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ORIGINAL ARTICLE

Effects of the temperature on activity patterns and torpor in *Saccolaimus saccolaimus* in Bangladesh with notes on its morphometrics and roosting behaviour

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ABSTRACT

Saccolaimus saccolaimus is one of the six Emballonurid bats and the only species from the genus *Saccolaimus* that occurs in South and Southeast Asia. This species utilizes tree hollows, damaged palm trees, and occasionally artificial structures as roosts. We recorded a total of 22 bats from 10 colonies located at two dormitories in Jahangirnagar University (JU) in a sub-urban setting in central Bangladesh. The number of bats per colony varied between 1-9 individuals, with an average of four bats per colony. We found that the colonies of *S. saccolaimus* emerged from roosting sites when the temperature was 22.5°C or higher. The highest bat activity was recorded in September (79.66 mins) when the air temperature was 27.66°C, and the lowest was in January (47.01 mins) when the air temperature was 17.46°C. We observed variations in bat activity in different months, and bat activity was strongly correlated (R-square = 0.52) with air temperature. The most extended torpor period for the colonies was recorded for 27 days. The mean weight for male *S. saccolaimus* in JU was 41.66 ± 0.29 (41.46-42) g, whereas for females was 45.32 ± 3.08 (43.14-47.5) g. Although some variation was observed in the morphological measurements, the morphometric analysis indicated no significant differences between specimens from Bangladesh and the neighbouring countries. Further research is needed to understand various ecological aspects of S. saccolaimus in Bangladesh. Therefore, to do so, the existing colonies on JU campus should be extensively monitored.

INTRODUCTION

Activity patterns play a critical role in resource acquisition, energy consumption, competition, predation, and exposure to environmental conditions (Bender & Hartman 2015). Low temperature (Anthony et al. 1981) and precipitation generally suppress bat activity (Kunz 1973, Fenton et al. 1977), possibly because these conditions may increase thermoregulatory costs or influence the amount of prey available to bats (Burles et al. 2009). Understanding how weather factors influence bat activity can provide insights into the limitations on their distributions, ecological and behavioral patterns in different species (Erickson & West 2002). For example, unfavourable conditions such as rain and low temperatures impose additional energetic costs on insectivorous bats by increasing thermoregulatory stress and decreasing the activity of insect prey (Racey & Speakman 1987). However, information on the relationships between environmental variables and the activity patterns of bats is poorly understood.

On the other hand, torpor is a temporary state of heterothermy defined by a reduction in metabolic rate and other physiological processes (e.g. heart rate, breathing rate, body temperature) (Geiser & Ruf 1995, Geiser 2004). Although torpor results in a pronounced reduction in daily energy expenditure (Geiser & Masters 1994, Geiser 2004), there are other advantages to torpor that are often overlooked, such as accumulation of fat, reduction of water requirements, and sperm storage (Geiser & Brigham 2012). Supporting a high metabolic rate, common in endothermic mammals like bats, requires high energy intake, which can be sustained through foraging. However, when food abundance decline, the cost of maintaining an elevated metabolic rate may become prohibitively expensive (Dzal & Brigham 2013).

Emballonuridae is a family of bats that are distributed in the tropical and subtropical regions in the Old World, and central and south America in the New World (Nowak & Paradiso 1983, Mickleburgh et al. 2002). These bats are characterized by the distinctive short tail that is loosely confined within the interfemoral membrane, while its tip remains free on the mid-point of the dorsal surface of the

membrane (Bates & Harrison 1997). Out of the 51 species of Emballonurids worldwide, six of them can be found in south to southeastern Asia and north to northern Australia, including Solomon Islands (Francis 2008, Srinivasulu & Srinivasulu 2012, Lumsden 2017).

