International Journal of Entomology Research
www.entomologyjournals.com
ISSN: 2455-4758
Received: 02-07-2022, Accepted: 16-07-2022, Published: 29-07-2022
Volume 7, Issue 7, 2022, Page No. 103-113

Roosting and reproductive behaviour of lesser mouse-tailed bat, *Rhinopoma hardwickii* (Gray, 1831)

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Abstract
Rhinopoma hardwickii, was a small sized free tailed bat, found in arid and semi-arid regions. The present study was designed to understand the roosting and reproductive behaviours of *R. hardwickii*. A total of 15 roost sites were recorded from seven districts of Bundelkhand region of Uttar Pradesh. The colonies of *R. hardwickii* were found in monuments, abandoned buildings, temples, and caves. *Rhinopoma hardwickii* sparsely roosted during summer while clumped during winter season. Male and female preferred to roost together, but lactating female roosts separately at the time of lactation. A total of 62 social and general behaviours recorded and the general behaviours were most frequent across the season while social behaviours occurred in specific months. They undergone breeding once in a year (February to March) just after winter dormancy, and after three months of gestation a single pup was given during June - July. Pups weaned from mother after two months of lactation. The results of current study reveal that *R. hardwickii* prefer to live in monuments, caves and abandoned building, they change the roosting behaviour according to seasons, and undergo mating during spring and parturition at monsoon when insects are abundant. Thus, the roost sites need to be protected to conserve this ecologically significant species.

Keywords: *Rhinopoma hardwickii*, Roosting, Reproduction, Behaviour, Colony composition, Distribution

Introduction
Bats are the excellent group of mammals capable of sustained flight [1]. This feature facilitate them to utilize nocturnal and arboreal mode of life. Over 1300 species of chiropterans fauna constitutes 20% of mammalian diversity and second largest group after rodent [2, 3].
The genus *Rhinopoma* is monophyletic group with only four known species such as *R. hardwickii* [4], *R. microphyllum* [5], *R. muscatellum* [6] and *R. macinnesi* [7]. *Rhinopoma hardwickii* form large colonies, which consists few hundred to several million individuals [8, 9]. *Rhinopoma hardwickii* is found in arid and semi-arid zones of Northern Africa, South Western Asia, India, Thailand and Sumatra [10]. *Rhinopoma hardwickii* is a small size bat with grayish to dark brown color, free tail and a small nose leaf snout [11].
Small animal adopts 'live fast – die young' strategy means rapid reproduction and high mortality in young [12], while in bat longevity with multiple reproduction, low litter size and delayed onset of sexually maturity. Mostly bats give single young in one birth [13], sometimes twins are common in some species [14]. Generally, it is found that smaller mammals give birth to relatively larger young but it is extreme in bat [15]. Many species of bats, females form a maternity colony or secondary roost to rear their offspring communally [16, 17]. At the time of pregnancy living in group benefits the bat as it reduces thermoregulatory cost, and at the time of reproduction low roost temperature effect on the development of offspring [18, 19, 20] and also reduces the risk of predation because they forage in group [21, 22].
Rhinopoma hardwickii live in colony and show sociality between individuals [20, 23]. *Rhinopoma hardwickii* preferred roosting in abandoned buildings, caves, crevices, rocky areas, deserted mountain and wells. *Rhinopoma hardwickii* adaptable to live in dry climates and hot summer. They also maintain water balance in their bodies, and prefer to live in cover shelters to avoid heat and they undergo torpor in winter season, when insects availability is reduced [24]. *Rhinopoma hardwickii* undergo a period of dormancy during winter season, and they come back from winter dormancy in late February and enter in to breeding season, they have a defined annual reproductive cycle [13]. *R. hardwickii* are monoestrous in nature. Their reproductive pattern influenced by seasonal movement [25]. The time required to attain sexual maturity was differed in male and female, female become sexually mature between 8.5 to 9 months, whereas male do not become sexually mature until 16 to 17 months [13]. The breeding season of *R. hardwickii* was started in spring, with three-month gestation period [13, 25, 26, 27]. Testis of *R. hardwickii* are permanently found abdominal with accessory reproductive organ and follow annual sexual cycle [25]. In *R. hardwickii* insemination occurs between late February and first week of March, although ovulation does not occur until mid-March, gestation last about three to four months and young born between June to July [25, 27].

All studies on reproductive behaviour of *R. hardwickii* were carried out by capturing and dissecting the bat, which is against the law of conservation while no systematic study was carried out on roosting and reproduction behaviours. Therefore, the aim of this study was to observe roosting and reproductive behaviours of *R. hardwickii*.

Materials and methods

Study area

Field surveys were carried out in residential and non-residential areas along with forest, hill, agriculture land and terrain of Bundelkhand region of U.P. between February 2019 and March 2022 to assess the distribution of *R. hardwickii*. Roost location was determined with the help of mobile GPS (Google earth). Population of bats was assessed by visual count at the time of emergence by following Easterla & Watkins [28]; Humphrey and Cope [29]; and Swift [30]. Photographs of each roost site were taken using Nikon D5300 with 18 – 55 mm Nikkor lens, and population of bats was also accessed by photographic count [31].

Medium size colony was captured using hoop net and the gender, colony compositions were assessed and Infra-red CCTV camera was installed at the roost to asses roosting behaviour. Play-back analysis was performed using VLC media player, and the frequency of behaviour was recorded by following key of Markus and Blackshaw [32] and Kerth [33], besides 13 new behaviors were added (Table 1).

The bats were released at the site of capture after taking morphology. Morphometric measurements were taken by vernier calipers, and bat was identified using the key of Bates and Harrison [34]. The Guidelines of American Society of Mammalogy were followed for capturing of bats [35].

Table 1: Behaviour of *R. hardwickii* observed at different behavioural context at day roost

No.	Behaviour	Behavioural context
1	Intruder	Another bat come in group.
2	Move away	When bat (intruder) come in group female shift in some distance.
3	Hanging	Bat hang with hind foot and move freely (wings folded around the body).
4	Move head	Movement of head in both sides while roosting (hang alert).
5	Head up	Movement of head up side while roosting (hang relax).
6	Suffle	Long distance movement with the help of thumb and foot.
7	Head groom	Cleaning of head with the help of claw (first claw insert in mouth for saliva than overhead).
8	Mouth groom	Cleaning of mouth portion (nose, and between eye and mouth) with the help of claw.
9	Belly groom	Scratching of belly region with the help of claw.
10	Foot groom	Cleaning of foot (one by one) with the help of tongue.
11	Vocalization	Emitting loud, harsh, voice towards another bat.
12	Circling	Male move 360 degree around female.
13	Mock hook	Hook but non-aggressive context.

