Faculty of Resource Science and Technology

A STUDY ON THE WING-LOADING AND ASPECT-RATIO FOR FRUIT BATS OF FAMILY PTEROPODIDAE

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Bachelor of Science with Honours
(Animal Resource Science and Management)
2007

A STUDY ON THE WING-LOADING AND ASPECT-RATIO FOR FRUIT BATS OF FAMILY PTEROPODIDAE

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This project is submitted in fulfillment of the requirements for the degree of

Bachelor of Science with Honors

(Animal Resource Science and Management)

ANIMAL RESOURCE SCIENCE AND MANAGEMENT

DEPARTMENT OF ZOOLOGY

FACULTY OF RESOURCE SCIENCE AND TECHNOLOGY

UNIVERSITI MALAYSIA SARAWAK

2007

DECLARATION.

No portion of the work referred to in this dissertation has been submitted in support of an application for another degree of qualification of this or any other university or institution of higher learning.

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ACKNOWLEDGEMENT

I thank God that now this project had been completed without much obstacle. Upon completion of this project, I would like to express my gratitude to several individuals for all the facilities, assistance, critics and guidance provided to me. Sarawak Forestry Department, for permit numbered 42/2006. En. Abol, land lord of Pulau Satang Besar for permission to do sampling on his island. My supervisor and co-supervisor, Mr. Charlie Justin Laman and Assoc. Prof. Dr. Mohd. Tajuddin Abdullah, Dr. Charles Leh and Dr. Petrus Bulan for advise and guidance. Logistic support from Department of Zoology, Faculty of Resource Science and Technology, Universiti Malaysia Sarawak. All tutors, all laboratory assistants, research assistants and post-graduate students for assistance. To fellow classmates especially Mohd. Farhan Ihsan, Wong Siew Fui and Izwan Ashraf, second year students and first year students involved in data collection. Lastly, to my parents and relatives who had always been there to provide me with moral and spiritual support.

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A Study on the Wing-Loading and Aspect-Ratio for Fruit Bats of Family Pteropodidae

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ABSTRACT

This study was conducted as an attempt to describe habitat use by fruit bats from data analysis of wing-loading and aspect-ratio. Study of wing-loading and aspect-ratio was successful in describing habitat use of fruit bats. The study revealed that the family Pteropodidae had relatively high wing-loadings and low aspect-ratio. There were also high degree of overlap in wing-loading and aspect-ratio within the fruit bat family which indicated overlap in habitat usage. Species that were of low wing-loading and aspect-ratio are able to use both cluttered and uncluttered habitat. This could be a strategy to reduce competition. Where else, species with higher wing-loading and aspect-ratio are only confined to uncluttered habitat. The value of these flight indices were also related to the load the bats carry and the distance they travel. Wing-loading and aspect-ratio were able to explain the flight behavior such as maneuverability, speed and agility of the animal.

Keyword: Fruit bats, wing-loading, aspect-ratio, habitat use.

ABSTRAK

Kajian ini bertujuan untuk menghuraikan penggunaan habitat oleh spesies kelawar buah menggunakan indeks muatan sayap dan nisbah luas permukaan sayap. Kajian ini telah berjaya mengaitkan indeks-indeks tersebut kepada penggunaan habitat oleh spesies. Kebanyakan spesies kelawar buah mempunyai muatan sayap yang tinggi dan nisbah luas permukaan sayap yang rendah. Pertindihan indeks antara spesies yang dikaji juga berlaku, ini menunjukkan pertindihan penggunakan habitat olah kelawar buah dari spesies berlainan. Spesies yang mempunyai kedua-dua indeks yang rendah menggunakan kawasan yang padat dan lapang sebagai habitatnya. Manakala spesies yang mempunyai muatan sayap yang tinggi hanya menghuni kawasan lapang. Perbezaan indeks-indeks ini mungkin merupakan strategi untuk mengelak daripada persaingan untuk mendapat sumber makanan. Nilai muatan sayap kelawar sangat bergantung kepada berat muatan yang dibawa oleh kelawar serta jarak penerbangan spesies tersebut. Ciri-ciri penerbangan seekor kelawar juga boleh dijangka menggunakan muatan sayap dan nisbah lusa permukaan sayap yang digunakan dalam kajian ini.

Kata Kunci: Kelawar buah, muatan sayap, nisbah luas permukaan sayap, penggunaan habitat.

