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Cover: Mixed media with fine liners, colour pencils, and watercolour background of an Indian funnel web spider. © Elakshi Mahika Molur.

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Diet composition and diet choice of Lesser Mouse-tailed Bat *Rhinopoma hardwickii* (Gray, 1831) (Rhinopomatidae: Chiroptera)

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Abstract: The food composition and food choice of *R. hardwickii* were assessed through guano analysis at different seasons and geographical locations. Guano samples of *R. hardwickii* were collected from the roost sites of the Gangetic plains and arid region of Uttar Pradesh. Each intact pellet was dissolved and recognizable insect body parts like legs, antennae, wings, and mouth parts were separated and photographed. Each insect remnant was identified to its lowest rank as much as possible. A total of 10 roost sites of *R. hardwickii* were observed in the arid region and Gangetic plains of Uttar Pradesh and all of them were found in historical monuments. A total of 61 pellets of 10 sites yielded 1,035 remnants of insects. The highest percentage of remnants belongs to legs, followed by wings, antennae, abdominal segments, and mouthparts. The remnants belong to eight insect orders such as Coleoptera, Hemiptera, Orthoptera, Hymenoptera, Dermaptera, Diptera, Lepidoptera, and Plecoptera. The remnants of order Hemiptera showed the highest frequency of occurrence followed by orders Coleoptera, Orthoptera, and Hymenoptera, and these four orders of insects constitute the major portion of the diet of *R. hardwickii*. The orders Dermaptera, Diptera, Lepidoptera, and Plecoptera contributed a small proportion to the diet of *R. hardwickii*. The remnants of orders Lepidoptera and Plecoptera were occasional. The result of the current study shows that the food choice of *R. hardwickii* did not differ significantly across roost sites, while differed seasonally. Further, it reveals that the Lesser Mouse-tailed Bat acts as a potential and natural insect balancing agent.

Keywords: Agricultural pest, arid zone, biological pest controller, guano analysis, insect remnant, insectivorous bat, seasonal food habit.

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Author details: Pawan Kumar Misra did his PhD on "Isolation and characterization of guanophilic fungi of the bats of Uttar Pradesh" and currently working on educational sector. Sayma Farheen has completed her postgraduation from Babasaheb Bhimrao Ambedkar University and currently pursuing her PhD in Lucknow University, Lucknow, UP. Shaktivardhan Singh has completed his PhD on "Behavioural ecology of the Mouse-tailed Bat, *Rhinopoma hardwickii*" and currently working on educational sector. Vadamalai Elangovan is professor in the Department of Zoology, Babasaheb Bhimrao Ambedkar University, Lucknow, Uttar Pradesh and working on behavioural ecology of bats since 1996. VE is currently working on "conventional and alternative reproductive strategies of the Indian Flying Fox".

Author contributions: PKM and SF performed the experimental work, analysed the data and drafted the manuscript. SS supported the field work and data collection. VE designed the experiment and edited the manuscript.

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INTRODUCTION

Bats are voracious in nature and feed on large scale of insects in a night. Insectivorous bats are the primary consumers of many nocturnal insects (Kunz & Pierson 1994). They prey on a variety of agricultural insect pests such as tobacco budworms, corn borers, plant hoppers, and oriental armyworms (Whitaker 1993). Noctuid moths are major agricultural pests which are popular for long-distance and seasonal migrations (Wolf et al. 1990; Westbrook et al. 1995), they are abundantly eaten by bats (Thompson 1982; Robinson 1990). Insectivorous bats can suppress the pest population to its lowest level than other known natural enemies (Van Driesche & Bellows 1996). A large colony of insectivorous bats can deplete the insect pest at large scale; therefore, they act as potential biological pest control agents (Lee & McCracken 2005). Several genera of bats including *Taphozous*, *Rhinopoma*, *Tadarida* and *Miniopterus* form large colonies, from few hundreds up to several million individuals (Constantine 1967; McCracken et al. 1994; Elangovan et al. 2018).