The Bare-rumped Sheathtail Bat (*Saccolaimus saccolaimus*) is the only Emballonurid in genus *Saccolaimus*. This species is categorized as 'Least Concern' (Lumsden 2017) both globally and in India (Molur et al. 2002). However, it is categorized as 'Critically Endangered' in Australia (Duncan et al. 1999) and Sri Lanka (IUCN & MENR 2007), and 'Data Deficient' in Bangladesh (IUCN Bangladesh 2015). Furthermore, there is a paucity of ecological information available on *S. saccolaimus*, particularly in South Asia. Natural history information for this species, like activity patterns, torpor behaviour, foraging, roosting and feeding habits, and parturition, is generally unknown (Mahoney & Walton 1988, Schulz & Thomson 2007).

In this paper, we assessed the effects of temperature on activity patterns and torpor behaviour in *S. saccolaimus* at the Jahangirnagar University in central Bangladesh. We predicted that temperature changes influenced the activity patterns of *S. saccolaimus* and eventually made them employ torpor. We also discussed some other ecological aspects of *S. saccolaimus* with highlights on its morphometrics and roosting behaviour. We conducted a morphometric analysis to identify if there were any morphological differences between populations of *S. saccolaimus* from Bangladesh and the neighbouring countries.

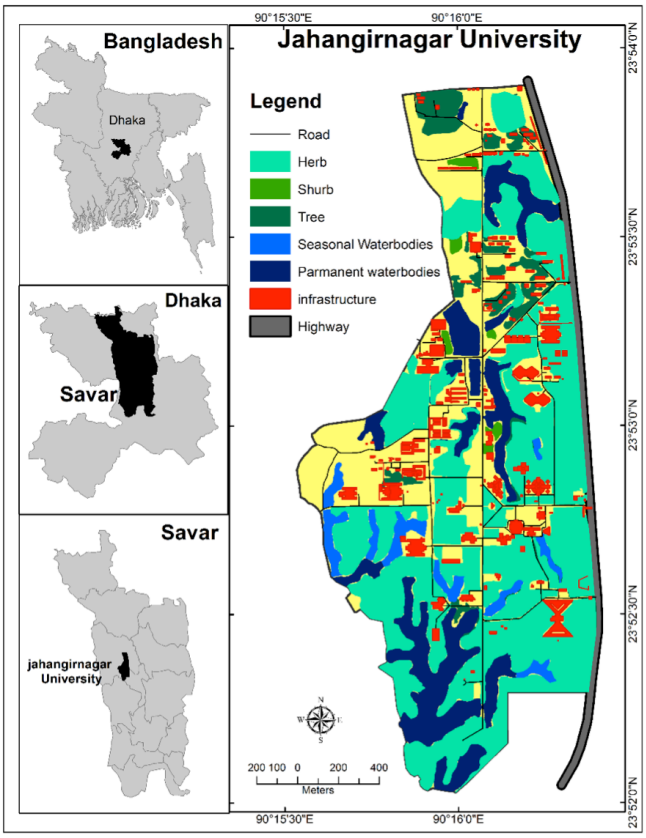

Fig. 1 - Map of Bangladesh showing the capital city, Dhaka and the study area, Jahangirnagar University.

MATERIALS AND METHODS

Study Area

The study was conducted at the Jahangirnagar University (JU) campus (23°52'53.11''N; 90°16'03.34''E) in central Bangladesh (Fig. 1) between September 2016 and April 2018. Due to unforeseen logistical concerns, we could not conduct fieldwork between May and July. Located about 30 kilometres northwest of the capital city, Dhaka, JU covers 700 acres (3 km^2). The campus was once connected with the deciduous forest of central Bangladesh, and it now hosts a highly diverse flora and fauna (Feeroz et al. 1988, Begum 2016). Established in 1970 as a residential university, JU houses represent a number of old infrastructures on the campus that provide suitable roosting sites for many chiropteran species.