Results

Rhinopoma hardwickii had a small free tail with dark grey colour pelage (Fig. 1a). The ear of *R. hardwickii* possesses transvers lines. The morphological measurement of *R. hardwickii* is given in Table 2. The female were larger than male, however, the forearm length of male was higher (Table 2). A total of 15 roosts of *R. hardwickii* were recorded from seven districts of Bundelkhand region of Uttar Pradesh (Table 3). *Rhinopoma hardwickii* formed small groups in a colony, the population of *R. hardwickii* was highest in Jhansi fort (530) and lowest in Gupt Godavari (6) (Table 3). Male and female found roosting together but lactating female roost separately at the time of lactation. A whole colony of *R. hardwickii* (16 individuals) was captured in Majhgawan during winter season (October), which consist more males (14) than females (2). A colony consist of 15 individuals were videographed using CCTV camera during October. The colony composed of 6 females, 3 pups, 5 sub-adults and 1 adult male.

Rhinopoma hardwickii lived as clump during winter season (November to January) (Fig. 1b), while they scattered in rest of the season (February to October). They vacated those roosts when temperature falls below 25ºC at the beginning of winter (November) but again return back during March.

Two types of behaviours were observed, one was solitary behaviour (non-social) and another was social behaviour. In Non-social behaviour, roosting, autogrooming, stationary actions and locomotion were observed while in social behaviour territorial, courtship and mother-infant juvenile beahviours observed.

Non-social behaviour observed throughout the year (Table. 4), while the social behaviours observed seasonally but their frequency differed (Table 5). Social behaviours such as courtship and copulatory behaviour found in February to March and mother-infant, juvenile behaviours observed June to October (Table 5). The diurnal behaviours of *R. hardwickii* consisted predominantly solitary and general behaviours like roosting, sleeping and grooming.

A total of nine behaviours associated with roosting were observed such as turn, sway alert, move away, hang relax, hang alert, swivel, wing drop, hang tense and hanging (Fig. 2). Amid of roosting, the individuals turn the whole body to 90° and seen the environment, most probably towards conspecific or intruders and thus the frequency of turn was higher than rest of the behaviours (Fig. 2). Two type of hang alert position was observed,

they hang with the help of hind foot and wings were loosely open. In second condition, they attached to the surface of wall, they posture in erect position (both hind foot and forearm touched with surface but belly region not touched surface). Wing drop found in the relax position. In hang tense wings folded along sides of body and slightly pulled back, head and ears inclined toward direction of perceived threat.

A total of eight types of behaviours associated with stationary actions were observed, such as stretch, wing flick, head up, wing fan, reach, sniff, yawn, and move head (Fig. 3). In day roosting they perform stretch many times for avoid laziness and thus the frequency of stretch was higher than other stationary actions (Fig. 3).

A total of ten behaviours observed under the category of autogrooming, such as general groom, foot groom, wing groom, genital groom, ear groom, head groom, belly groom, tooth groom, scent bath and mouth groom (Fig 4). The bats performed autogrooming for cleaning their body The most frequent behaviour was general groom in which they clean their body with the help of tongue (Fig. 4). They used foot claws to clean ear canals and teeth.

A total of eight types of locomotion were observed such as glide, fly in, fly out, flight, shuffle, crawling, land and shuffle (bp) (Fig. 5). They performed locomotion behaviour to move within the roost or outside the roost. They perform mostly glide in which they perform smooth forward flight motion with decreasing altitude (Fig. 5).

Territorial behaviour only observed during reproductive (mating/courtship) period. A total six types of territorial behaviours were observed, such as wing flex, hook, chase scent mark, wrestle and bite (Fig. 6). Male bat defended their territory for mating and they opening their wings in other bat to show their potency. Wing flex was higher in reproductive season as compared to other territorial behaviours (Fig 6). The male bat hooks another bat by thumb claw and some time they bite or wrestle each other for defending territory, after successful defending potential female select mate for mating. If any intruder male come in group, then female shifted one side and male shows their potency by wing flex to protect their territory from another male (intruder). Male mark their territory area by scent mark (vigorous rubbing of neck along edges of territory). After the reproductive season lactating female separates herself in to different roost and now colony defended by the females. *Rhinopoma hardwickii* show high parental care for their young once.

A total of 12 type of reproductive behaviours were observed under the category of courtship and copulatory behaviours, such as circling, approach scruff bite uro-genital lick, grasp-restraint, face reject, vocalization, intromission, copulation, push away, aggression, and break (Fig. 7). Courting behaviour occurs during February to March. Before copulation male move around female in 360 degrees pathway for showing their aggression. Frequency of circling was higher among the courtship and copulatory behaviours (Fig. 7). Male bat held female from backside during copulation, and after copulation male was pushed away by female if copulation successful.

Mother-infant and juvenile behaviours were seen from July to August. A total of eight behaviours observed in these categories, such as static flight, mock wrestle, mock biting, suckle, greeting, infant groom, play wrestle and mock hook (Fig. 8). When infant hang with the body of female they perform many static flight probably for strengthening of wing and chest muscles in preparation for flight so frequency of static flight higher than other behaviours (Fig. 8). Greeting occurs when pups separated from the body of female and learn according to mother.

