MALAYSIAN JOURNAL OF SCIENCE
MJS
ISSN 1394-3065

Regular Issue

Malaysian Journal of Science 43 (4): 10-19 (December 2024) https://mjs.um.edu.my

Wing Morphology and Echolocation of *Rhinopoma hardwickii* (Lesser Mouse-tailed Bat, Gray, 1831)

Shaktivardhan Singh[1a], Vadamalai Elangovan[2a], Sanjay Kumar Bharti[3a], Pawan Kumar Misra[4a]

Abstract: *Rhinopoma hardwickii* is currently classified as a member of the Yinpterochiroptera suborder, which includes frugivorous and some insectivorous bats. This species is the smallest in the Rhinopomatidae family and easily identified by its long tail. The wing morphology and echolocation calls of this species were studies to see if there were any changes in wing morphology between sexes, echolocation calls across different environments such as natural (roost and field) and controlled (captive), as well as different geographical areas. In this study, a total of 41 individuals (27 male and 14 female) of *R. hardwickii* were captured and their wing morphology was measured. The results show that there were no statistically significant variations in their morphometric characteristics or in wing morphology between the sexes. This species has with high wing loading and a high aspect ratio, as well as pointed wing tips. The echolocation calls consisted up to five harmonics of FM and CF- FM sweeps. Peak frequencies, start frequency, end frequency, and IPI of three separate environment parameters (roost, capitative, and field recording) differed significantly ($p > 0.001$). Moreover, we compared the frequency at maximum energy with four different geographical regions such as Kerala, Gujrat, and Israel to current study, and found that the frequencies of bat calls do not vary with geographical region ($H=0.667$, $df=3$, $p=0.881$). Therefore, the current study provides accurate identification of *R. hardwickii* on the basis of echolocation call in a different environment. The echolocation call and wing morphology data clearly show that this species is a fast flyer with limited manoeuvrability that feeds on forest canopy or over water bodies.

Keywords: *Echolocation, frequency, rhinopoma, morphology, multi-hormonic, wing.*

1. Introduction

Members of Rhinopomatidae family are insectivorous bats native to Old-World tropics that live primarily in deserts and steppes. Rhinopomatidae is a monotypic family with a single known genus, Rhinopoma (Geoffroy, 1818), with five species: Rhinopoma hardwickii (Gray, 1831), R. microphyllum (Brünnich, 1782), R. muscatellum (Thomas, 1903), R. cystops (Thomas, 1903) and R. macinnesi (Hayman, 1937). Rhinopoma hardwickii, commonly known as the Lesser Mouse–Tailed Bat or Long-Tailed Bat, was named after Major General Thomas Hardwicke (1755–1835), an English soldier and naturalist who served many years in India. These bats are smallest in their family and are easily identified by their long tail. They primarily roost in natural caves, monuments, abandoned buildings, dry bushes, rocky places, and barren mountains (Prakash, 1961; Benda et al., 2004). Their colony consists of hundreds to thousands of individuals (Purohit and Senacha, 2004; Benda et al., 2004). They also share colonies with Taphozous spp. (Singh et al., 2021). They are distributed over a wide range of geographic areas from Morocco, Senegal, and Kenya, as well as Arabia and the Middle East, India, Thailand, and the Sudan Archipelago (Van Cakenberghe and De Vree, 1994; Hill, 1977). The Rhinopomatidae family has been classified into a new suborder, Yinpterochiroptera (Springer, 2001) along with Pteropodidae, Rhinolophidae, Hipposideridae, Megadermatidae and Craseonycteridae (Hulva and Horacek, 2002; Teeling et al., 2002; Van Den Bussche and Hoofer, 2004). Simmons and Stein (1980) reported that R. hardwickii as a primitive echolocating bat, however, Habersetzer (1981) research revealed that R. hardwickii possesses a complex echolocating system that produces at least two distinct types of sounds: Frequency Modulated (FM)-sounds are produced when approaching an obstacle and during cluster outfly, while Constant Frequency (CF) sounds are generated in the open by both solitary and group flying bats.

Few studies have been conducted on the echolocation of R. hardwickii (Hackett et al., 2016; Srinivasullu and Srinivasullu, 2017; Shah and Srinivasullu, 2020), but none have taken into account changes in habitats such as the captive, field and roost recording. In addition to echolocation, wing morphology is a key element in determining the behavior of any bat species (Norberg and Rayner, 1987; Pennycuick 1989). Except for Norberg and Rayner (1987), no information on the wing morphology of R. hardwickii is currently available. There is a possibility of species misidentification due to lack of bat call data accessible for comparative purposes, particularly survey calls (Duffy et al., 2000; Gannon et al., 2004). Many factors contribute for the intraspecific call variability, including age (Jones and Kokurewicz, 1994),

Authors information:
[a]Department of Zoology, School of Life Science, Babasaheb Bhimrao Ambedkar University Lucknow-226025, INDIA. E-mail: shaktivardhansingh7@gmail.com[1]; elango17@yahoo.com[2]; sanjaybharti.kumar64@gmail.com[3]; pawanmshr17@gmail.com[4]
*Corresponding Author: pawanmshr17@gmail.com

Received: January 24, 2023
Accepted: July 5, 2023
Published: December 31, 2024

DOI: https//doi.org/10.22452/mjs.vol43no4.2
Malaysian Journal of Science 43(4): 10-19 (December 2024)

individual identity (Masters et al., 1995), foraging mode (Griffin et al., 1960), flight situation (Berger-Tal et al., 2008), acoustic clutter (Broders et al., 2004), ambient noise (Gillam and McCracken, 2007) and presence of conspecifics (Chiu et al., 2009). The problem became much more complicated when regional call comparisons were not performed (Thomas et al., 1987; Barclay et al., 1999; O'Farrell et al., 2000; Reinhold et al., 2001; Law et al., 2002).