We located and monitored ten roosting colonies in two student dormitories (male only) on JU campus. Five roost sites were found in Kamal Uddin Hall (KUH: K1, K2, K3, K4, and K5) and five other sites in Salam Barkat Hall (SBH: S1, S2, S3, S4, and S5). The dormitories are four-storey buildings constructed in the 1980s, and each building accommodates over 800 students. Each dormitory has eight concrete clefts (vertical structures of 6.25m x 1m) by the staircases with an opening of 75 mm between each structure (Fig. 2). These concrete clefts provide ideal roosting sites for *Saccolaimus saccolaimus*.

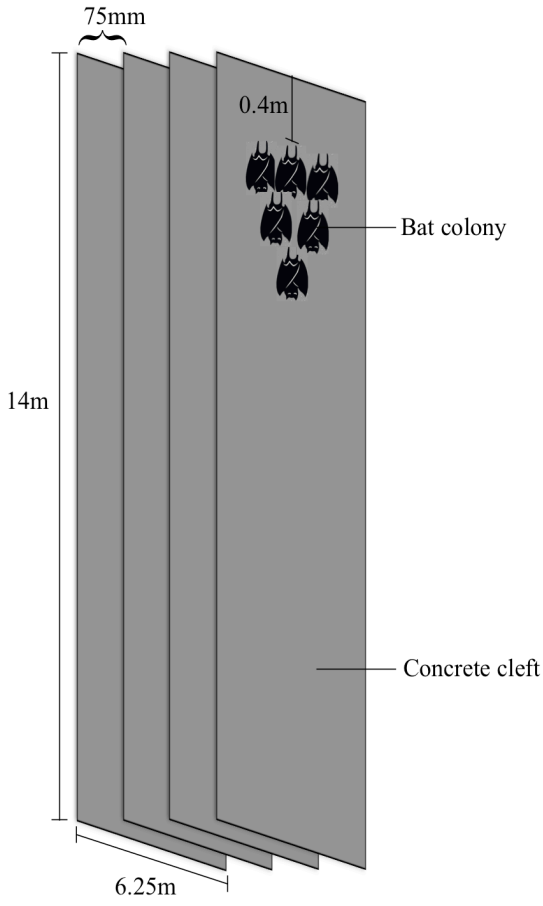

Fig. 2 - Diagram of the roosting colony of *Saccolaimus saccolaimus* in the concrete clefts at the JU campus.

Study Species

The Bare-rumped Sheathtail Bat, *Saccolaimus saccolaimus* Temminck, 1838 is one of the six species of Emballonuridae bats, and can be easily recognized based on its blackish and moulted appearance with variably irregular white patches on the dorsal surface on the body (Nowak & Paradiso 1983). A distinct granular pouch is present under the chin, most prominent in males and rudimentary in females (Bates & Harrison 1997). It has a robust ear, a radio-metacarpal pouch absent, a wing membrane attached to the ankle, inter-femoral membranes, and legs and feet without hair (Bates & Harrison 1997). This species is nocturnal, insectivorous and forages in the canopy. It inhabits forests and woodlands, and its roosts include hollows of old and decaying trees, shallow caves and buildings.

Saccolaimus saccolaimus is reported to be present in Bangladesh along with two other Emballonurrid species: *Taphozous longimanus* Hardwicke, 1825 and *Taphozous melanopogon* Temminck, 1841 (Bates & Harrison 1997, Srinivasulu & Srinivasulu 2005). Even though there was anecdotal information on the distribution of this species in Bangladesh (Khan 2001, 2008), the first confirmed record was reported by Saha et al. (2014) from the Dhaka division and later by Al-Razi et al. (2015) from Tangail District, which is about 100 km north from the location of the first confirmed record. We used Bare-rumped Sheathtail Bat as the Common English name of *Saccolaimus saccolaimus* following Lumsden (2017). Other common names used in different literature refer to the same species are: Pouch-bearing Sheath-tailed Bat (Nanayakkara et al. 2012), Pouch tomb Bat (Saha et al. 2014), Naked-rumped Pouched Bat (Edirisinghe et al. 2013), Pouch-bearing Bat, and Pouched Bat (Lumsden 2017).