The genus *Rhinopoma* is monophyletic with only four known species such as *R. hardwickii* (Gray, 1831), *R. microphyllum* (Brünnich, 1792), *R. muscatellum* (Thomas, 1903), and *R. macinnesi* (Hayman, 1937). They preferred to live in groups, forming colonies of hundreds to thousands of individuals (Elangovan et al. 2018). Very few studies have been carried out on the diet selection of *R. hardwickii*. Feldman et al. (2000) reported that they foraged exclusively in open areas but did not discuss about diet choice. Advani (1981) reported that *R. microphyllum kinneari* (Wrougthon, 1912) mainly fed on Coleoptera, Lepidoptera, and Orthoptera throughout the year, while Isoptera was the preferred diet during summer and monsoon seasons. No detailed report is available on diet composition and diet selection of *R. hardwickii* at various seasons and habitats in India. Thus, to fulfil the lacuna, a study on diet composition and diet selection of *R. hardwickii* was carried out in arid zones of Bundelkhand and adjoining area of Gangetic plains in Uttar Pradesh.

MATERIALS AND METHODS

Faecal pellets collection and analysis

Field surveys were carried from April 2019 to February 2020 at arid zones of Bundelkhand (i.e., Hamirpur, Lalitpur, Jalaun, and Jhansi) and its adjacent districts of Gangetic plains (i.e., Lucknow and Barabanki) in Uttar Pradesh. Guano samples were collected from the roost sites by spreading 2 x 2 m polythene sheet beneath the roost. In addition, the bats were captured using mist net, each individual was kept in a cotton bag until defecation, and thereafter they were released at the site of capture. Fresh faecal pellets were collected seasonally, i.e., summer (March–June), monsoon (July–August), and winter (November–February). Guano samples were kept in sample vials and stored at -20˚C until analysis. Each intact pellet was soaked and dissolved in distilled water, teased gently using a fine brush and the insect remnants were separated using forceps. The recognizable insect body parts like legs, antennae, wings and mouth parts were separated and photographs were taken under a stereo microscope (RSMr3, Radical Scientific) using Digital Camera. Each insect remnant was identified to its lowest rank as much as possible by following Brues et al. (1954) and online resources. The identified remnants of different sites were grouped into legs, antennae, wings, and mouth parts and the frequency of occurrence was obtained.

Statistical analysis

Normality tests were performed to determine the distribution of the data set ($p < 0.05$), therefore non-parametric test (Kruskal Wallis H test) was applied to determine the seasonal and regional variations in the food choice of *R. hardwickii*. Guidelines of the American Society of Mammologists for the care and use of mammals were followed (Sikes et al. 2011).

RESULTS

A total of 10 roost sites of *R. hardwickii* were observed in the arid region (Hamirpur, Lalitpur, Jalaun, and Jhansi) and Gangetic plains (Lucknow and Barabanki) of Uttar Pradesh (Figure 1). All the roosts of *R. hardwickii* were found in historical monuments of the Uttar Pradesh. A total of 61 pellets of 10 roost sites yielded 1035 remnants of insects. The highest proportion of remnants was legs (47.29%) followed by wings (26.44%), antennae (7.62%), abdominal segments (5.31%), and mouth parts (0.19%), while the proportion of unidentified body parts of insects was 13.12%.