Therefore, the following questions were arising: (1) are there any differences in wing morphology between sexes, (2) are there any difference in echolocation calls between natural (field and roost recording) and controlled (captive), and (3) are there any differences in echolocation calls between different geographical areas (frequency at maximum energy; FMaxE). FMaxE, which occurs in the outward pulse of a call, is regarded one of the most consistent and crucial echolocation call parameters (Fullard et al., 1991). The study was conducted to fill the current knowledge gap, considering the three questions listed above.

2. Materials and Methods

Field Survey and Identification of Bats

Field surveys were carried out from April 2019 to February 2020. Bats were captured for individual identification at their roosting sites using nylon mist nets (9.0 m X 2.0 m, with mesh size 38.0 mm, Avinet, Dryden, USA), and hoop net. Maps of roosting sites were prepared using Arc GIS. Morphological measurements of adult bats such as body length, forearm length, hind arm, metacarpals, tail, head length and wingspan etc. were taken using digital venire calipers (Mitutoyo, Japan), and body mass was measured with electronic balances (ACCULAB Sartorius group, EC-211). Bats were recognized using morphological criteria, as described by Bates and Harrison (1997). Bats were captured and handled in accordance with the guidelines of the American Society of Mammologists (Sikes et al., 2011) and relevant ethical permits were secured for data collection vide Letter No. 214/11/DAAS/BBAU/2011 of Babasaheb Bhimrao Ambedkar University and Archaeological Survey of India, Lucknow circle for bat survey (F. No. 10-16/23/2013-M 11535).

Wing Morphology and Call Analysis

The bat was positioned on its ventral side on a large graph paper, with their wings stretched to their leading-edge perpendicular to the body axis. The wing outlines were then traced onto the graph paper and the area of wings was assessed. Arm length, wing length (cm) and hand wing (cm), arm wing area (cm^2) and hand wing area (cm^2), wing span (cm) and wing area (cm^2) were also measured, as reported (Norberg and Rayner 1987). The wing loading (WL), aspect ratio (AR), and tip shape index (TSI) were estimated as per the Norberg and Rayner (1987) and Pennycuick (1989) reports. Relative wing loadings (RWL) were estimated using Norberg et al. (2000).

The echolocation calls of *R. hardwickii* were recorded at four separate places (Fig. 1) in three environments: roost, field and captivity. The conditions for three separate ecosystems were as follows.

a) Roost: bat detector was placed on unattended mode overnight to record calls under the roosts.
b) In the field: manual recoding was performed at the moment of emergence near the roost in open ground.
c) Captive: Individuals of this species were captured using mist and hoop nets, then released in a room (10X10 feet). Once relaxed, the recorder was set to unattended mode for at least 2 hours per recoding.

The calls were recorded using a heterodyne in an unattended mode with time expansion (10X). The fast fourier transform (FFT) size was 512 samples with Hanning window. Each 20 sec recording lasted 2 min and included a maximum of five strings at a five-minute interval. The bat calls were analyzed using Bat sound Pro analysis software (version 2.1), which yielded the following call parameters: peak frequency, start and end frequencies, call duration, inter-pulse interval, band width, maximum and minimum frequency. We also compare the echolocation call of *R. hardwickii* with previous studies (Hackett et al., 2016; Srinivasullu and Srinivasullu, 2017; Shah and Srinivasullu, 2020) and the current study in Uttar Pradesh, which are from different geographical areas (Fig. 2, Table 4).

Statistical Analysis

The data was analyzed using SPSS 21.0 (SPSS Inc, USA). The distribution of data sets was analysed using a descriptive statistic, with normality and homogeneity being considered. $P < 0.05$ was considered for normally distributed data sets. All morphological data were abnormally distributed ($p > 0.05$), so the Kruskal Wallis H-test was applied to see whether there were any statistical variations in wing morphology between sexes.

3. Results

A total of 41 *R. hardwickii* individuals (27 male and 14 female) of were captured from their day roost utilizing hoop and mist nest. Table 1 shows the morphological measurements of *R. hardwickii*. Males had little higher body mass (20.71 ± 2.95 g) then females (19.86 ± 3.38 g) but there was no significant differenc in weight (H = 0.41, p=0.522). Females had somewhat larger forearms (60.73 ± 1.62) than males (58.83 ± 2.26 mm), although the differences was not significant (H=0.126, p=0.723). There were no statistical significance differences in arm wing length, hand wing length, arm wing area, hand wing area, aspect ratio, tip length ratio, wing-loading and relative wing loading between the sexes ($p > 0.05$, Table 2). Therefore, we pooled the wing morphology data of

DOI: https//doi.org/10.22452/mjs.vol43no4.2
Malaysian Journal of Science 43(4): 10-19 (December 2024)

males and females. The average wing loading of *R. hardwickii* was 11.92 ± 1.87 (N/m^2) with an aspect ratio was 7.04 ± 0.44. The relative wing loading for *R. hardwickii* was 8.41 ± 5.57. The tip length ratio and tip area ratios were 0.68 ± 0.04 and 0.44 ± 0.05, respectively. The tip shape index was measured and found 1.57 ± 0.15.