Data Collection

We collected field data by visiting pre-identified roosting sites of *S. saccolaimus* twice a week at dusk between September 2016 and April 2018. During winter, between November and February, bats were monitored daily. Other old buildings on the JU campus were thoroughly surveyed to record any additional bat colonies. We used standardized roost counts to estimate the number of individuals in each colony (Kunz et al. 1996, Hoying & Kunz 1998). Total numbers were then confirmed by direct observation using red light and photographic capture (Kunz & Lumsden 2003). We employed a non-invasive approach to record the air temperature of the roost to minimize disturbance, using a Testo 0610 pocket air moisture and temperature meter (Testo North America, West Chester, USA) with an accuracy of +/- 0.9 degrees.

Activity patterns and torpor behavior of *S. saccolaimus* were recorded following Wilkinson (1985). Our initial observations found that none of the colonies left the roost and were active in the early morning and midday. Hence routine observation started in the afternoon. Two of the 10 permanent bat colonies were continuously monitored for 5 hours, starting from an hour before sunset. During the observation periods, all activities were recorded, including all the emergences and returns of the colony. The duration spent outside the roost was estimated based on the time when an individual bat emerged from the roosting site until the last individual returned.

For morphometric studies, we used two mist nets to capture a total of eight adults Bare-rumped Sheathail bats (three males and five females), following Kunz & Kurta (1988). Morphometric measurements were taken using digital slide callipers with an accuracy of 0.01mm. Body mass (g) was measured using digital laboratory balance (0.01 g - 5000 g). All captured bats were released at the same location immediately after measurement, following the ASM guidelines (Sikes & Gannon 2011). An adult female was transported to the JU wildlife biology lab and euthanized for further study. The specimen was later catalogued in the collection of the JU Wildlife Biology Laboratory Museum (Fig. 3).

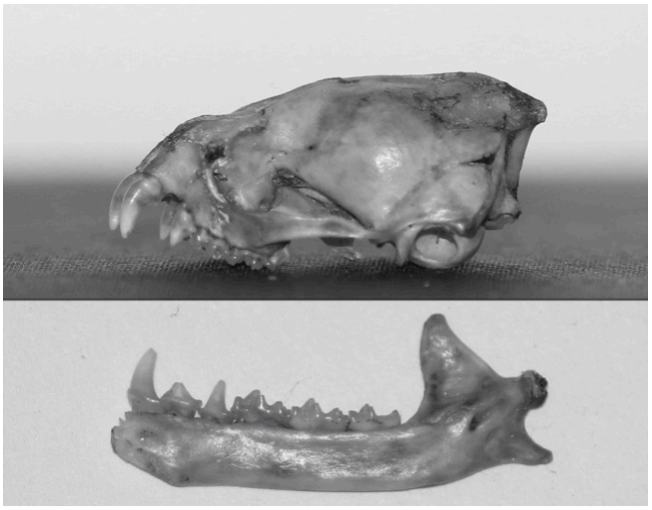

Fig. 3 - Lateral skull view and mandible of an adult female *Saccolaimus saccolaimus* form JU, Bangladesh.

For all the morphometric measurements, we used the following attributes – HB: head and body length; FA: forearm length; TIB: tibia length; HF: hind feet; EL: ear length; TR: tragus; TL: tail length; GTL: greatest length of the skull; CCL: condylo-canine length; ZB: zygomatic breadth; BB: breadth of the braincase; ML: mandible length; 3MT: third metacarpal; 1PH3MT: first phalanx of third metacarpal; 2PH3MT: second phalanx of the third metacarpal; C^1-C^1: anterior palatal width; M^3-M^3: posterior palatal width; C-M^3: maxillary tooth row (upper); and C-M_3: mandibular tooth row (lower). Illustrations of these measurements are provided by Bates & Harrison (1997).

