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Morphometric Analysis of the Fawn Roundleaf Bat, *Hipposideros cervinus* (Gould, 1854) (Chiroptera: Hipposideridae), from Several Populations in Sarawak

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ABSTRACT.– **A morphometric analysis of three different populations of *Hipposideros cervinus* in Sarawak, Malaysian Borneo, was performed using voucher specimens deposited in the UNIMAS Zoological Museum that had been collected from the three different geographical regions (populations) of Kubah National Park, Tubau and Niah National Park. A total of 27 characters, derived from external, cranial and dental measurements, were used. The measurements were recorded and analyzed using Discriminant Function Analysis (DFA) with the SPSS Version 18.0 software. The highest character loading for Functions 1 and 2 were the canine molar length or maxillary tooth row length (C1M3L) and the ear length (EL), with standardized canonical discriminant function coefficient values of 0.680 and 0.711, respectively. These two characters are identified as the best predictors to distinguish the three populations based on their morphological measurements. Accordingly, it is proposed that the different types of habitats, foraging behavior and food availability are among the factors that could lead to morphological variations among *H. cervinus* populations.**

KEY WORDS: ***Hipposideros cervinus*, morphometric, discriminant function, Malaysian Borneo**

INTRODUCTION

The tropical rainforest of Malaysia is a home for many animal species. The fawn roundleaf bat, *Hipposideros cervinus* (Gould, 1854), is one of the species that is common and widely distributed in Sarawak. *H. cervinus* was formerly confused with *H. galeritus*, but can be differentiated by having a narrower median noseleaf than the posterior noseleaf, whilst in *H. galeritus* the median noseleaf is broader than the posterior one (Payne et al., 1985). The body coloration of *H. cervinus* varies from grey-brown or yellowish-brown to red-brown or orange, the noseleaf is greyish-pink with two lateral leaflets, and the ear is broad and triangular (Payne et al., 1985). They usually roost in caves, sometimes in very large colonies, and they feed in the forest understory (Payne et al., 1985). However, there are no recent and specific studies conducted on this species in terms of the morphological variations between different populations. This study aimed to assess and review the morphological variation of *H. cervinus* from different localities in Sarawak by using their morphometrical characters.

MATERIALS AND METHODS

A total of 32 adult male specimens were used in this study that consisted of 13 individuals from Kubah, five individuals from Tubau and 14 individuals from Niah (Fig. 1). These specimens were deposited in the Universiti Malaysia Sarawak (UNIMAS) Zoological Museum. The place

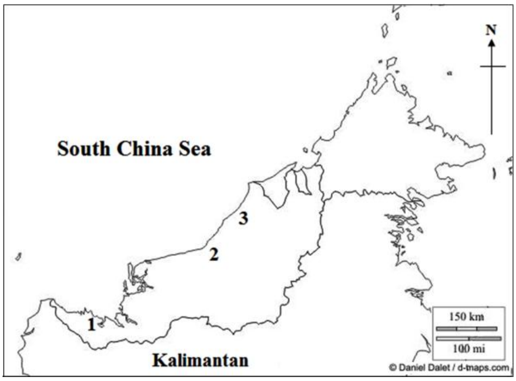

FIGURE 1. Map showing the localities of the *H. cervinus* specimens used in this study. 1: Kubah, 2: Tubau and 3: Niah (modified from Dalet, 2011).

and date of collection and the museum accession code for each specimen examined is given in Table 1. Adult specimens were identified according to Kunz and Kurta (1988). A total of 27 characters (Fig. 2); third digit metacarpal length (D3MCL), third digit first phalanx length (D3P1L), third digit second phalanx length (D3P2L), fourth digit metacarpal length (D4MCL), fifth digit metacarpal length (D5MCL), ear length (EL), forearm length (FA), pes length (PES), tibia length (TB), tail to ventral length (TVL), bulla length (BL), cranial length (CW), distance between cochleae (DBC), dentary length (DL), greatest basial pit length (GBPL), greatest skull length (GSL), interorbital width (IOW), mastoid width (MW), palatal length (PL), post palatal length (PPL), zygomatic width (ZW), canine tooth basal width (C1BW), breath across both canines outside surfaces (C1C1B), canine molar length or maxillary tooth row length (C1M3L), second molar tooth crown length (M2L), second molar tooth crown width (M2W) and the breadth across both third molar teeth outside surfaces (M3M3B), were measured using a digital caliper (calibrated to 0.01 mm) following Sazali et al. (2008a, 2008b) and recorded. The data were analyzed with Discriminant Function Analysis (DFA) with the stepwise procedure using the Statistical Package for Social Sciences (SPSS) Version 18.0 software (SPSS Inc., 2010) to find the significant characters for discriminating the three populations.