We recorded 5330 *R. hardwickii* calls throughout a 15-hour 50-minutes period at four sites, and 167 of them were selected for analysis. The calls consisted up to five harmonics of FM and CF-FM sweeps, with the fourth harmonic being the most common; the second harmonic was the most strong. The second harmonic's peak frequency is 28.8 – 38.7, the third harmonic is 37.9 – 50.6, and the fourth harmonic 42.7 – 62.7 kHz. The Frequency at maximum energy (FMaxE) ranged from 28.8 to 38.7 (33.23 ± 2.38) kHz. The start frequency ranged from 19.90 to 36.90 kHz (30.78 ± 3.04), and the end frequency ranged from 21.4 to 38.8 kHz (32.15 ± 2.84). The pulse interval was 39.92 ± 46.86 ms. When we analysed start frequency, end frequency and peak frequency along with Inter Pulse Interval (IPI) at three different sites (roost, captive and field recording), we found that there were significant differences between captive, field and roost sites (p = 0.001, Table 3). When we compared the frequency at maximum energy of *R. hardwickii* to four different geographical regions, namely Kerala, Gujrat, and Israel, with the current study, we found that the frequency did not vary by geographical region (H=0.667, df=3, p=0.881) (Table 4).

4. Discussion

The current study reveals that *R. hardwickii* is a fast flyer with poor maneuverability that feeds on forest canopy or over water body, has a larger aspect ratio (AR > 8.0), a short wing span, high wing loading, average relative wing loading, and a small surface area. Bats with high AR and RWL are fast flyer but have poor flight maneuverability (Freeman, 1981), and they feed in open unobstructed environment such as over forest canopy or over water (Marinello and Bernard, 2014). Kingdon (1974), Smith and Starrett (1979) report rhinopomatids foraging in open ground, apart from impediments, at relatively high altitude, but Neuweiler (1984), Habersetzer (1986) describe their fly at intermediate heights in open spaces of forest around the canopy, but below the high and fast flyer Emballonuridae and Molossidae in the same habitat. *Rhinopoma hardwickii* have a series of alternating flutters and glides, with a rising and falling motion (Harrison, 1964).

Previously, only five studies on *R. hardwickii* echolocation calls were conducted, some of which were incomplete (Chaturvedi et al., 2018), and no one considered the wing morphology, despite the fact that wing morphology is directly related to echolocation and feeding behavior in all insectivorous bat species.

Rhinopoma hardwickii produces narrowband, multi harmonic signals with CF/FM, which are dominated by harmonic other than fundamental harmonic, as supported by other authors (Habersetzer, 1981; Jones and Teeling, 2006). The narrow broadband call with low frequency is associated with high wing loading and high aspect ratio reported in fast flying, open area foraging species (Norberg and Rayner, 1987); consequently, the foraging result clearly show that *R. hardwickii* is fast flyer who forages in open space. Many authors also reported that this species generates multi hormonic calls with CF/FM (Srinivasullu and Srinivasullu, 2017; Shah and Srinivasullu, 2020), quasi constant frequency (QCF) calls (Hackett et al., 2016), second harmonics with maximal energy. The call frequency of R. hardwickii differs from previous findings, which ranges from 32–35 kHz (Hackett et al. (2016), 31.3 - 33.6 kHz (Srinivasulu and Srinivasulu 2017), 30.90 - 32.25 kHz (Shah and Srinivasulu 2020) while the current result shows the 28.8 – 38.7 kHz, that's is approx. 2 kHz less than minimum call frequency and 3 kHz higher call frequency in previous reports. Lower frequency calls with narrow band widths are required for long range detection of prey, which is characteristic feature of fast flyer species (Neuweiler, 1984), these assertions supports the current finding.

All of the author mentioned did not investigate the differences in *R. hardwickii* echolocation calls in different environments, such as natural (field and roost), controlled (captive), although the result of this study clearly indicated that the *R. hardwickii* has varied call frequencies at different habitats. Habersetzer (1981) also reported that *R. hardwickii* has complex echolocating system which alters the form of signals in different situation. The result of current study, which is also supported by many authors, found that individuals of bats species changes their calls in response to changing habitats as well as distance from obstacles (Kalko and Schnitzler, 1993; Bartonicka and Rehak, 2005) or proximity to other bats (Obrist, 1995; Ratcliffe et al., 2004; Ulanovsky et al., 2004; Gillam et al., 2007; Bates et al., 2008; Amichai et al., 2015).

This study found that the call frequency and structure of *R. hardwickii* did not vary by geographical regions, however, some authors reported that the populations of same species in different geographical region may have different call structures (Thomas et al., 1987 and Murray et al., 2001).