The work was conducted under the permit FD-22.01.0000.101.23.2018.3201, issued by Bangladesh Forest Department. Proper protocol was followed (Barlow 1999) to euthanize the bat.

Data analysis

In order to determine the relationship between air temperature and bat activity, we conducted a regression analysis using a linear regression model. Morphometric data from this study was compared with measurements of

S. saccolaimus obtained from various studies from South Asia, Vietnam, and Cambodia. Detailed morphological measurements (11 factors) were only available for Bangladesh, Cambodia, and South Asia (Table 1). We used basic statistics to compare values between countries (mean and range values).

RESULTS

Roost population

The total population estimate of *S. saccolaimus* at any given month varied between 15 and 22 individuals in the ten roosting colonies. The highest number of individuals per colony was recorded in May (19-22 individuals), followed by April (17-21 individuals) and March (15-21 individuals). Meanwhile, the lowest number of individuals per colony was recorded in July (17-18 individuals). Most colonies were found roosting close to the outer edge of the concrete clefts. Only 10-20% of the roosts were occupied in the middle of the clefts, where members of the colony were observed roosting in a cluster of four to seven bats on top of each other (Fig. 4). Meanwhile, the individuals that were closer to the outer edge of the clefts were roosting in solitary (one to three bats roosting far apart). The colonies in all ten roosting sites were found to be perpendicular to the concrete wall, roughly 0.4 m down from the roof.

We found four permanent roosts (K1, K2, S1, and S5) and six temporary roosts (K3, K4, K5, S2, S3, and S4) (Table 1). Moreover, two temporary roosts (K4 and S3) were occupied only by male individuals, whereas only one temporary site (K5) was identified as a maternity roost. Only two maternity roosts (K2 and S1) were permanently occupied by bats throughout the entire study period. Two clefts (K1 and K4) were shared by *S. saccolaimus* and *Scotophillus kuhlii*. However, these two species occupied different parts of the clefts, roosting 4.5m apart.

Torpor behaviour

Saccolaimus saccolaimus was observed to enter torpor during the cooler months (ca. 15°C), particularly from late December to late January. During our study period, the most extended torpor period was recorded for 27 days (30 December to 25 January) when members of the colonies remained totally inactive. The shortest torpor duration where members of the colonies spent inactive for two days (19 to 20 December) when the air temperature oscillated between 14.4°C and 18.8°C. The colony members formed a cluster in the middle of the cleft during the cooler months to regulate body temperature and remained stationary and inactive (Fig. 4). The colony members became gradually active as the temperature got warmer in late February.

Table 1 - Details on the roosting sites and colony sizes of *Saccolaimus saccolaimus* in Jahangirnagar University campus in Bangladesh.

Roost N°	N (Min-Max) (Mean Value)	Cleft diameter (mm)	Remarks on the roost	GPS Location
K1	2-7 (5)	35	Permanent, mixed	23°52.881' N 90°15.857' E
K2	3-9 (6)	32	Permanent, maternity	23°52.889' N 90°15.886' E
K3	3-4 (4)	43	Temporary	23°52.886' N 90°15.872' E
K4	1 (1)	34	Temporary, solitary, mixed	23°52.881' N 90°15.857' E
K5	5	50	Temporary, maternity	23°52.885' N 90°15.894' E
S1	1-4 (2)	35	Permanent, maternity	23°52.922' N 90°15.856' E
S2	4	44	Temporary	23°52.952' N 90°15.858' E
S3	1	35	Temporary, Solitary	23°52.961' N 90°15.881' E
S4	1-6 (3)	37	Temporary	23°52.922' N 90°15.856' E
S5	1-6 (3)	45	Permanent	23°52.928' N 90°15.883' E

[**Note**: A total of 13 observations were made during the study, and the following are the definition of the terminologies used. *Permanent*: when we found colony members eight or more times out of our 13 observations; *Temporary*: between one and six times out of 13 observations; *Mixed*: when we found more than one species in the same colony; *Maternity*: when we recorded newborn pups attached with the females. This type of colony can be permanent or temporary]

Fig. 4 - *Saccolaimus saccolaimus* roosting colony showing no activity for 27 days between December and January, which was referred to as a torpor condition.

