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Prediction of Foraging Strategy Through The Wing Morphology of Three Forest Fruit Bats

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Abstract

Wing morphology is an important indicator of the foraging ecology of bats, as they may constrain the foraging habitats bat can use, the types of food items that they can detect, and how those resources are perceived. The fruit eating bats differ from insect eating bats in their foraging patterns. Low aspect ratio, short wingspan and high wing loading in respect to that of the body size has provided them with commuting foraging flights covering wider area. Three of the megachiropterans species of the present study shown remarkable variation in their flight patterns depending on their wing morphology. But all of them show broad wing with high wing loading enabling them to attain a moderate flight speed which provide them sufficient foraging time and long-distance commuting flight. But they show variation in their wingspan, aspect ratio and wing tip length and wing tip shape. This variation helps each one of them to attain species-specific manoevrability flight in cluttered area, low cost of transport and agility. This variation in turn reflects their foraging pattern and selection of food items. The present study has made an attempt to focus on the variation in the wing morphology of three forest fruit and correlated with foraging strategy.

Keywords – Wing morphology, aspect ratio, wing span, wing loading, fruit bats and foraging pattern

1. Introduction

Flying animals require different wing designs and energy expenditures (1). Variation in the wing shape of bats results in different flight demands. Flight adaptation in bats allows them to radiate widely to adopt highly specialized tropic strategies (2). Bats are more highly diversified in their feeding strategies than any other mammalian order. A strong relationship between wing morphology, habitat structure, and foraging strategy (3-5), and between tropic characters and dietary niche (6-9) has been demonstrated in multiple taxonomic groups and local assemblages. Knowledge about the diet of an organism is essential for a study in ecology and behaviour of any organism. Such dietary information is essential for proper management and conservation of any species (10). The dietary adaptations of bats are commonly reflected in the morphology of their wing (flight apparatus). Body mass, wingspan and wing area are the primary measures of design in flying organisms. From these parameters, wing loading and aspect ratio are derived, which describe the size and shape of the wings respectively (11). The study on the wing morphology of bats will reveal their foraging strategy and food selection (12). So, it is needed to study the wing morphology in terms of aerodynamic principles which has its impact on the foraging behaviour of bat species. Only a few studies have approached the relationship among feeding behaviour and morphological diversity of wing in these flying mammals. The present study is an attempt to investigate the wing morphology of three forest fruit bats. The observations on the wing morphology have been co-related with their foraging strategy.

2. Materials And Methods

The diversity in the morphology and its impact on the ecology of the three fruit bats *Cynopterus brachyotis*, *Latidens salimalii* and *Eonecteris spelaea* were assessed by studying the flight apparatus. The flight adaptations like the body size, tail and wing morphology were recorded on three bat species captured in fields either near the roosting sites or in the foraging grounds by using mist nets. Bats were released immediately after taking all measurements.

The wing morphological parameters Wing area, S (m^2), Hand wing area, Shw and Arm wing area, Saw were measured by following methods described by Norberg and Rayner (11). The various wing parameters were measured for each bat species. Each individual was placed on a graph sheet extending the wing and the tail membranes and the perimeter was traced. The overall size of the bat was measured by the total body mass, M (kg) weighed to the nearest 05 g using Avinet spring scales. The wing area, hand wing area arm wing area were measured to the nearest 1 mm^2 by directly counting the squares (mm) from the tracings on the graph sheet. Wingspan, B (m) Arm wing length, law and Hand wing length, lhw parameters were also measured directly from the tracings on the graph sheet. From these measured values (M, B and S) the wing loading, aspect ratio, tip area ratio and tip shape index were calculated.

The morphological parameters of the wings were calculated by using the following method.

Wing area, S (m^2)	:	Area of wings, the entire tail membrane and the body area between the wings excluding head.
Hand wing area, Shw	:	Area of membrane spanned by the second to fifth digit.
Arm wing area, Saw	:	Area of wing between the fifth digit, the body and the legs.

The wing area, hand wing area arm wing area were measured to the nearest 1 mm^2 by directly counting the squares (mm) from the tracings on the graph sheet.