5. Conclusion

The result of current study found that there were no differences in wing morphology between the sexes. *Rhinopoma hardwickii's* echolocation calls vary according to situation, such as natural (roost and field recording) and controlled (captive), but do not change with geographical regions. The wing morphology data clearly indicates that *R. hardwickii* is fast flyer with limited maneuverability, and this species feeds on forest canopy or over water bodies. The data provided in this study may provide to other researchers in accurately identifying of *R. hardwickii* based on echolocation calls in various habitats, whereas wing morphology indicates foraging nature.

DOI: https//doi.org/10.22452/mjs.vol43no4.2
Malaysian Journal of Science 43(4): 10-19 (December 2024)

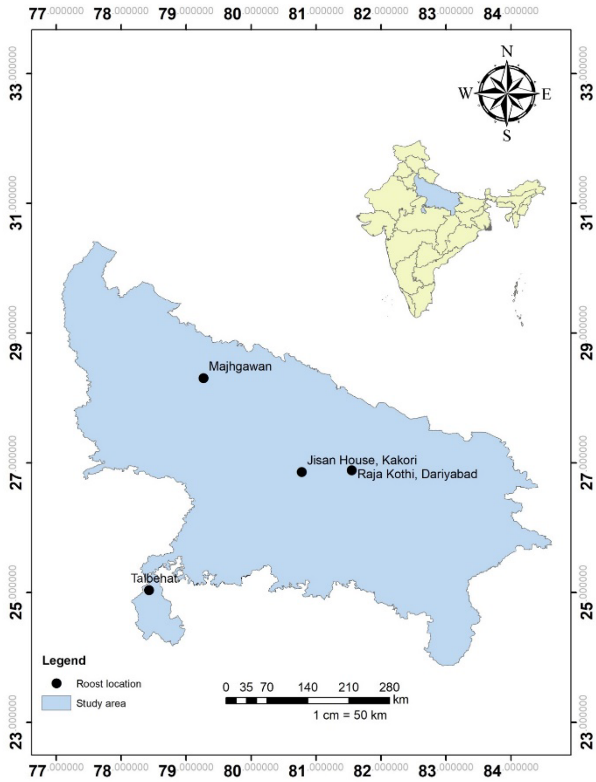

Figure 1. The roosts location of *R. hardwickii* in Uttar Pradesh, India.

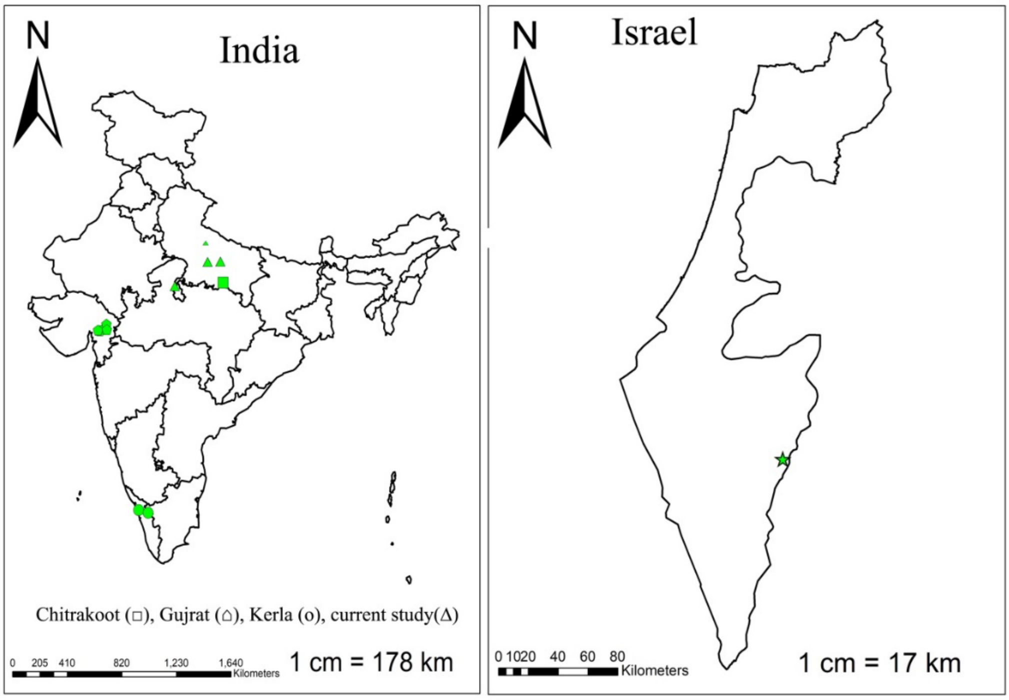

Figure 2. The echolocation calls of *R. hardwickii* recorded from various geographical regions. Right panel map shows location within India (Chitrakoot, Gujrat, Kerala) whereas, left panel indicates location in Israel.

DOI: https//doi.org/10.22452/mjs.vol43no4.2
Malaysian Journal of Science 43(4): 10-19 (December 2024)

Table 1. Morphological measurements of males and females *R. hardwickii* in millimetre (mm), unless otherwise mentioned. Values are given Mean ± SD.