Table 2: Morphological measurements of *Rhinopoma hardwickii*. Values are given in Mean ± SD

Parameter	Male (n = 34)	Female (n = 27)
Body mass(gm)	20.71 ± 4.72	21.00 ±6.06
BH length (mm)	71.30 ± 3.94	72.13 ± 4.03
Head length (mm)	20.19 ± 4.03	22.93 ± 2.10
Tail length (mm)	56.73 ± 10.91	58.61 ± 6.10
Forearm length (mm)	59.07 ± 2.73	57.82 ± 3.34
5^{th} Metacarpal (mm)	43.10 ± 1.60	42.78 ± 2.31
First phalanx (mm)	10.80 ± 0.67	10.52 ± 0.55
Second phalanx (mm)	9.54 ± 0.91	9.62 ± 0.54
4^{th} Metacarpal (mm)	38.10 ± 1.79	37.39 ± 1.63
First phalanx (mm)	12.70 ± 0.76	13.04 ± 0.68
Second phalanx (mm)	9.33 ± 2.43	10.16 ± 2.03
3^{rd} Metacarpal (mm)	43.83 ± 2.21	42.16 ± 2.24
First phalanx (mm)	9.17 ± 0.90	9.24 ± 0.95
Second phalanx (mm)	17.28 ± 1.66	17.88 ± 1.26
2^{nd} Metacarpal (mm)	43.62 ± 3.77	42.54 ± 2.68
Wing span (mm)	312.98 ± 25.51	293.91 ± 18.22
Thumb length (mm)	7.07 ± 0.60	6.88 ± 0.99
Hind arm (mm)	30.35 ± 1.67	29.38 ± 1.16
Foot (mm)	7.56 ± 3.09	7.81 ± 3.33
Body width (mm)	28.14 ± 7.31	26.01 ± 7.82

Table 3: Roost sites and roost microclimates of *Rhinopoma hardwickii* observed in Bundelkhand region of Uttar Pradesh

Roost site	GPS location		Population	Temperature (ºC)	Humidity (%)	Light intensity (Lux)
	North	East				
Baradari, Majhgawan, Hamirpur	25º18'28"	79º16'35"	45	30.86 ± 5.60	61.20 ± 20.03	0
Cave, Belatal, Mahoba	25º15'31"	79º33'54"	21	24.27±6.18	59.25 ± 24.90	0
Boundary of Badal mahal, Belatal, Mahoba	25º15'43"	79º34'35"	11	25.50±6.24	63.00 ± 21.60	0
Badal mahal, Belatal, Mahoba	25º15'59"	79º34'43"	20	31.17 ± 11.30	59.75 ± 23.47	8
Rahila Sagar Sun Temple, Mahoba	25°15'50"	79°50'34"	12	27.00 ± 6.98	62.00 ± 22.94	0
Dark cave, Mahoba	25°16'55"	79°51'31"	27	29.25 ± 6.39	64.75 ± 19.60	0
Senapati Mahal, Kulpahar, Mahoba	25º18'57"	79º38'22"	22	29.50 ± 8.34	62.50 ± 24.63	5
Barua Sagar fort, Jhansi	25°22'31"	78°44'28"	35	27.00 ± 3.00	69.00 ± 23.25	0
Jhansi fort, Jhansi Site- 1	25°27'28"	78°34'36"	185	28.62 ± 1.51	66.2 ± 24.99	0
Jhansi fort, Jhansi Site- 2	25°27'31"	78°34'40"	323	28.62 ± 1.51	66.2 ± 24.99	0
Jhansi fort, Jhansi Site- 3	25°27'17"	78°34'47"	540	28.62 ± 1.51	66.2 ± 24.99	0
Kalinjar fort, Banda	24°59'46"	80°29'04"	83	27.88 ± 6.21	64.40 ± 19.96	0
Gupt Godavari cave, Chitrakoot	25°05'52"	80°46'07"	6	27.30 ± 0.60	80.66 ± 13.05	-
Fort (Talbehat) Lalitpur	25°02'20"	78°26'09"	35	27.02 ± 3.88	71.50 ± 20.72	0
Garhi, Malehta, Hamirpur	25°35'04"	79°25'16"	33	29.38 ± 7.3	66.25 ± 21.23	0

Table 4: Non-social behaviours *R. hardwickii* observed at day roost

Behaviour	Months/Types	February	March	April	May	June	July	August	September	October
Roosting behaviours	Turn	+	+	-	+	-	+	+	+	+
	Sway alert	-	+	+	+	+	+	+	+	+
	Move away	-	-	+	+	+	+	+	+	+
	Hang relax	+	+	+	+	+	+	+	+	+
	Hang alert	+	-	+	+	+	+	+	+	+
	Swivel	-	+	+	+	+	+	+	+	+
	Wing drop	+	+	+	+	+	+	+	+	+
	Hang tence	-	-	+	+	+	+	+	+	+
	Hanging	+	+	+	+	+	+	+	+	+
	Intruder	-	+	-	-	-	-	-	-	-
Autogrooming behaviours	General groom	+	+	+	+	+	+	+	+	+
	Foot groom	+	+	+	+	+	+	+	+	+
	Wing groom	+	+	+	+	+	+	+	+	+
	Genital groom	+	+	-	+	+	+	+	+	-
	Ear groom	+	+	+	+	+	+	+	+	+
	Head groom	+	+	+	+	+	+	+	+	+
	Belly groom	+	+	+	+	+	+	+	+	+
	Tooth groom	+	+	+	+	+	+	+	+	+
	Scent bath	+	+	+	+	+	+	+	+	+
	Mouth groom	+	+	+	+	+	+	+	+	+
Stationary actions	Stretch	+	+	+	+	+	+	+	+	+
	Wing flick	+	+	+	+	+	+	+	+	+
	Head up	+	+	+	+	+	+	+	+	+
	Wing fan	+	+	+	+	+	+	+	+	+
	Reach	+	+	+	+	+	+	+	+	+
	Sniff	+	+	+	+	+	+	+	+	+
	Yawn	+	+	+	+	+	+	+	+	+
	Move head	+	+	+	+	+	+	+	+	+
Locomotion behaviours	Glide	+	+	+	+	+	-	+	+	+
	Fly in	+	+	+	+	+	+	+	+	+
	Fly out	+	+	+	+	+	+	+	+	+
	Flight	+	+	+	+	+	+	+	+	+
	Suffle	+	+	+	+	+	+	+	+	+
	Crawling	+	+	+	+	+	+	+	+	+
	Land	+	+	+	+	+	-	+	+	+
	Suffle (bp)	+	+	+	+	+	+	+	+	+

The bats were undergone winter dormancy during November, December and January, thus no behavioural observations were made