1.0 INTRODUCTION

Bats are grouped into the order Chiroptera (Payne *et al.*, 1985; Corbet and Hill, 1992; Francis, 2001). With a total of 177 genera, they contribute to one quarter of the total mammal species in the world (Mickleburgh *et al.*, 1992; Wilson and Reeder, 1993; Altringham, 1996). They are well distributed around the world and a large number of them occur in the tropical or subtropical region (Corbet and Hill, 1992). In Borneo, eight families of bats are found (Pteropodidae, Emballonuridae, Megadermatidae, Nycteridae, Rhinolophidae, Hipposideridae, Vespertilionidae and Molossidae) (Payne *et al.*. 1985).

Bats exist in two suborders; the megachiroptera and microchiroptera (Corbet and Hill, 1992). Megachiroptera are commonly known as fruit bats while microchiroptera are known as insect bats (Harrison, 1952). Megachiroptera feeds mainly on plant materials and belong to the family Pteropodidae which were further divided into two subfamilies which are Pteropodinae and Macroglossinae (Wilson and Reeder, 1993). The macroglossine bats are different of those from subfamily Pteropodinae. They feed specifically on nectar and have long narrow muzzle, weaker jaws and reduced teeth (Payne *et al.*, 1985). Megachiropterans in the world consist of 42 genera and 166 species (Wilson and Reeder, 1993).

The evolutionary history of bats started when a fully developed flying mammal (microchiroptera) was recorded from the Eocene era (Mickleburgh *et al.*, 1992; Nikaido *et al.*, 2000; Simmons, 2005). Fossil of megachiropterans were only recovered in the Oligocene era some 35 million years ago (Mickleburgh *et al.*. 1992; Atringham, 1996; Nikaido *et al.*, 2000).

According to Mickleburgh *et al.* (1992), megachiropterans and microchiropterans evolved at different time and they do not share a common ancestor. Megachiropterans were suggested to be more closely related to the primate's lineage (Mickleburgh *et al.*, 1992). However a recent study on mitocondrial DNA of bats by Nikaido *et al.* (2000) suggested that the megabats and microbats evolved from a monophyletic lineage and were more closely related to the Fereuungulata (Carnivora + Perissodactyla + Cetartiodactyla).

Generally, phenotype of megachiropterans includes the fact that their body sizes are larger compared to microchiropterans (Payne *et al.*, 1985; Altringham, 1996; Gumal *et al.*, 1998). The megachiropterans also have large eyes because they depend much on eyesight for foraging (Payne *et al.*, 1985). Megachiropterans are unable to echolocate. Therefore, nose leaf is absent and only simple ears without tragus are present. However, *Rousettus* do echolocate by clicking their tongue (Mickleburgh *et al.*, 1992). Their second finger is relatively independent of their third finger and their third finger has claw except in *Eonycteris* (Payne *et al.*, 1985; Mickleburgh *et al.*, 1992). Tails are normally short or absent in some species of megachiroptera (Payne *et al.*, 1985).

Wings in bats were the only character that distinguished this mammal from others (Gumal *et al.*, 1998). This is the only mammal able of powered flight (Kunz, 1982; Simmons, 2005). Bats have undergone several modifications including bones of arm were elongated and slender, adapted for flight and thin aerofoil and chambered wing for lift during flight (Vaughan, 1986; Altringham, 1996; Martin *et al.*, 2001). Flight in bats had led to effective exploitation of food resources, roosting environment and avoiding predators (Kunz, 1982). Besides that, they are also ecologically important as pollinators and seed dispersers of valuable plant species (Gumal *et al.*, 1998).

Ecomorphology is a field that study the relationship between morphology and ecological behavior (Findley, 1993). This study analyses structures found on animals and make refined prediction on the ecology of the animal (Kunz, 1982). Similar to birds, flights performance of bats and how they relate to habitat use or foraging style can be predicted through study of the wing structure (Pennycuick, 1989). Two common measurements used to study flight performance and characters were wing-loading and aspect-ratio (Altringham, 2003). These measurements alone are capable of categorizing bats into different flight groups (Altringham, 2003).