Parameter	Male (n=27)	Female (n=14)	H value	P value
Body mass (g)	20.71 ± 2.95	19.86 ± 3.38	0.41	0.522
BH length	71.46 ± 3.69	71.12 ± 3.39	0.261	0.61
Head length	19.71 ± 4.33	23.05 ± 1.25	2.847	0.092
Tail length	58.37 ± 6.49	60.73 ± 6.34	1.557	0.212
Ear length	14.23 ± 1.44	13.96 ± 1.13	0.001	0.974
Ear width	8.96 ± 1.09	8.09 ± 1.11	3.031	0.082
Targus	5.90 ±0.81	5.82 ± 0.39	0.39	0.532
Forearm length	58.83 ± 2.26	60.01 ± 1.62	0.126	0.723
5th Metacarpal	43.54 ± 1.53	42.60 ± 1.43	2.185	0.139
First phalanx	10.80 ± 0.59	10.85 ± 0.69	0.002	0.964
Second phalanx	9.52 ± 0.86	9.28 ± 0.42	1.155	0.282
4th Metacarpal	38.26 ± 1.67	36.66 ± 1.70	5.013	0.025
First phalanx	12.87 ± 0.67	13.32 ± 0.40	2.187	0.139
Second phalanx	10.55 ± 1.63	10.98 ± 0.13	0.032	0.858
3rd Metacarpal	44.05 ± 2.26	40.82 ± 1.65	5.43	0.2
First phalanx	8.76 ± 0.75	9.03 ± 1.32	0.98	0.754
Second phalanx	17.72 ± 1.06	18.10 ± 0.41	0.393	0.531
2nd Metacarpal	43.47 ± 2.26	42.08 ± 1.10	2.896	0.89
Thumb length	7.00 ± 0.49	6.46 ± 0.59	7.967	0.005
Hind arm	30.19 ± 1.75	29.76 ± 1.11	1.287	0.257
Foot	7.47 ± 3.10	8.30 ± 3.74	0.586	0.444
Body width	28.85 ± 7.93	25.83 ± 10.17	1.001	0.317
Wing span (cm)	20.51 ± 6.18	29.88 ± 0.87	3.509	0.061

Table 2. Wing morphology of male and female *Rhinopoma hardwickii*. Values are given Mean ± SD.

Wing characteristics	Male (n = 27)	Female (n = 14)	H	*P*
Arm Wing Length	10.23 ± 0.34	10.20 ± 0.42	0.077	0.782
Arm Wing Area	58.35 ± 6.63	58.96 ± 3.59	0.049	0.826
Hand Wing Length	6.90 ± 0.33	6.99 ± 0.34	0.292	0.589
Hand Wing Area	25.22 ± 1.84	25.80 ± 2.29	0.291	0.590
Wing Area	1.67 ± 0.14	1.70 ± 0.11	0.206	0.650
Tip Length Ratio	0.68 ± 0.04	0.69 ± 0.04	0.219	0.640
Tip Aspect Ratio	0.44 ± 0.06	0.44 ± 0.03	0.027	0.869
Tip shape index	1.56 ± 0.17	1.57 ± 0.09	0.170	0.680
Wing Loading	12.27 ± 1.83	11.23 ± 1.82	2.676	0.102
Relative Wing loading	8.83 ± 2.54	7.60 ± 2.51	2.287	0.130
Aspect Ratio	7.06 ± 0.47	6.99 ± 0.39	0.076	0.783

H= Kruskal – Wallis H test

DOI: https//doi.org/10.22452/mjs.vol43no4.2
Malaysian Journal of Science 43(4): 10-19 (December 2024)

Table 3. Echolocation calls of *R. hardwickii* in three different habitats. Values were presented in Mean ± SD.

Echolocation	Captive (n =94)	Field (n =35)	Roost (n = 38)	H*	p – value
Start Freq.	31.04 ± 2.19	26.81 ± 1.53	29.39 ± 0.97	80.165	0.001
End Freq.	34.77 ± 1.71	30.83 ± 1.21	36.12 ± 1.34	85.403	0.001
Peak Freq.	32.83 ± 2.13	30.04 ± 0.81	32.76 ± 0.87	101.791	0.001
I.P.I. (ms.)	38.75 ± 7.59	112.09 ± 49.76	24.00 ± 16.56	64.401	0.001
Bandwidth	3.73 ± 1.71	4.02 ± 1.08	6.72 ± 1.18	81.245	0.001

Freq. = Frequency, all frequency in KHz, H = Value of Kruskal Wallis H – test

DOI: https//doi.org/10.22452/mjs.vol43no4.2
Malaysian Journal of Science 43(4): 10-19 (December 2024)

Table 4. Caparison of wing morphology and Echolocation of *Rhinopoma hardwickii* bats with other studies, frequencies were given in kHz, pulse duration and pulse interval were given in millisecond (ms.). Values are given in Mean ± SD