The insect remnants belong to eight insect orders such as Coleoptera, Hemiptera, Orthoptera, Hymenoptera, Dermaptera, Diptera, Lepidoptera, and Plecoptera. Further, the valuable diagnostic features of the remnants allowed us to identify up to family level, e.g., Scarabaeidae, Carabidae and Staphylinidae

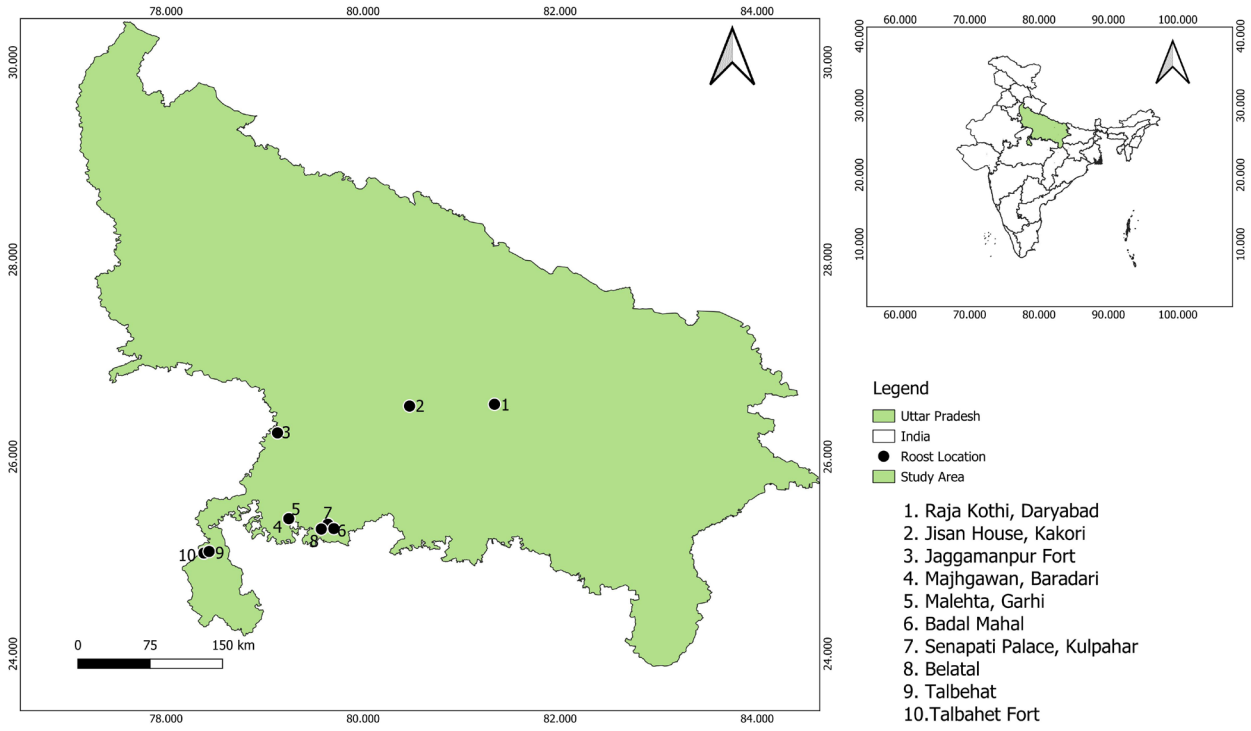

Figure 1. Roost sites of *Rhinopoma hardwickii* in Uttar Pradesh.

Table 1. The insect remnants retrieved from faecal pellets of *Rhinopoma hardwickii* at different roost locations. The values are given in percentage.

Roost locations/ insects order	Lucknow	Barabanki	Lalitpur	Jalaun	Jhansi	Mahoba	Hamirpur
Coleoptera	29.55	9.09	7.58	8.33	9.85	15.91	19.70
Hemiptera	5.34	0.00	13.74	1.53	6.11	14.50	58.78
Orthoptera	7.89	2.63	13.16	10.53	39.47	7.89	18.42
Hymenoptera	3.45	0.00	93.10	0.00	3.45	0.00	0.00
Dermaptera	33.33	0.00	33.33	0.00	33.33	0.00	0.00
Diptera	0.00	100.00	0.00	0.00	0.00	0.00	0.00
Lepidoptera	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Plecoptera	0.00	100.00	0.00	0.00	0.00	0.00	0.00