1.1 Objectives

The purposes of the present study were:

i. To determine two flight indices which were wing-loading (WL) and aspect-ratio (AR) of selected fruit bats.

ii. To study also attempts to relate WL and AR of the fruit bats to habitat usage in a qualitative way

iii. To investigate if WL and AR could be used for taxonomic classification of fruit bats

1.2 Hypothesis

For this study, the general working hypotheses are:

H_{O1}: There is no significant difference in the wing-loading and aspect-ratio between members of family Pteropodidae

H_{A1}: There is significant difference in the wing-loading and aspect-ratio between members of family Pteropodidae

2.0 LITERATURE REVIEW

Small changes in morphology are capable of producing novel functions in animals (Koehl, 1996). Ecomorphological studies are applied to almost any kind of animals. For example, hairy little legs in euphausid were used to assist suspension-feeding (Koehl, 1996).

Bats are groups of animals that have been and are being studied vigorously. Various form of studies such as molecular biology, ecology, morphometrics and ecomorphological studies have been conducted in effort to distinguish species, explain and predict behaviors of bat species (Jayaraj and Abdullah, 2005; Abdullah 2003; Kunz, 1982).

Various aspects of ecomorphology such as wing morphology, jaw structure, brain size, general external dimensions and geographical variation had been used to study bats (Kunz, 1982). There were many ecomorphology studies conducted by several experts on wing morphology of bats. Among the earliest was Revilliod (1916) cited in Kunz (1982) who tried to relate wing morphology to flight characteristics of bats.

Wing loading and aspect ratio measurements are capable of determining flight behavior such as agility, maneuverability and speed in both birds and bats (Pennycuick, 1989). Common flight performance can be described by these measurements. Wing-loading describes the area of a bat's wing in relation to its body weight and can be obtained by simple mathematical formula (Neuweiler, 2000; Altringham, 2003). Wing loading is associated with flight speed and maneuverability (Norberg and Rayner, 1987). While aspect-ratio is used to describe the general shape of a bat's wing (Altringham, 2003; Hodgkison *et al*., 2004).

Vaughan (1966) studied the morphology and flight characteristics of molossid bats. This study was conducted on specimens preserved in alcohol. This study found that the broad ears in mollosid bats were associated with the rapid flight in the bats. The leathery and elastic wing membrane was probably of aerodynamic importance and the wing-loading of these bats were generally higher than those of vespertilionids which indicate greater flight speed in mollosids.

In 1981, Norberg conducted allometry comparison on bat wings to those of birds. In the study, it was concluded that comparison of wing and leg morphology in bats showed different allometric equations for different bat from different families. Aspect-ratio and wing-loading were also able to associate bats to different foraging behavior and flight style. Insectivorous bats were highly diverse in wing structure and make up different groups with different flight habits. While, fruigivorous bats were not as maneuverable as nectarivorous and phyllostomids. Molossid bats showed strong convergence with the swifts and in terms of foraging behavior, wing form and size they are similar to the swallows.

A study on ecological morphology and flight in all families of bats was also conducted by Norberg and Rayner (1987). This study described wing-loading and aspect-ratio of bats from and relates these results to feeding behavior and commuting behavior of the bats. The study also was able to clarify size scaling of performance and size range of bats and community ecology and ecological morphology of bat flight. It was concluded that evolution has dominant influence on the adaptive specializations of bats which produce variation in flight performance within bat communities. However, the study was not able to test out the predictions made at community level.

Webb *et al.* (1992) used wing loading and body mass to study inter and intra individual variation in female Pipistrelle bats in north-east Scotland. This study revealed that there were three major potential sources of inter-individual variation of body mass in pregnant bats which were the body size, body fat and the mass of the fetus with associated fluid and tissue. Besides that adaptive interpretation of wing form based on the calculated wing-loading for pregnant bats collected could not reflect the actual nature of adaptation in wing morphology.

Brigham *et al.* (1997) used ecomorphological study to compared microhabitat use of two species of *Nyctophilus* by wing-loading method. The two species had similar wing morphology (low wing loading and aspect ratio) and echolocation-call design (high-frequency, frequency-modulation calls). They were found to forage at the same habitat preferring the open canopy area. The study also found no evidence for any change in habitat use by these bats with changing lunar condition.

McKenzie et al., (1995) conducted a study on the correspondence between flight morphology and foraging ecology in some palaeotropical bats on Lombok Island, Indonesia. This study discovered that aspect-ratio, wing-loading and wing tip index were all important in separating insect bats into three different foraging strategies and fruit bats into two foraging strategies. This study also concluded that relationship between flight morphology and foraging ecology of bats crossed the family- level phylogenetic relationship in some instance.