	Parameters/ Studies	Habersetzer, 1981 (n =)	Hackett et al., 2016 (*n =257/3)	Srinivasulu & Srinivasulu, 2017 (*n=1/12)	Chaturvedi et al. 2018 (*NM)	Shah and Srinivasulu, 2020 (*n=58)	Present study (*n = /167)
Echolocation calls	Peak Frequency	30	33.99 ± 1.13	32.48 ± 0.75	32	31.32 ± 0.93	33.23 ± 2.38
	Start frequency	32.50	35.85 ± 1.81	37.05 ± 0.46	-	34.52 ± 2.40	32.15 ± 2.84
	End frequency	35.0	32.72 ± 1.39	26.66 ± 0.94	-	28.32 ± 3.58	30.78 ± 3.04
	Pulse duration		8.57 ± 1.28	2.21 ± 0.44	-	3.86 ± 1.48	
	Pulse interval		-	-	-		39.92 ± 46.86
	Band width						4.47 ± 1.78
Wing morphology (n= 41)	Wing span (cm)	-	-	-	-	-	34.31 ± 0.96
	Wing area (×10^{-3} m^2)	-	-	-	-	-	1.68 ± 0.13
	Aspect ratio	-	-	-	-	-	7.04 ± 0.44
	Wing loading (N/m^2)	-	-	-	-	-	11.92 ± 1.87
	Hand-wing area (×10^{-3} m^2)	-	-	-	-	-	25.42 ± 1.99
	Arm-wing area (×10^{-3} m^2)	-	-	-	-	-	58.56 ± 5.73
	Tip length ratio	-	-	-	-	-	0.68 ± 0.04
	Tip area ratio	-	-	-	-	-	0.44 ± 0.05
	Tip shape index	-	-	-	-	-	1.57 ± 0.15

DOI: https//doi.org/10.22452/mjs.vol43no4.2
Malaysian Journal of Science 43(4): 10-19 (December 2024)

6. Acknowledgements

We are greatly thankful to the Archeological survey of India (ASI) for the permitting us in the monuments to collects the samples, vide letter no. 16/23/2019/-Monuments 9970. This work was supported by Science Engineering Research Board, New Delhi [EEQ/ 2018/000104]. We thank the Dr. Rahul Shukla for proofreading the manuscript.

7. References

Amichai E., Blumrosen G and Yovel Y. (2015) Calling louder and longer: how bats use biosonar under severe acoustic interference from other bats. *Proceedings of the Royal Society B* 282: 1-10. https://doi.org/10.1098/rspb.2015.2064

Barclay R M R., Fullard J H and Jacobs D S. (1999) Variation in the echolocation calls of the hoary bat (*Lasiurus cinereus*): influence of body size, habitat structure, and geo graphic location. *Canadian Journal of Zoology* 77: 530–534. DOI: 10.1139/cjz-77-4-530

Bartonicka T and Rehak Z. (2005) Variability in echolocation calls of *Pipistrellus pygmaeus* (Chiroptera: Vespertilionidae) during search flight in different habitats, *Acta Theriologica* 50 (2): 145–160. DOI: 10.1007/BF03194478

Bates P J J and Harrison D L. (1997) Bats of the Indian subcontinent. *Harrison zoological museum, Publications, Sevenoaks* 258pp. https://doi.org/10.2307/1383036

Bates P., Bumrungsri S., Francis C., Csorba G., Walston J., Molur S and Srinivasulu C. (2008) Arielulus circumdatus. The IUCN Red List of Threatened Species e.T41534A10493431. https://dx.doi.org/ 10.2305/IUCN.UK.2008.RLTS.T41534A10493431.en.

Benda P., Andreas V H., Reiter M A and Uhrin M. (2004) Two new species of bats (Chiroptera) for the fauna of Libya: *Rhinopoma hardwickii* and *Pipistrellus rueppellii*, *MYOTIS* 41-42: 109-124.

Berger-tal O., Berger-tal R., Korine C., Holderied M W and Fenton M B. (2008) Echolocation calls produced by *Kuhl's pipistrelles* in different flight situations, *Journal of Zoology* 274: 59–64. DOI: 10.1111/j.1469-7998.2007.00357.x

Broders H G., Findlay C S and Zheng L. (2004) Effects of clutter on echolocation call structure of *Myotis septentrionalis* and *M. lucifugus*, *Journal of Mammalogy* 85: 273–281. https://doi.org/10.1644/BWG-102

Brunnich M T. (1782) Dyrenes Histoireog Dyre-Samlingenudi Universitets Natur-Theater. Nicolaus Moller, *Copenhagen* 4: 1-76.

Chiu C., Xian W and Moss C F. (2009) Adaptive echolocation behavior in bats for the analysis of auditory scenes, *Journal of Experimental Biology* 212: 1392–1404. DOI: 10.1242/jeb.027045

Duffy A M., Lumsden L F., Caddle C R., Chick R R and Newell G R. (2000) The efficacy of Anabat ultrasonic detectors and harp traps for surveying microchiropterans in south-eastern Australia, Acta Chiropterologica 2(2): 127–144.

Freeman P W. (1981) A multivariate study of the family (Molossidae Mammalia, Chiroptera): Morphology, ecology, evolution. Fieldiana Zoology, New Series 7: 1–173. https://doi.org/10.5962/bhl.title.3128

Fullard J., Koehler C., Surlykke A. and Mckenzie N. (1991) Echolocation ecology and flight morphology of insectivorous bats (Chiroptera) in south-Western Australia. Australian Journal of Zoology, 39(4): 427 – 438. https://doi.org/10.1071/zo9910427

Gannon W L., O'Farrell M J., Corben C. and Bedrick E J. (2004) Call character lexicon and analysis of field recordings of bat echolocation calls. Pp. 478–484, in Echo - location in bats and dolphins (eds. J.A. Thomas, C.F. Moss, and M. Vater). The University of Chicago Press, Chicago, IL, USA 604 pp.