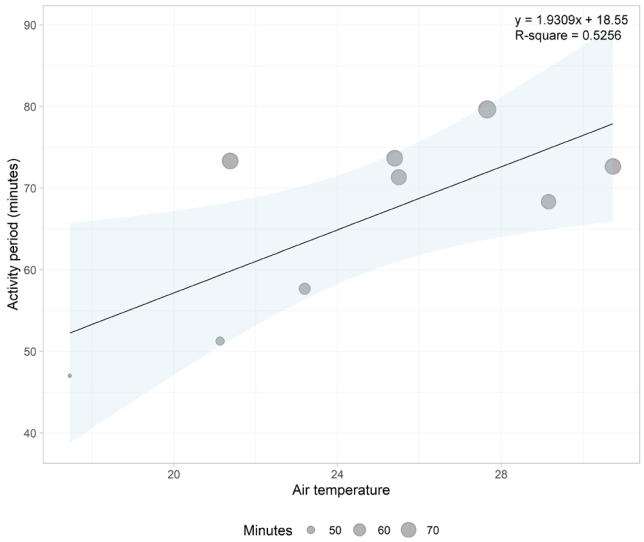

Fig. 5 - Correlation between the activity period and the air temperature of *Saccolaimus saccolaimus* at the Jahangirnagar University, Central Bangladesh.

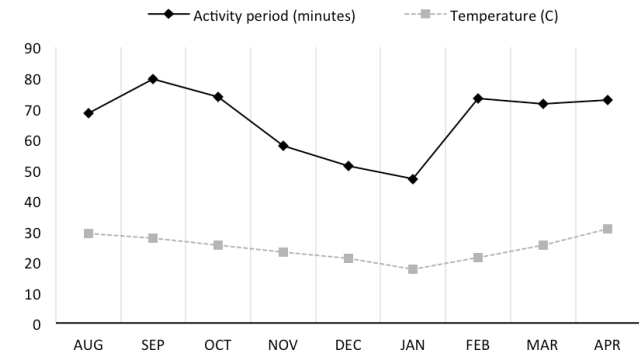

Fig. 6 - Comparison between the activity pattern of *Saccolaimus saccolaimus* and air temperature between August and April.

We found that *S. saccolaimus* became active when the temperature was 22.5°C or warmer. However, we also observed some individuals turning active when the air temperature was around 21.5°C. Within the temperature range of 19-22°C, a short torpor bout was observed when up to two-thirds of the colony left the roost and the remaining bats remained inactive. This behaviour was observed among

the colony members during the third week of December before entering long torpor in the third week of January until the first week of February.

Activity Patterns

Our study revealed that *S. saccolaimus* became active early in the season as opposed to other sympatric species. Colonies emerged from their roosts between 15 and 23 minutes after sunset. Sunset time varies in different seasons in Bangladesh: from 5:18 pm in December to 6:45 pm in July. Before the emergence (ca. 30 minutes), individuals became more vigorous, continuously stretching their wing membranes, grooming, and clinging inside the concrete cleft's edge with their claws and feet. It took up to five minutes (range: 15 sec for a colony of two individuals, five minutes for a colony of six bats) for all the members of the colonies to leave the roost, whereas in the cooler months (December to February) emergence time increased up to 19 minutes.