Table 5: Social beahviours of *R. hardwickii* observed at day roost

Behaviour	Months/Types	February	March	April	May	June	July	August	September	October
Territorial behaviours	Wing flex	+	+	+	+	+	+	+	+	+
	Hook	+	+	-	-	+	+	+	+	+
	Chase	+	+	+	+	+	+	+	+	+
	Scent mark	+	+	-	-	+	+	+	+	+
	Wrestle	+	+	+	-	+	+	+	+	+
	Bite	+	+	-	-	+	+	+	+	+
Courtship behaviours	Circling	+	+	-	-	-	-	-	-	-
	Approach	+	+	-	-	-	-	-	-	+
	Scruff-bite	+	+	-	-	-	-	-	-	-
	Uro-genital lick	+	+	-	-	-	-	-	-	+
	Grasp-restraint	-	+	-	-	-	-	-	-	-
	Face-reject	-	+	-	-	-	-	-	-	-
	Vocalization	+	+	-	-	-	-	-	-	-
	Intromission	+	+	-	-	-	-	-	-	-
	Copulation	-	+	-	-	-	-	-	-	-
	Push away	+	+	-	-	-	-	-	-	-
	Aggression	+	+	-	-	-	-	-	-	-
	Break	-	+	-	-	-	-	-	-	-
Mother - infant and juvenile behaviours	Static-flight	-	-	-	-	+	+	+	-	-
	Mock wrestle	-	-	-	-	-	+	+	+	+
	Mock biting	-	-	-	-	-	+	+	+	+
	Suckle	-	-	-	-	+	+	+	-	-
	Greeting	-	-	-	-	-	+	+	+	+
	Infant groom	-	-	-	-	+	+	+	-	-
	Play wrestle	-	-	-	-	-	+	+	+	-
	Mock hook	-	-	-	-	-	+	+	+	-

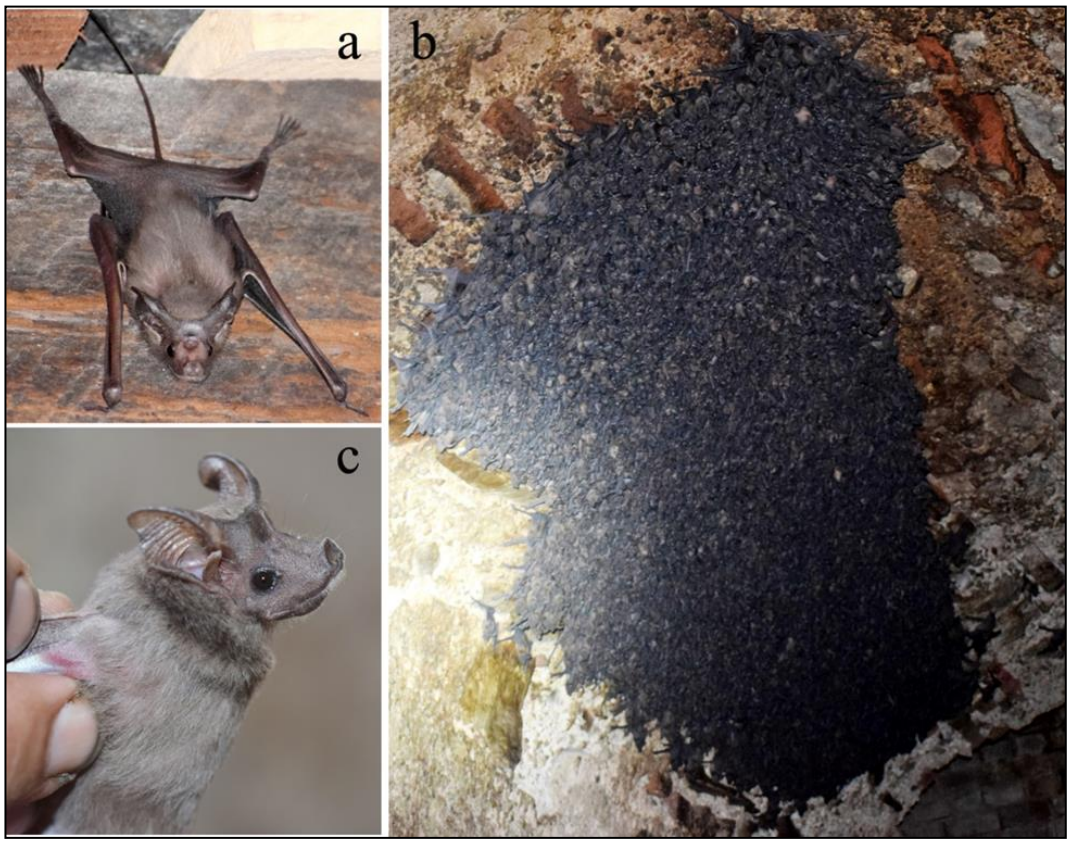

Fig 1: An individual of *R. hardwickii* roost on a wooden ceiling (a), aggregation of *R. hardwickii* during winter dormancy (b) and close view of *R. hardwickii* (c)