Geoffroy Saint-Hilaire E. (1818) Description de l'Egypt. Historire naturelle. Description des mammiferes qui se trouvent en, *Egypte* 2: 99- 135.

Gillam E H and Mccracken G F. (2007) Variability in the echolocation of *Tadarida brasiliensis*: effects of geography and local acoustic environment, *Animal Behaviour* 74: 277–286. DOI:10.1016/j.anbehav.2006.12.006

Gray J E. (1831) Description of some new genera and species of bats, *The Zoological Miscellany* 1: 37-38.

Griffin D R., Webster F A and Michael C R. (1960) The echolocation of flying insects by bats, *Animal Behaviour* 8 (3-4): 141–154. https://doi.org/10.1016/0003-3472(60)90022-1

Habersetzer J. (1981) Adaptive echolocation sounds in the bat *Rhinopoma hardwickei*, *Journal of Comparative Physiology* 144: 559–566. https://doi.org/10.1007/BF01326841

Habersetzer J. (1986) Vergleichende fl?gelmorphologische Untersuchungen an einer Fledermausgesellschaft in Madurai. In *Biona Reporte, Bat flight* – Fledermausflug, ed. W. Nachtigall, 75-106. Stuttgart: Gustav Fischer.

Hackett T D., Holderied M W and Korine C. (2016) Echolocation call description of 15 species of Middle-Eastern desert dwelling insectivorous bats, *Bioacoustics* 26: 217–235. https://doi.org/10.1080/09524622.2016.1247386

Harrison D L. (1964) The mammals of Arabia. Ernest Benn Ltd., London 1:1-192

Hill J E. (1977) A review of the Rhinopomatidae (Mammalia: Chiroptera), *Bulletin of the British Museum (Natural History) Zoology* 32 (2): 29-43.

Hulva P. and Horacek I. (2002) *Craseonycteris thonglongyai* (Chiroptera: Craseonycteridae) is a rhinolophoid: Molecular evidence from cytochrome b. *Acta Chiropterologica* 4(2):107-120. doi: 10.3161/001.004.0201

Jones G and Kokurewicz T. (1994) Sex and age variation in echolocation calls and flight morphology of Daubenton's bats *Myotis daubentonii*, *Mammalia* 58: 41–50. https://doi.org/10.1515/mamm.1994.58.1.41.

Jones G and Teeling E C. (2006) The evolution of echolocation in bats, *Trends in Ecology and Evolution* 21(3): 149–156. doi:10.1016/j.tree.2006.01.001

Kalko E K V and Schnitzler H U. (1993) Plasticity in echolocation signals of European pipistrelle bats in search flight: implications for habitat use and prey detection. *Behavioral Ecology and Sociobiology* 33: 415–428. https://doi.org/10.1007/BF00170257

Kingdon J. (1974) East African Mammals: An Atlas of Evolution in Africa vol. II, part A (Insectivores and Bats). *University of Chicago Press*.

Law B S., Reinhold L and Pennay M. (2002) Geographic variation in the echolocation calls of Vespadelus spp. (Vespertilionidae) from New South Wales and Queensland, Australia. *Acta Chiropterologica* 4: 201–215. https://doi.org/10.3161/001.004.0208

Marinello M M and Bernard E. (2014) Wing morphology of Neotropical bats: a quantitative and qualitative analysis with implications for habitat use, *Canadian Journal of Zoology* 92 (2): 141–147. https://doi.org10.1139/cjz-2013-0127

Masters W M., Raver K A S and Kazial K A. (1995) Sonar signals of big brown bats, Eptesicus fuscus, contain information about individual identity, age and family affiliation, *Animal Behaviour* 50 (5): 1243–1260. https://doi.org/10.1016/0003-3472(95)80041-7

Murray K L., Britzke E R and Robinsons L W. (2001) Variation in search phase call of bats, *Journal of Mammolgy* 82(3): 728 – 737. https://doi.org/10.1644/1545-1542

Neuweiler G. (1984) Foraging, echolocation and audition in bats, *Naturwissenschaften* 71: 446-455. https://doi.org/10.1007/BF00455897

Norberg U M and Rayner J M V. (1987) Ecological morphology and Flight in bats (Mammalia; Chiroptera): wing adaptations, Flight performance, foraging strategy and echolocation, *Philosophical Transactions of the Royal Society B: Biological Sciences* 316 (1179): 335-427. DOI: 10.1098/rstb.1987.0030

Norberg U M L., Brooke A P And Trewhella W J. (2000) Soaring and non-soaring bats of the family Pteropodidae (flying foxes, Pteropus spp.): wing morphology and flight performance, *The Journal of Experimental Biology* 203 (3): 651–664. https://doi.org/10.1242/jeb.203.3.651

O'farrell M J., Corben C and Gannon W L. (2000) Geographic variation in the echolocation calls of the hoary bat (*Lasiurus cinereus*), *Acta Chiropterologica* 2 (2): 185–195.