RESULTS

The mean ±1 standard deviation and range of the 27 morphological characters *H. cervinus* measured in the bats from Kubah, Tubau and Niah are summarized in Table 2. Overall, the Tubau population showed the largest average measurement of most of the characters, whilst the Niah population showed the smallest average measurement for all 27 characters.

The DFA revealed two significant functions. Function 1 and Function 2 explained 76.6% and 23.4% of the variance respectively. Therefore, Function 1 has a higher variability of characters in this analysis (Table 3). The Wilks' Lambda statistics for Function 1 through 2 is 0.042 with a probability of P = 0.000, whereas the Function 2 through 2 is 0.326 with a probability of P = 0.000 (Table 4). The highest character observed for Functions 1 and 2 were the canine molar length or maxillary tooth row length (C1M3L) and the ear length (EL), respectively (Table 5). Based on the canonical discriminant plot (Fig. 3), each population forms their own cluster. Function 1 separated the Niah population from the Kubah and Tubau populations, and Function 2 separated the Kubah population from the Tubau population.

DISCUSSION

In this study, the three different geographical localities (populations) of *H.*

TABLE 1. List of the specimens of *H. cervinus* used in this study.

No.	Population	Locality	Field No.	Sex	Date of Collection
1	1	Kubah NP	KNP003	M	14.04.2005
2	1	Kubah NP	KNP004	M	14.04.2005
3	1	Kubah NP	KNP006	M	14.04.2005
4	1	Kubah NP	KNP008	M	14.04.2005
5	1	Kubah NP	KNP010	M	14.04.2005
6	1	Kubah NP	KNP011	M	14.04.2005
7	1	Kubah NP	KNP013	M	14.04.2005
8	1	Kubah NP	KNP014	M	14.04.2005
9	1	Kubah NP	KNP015	M	14.04.2005
10	1	Kubah NP	KNP017	M	14.04.2005
11	1	Kubah NP	KNP018	M	14.04.2005
12	1	Kubah NP	KNP019	M	14.04.2005
13	1	Kubah NP	KNP025	M	15.04.2005
14	2	Tubau	GP7	M	04.05.2005
15	2	Tubau	GP9	M	04.05.2005
16	2	Tubau	GP16	M	05.05.2005
17	2	Tubau	GP17	M	04.05.2005
18	2	Tubau	GP21	M	05.05.2005
19	3	Niah NP	A.1554	M	2004
20	3	Niah NP	A.1555	M	2004
21	3	Niah NP	A.1572	M	2004
22	3	Niah NP	A.1578	M	2004
23	3	Niah NP	A.1580	M	2004
24	3	Niah NP	A.1581	M	2004
25	3	Niah NP	TK153723	M	2007
26	3	Niah NP	TK153726	M	2007
27	3	Niah NP	TK153727	M	2007
28	3	Niah NP	TK153740	M	2007
29	3	Niah NP	TK153745	M	2007
30	3	Niah NP	TK153746	M	2007
31	3	Niah NP	TK153748	M	2007
32	3	Niah NP	TK153750	M	2007

cervinus can be distinguished by their canine molar length or maxillary tooth row length (C1M3L) and ear length (EL). Dentition plays an important role in the ecology and feeding behavior of bats. Phillips (2000) claimed that dentition and dental characters are still important to modern bat systematists. The dentition affects the selection of food items and diet preferences. Different diets will affect the growth rate and body size of the animals. The same species from different populations might show morphological variation in their dentition since the dental features are very important when considering the food, in terms of hardness, softness and brittleness (Phillips, 2000). Long term dietary preferences can lead to variations in dental morphology between different populations through natural selection for adaptation. Freeman (1979) showed that in insectivorous molossids, individuals that prefer hard-shelled insects, such as beetles, can be distinguished from those which consume only soft-shelled insects, such as moths, based on their dentition, and the author suggested that the same trend could possibly be observed in all chiropteran insectivores.