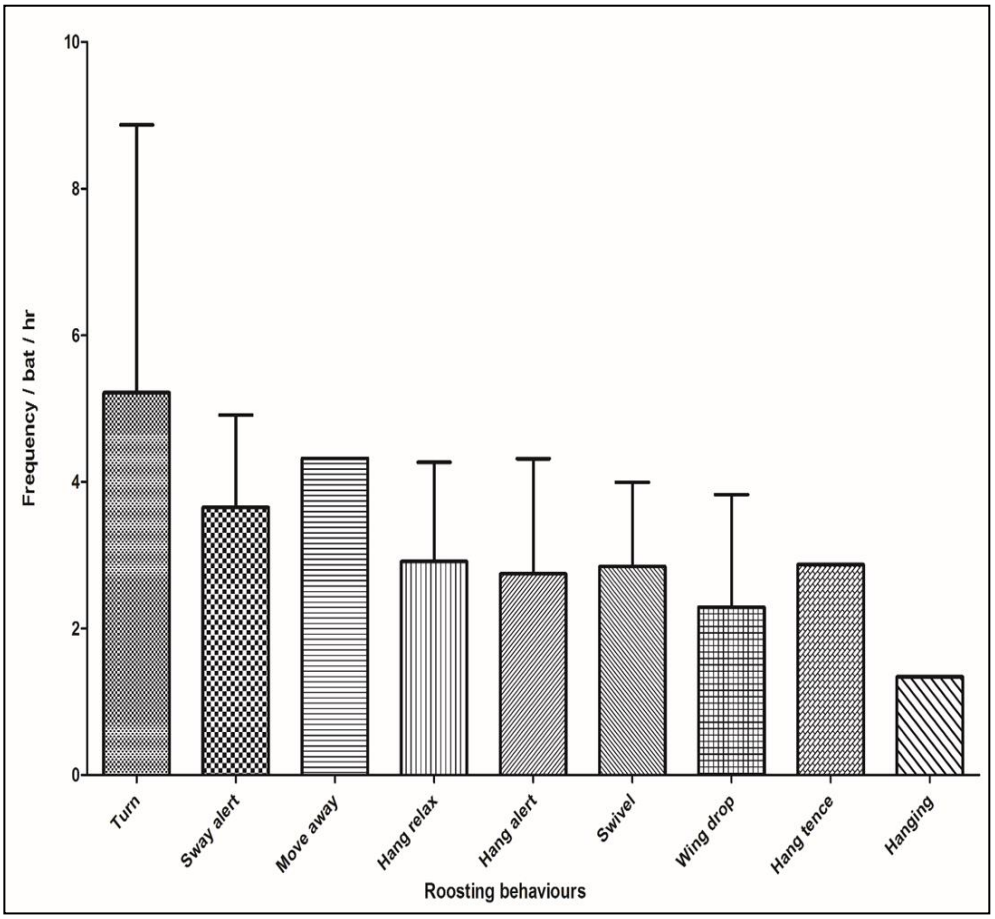

Fig 2: Roosting behaviours of *R. hardwickii*. The average frequency of roosting behaviour of *R. hardwickii*. The average frequency of behaviour given as bar and sd given as error bars

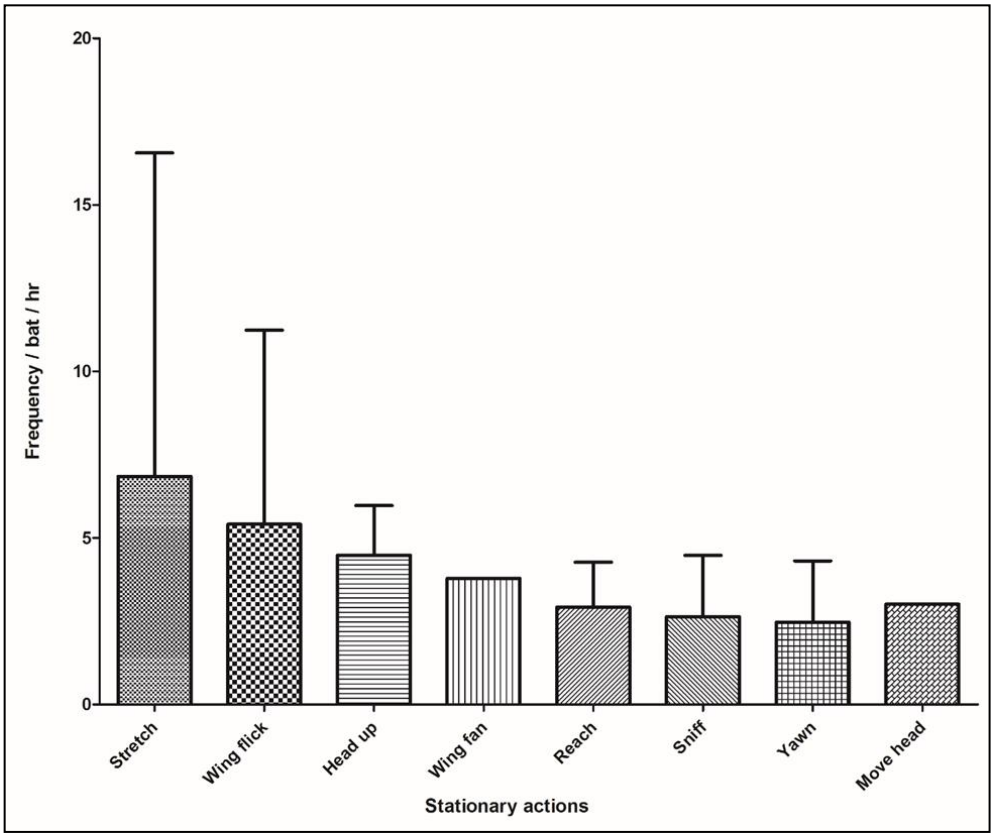

Fig 3: Stationary actions of *R. hardwickii*. The average frequency of behaviours given as bars and SD are given as error bars