Rhodes (2002) did an assessment of source of variance and patterns of overlap in 21 species of insect bats using wing morphology in Australia and found out that species overlap occurred higher in lower aspect-ratio and wing-loading. Prediction on flight behavior of these species was also made based on wing-loading and aspect-ratio.

In Malaysia, Hodgkison *et al.* (2004) used ecomorphological approach to investigate vertical stratification of old world fruit bats. This study revealed that small difference in wing-loading was likely to be ecologically significant to the vertical stratification of bats in Malaysian lowland rainforest.

Most study on bats using wing-loading and aspect-ratios were conducted on the insect bat communities. Little studies had been done on the fruit bat communities. Therefore this study attempts to add more information on habitat usage of fruit bats based on the currently available literature.

Other forms of studies were such as the study of cryptic *Cynopterus brachyotis*, a molecular study was conducted by Abdullah (2003) using cytochrome *b* mitochondrial DNA gene. The result shows that a major subdivision occurs in the *C. brachyotis* populations and there were two distinct forms of *C. brachyotis* (large form and small form) that has two distinct lineage (Abdullah, 2003). The difference in size maybe due to the vegetation type that act as a selective force over time (Abdullah *et al.*, 2000).

Ecology modeling and morphometrics study was studied by Jayaraj and Abdullah (2005) on the same species. In his study, cranial character measurements and morphological characters were used to discriminate *C. brachyotis* that exist in two forms.

3.0 MATERIALS AND METHODS

3.1 Study area

In this study, data were collected from four different localities, namely, Bako National Park, Pulau Satang Besar, Kubah National Park, and Batang Ai National Park.

Figure 1: Sampling sites for the present study (Source: Google Earth, 2007).

<u>Bako National Park</u>

Two separate sampling sessions were conducted in Bako National Park. The first sampling session was conducted at Bukit Gondol from 26 August 2006 to 2 September 2006. The second sampling session was conducted from 23 November 2006 to 27 November 2006 around the headquarters area and along Bukit Tambi trail.

The park headquarters was located at a GPS reading of N 01^0 43.35' E 110^0 26.80'. The sampling areas were located along the headquarters to Teluk Assam trail. Capture of fruit bats were conducted in the beach forest, mangrove forest, heath forest and mixed dipterocarp forest (Hazebroek and Abang Morshidi, 2000).

Bukit Gondol was located at N 01^0 42.09' E 110^0 28.27' and 260 m above sea level. The loop of Bukit Gondol consisted of two trails which were the Paya Jelutong trail and Bukit Gondol trail. Vegetation that occurred along the Paya Jelutong trail was riverine forest and mixed dipterocarp forest (Hazebroek and Abang Morshidi, 2000). Among plant species that can be found in the area were palm and large Jelutong trees. Bukit Gondol trail on the other hand were dominated by heath forest (Hazebroek and Abang Morshidi, 2000). Based on observation on randomly selected 1 m x 1 m quadrate, the area was heavily covered by poles and saplings. The forest floor was exposed to sunlight with canopy cover of only about 40 percent (Whitmore, 1991).

Bukit Tambi was positioned at N 01^0 43.33' E 110^0 27.14'. This trail was heavily dominated by heath forest, shrubs and exposed rock surfaces (Hazebroek and Abang Morshidi, 2000). Large trees were scarce. Plants that occurred here had thick cuticles and small surface area. No fruiting tree was observed in the vicinity of the sampling area.

Pulau Satang Besar

A sampling period of five days was conducted in Pulau Satang Besar from 8 September 2006 to 12 September 2006. The island was located at N 01^0 46' E 110^0 9' about one hour boat ride from Telaga Air jetty.

This small island consisted of three vegetation types (Hazebroek and Abang Morshidhi, 2000). Along the beach was a stretch of beach forest with the occurrence of *Cocos* spp. The land around the headquarters was cultivated land planted with fruit trees such as *Carica papaya* and *Musa* spp. Further into the island was primary mixed dipterocarp forest with large dipterocarp trees and little forest litter.

Kubah National Park

Two separate sampling sessions were conducted in Kubah National Park from 26 August 2006 to 2 September 2006 and 16 December 2006 to 22 December 2006. The samplings were conducted at both lower and upper elevation.