(Coleoptera), Gryllidae and Gryllicrididae (Orthoptera), Cynidae (Hemiptera), Formicidae (Hymenoptera). The remnants of order Hemiptera consist of legs (tarsi with claw; Images 1AH–AI) and wings (hemi-elytra; Images 2L–O). The remnants of order Coleoptera consist of legs (femur, coxae and tibia, tarsi with claw; Images 1A–V), and wings (elytra; Images 2A–K), while the order Orthoptera consists of coxae and tibia with claw (Images 1W–AG) and leathery non–membranous wings (Images 2P–S). Tarsi of Coleoptera were usually heteroamorous and apparently with three to five segments and one pair of claws (Images 1A–V), while of Hemiptera with three segments and claw (Images 1AH–AI). The wing remnants of Orthoptera were membranous, venation rather complete but not complex with pentagonal or quadrant shape cells (Images 2P–S). They had large legs with spines, tibia with stout spines and movable spur, tympanum located in front of tibia/rarely spinose and tarsi with 4–5 segmented claws (Images 1W–AG).

The remnants of Hemiptera showed the highest frequency in faeces (14.69%) followed by Coleoptera (13.27%), Orthoptera (5.21%), and Hymenoptera (2.65%). The remnants of orders Dermaptera (0.26%), Diptera (0.17%), Lepidoptera (0.088%), and Plecoptera

Table 2. Seasonal variation in food preference of *Rhinopoma hardwickii*. Values are given as Mean ± SD. The dash (-) indicates the absence of particular insect order during the season.

Season	Summer	Monsoon	Winter	χ^2	p -value
Coleoptera	3.70 ± 0.75	1.88 ± 0.49	2.80 ± 1.94	3.42	0.18
Hemiptera	1.75 ± 0.25	2.27 ± 0.798	3.58 ± 3.18	0.38	0.82
Orthoptera	0.95 ± 0.08	1.22 ± 0.86	1.08 ± .12	1.293	0.52
Hymenoptera	-	7.00 ± 6.00	-	0.50	0.48
Dermaptera	-	-	-	-	-
Diptera	1	1	1	-	1
Lepidoptera	1	-	-	-	-
Plecoptera	-	-	-	-	-
Unidentified	8.42 ± 5.45	16.1 ± 8.92	11.45 ± 4.42	1.5	0.47
χ^2	15.285	9.414	9.106	-	-
p-value	0.018	0.152	0.059	-	-