Obrist M K. (1995) Flexible bat echolocation: the influence of individual, habitat and conspecifics on sonar signal design, *Behavioral Ecology and Sociobiology* 36 (3): 207–219. DOI: 10.1007/BF00177798

Pennycuick C J. (1989) Bird Flight Performance: a Practical Calculation Manual. Oxford: *Oxford University Press* 153pp.

Prakash I. (1961) Die Saugetiere der Rajasthan—Wustein Indien. *Nature* 91:443-448.

Purohit A K and Senacha K R. (2004) Distribution of bats in and around Jaisalmer of the Great Indian Desert, India, *Vespertilio* 8: 99-104.

Ratcliffe J M., Hofstede H M T., Avila-Flores R., Fenton M B., McCracken G F., Biscardi S., Blasko J., Gillam E., Orprecio J and Spanjer G. (2004) Conspecifics influence call design in the Brazilian free-tailed bat, *Tadarida brasiliensis*, *Canadian Journal of Zoology* 82(6):966–971. https://doi.org/10.1139/cjz-2017-0284

Reinhold L., Herr A., Lumsden L., Reardon T., Corben C., Law B., Prevett P., Ford G., Conole L., Kutt A., Milne D and Hoye G. (2001) Geographic variation in the echolocation calls of Gould's wattled bat *Chalinolobus gouldii*, *Australian Zoologist* 31 (4): 618–624. https://doi.org/10.7882/AZ.2001.008

Shah T A and Srinivasulu C. (2020) Echolocation calls of some bats of Gujarat, India, *Mammalia* 84 (5): 1-10. https://doi.org/10.1515/mammalia-2019-0015

Sikes R S., William L G and the Animal Care and Use Committee of the American Society of Mammalogists. (2011) Guidelines of the American Society of Mammalogists for the use of wild mammals in research, *Journal of Mammalogy* 92(1): 235-253. DOI: 10.1644/10-MAMM-F-355.1

DOI: https//doi.org/10.22452/mjs.vol43no4.2
Malaysian Journal of Science 43(4): 10-19 (December 2024)

Simmons J A and Stein R A. (1980) Acoustic imaging in bat sonar: echolocation signals and the evolution of echolocation, *Journal of Comparative Physiology* 135:61-84. https://doi.org/10.1007/BF00660182

Singh S., Misra P K and Elangovan V. (2021) Distribution of Sheath-Tailed bats (Emballonuridae) in Bundelkhand region of Uttar Pradesh, *Journal of Advanced Zoology* 42 (2): 176–185. https://doi.org/10.17762/jaz.v42i02.52

Smith J D and Starrett A. (1979) Morphometric analysis of chiropteran wings. In *Biology of bats of the New World family Phyllostomidae*, ed. R. J. Baker, J. K. Jones, Jr., and D. C. Carter. 427-437. Special Publication Museum Texas Tech University.

Springer M S., Teeling E C., Madsen O., Stanhope M J., and de Jong, W W. (2001) Integrated fossil and molecular data reconstruct bat echolocation. *Proceedings of National Academy of Science U. S. A.* 98: 6241–6246. doi:10.1073/pnas.111551998

Srinivasulu B and Srinivasulu C. (2017) A first record of three hitherto unreported species of bats from Kerala, India with a note on *Myotis peytoni* (Mammalia: Chiroptera: Vespertilionidae), *Journal off Threattened Taxa* 9 (5): 10216–10222. DOI: 10.11609/jott.3324.9.5.10216-10222

Teeling E C., Madsen O., Van Den Bussche R A., de Jong W W., Stanhope M J. and Springer, M S. (2002) Microbat paraphyly and the convergent evolution of a key innovation in Old World rhinolophid microbats. *Proceedings of National Academy of Science U. S. A.* 99**:** 1431 – 1436. doi.org/10.1073/pnas.02247719

Thomas D W., Bell G P and Fenton M B. (1987) Variation in echolocation call frequencies recorded from North American vespertilionid bats: a cautionary note, *Journal of Mammalogy* 68 (4): 842–847. https://doi.org/10.2307/1381562

Thomas O. (1903) On the species of the genus Rhinopoma, *Annals and Magazine of Natural History* 11(7): 496-499.

Ulanovsky N., Fenton M B., Tsoar A and Korine C. (2004) Dynamics of jamming avoidance in echolocating bats, *Proceedings of the Royal Society B: Biological Sciences* 271 (1547): 1467–1475. doi:10.1098/rspb. 2004.2750

Van Cakenberghe V., De Vree F. (1994) A revision of the Rhinopomatidae Dobson 1872 with the description of a new subspecies (Mammalia: Chiroptera), *Senckenbergiana Biologica* 73 (1-2):1-24.

Van Den Bussche R A. and Hoofer S R. (2004) Phylogenetic relationships among recent chiropteran families and the importance of choosing appropriate out-group taxa. *J. Mammal.* 85**:** 321 – 330. doi.org/10.1644/1545-1542(2004)085<0321:PRARCF>2.0. CO;2

DOI: https//doi.org/10.22452/mjs.vol43no4.2
Malaysian Journal of Science 43(4): 10-19 (December 2024)