Wingspan, B (m)	:	Distance between the wing tips of the bat with extended wings (leading edges should be held along a straight line of the body).
Arm wing length, law	:	Distance from the shoulder joint to the wrist.
Hand wing length, lhw	:	Distance from the wrist to the wing tip.

The above parameters were also measured directly from the tracings on the graph sheet. From these measured values (M, B and S) the wing loading, aspect ratio, tip area ratio and tip shape index were calculated.

$$\text{Aspect ratio (A)} = B^2/S = \frac{\text{Square of wingspan}}{\text{Wing area}}$$

$$\text{Wing loading} = Mg/S\ (Nm^{-2}) = \frac{\text{Body mass x g}}{\text{Wing area}}$$

g = gravitational acceleration which is 9.81

Wing loading index = $Mg/S\ /\ gM^{1/3} = M^{2/3}\ /\ S$

Since wing loading varies with mass it is possible to estimate the wing loading index, which is independent of body mass nondimensional (13). The aerodynamic abilities of the bat species were expressed when wing loading index was plotted against the aspect ratio.

Tip length ratio, Tl = Hand wing length / Arm wing length = lhw / law

Tip area ratio, Ts = Hand wing area / Arm wing area = Shw / Saw

Tip shape index, I = Ts / (Tl – Ts)

Statistical Analysis

Statistical analysis includes statistics expressed as mean ± SD. The aerodynamic structural relationship of the bat species was studied by correlating wing morphological parameters (wingspan, wing area, aspect ratio and wing loading) and body mass. The results were expressed in power regression lines.

3. Result and Discussion

The resulting values were tabulated and correlated with the isometric scaling model of Norberg and Rayner (11) to predict the flight performance and the foraging behaviour. The variation in the wing morphology of Megachiroptera is shown in Plate 1.

The variation in the wing morphology of three fruit bat species is described as follows. Abbreviations used to denote bat species were *Las – Latidens salimalii, Eos –Eonecteris spelaea, Cyb - Cynopterus brachyotis respectively* in the figures. Table 1 shows the measurements of wing morphology of the studied Pteropodidae family members**.** Body mass and wing dimensions of Megachiroptera (Fruigivorous bats) is given in Table 2.