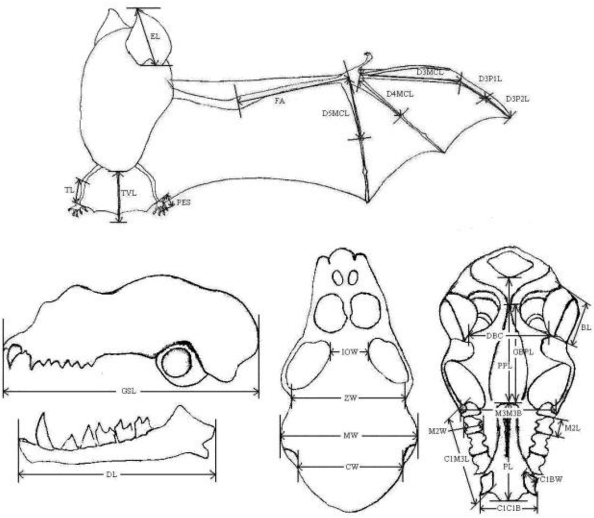

FIGURE 2. The 27 characters used in the morphometrical analysis of *Hipposideros cervinus*. The figure was adapted from Sazali et al. (2008b) and the drawing is not to scale.

Canine molar length or maxillary tooth row length (C1M3L) affects the degree of mouth opening (gape angle). According to Dumont and Herrel (2003), gape angle and the location along the tooth row at which the force is transferred (bite point) affects the bite force, with the bite force decreasing as the gape angle increases, both between species and within species, given the same bite point. The variation in bite force may possibly be due to architectural details of the skull, including the muscle size, muscle fiber orientation and bone morphology (Aguirre et al., 2002; Dumont and Herrel, 2003), and as mentioned may indicate the material properties of the prey in insectivorous bats, ranging from say hard beetles to soft moths. Amongst the three populations of *H. cervinus* studied here, the population from Niah had a relatively smaller canine molar length or maxillary tooth row length (C1M3L) compared to those from Kubah and Tubau. It is assumed then that the Niah population consumed softer food items compared to the Kubah and Tubau populations. Bite force is an important factor in feeding behavior because it can affect the feeding efficiency. Increasing the bite force can reduce the feeding time and enable bats to consume more prey items within a given period of time.

Ear size is associated with flight performance as larger ears cause more drag and reduce the flight speed, but also can act as canard structures to produce additional lift and control in flight (Gardiner et al., 2011). A study conducted by Fenton and Bogdanowicz (2002) on bats in the genus *Myotis* found that they can be discriminated by their ear length, and that this affected their foraging behavior. The significant difference in the ear length between these three populations of *H. cervinus* in Sarawak may indicate that they forage in habitats that have a different degree of clutter. Ear length is an important factor in the ecological behavior of insectivorous bats as it affects the echolocation call frequency. As a result of the negative correlation between size and dominant call frequency, the bigger the size of drum membranes and string, the lower the frequency will be produced (Bogdanowicz et al., 1999). There is evidence for geographic, habitat and individual variation within species (Barclay et al., 1999). As mentioned, the dentition morphology affects the selection of food items, which in *H. cervinus* are insects. Similarly, the call frequency also correlates with diet composition on the basis that their calling frequency will determine the type of prey that they can detect and capture efficiently.

TABLE 2. Descriptive statistics for the studied specimens of *H. cervinus* from three different geographical localities (populations).