The lower elevation was read at N 01^0 35' E 110^0 11' with altitude of 119 meters to 400 meters above sea level. At upper elevation, the GPS reading was N 01^0 35' 17.9" E110^0 11' 19" with elevation of 787 meters onwards above sea level. The sampling area was inhabited by heath forest and lower montane forest (Hazebroek and Abang Morshidi, 2000). Plants were mostly small, twisted and short. Ferns were also common in the sampling area.

Batang Ai National Park

Sampling for bats was conducted during at Lubang Baya, Batang Ai National Park during the fruiting season from 11 December 2006 to 14 December 2006.

Sampling sessions in Batang Ai National Park was carried out around the ranger quarters at N 01^0 18.2' E 112^0 4.3'. The sampling area was within the vicinity of the quarters. Sampling area was dominated by cultivated land and secondary forest (Hazebroek and Abang Morshidi, 2000). Fruit trees planted were *Durio* spp., *Garcinia* spp. and *Musa* spp.

3.2 Field methodology

During this study, mist nets and harp traps were deployed from 1800 hours to 0600 hours. Nets were checked once every two hours until 2400 hours and the last check was done early in the morning at 0600 hour.

Adult individuals were separated from the juveniles based on the degree of ossification on the third, fourth and fifth metacarpals (Brigham *et al.*, 1997; Jayaraj and Abdullah, 2005) and identified based on Payne *et al.* (1985). Wings were spread above a light source to observe ossification.

For cryptic animal such as *C. brachyotis*, the large form and small form were distinguished by forearm measurement. Those with forearm between 60 to 66 mm were classified as *C. brachyotis* I (large form) while those with forearm less than 60 were classified as *C. brachyotis* II (small form) (Fukuda *et al.*, 2007).

All captured individuals were weighed and measured to collect standard measurements (Hall *et al.*, 2004). The weight (in grams) was taken using a Pesola spring balance. Standard measurements which are forearm length, head and body length, ear length, tibia length and tail length were taken using calipers (Payne *et al.*, 1985). Graph papers and pencil were used to trace the outline of wing span of the bats.

Several wing tracings were also taken from the personal collections by MT Abdullah to increase number of species and individuals to support the result of the data analysis. The preferable sample size wherever possible was at least 10 adult individuals of each sex and strictly non-pregnant adult female.

The wing span was measured from tip to tip of the extended wings and the wing area were the combined area of both wings, the entire uropatagium (tail membrane) and the body area between the wings, excluding the head (Norberg and Rayner, 1987; Brigham *et al.*, 1997). Figure 2 illustrates how to trace the wing area of a bat based on Norberg and Rayner (1987).

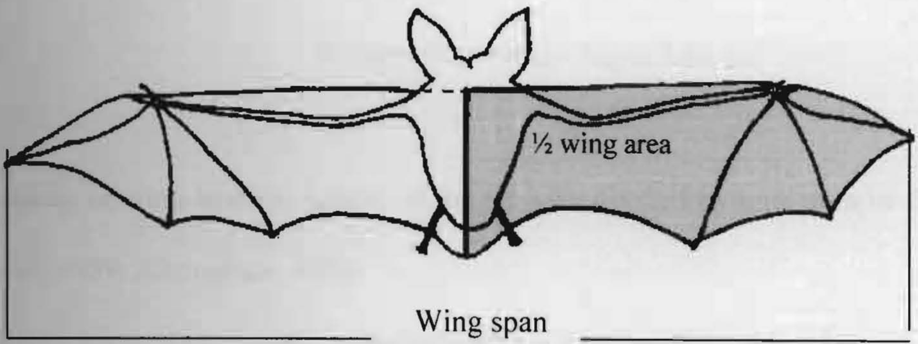

Figure 2: Measurement of wing spans and wing area of a bat.

Bats that had been measured were marked by numbered rings before they were released alive. Traced outline of the bat's wing were run through the Leaf Area Measurement System (CB-370795 220V) which functions together with a Baxial ¼" camera and monitor television to produce the wing area in centimeters.

3.3 Statistical analysis

In this study, various analyses were used to describe species through wing morphology was via various analyses.

3.3.1 Standardizing data and calculating flight indices

To calculate wing-loading (WL) and aspect-ratio (AR), first of all, the measurements of weight (Wt), wing span (B) and wing area (S) had to be converted into standard units of kilogram per gravitational acceleration (Kg ms^{-2}), meter (m) and meter square (m^2).