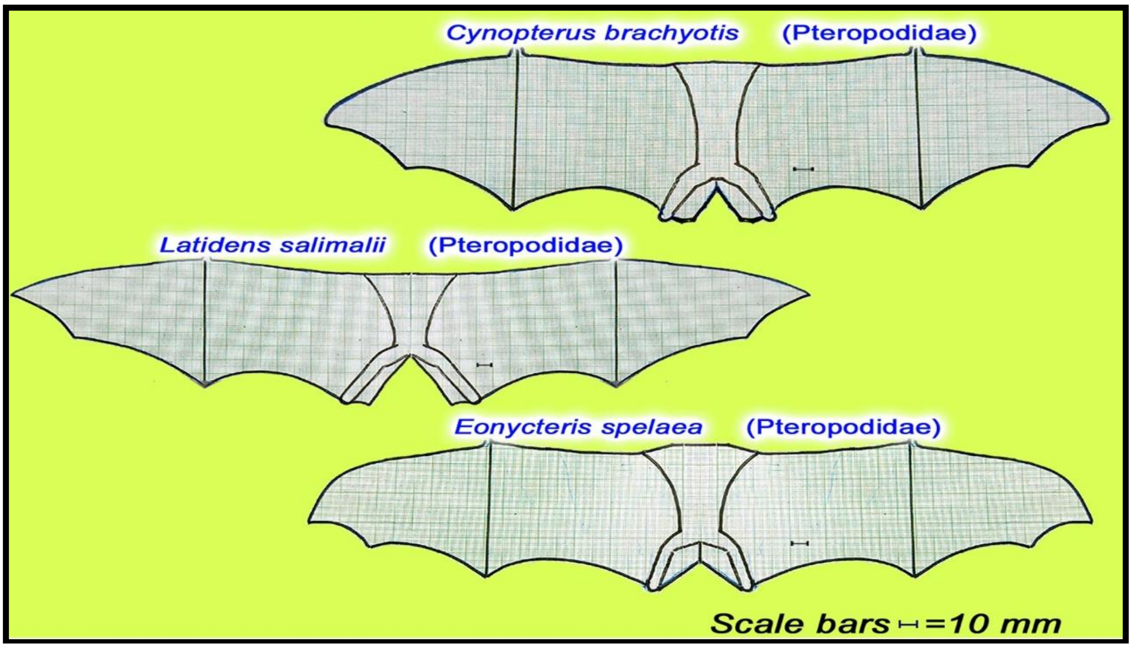

Plate 1. Variation in the wing morphology of studied Megachiroptera

Name of the bat species	N	Sex	Wing span (mm)	Fingers (mm)												
				Thum-b	2 metacarpal	3 metacarpal	4metacarpal	5metacarpal	1ph 2mt	1ph 3mt	2ph 3mt	1ph 4mt	2ph 4mt	1ph 5mt	2p-h 5mt
Cynopterus brachyotis	5	♂	406.4 ± 15.789	26.8 ± 1.789	27 ± 1.414	42.8 ± 1.304	39.8 ± 0.447	40.8 ± 0.837	8.8 ± 2.683	27.4 ± 1.673	37.2 ± 1.789	20.4 ± 0.548	22.6 ± 2.074	19.8 ± 0.447	19.6 ± 1.14
	5	♀	411.4 ± 24.44	25.4 ± 2.702	28.2 ± 1.304	41.6 ± 2.702	40.4 ± 2.302	41.6 ± 3.362	10.6 ± 2.074	29.4 ± 0.894	38.4 ± 1.517	21.2 ± 0.837	24.2 ± 0.447	19.6 ± 0.548	19.8 ± 0.447
Latidens salimalii	5	♂	479 ± 6.52	19 ± 1.581	26.4 ± 1.949	44.6 ± 0.894	44.6 ± 0.894	43.4 ± 0.894	14.2 ± 1.304	32.2 ± 1.304	41.8 ± 0.447	25.2 ± 1.643	28.2 ± .837	21.8 ± 0.837	21.8 ± 1.095
	5	♀	485.6 ± 10.213	21.4 ± 2.608	24.4 ± 2.51	47.4 ± 1.517	45.4 ± 1.342	44.8 ± 1.095	13.4 ± 1.673	32.6 ± 1.673	45.8 ± 2.168	27 ± 1.225	29.4 ± 0.894	21.4 ± 0.894	21.8 ± 0.447
Eonycteris spelaea	5	♂	430± 5.1	26± 2.1	34± 2.3	50± 1.6	50± 1.3	45± 1.1	10± 1.2	33± 1.3	40± 2.6	23 ± 1.5	25± 0.9	22± 0.8	25± 1.1

5	♀	425± 4.1	25± 2.2	34± 2.4	49± 1.8	48± 1.5	44± 1.3	10± 1.5	32± 1.2	39± 2.5	22 ± 1.6	24± 1.0	21± 0.9	24± 1.2

Table 1. Measurements of wing morphology of the studied Pteropodidae family members.
Value: Mean ± Standard deviation. **N**: number of individuals. Abbreviations used to denote fingers.
1ph 2mt - 1 Phalanx of 2 metacarpal; **1ph 3mt** - 1 Phalanx of 3 metacarpal; **2ph 3mt** - 2 Phalanx of 3 metacarpal; **1ph 4mt** - 1 Phalanx of 4 metacarpal; **2ph 4mt** - 2 Phalanx of 4 metacarpal; **1ph 5mt** - 1 Phalanx of 5 metacarpal; **2ph 5mt** - 2 Phalanx of 5 metacarpal.