Population	**Kubah (n = 13)**			**Tubau (n = 5)**			**Niah (n = 14)**		
Character	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**	**Min**	**Max**
^{a}FA	48.18 ±1.01	47.00	50.27	48.66 ± 0.43	48.15	49.30	46.55 ± 1.13	44.11	48.48
^{b}EL	14.33 ±0.46	13.87	15.60	15.79 ± 0.39	15.24	16.26	14.65 ± 0.57	13.78	15.43
^{c}TB	18.13 ± 0.55	17.49	19.36	18.15 ± 0.50	17.69	18.93	17.19 ± 0.70	15.83	18.00
PES	6.24 ± 0.55	5.29	7.30	6.31 ± 0.14	6.15	6.50	6.04 ± 0.43	5.18	6.58
TVL	25.50 ± 3.07	16.97	29.55	25.17 ± 0.96	24.20	26.39	24.57 ± 1.01	23.19	26.23
^{d}D3MCL	36.94 ± 1.11	35.41	39.19	37.87 ± 0.73	37.12	39.07	35.68 ± 1.43	31.98	37.60
^{e}D3P1L	15.33 ± 0.68	14.26	16.71	15.76 ± 0.48	15.20	16.42	14.64 ± 0.45	13.70	15.33
^{f}D3P2L	16.46 ± 0.93	15.06	18.10	17.33 ± 0.35	16.75	17.68	15.61 ± 0.73	14.39	17.15
^{g}D4MCL	35.47 ± 1.08	33.96	37.86	35.96 ± 0.63	34.97	36.67	33.86 ± 1.32	30.95	35.67
^{h}D5MCL	31.57 ± 0.91	30.24	33.22	31.90 ± 0.81	30.77	33.03	29.90 ± 1.01	27.29	31.20
^{i}GSL	18.68 ± 0.22	18.38	19.11	18.63 ± 0.75	17.64	19.61	17.66 ± 0.43	16.72	18.14
IOW	2.75 ± 0.09	2.59	2.88	2.78 ± 0.13	2.67	2.96	2.65 ± 0.15	2.42	2.92
^{j}CW	7.78 ± 0.18	7.45	8.06	8.01 ± 0.17	7.84	8.26	7.48 ± 0.15	7.17	7.87
^{k}MW	9.38 ± 0.17	9.06	9.73	9.44 ± 0.11	9.33	9.61	9.02 ± 0.11	8.81	9.27
^{l}ZW	8.31 ± 0.17	7.94	8.51	8.42 ± 0.18	8.20	8.68	8.00 ± 0.15	7.78	8.29
^{m}PPL	8.77 ± 0.19	8.52	9.16	8.39 ± 0.58	7.40	8.89	8.30 ± 0.26	7.84	8.72
^{n}PL	6.03 ± 0.13	5.80	6.23	6.14 ± 0.22	5.88	6.47	5.66 ± 0.24	5.25	6.07
DBC	5.09 ± 1.30	4.67	5.86	4.99 ± 0.23	4.77	5.34	4.84 ± 0.38	4.39	5.96
BL	2.57 ± 0.09	2.45	2.73	2.59 ± 0.06	2.50	2.65	2.51 ± 0.13	2.25	2.80
GBPL	7.58 ± 0.58	7.01	9.23	7.54 ± 0.49	6.69	7.94	7.42 ± 0.24	6.99	7.77
^{o}DL	12.31 ± 0.19	11.99	12.51	12.23 ± 0.34	11.92	12.77	11.54 ± 0.20	11.07	12.00
^{p}C1BW	2.59 ± 0.11	2.38	2.72	2.51 ± 0.07	2.39	2.58	2.40 ± 0.17	2.11	2.69
^{q}C1C1B	3.82 ± 0.13	3.58	4.01	3.95 ± 0.16	3.71	4.11	3.54 ± 0.29	2.85	3.89
^{r}M3M3B	6.76 ± 0.15	6.48	6.97	6.97 ± 0.06	6.91	7.04	6.45 ± 0.18	5.98	6.80
^{s}C1M3L	6.56 ± 0.06	6.48	6.67	6.64 ± 0.18	6.35	6.78	6.23 ± 0.10	6.05	6.47
^{t}M2L	1.53 ± 0.08	1.39	1.66	1.52 ± 0.07	1.46	1.62	1.45 ± 0.06	1.38	1.56
^{u}M2W	1.73 ± 0.05	1.66	1.81	1.81 ± 0.07	1.72	1.89	1.67 ± 0.05	1.61	1.74

($^{a-u}$)= Means within a row followed by a different superscript letter are significantly different ($P < 0.05$, ANOVA).

