10= Sungai Murum), Northeast Sarawak Region (11= Similajau National Park; 12= Mulu National Park; 13= Mount Murud) and Sabah Region (14= Trus Madi Forest Reserve; 15= Poring Hot Spring; 16= Danum Valley; 17= Gunung Silam; 18= Tawau Hills;) (Modified from Google Map, 2013).

Table 3.1 List of the locations of the specimens and number of individuals of *M. minimus* based on the available museum data and fieldwork during this study.

Geographical region	Location				Habitat type	No. of indv.
	Map point	Sites	Latitude	Longitude		
Southwest Sarawak	1	Samunsam Wildlife Sanctuary	1.9602	109.6665	Mangrove Forest	2
	2	Pulau Satang Besar	1.7918	110.1656	Beach Forest	1
	3	Bako National Park	1.7167	110.4667	Kerangas Forest	5
	4	Kubah National Park	1.6128	110.1969	Mixed Dipterocarp Forest	1
	5	Kg. Tembirat, Asa Jaya	1.541	110.5144	Peat Swamp Forest	1
	6	Mount Penrissen Borneo Heights	1.497	110.3465	Mixed Dipterocarp Forest and Secondary Forest	5
Central Sarawak	7	Tanjung Manis, Sarikei	2.5027	112.3157	Mixed Dipterocarp Forest	2
	8	Sebangkoi Recreational Park	1.5756	111.2582	Secondary Forest	5
	9	Batang Ai National Park	1.1472	111.8739	Mixed Dipterocarp Forest	1
	10	Sg. Murum	1.9602	109.6665	Mangrove Forest	5
Northeast Sarawak	11	Similajau National Park	3.5171	113.3418	Peat Swamp Forest	5
	12	Mulu National Park			Plantation Forest	5
	13	Mount Murud	3.9167	115.3333	Montane Forest	5
Sabah	14	Trusmadi Forest Reserve	5.5500	116.5167	Lowland Dipterocarp Forest	5
	15	Poring Hot Spring	6.0444	116.7008	Lowland Montane Forest	1
	16	Danum Valley	5.4174	118.3927	Lowland Montane Forest	2
	17	Gunung Silam Lahad Datu	4.9783	118.2296	Lowland Montane Forest	3
	18	Tawau Hill	4.2825	117.9148	Lowland Montane Forest	2