Species name	Body mass M (Kg)	Wing span B (m)	Wing area S (m^2)	Aspect ratio (A)	Wing loading (Mg/S (NM^{-2})	Tip length ratio Tl	Tip area ratio Ts	Tip shape index I	Wing loading index M2/3 /S	No.
Cynopterus brachyotis	0.0354	0.405	0.0234	7.06	15.06	1.4	0.77	1.54	4.61	5
Latidens salimalii	0.0681	0.449	0.0312	6.46	21.5	1.02	0.67	2	5.35	5
Eonycteris spelaea	0.043	0.440	0.0231	8.40	18.26	1.09	0.666	1.571	5.31	1

Table 2 Body mass and wing dimensions of Pteropodidae family members

Wing Morphology

Correlation between the wing morphology (wing span, wing area, wing loading and aspect ratio) and mass expressed in power log regression are given in Figures 1 to 4. The scatter plots explain that mass has linear relationship with wingspan, wing area and wing loading. As the mass increases these morphological factors also increase. The plot of mass against aspect ratio reveals an unusual phenomenon and explains that the mass apparently has no influence on the aspect ratio in all three species (Figure 4).

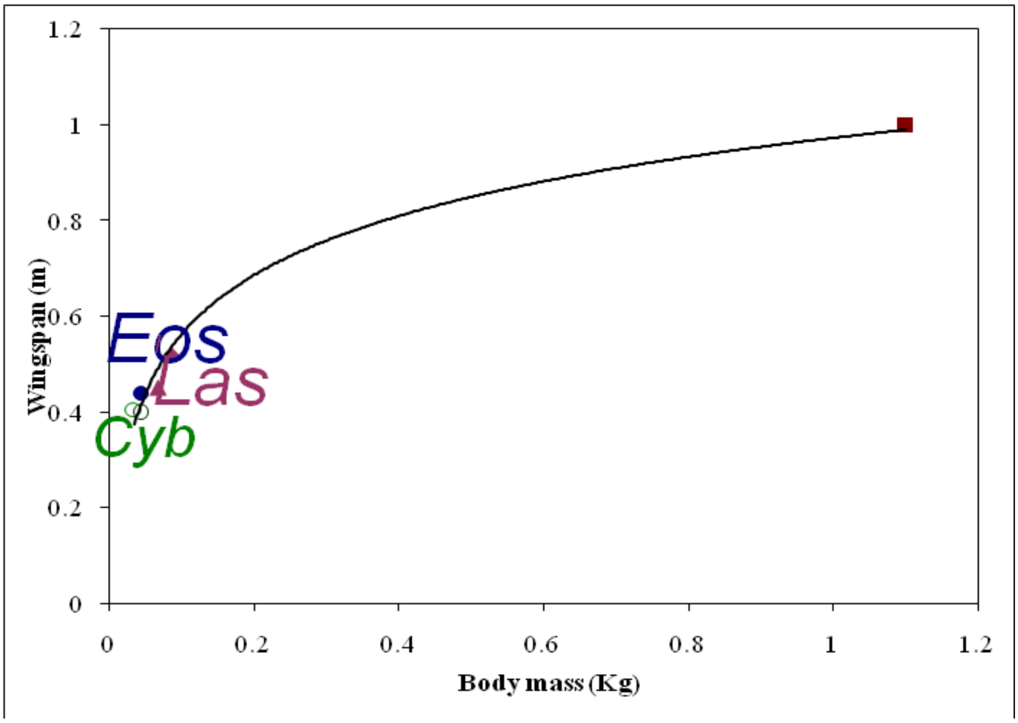

Figure 1: Wingspan plotted on power regression lines against body mass in the studied megachiropteran species