We observed some variation in the duration that Bare-rumped Sheathtail bat colonies spend outside the roosts throughout the year. The duration of bat activity was strongly correlated with air temperature (R-square= 0.52, P-value= 0.02)) (Fig. 5). As the air temperature warmed up, *S. saccolaimus* spent more time being active outside the roost, presumably for foraging. During the rainy season, they stayed out of the colony for 68.33 ± 3.05 minutes in August (29.16°C), 79.66 ± 4.50 minutes in September (27.66°C), and 73.66±8.08 minutes in October (25.40°C) (Fig. 5). In winter, mean temperature dropped below 20.79°C. The activity of the colony gradually decreased to 57.66 ± 5.03 minutes in November (23.20°C), 51.25 ± 10.81 minutes in December (21.13°C), and 47.00 ± 2.11 minutes in January (17.46°C). We observed an increase in activity (73.33 ± 2.88 minutes) at the end of February when the temperature was 21.38°C (Fig. 6). Moreover, the duration of bat activity was more uniform in early Summer: March (25.5°C; 71.33 ± 3.05 minutes) and April (30.73°C; 72.66 ± 3.05 minutes) (Fig. 6).

Morphometric measurements

We observed that specimens from Bangladesh had larger HB, FA, TL, GTL, CCL, ZB, C-M^3, C-M_3, and ML (Table 2). However, the morphometric analysis indicated no significant differences between the specimens from this study and those from other localities (F 0.0072 < F crit 3.31, p = 0.99).

Table 2 - Comparative study on morphometric measurements (external and craniodental) of *Saccolaimus saccolaimus* in South Asia (all measurements are in mm). *References*: [1]This study, [2]Srinivasulu et al. (2010), [3]Saveng et al. (2011), [4]Borissenko & Kruskop (2003), [5]Edirisinghe et al. (2013).

	Bangladesh[1] (n=8)	Sri Lanka[5]	Cambodia[3]	Vietnam[4]	South Asia[2]
HB	89.93 (86.06-95.99)	85	82.5	88 (84-92)	84.8 (80-93)
FA	71.30 (68.16-73.50)	70	69.2	67.8 (66.7-69.2)	65.5 (63-68.2)
EL	17.51 (16.73-19.06)	-	17.4	19.4 (17.8-21.6)	18.7 (16-20)
TL	27.17 (24.28-31.31)	24	28.5	24.3 (23-26)	25.5 (31-35)
HF	14.21 (12.03-16.56)	16	12.5	-	14.6 (12-17)
GTL	25.35	-	25.04	-	25 (24-26.8)
CCL	22.64	-	22.24	-	22.6 (21.7-24.6)
ZB	15.49	-	15.69	-	15.1 (14.2-15.6)
BB	10.86	-	-	-	10.9 (10.4-11.9)
C-M^3	10.31	-	10.0	-	10.3 (9.8-11.2)
C-M_3	11.52	-	11.26	-	11.4 (10.8-12.3)
ML	18.72	-	18.09	-	18.3 (17.5-19.8)
3MT	70.02 (66.37-72.40)	-	-	-	-
1PH3MT	27.92 (27.31-28.92)	-	-	-	-
2PH3MT	28.02 (25.09-29.69)	-	-	-	-
TIB	27.37 (24.57-29.63)	29	-	-	-
TR	5.49 (5.07-6.10)	-	-	-	-
C^1-C^1	4.87	-	-	-	-
M^3-M^3	10.68	-	-	-	-

DISCUSSION

Saccolaimus saccolaimus is described as a gregarious bat species in nature, and its colony size varies from five to six individuals (Phillips 1980), three to 40 (Compton & Johnson 1983, Murphy 2001) or few to hundreds of individuals (Payne & Francis 1998) in a single roost. Similarly, *S. saccolaimus* colonies are small in Bangladesh, ranging from one to nine individuals. In Sri Lanka, this species has been reported using the roof (Phillips 1980) and the basement (Edirisinghe et al. 2013) of old buildings as roosting sites. Moreover, *S. saccolaimus* forages in the upper canopies of forests and prefer decayed tree hollows as roosting site (Churchill 1998, Murphy 2001). In our study, we recorded all the *S. saccolaimus* colonies under the roofs of occupied buildings. We found females with offspring in three out of seven colonies, which led us to infer that these are permanent roosting sites.