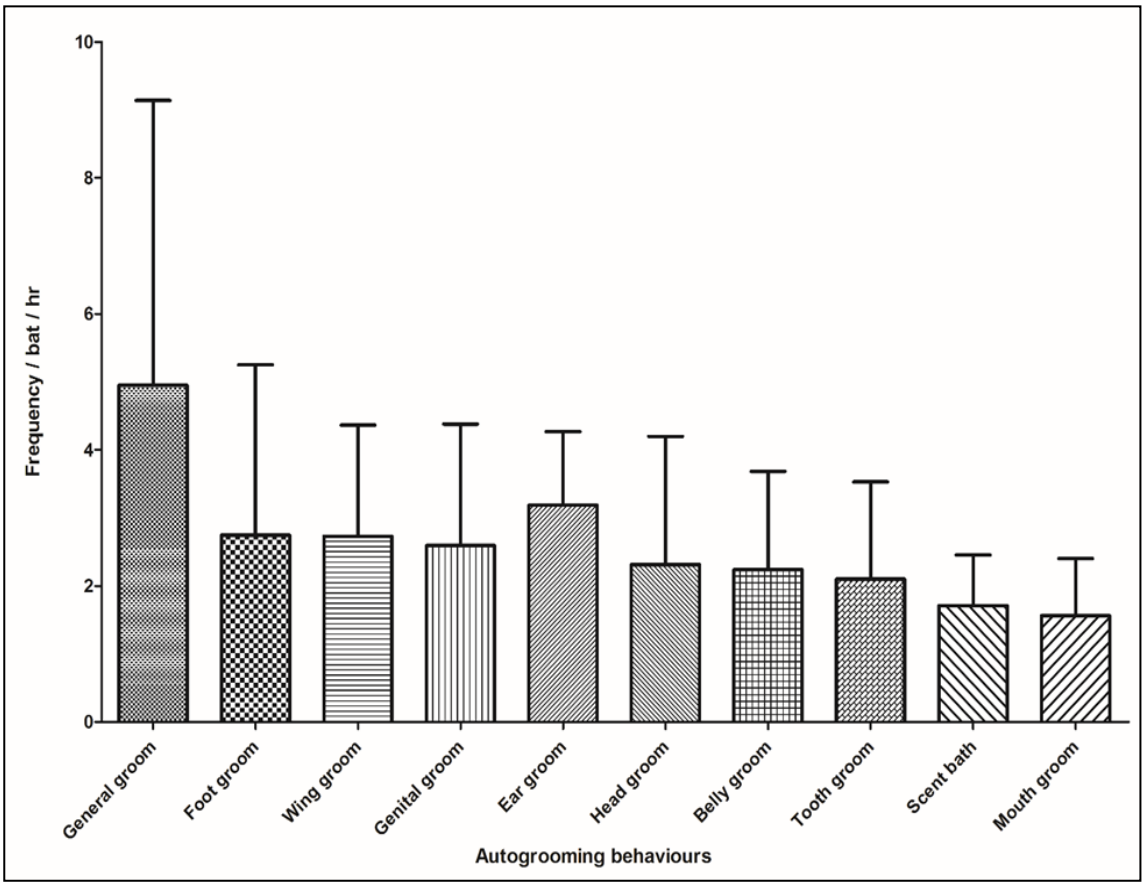

Fig 4: Autogrooming behaviours of *R. hardwickii*. The average frequency of behaviours given as bars and SD are given as error bars

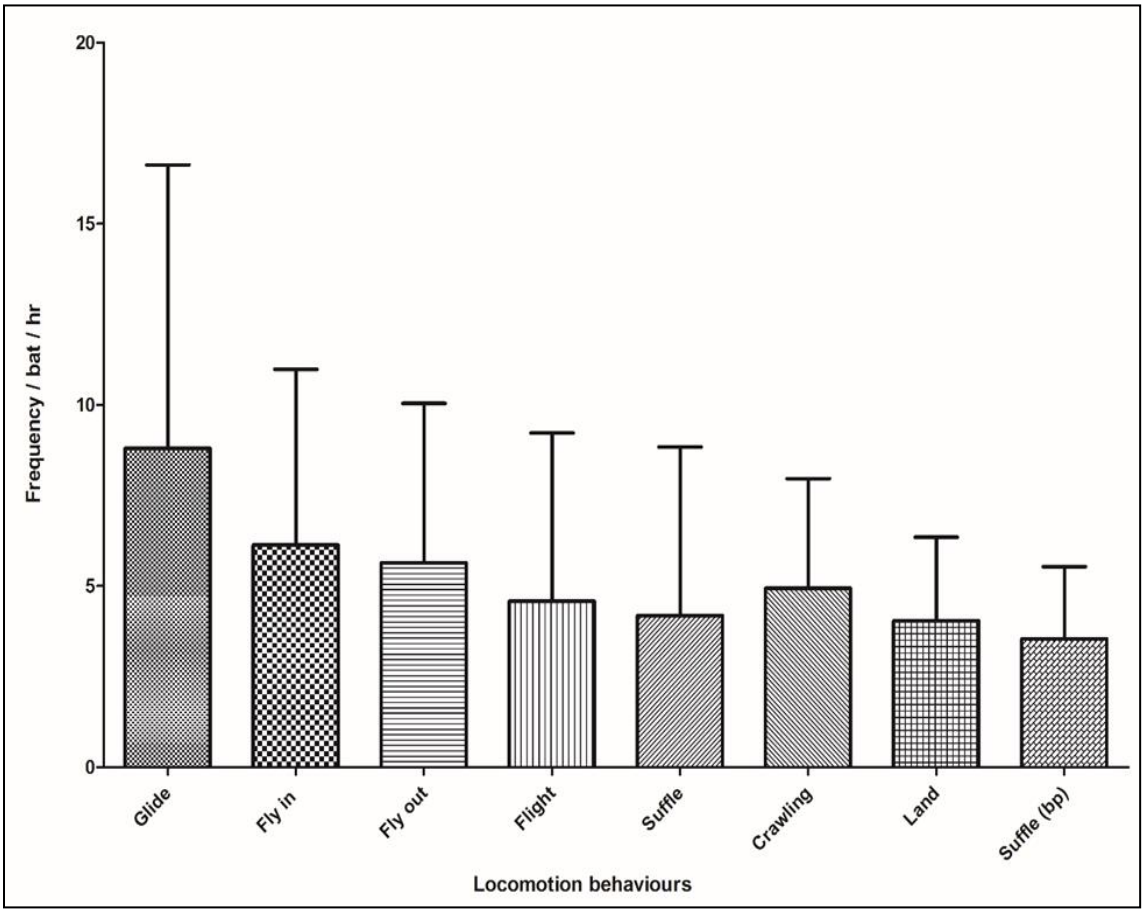

Fig 5: Locomotary behaviours of *R. hardwickii*. The average frequency of behaviours given as bars and SD are given as error bars