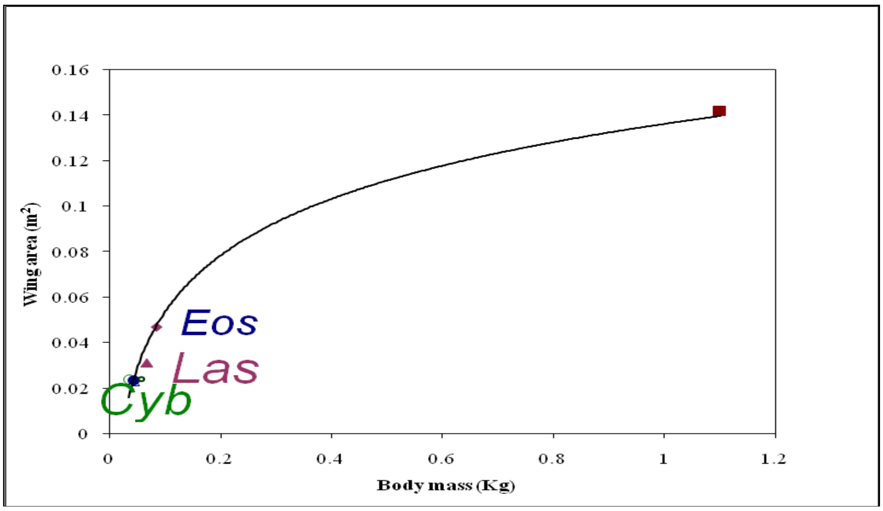

Figure 2: Wing area plotted on power regression lines against body mass in the studied megachiropteran species

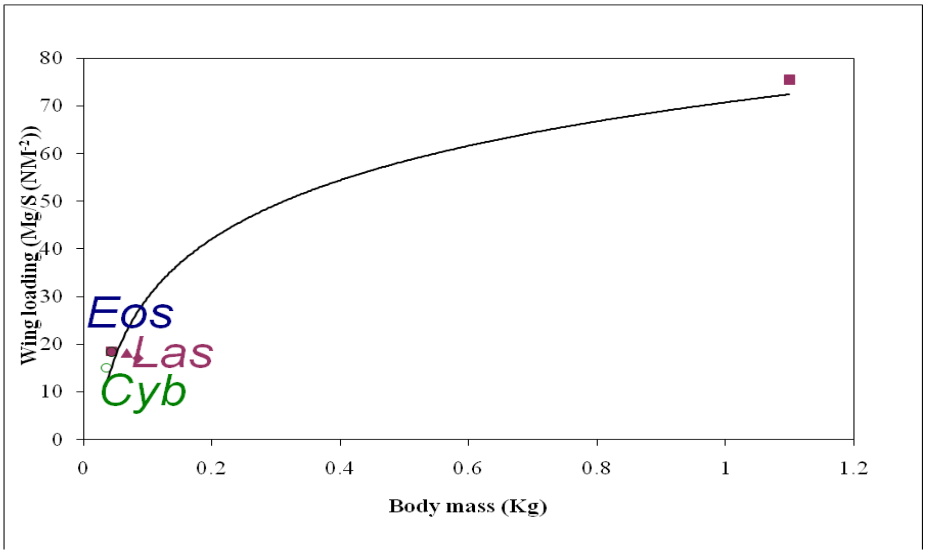

Figure 3: Wing loading plotted on power regression lines against body mass in the studied megachiropteran species

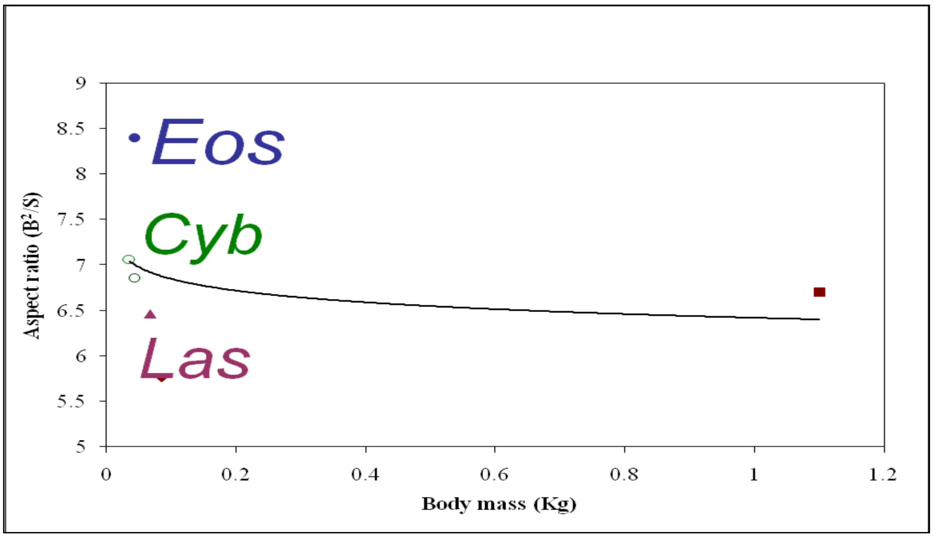

Figure 4: Aspect ratio plotted on power regression lines against body mass in the studied megachiropteran species. body mass