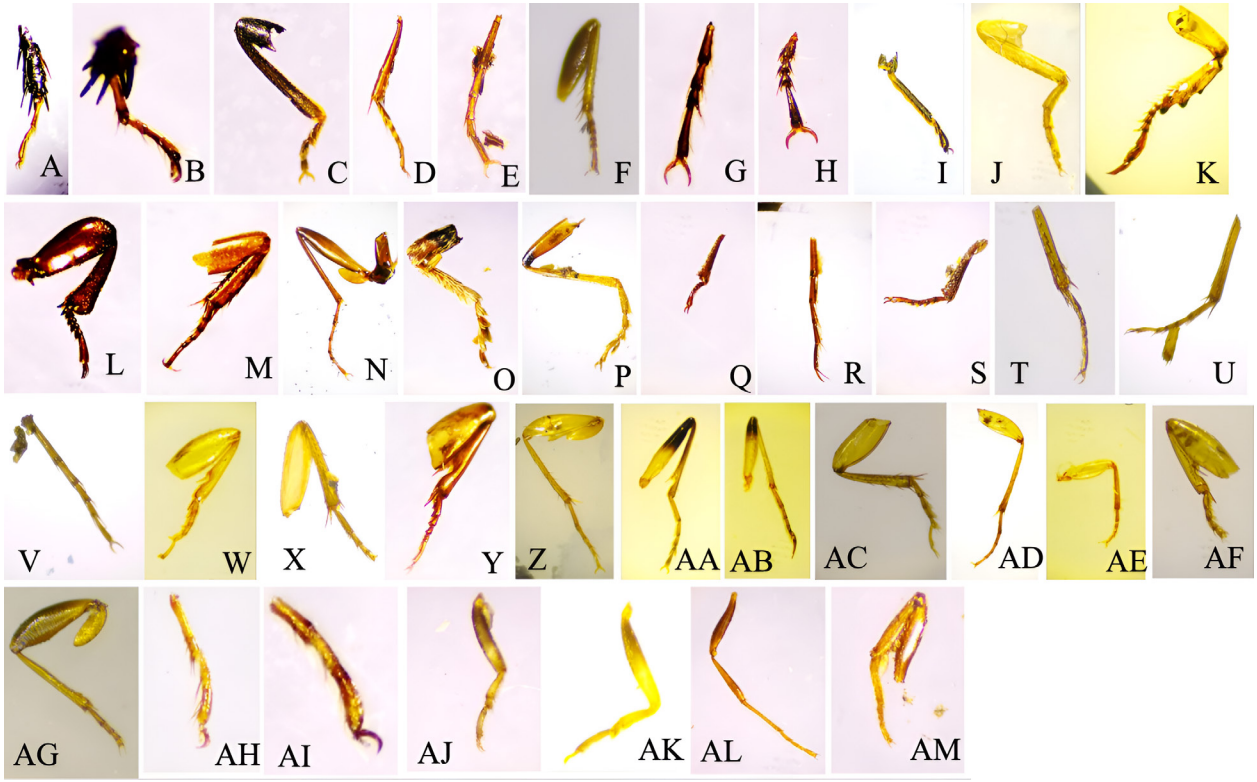

Image 1. Legs of insects isolated from the guano of *Rhinopoma hardwickii*: A–V—Coleoptera | W–AG—Orthoptera | AH–AI—Heteroptera | AJ–AK—Dermaptera | AL–AM—Hymenoptera. © Pawan Kumar Misra & Sayma Farheen.

(0.088%) were found in a small proportion. Further, a major proportion of insect remnants was unidentifiable (63.53%) because they were either broken or incomplete. The remnants of orders Lepidoptera and Plecoptera were occasional (Table 1). The remnants retrieved from faecal pellets showed variation in diet choice of *R. hardwickii* at different localities, i.e., coleopterans were highest in Kakori, hemipterans in Hamirpur (Maleta), orthopterans in Jhansi and hymenopterans in Lalitpur (Table 1). There was no significant difference observed in the occurrence of remanence of various insect orders in 10 different roost sites, Coleoptera (χ^2 = 0.800, p = 0.999), Hemiptera (χ^2 = 0.788, p = 0.990), Orthoptera (χ^2 = 4.50, p = 0.342), Hymenoptera (χ^2 = 0.330, p =