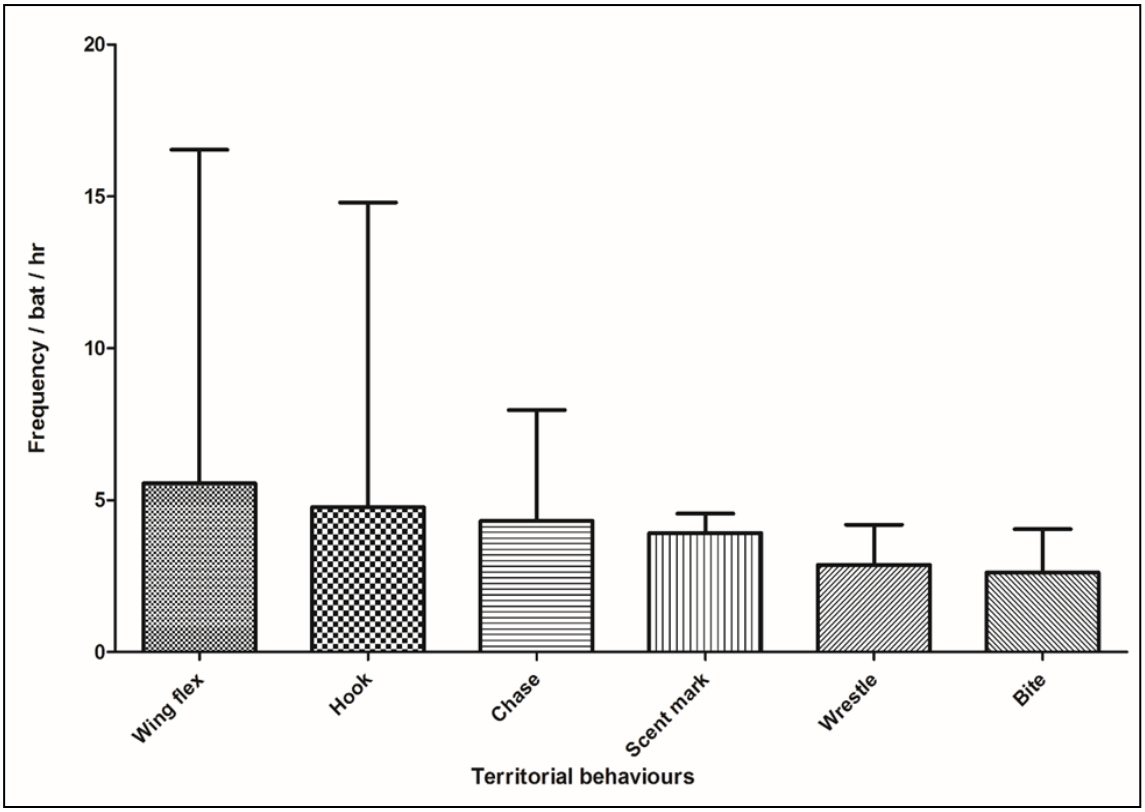

Fig 6: Territorial behaviours of *R. hardwickii*. The average frequency of behaviours given as bars and SD are given as error bars

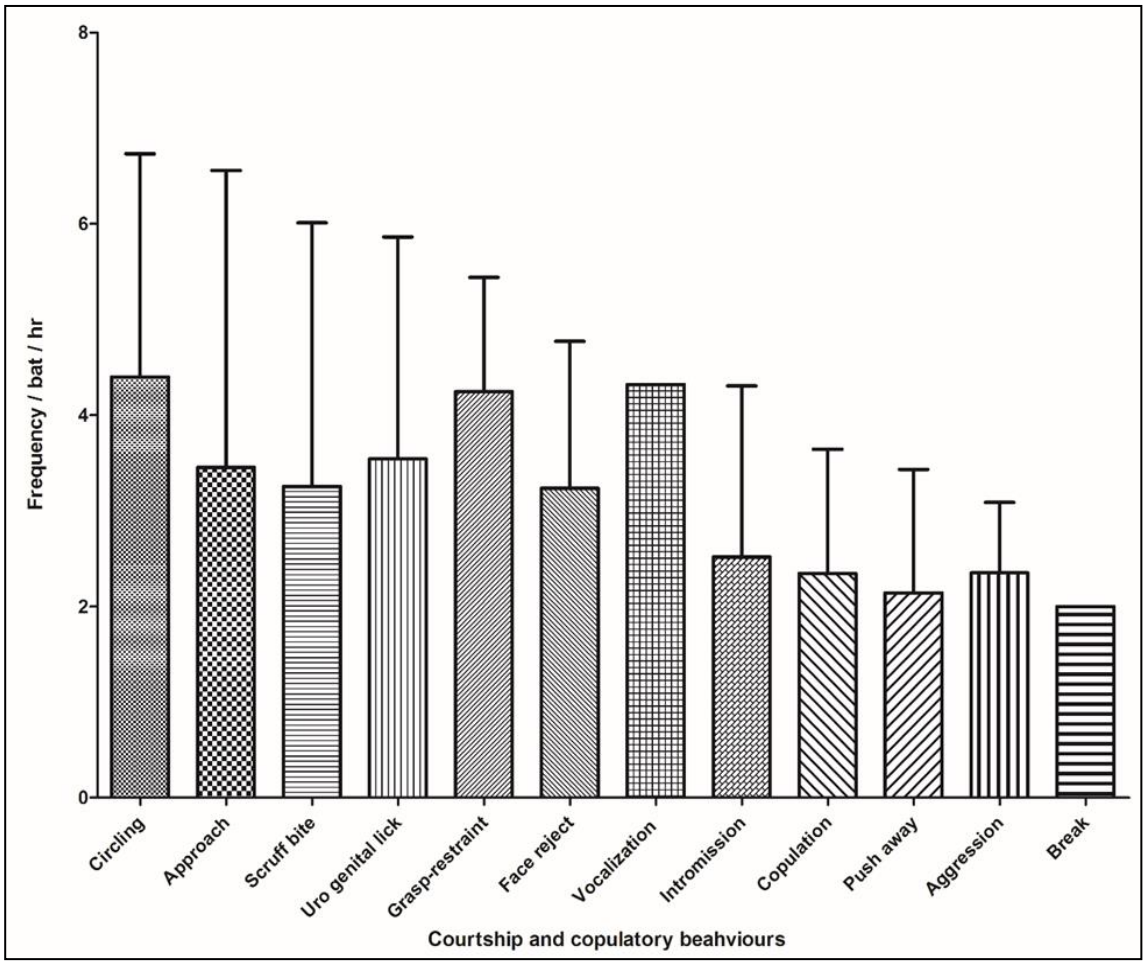

Fig 7: Courtship and copulatory behaviours of *R. hardwickii*. The average frequency of behaviours given as bars and SD are given as error bars