Wing tip shapes
Scatter plots of wing tip length against wing tip area indicates, the bat species, plotted above the solid line (1 = triangular wing tip) have rounded wing I > 1 and plotted below the line have long pointed wing tips I < 1.

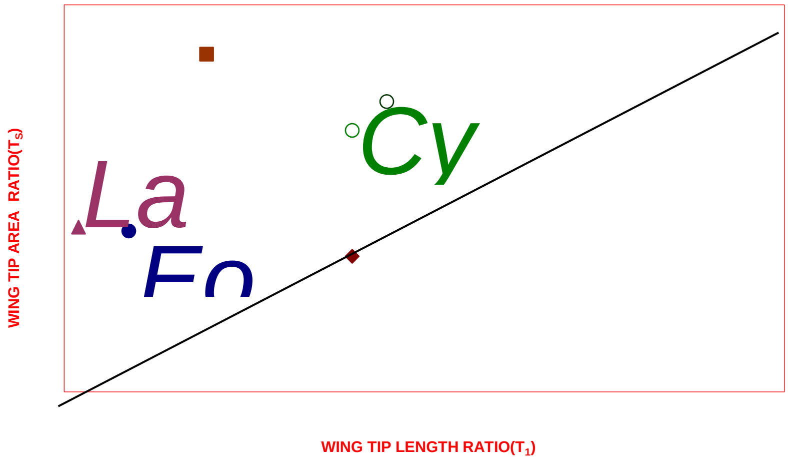

Figure 5: Wing Tip area plotted on power regression lines against Wing Tip length in the studied megachiropteran species.

Manoeuvrability and agility
Manoeuvrability and agility are the two factors that are strongly influenced by flight adaptation. These two factors explain the ability of bats to change the flight direction without loss of speed and with small turning radius. These aerodynamic abilities of the bat species are expressed when wing loading index is plotted against aspect ratio. Since the wing loading varies with mass $M^{1/3}$ wing loading index $M^{2/3}$ / S which is independent of body mass has been calculated. Now both the wing loading and aspect ratio are non-dimensional. Figure 6 explains wing loading index against aspect ratio, the slow fliers are marked on the left side of the diagram and faster fliers on the right. Those with high aspect ratios have lower flight costs than those with lower aspect ratio. The most inexpensive flight is obtained by those, which have a high aspect ratio in combination with a low wing loading. The diagram also shows the bats with most expensive flight towards the bottom left side of the plot and inexpensive flight on the top right side of the plot.