In general, torpor behaviour in Bare-rumped Sheathtail Bats is not well documented, and we could not find any published literature on this topic from South Asia. Kulzer (1965) studied the torpor in *Taphozous melanopogon* in captivity and observed that this species employed torpor to maintain body temperature when exposed to 15-20°C in the laboratory. Although most of the information on torpor is generated from captive individuals, some studies were conducted in natural environments (Stawski et al. 2014). In our study, we report that *S. saccolaimus* can employ torpor for a maximum of 27 days when the air temperature ranges between 14.4°C and 18.8°C. We recorded short torpor bouts at mild temperatures between 19°C and 22°C, which is similar to the findings from other studies on tropical Emballonurids (Stawski et al. 2014).

The morphometric measurements revealed that *S. saccolaimus* from Bangladesh were very similar to other specimens from South Asia (Table 2). Due to the scarcity of published literature on *S. saccolaimus*, we used data from Srinivasulu et al. (2010) and Saveng et al. (2011), which provided morphological measurements of *S. saccolaimus* from South Asia and Cambodia, respectively. The morphometric analysis we conducted found no significant difference between specimens from this study and those from South Asia and Cambodia. However, many factors may have influenced these results (e.g. different morphometric analyses or the effects of different sample sizes).

Saccolaimus saccolaimus is an insectivorous bat (feeds on termites and beetles) and occasionally forage close to the ground in open areas (Lumsden 2017). Detailed feeding ecology and food preference of Bare-rumped Sheathtail Bat is unavailable from most of its distribution range (Mahoney & Walton 1988, Churchill 1998). During our study, we could not provide detailed foraging information except for sporadic observations where we observed individual bats

pursuing insects after emergence. However, further detailed data would be required to support our observations.

Bat activity drastically decreased in winter in response to cooler temperatures. In our study, the longest duration *S. saccolaimus* spent outside the roost was recorded in September (79.7 minutes) when females were attached to their young. Lactating females probably needed more energy, hence, foraging for a longer duration. The minimum activity period was recorded in January (47.0 minutes) when bats just got out from the long torpor bout (Fig. 6).

Sheath-tail bats are fast-flying, nocturnal, inconspicuous species from tropical and subtropical regions but remain poorly studied (Geiser & Stawski 2011). In fact, *S. saccolaimus* is one of the least known bat species in Bangladesh and is categorized as 'Data Deficient' in the Red Book of Threatened Mammals of Bangladesh (IUCN Bangladesh 2015). Even though the Bare-rumped Sheathtail Bat is categorized as 'Lest Concern' in the IUCN Red List (Lumsden 2017), a matter of concern exists among biologists as the population falls well below the sustainable level in some regions. There is a lack of information on this species, except for incidental records from Australia and Southeast Asia (Schulz & Thomson 2007). In the Philippines, this species is poorly known, but it might be common in agricultural areas (Heaney et al. 1998), although this requires confirmation as there have been few surveys on *S. saccolaimus* in modified habitats (Lumsden 2017). In South Asia, *S. saccolaimus* is regarded as common species in some parts of India (Molur et al. 2002), very rare in Sri Lanka (Nanayakkara et al. 2012) and had only two confirmed records from Bangladesh before the current study (Saha et al. 2014, Al-Razi et al. 2015).

There were no published papers on *S. saccolaimus* in Bangladesh except for Saha et al. (2014) and Al-Razi et al. (2015), the former published as part of the initial phase of this project. Populations of *S. saccolaimus* in Bangladesh should be monitored regularly to record changes in abundance and to improve information on its distribution. We recommend that buildings identified as roosting sites for *S. saccolaimus* in the JU campus should be protected and monitored on a long-term basis. We also recommend a wider national conservation management plan involving all stakeholders to be developed for bat conservation in Bangladesh.

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