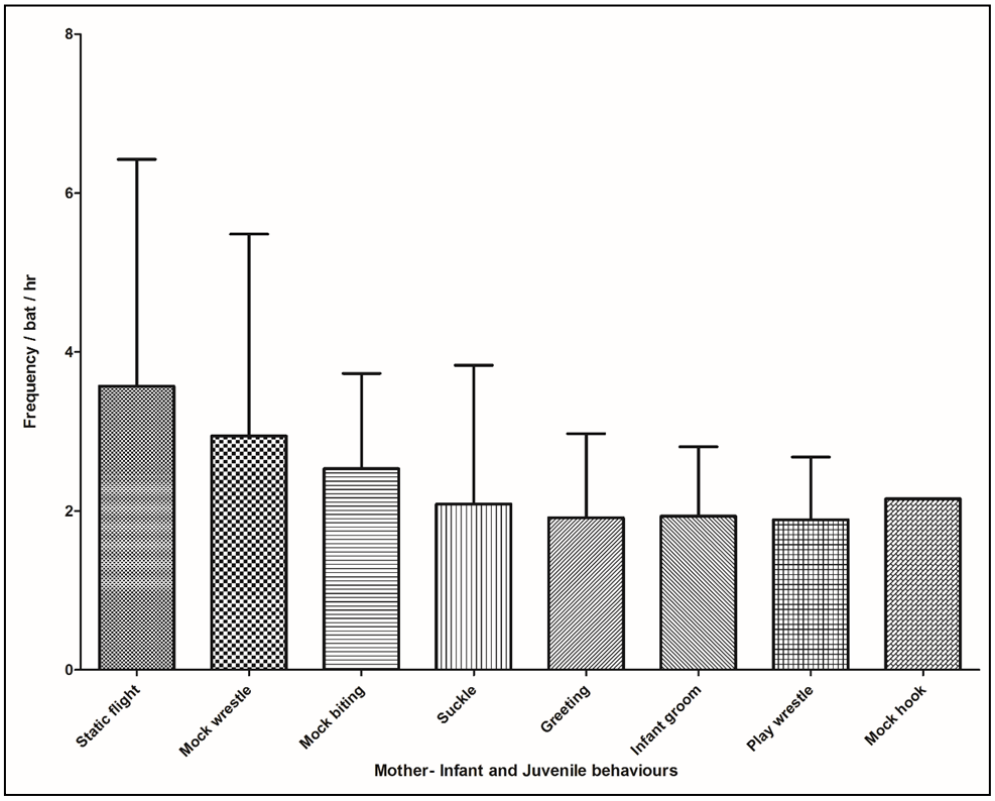

Fig 8: Mother-infant and juvenile behaviours of *R. hardwickii*. The average frequency of behaviours given as bars and SD are given as error bars

Discussion

A total 15 roosts sites of *R. hardwickii* were found, where they roosting in abounded building, cave temple and fort with zero light intensity. They prefer roosting in monument and abounded buildings of wooden roof because there are a lot of crevices available. They hang with the help of foot [34, 36, 37]. The population of *R. hardwickii* was highest in Jhansi fort due to almost constant temperature (25 to 30 °C) maintained whole year. The lowest population was recorded in Gupt Godavari because it is a tourist place and artificial lights were installed on the roof of the monuments. There was a peculiar observation that's all roost possess water source nearby roost.

Rhinopoma hardwickii aggregate and form heavy clump during winter to save heat and regulate the body temperature [33]. They undergo winter dormancy by lowering their metabolic rate, because insect availability was very low and risk of predation was high [38]. Winter dormancy of *R. hardwickii* increases the survival in extreme condition [38].

A few reports are available on the reproductive behaviour of *R. hardwickii* [27], in which they not observed roosting behaviour. *Rhinopoma hardwickii* probably shows multifarious reproductive behaviour than any other mammalian order like sperm storage, delayed ovulation, fertilization and implantation [27]. They have evolved a number of mechanisms to ensure that birth place in favorable season and environment to give the greater chance of survival to both the mother and its young.

Rhinopoma hardwickii monstrous in nature and reproduce only one time in a year and give birth only one young at a time. *Rhinopoma hardwickii* start grouping in early February, in which a harem formed, a harem dominated by a single male with 5-6 individual of females. Copulation occurs in February to March and after three months of gustation period parturition from June to July because in this time insect availability was highest so food is easily available nearby the roost.

Male and female prefer roosting together, but lactating female roost separately at the time of lactation. Lactation lasts up to 60 days, during which lactating females were segregated from the group. They showed kin ship behaviour for rearing young ones, and in roost those females are non-reproductive phase they help to protect the territory from intruder [27]. Pups attached to the body of female with the help of hind arm. After two months of lactation period pups detached from body of female [13], and before detaching pups perform many static flights and many times pups detached from female body and after some time pups again attached with the body of female. At the time of pregnancy living in group benefits them as it reduces thermoregulatory cost, which require for rearing young, via co-operative breeding [20] and at the time of reproduction low roost temperature effect on the development of offspring [18, 19]. Living in colony also reduces the risk of predation because they forage in group from roost [21, 22].

Play behaviours seen in August to October in which juvenile try to learn survival behaviour from mother. Sub-adult tries to copulate with female but female reject and this type of behaviour shown in October month. Except Courtship and Mother-infant juvenile behaviour seen in all month, and highest frequency of stretch was found in all month; which is a stationary action.

Parturition in late spring and early summer favorable to provide time for young ones to learn forage successfully, which should establish adequate fat stores before winter, which needed for winter survival [39, 40, 41]. Parturition held during mid-June to July because in this time insect availability was high.

Rhinopomatidae is a monophyletic group which possesses unique character like free tail and laryngeal echolocation. *Rhinopoma hardwickii* was found only arid and semi-arid region so their distribution limited. *R. hardwickii* perform very crucial role in ecosystem in term of insect pest controlling. The population of *R. hardwickii* is declining day by day due to human activity that destroying their roost. Human are removing bats from their roosting and killing them by smoke under their roost. Protected monuments were also vacating the roosts of bats by putting the iron grids on entrance and installing the high beam lights in the roosts. The population of *R. hardwickii* declining very sharply and if these practices continue, no steps were taken for the conservation one day we lost a novel creature which provide many services to us.

Acknowledgements

We thank the Archeological survey of India for the permitting us in the monuments. The financial assistance of Science Engineering Research Board, New Delhi through a Major research project (EEQ/2018/000104) to VE is acknowledged.

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