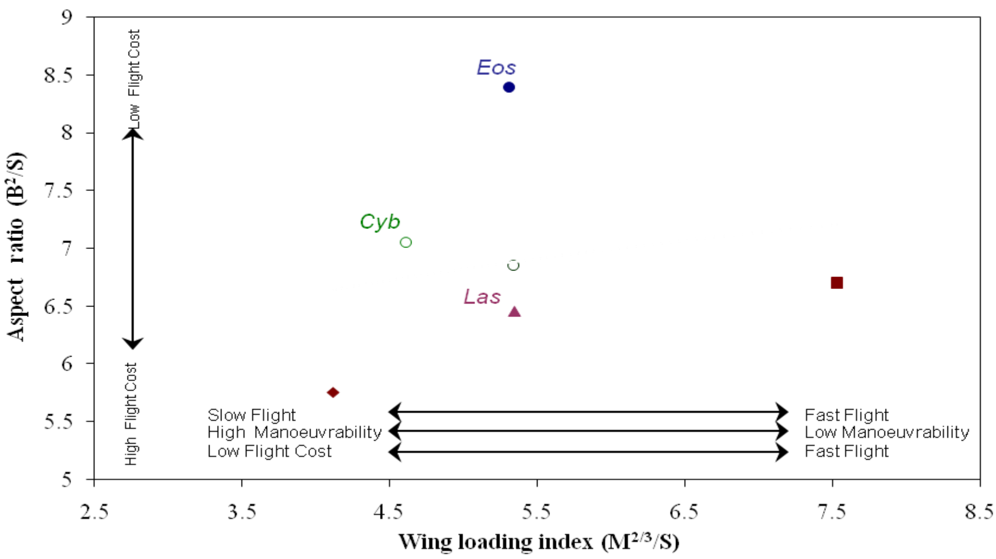

Figure 6: Wing loading index plotted on power regression lines against Aspect ratio in the studied megachiropteran species

The wing morphology of bat is very diverse and may correlate with energetic, behavioral and ecological demands (14). In the present study all the bat species show a marked variation in their wing morphology, which denote their diversity in food selection and preference. It is proved that there is a predictable link between wing morphology (11) and their diet preferences in these flying vertebrates. Analysis of data predicted that the all-bat species forage in different places. They differ in their choice of foraging sites and flight behaviour. These variations are the result of different flight demands and minimization of flight costs. Wingspan and wing area in fruit bats are increased slightly faster with body mass. Megachiroptera may fly long distances nightly between roosting and feeding places (15).

Most pteropodidae use flight to reach food source and do not feed while foraging, they usually fly straight and relatively fast. Their body size and broad wing enable them to carry fruits from the tree to the retiring sheltered place or to the roost. But some species have good maneuverability and slow flight in clutter and hover while taking fruit or nectar. They have reduced tail membranes or lack tails altogether. Absence of uropatagium gives freedom of hind limbs to crawl over vegetation.

All the three fruit bats of the present study have high wing loading which enables them to attain high flight speed with sufficient time during their foraging flight. The large wing area with average wingspan and low aspect ratio give them moderate maneuverability to avoid obstacles and fly fairly fast with in vegetation.

C. brachyotis have higher aspect ratio than *C. sphinx* and slightly rounded wing tips, which are shorter than average, together with the low wing loading. These features are typical of slow, maneuverable flight. Among bat species, wing shape correlates with flight maneuverability and habitat use, with species that possess broader wings typically foraging in more cluttered habitats (16).

L. salimalii has average aspect ratio, high wing loading and high wing tip shape index. This indicates that bats can do less maneuverable and low agility flight in cluttered area but are adapted for long distance flight with heavier load especially larger fruits. *L. salimalii* has narrow and shorter wings, with small wing area, High wing loading similar to Molossid bat species, an indication for the possession of high flight speed. Low aspect ratio indicates they are very agile and the rounded wing tip provides high manoeuvrability. Absence of uropatagium gives freedom of hind limb to crawl over vegetation while selection of fruits and nectar from the wide-open bat preferred flowers *L. salimalii* does not feed while on wings. Consume fruits in secluded night roosts (17). The aerodynamickally adapted wings help maneuverable flight during foraging (11).

E. spelaea has high aspect ratio with high wing loading. High aspect ratio is more efficient for prolonged flight in the open where extreme maneuverability is not important (18) and causes a very low cost of transport. Gould (19) reported that *E. spelaea* hover close to flowers before feeding while clinging to the plant and is also adopted to fly in clutter. A behavior unique to *E. spelaea is* the production of wing-clapping sounds during movement in dark situations. This is thought to be a primitive form of echolocation that aids orientation, or simply a product of slowed flight which may reduce the force with which bats collide with other objects in dark caves. (19, 20,21, 22)

4. Conclusion

The findings presented here show that diet is related to the specific morphological modification in wings. The verification of wing adaptations reflects the relationship between morphology and ecology. The findings made available here indicate that even small variations in wing morphology can significantly affect feeding performance.

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Conflict of Interests:

Authors have declared that no competing interests exist

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