Kingston et al. (2000) suggested that the call frequency indicates the size of the prey that an insectivorous bat can get. The calling frequency of bats must be outside of the detection range of the tympanate prey to enable the bats to capture more efficiently these prey items (Fenton et al., 1998; Zhao et al., 2003). In order to change the calling frequency to within a range that cannot be detected by the prey, modification in the bats ear length or size is required. Zhao et al. (2003) reported that the call frequency used for echolocation shows significant impacts on the ear size in hipposiderids. Echolocation call is also important to enable bats to distinguish between echoes returning from their potential prey items and the background vegetation. A highly effective echolocation system improves directionality and so enables insectivorous bats to capture their prey even in an aerial mode. Echolocation is associated with foraging strategies in different types of habitat and can restrict some species or populations to certain habitats. According to Jacobs (1999), the calls used by bats in open habitats are of a shorter duration and a higher frequency compared to those used by bats foraging in clutter. Zhao et al. (2003) also suggested that echolocation and morphology were highly correlated in evolution.

TABLE 3. Eigenvalues for the discriminant function analysis (DFA).

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	6.787*	76.6	76.6	0.934
2	2.067*	23.4	100.0	0.821

*First two canonical discriminate functions were used in the analysis.

TABLE 4. Wilks' Lambda values for the DFA.

Test of Function (s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 2	0.042	87.265	8	0.000
2	0.326	30.824	3	0.000

TABLE 5. Standardized canonical discriminant function coefficient for the 27 morphological characters.

	Function	
Character	**1**	**2**
EL	-0.518	0.843*
PPL	-0.792	-0.771
DL	0.763	-0.403
C1M3L	1.036*	0.628

***** Diagnostic character in each function.

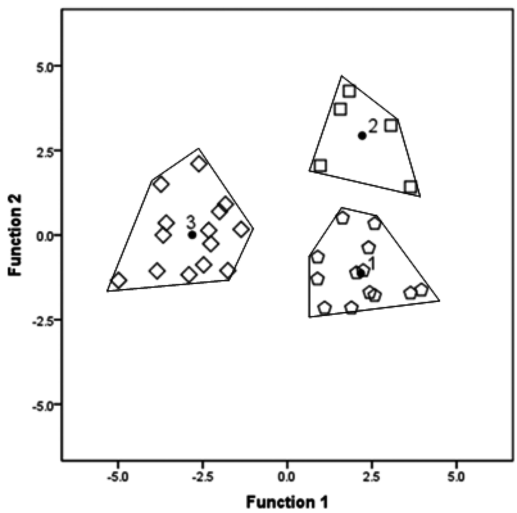

FIGURE 3. Canonical discriminant plot of *H. cervinus* populations from (1) Kubah, (2) Tubau and (3) Niah.

CONCLUSION

The three populations of *H. cervinus* from Sarawak can be distinguished by using their morphological characters. The best predictors for differentiating these populations are the canine molar length or maxillary tooth row length (C1M3L) and the ear length (EL). These morphological variations between the three populations could have been affected by various factors, such as the types of habitats, foraging behavior and food availability. Therefore, each population might undergo a different rate of change in terms of their morphology, with selection favoring certain rare existing morphologies or new mutations to spread within the population in order to adapt to the new environment. To validate these morphological trends reported here, a molecular analysis is essential in order to validate and reconstruct the phylogenetic relationship of *H. cervinus* from these populations and evaluate potential gene flow levels between them, in addition to the need to include more representatives from Peninsular Malaysia, Kalimantan, Sumatera and Java for further studies in the future.

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