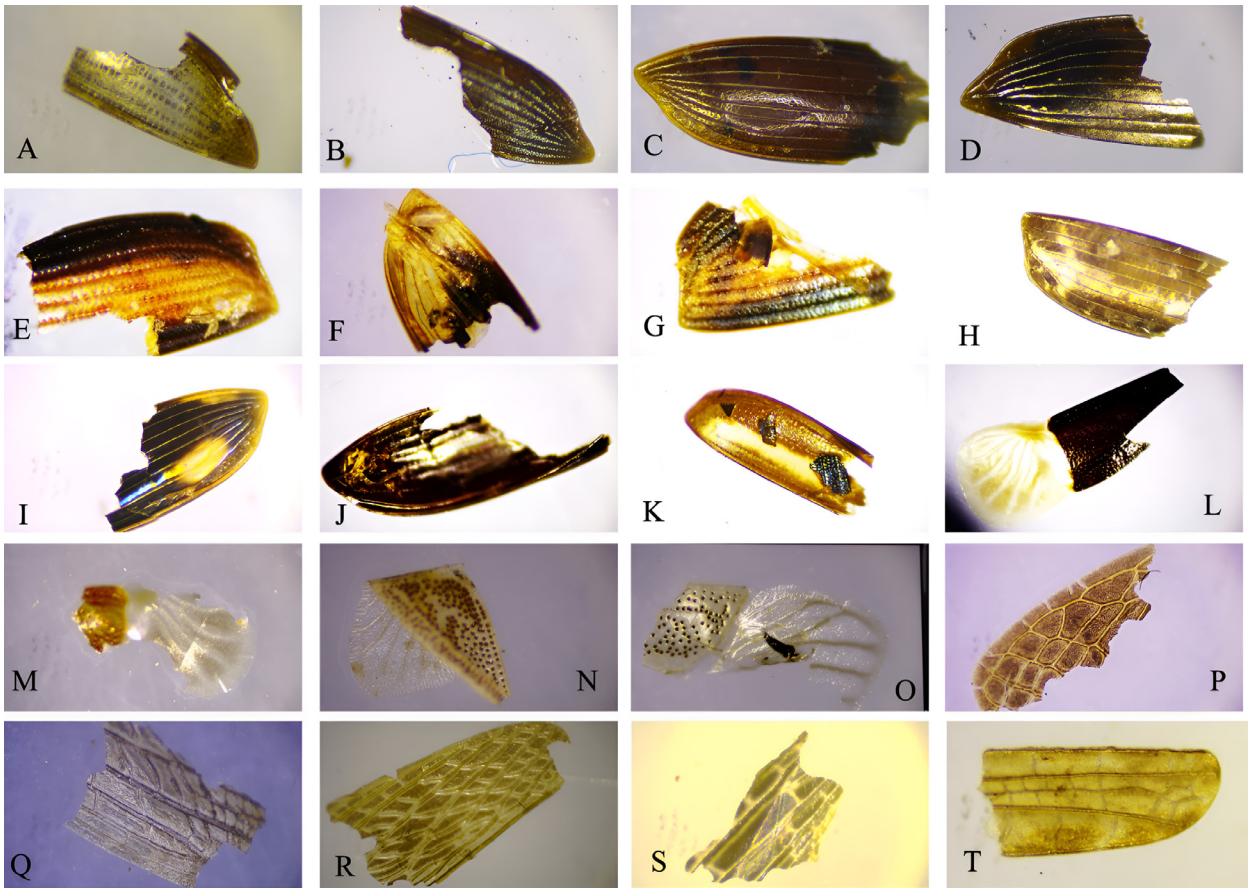

Image 2. Remnants of insect wings isolated from the guano of *Rhinopoma hardwickii*: A–K—Coleoptera | L–O—Hemiptera | P–S—Orthoptera | T—Plecoptera. © Pawan Kumar Misra & Sayma Farheen.

0.563), Diptera (χ^2 = 1.00, p = 0.317), Lepidoptera and Plecoptera (χ^2 = 0.00, p = 1.00).

The food choice of *R. hardwickii* varied with seasons, the remnants of Coleoptera were higher during summer, Hemiptera during winter, and Orthoptera during monsoon seasons (Table 2). The food choice of *R. hardwickii* showed a significant difference during summer (χ^2 = 15.285, p = 0.018), while the food choice did not differ during monsoon and winter seasons (p >0.05, Table 2).

DISCUSSION

The results of present study showed that the Lesser Mouse-tailed Bats consumed insects belonging to eight insect orders across the geographical locations and seasons. The most preferred food items belong to orders Hemiptera, Coleoptera, Orthoptera and least preferred items belong to orders Dermaptera, Diptera, Lepidoptera and Plecoptera. Feldman et al. (2000) and Whitaker & Yom-Tov (2002) investigated the habitat utilization and dietary composition of *R. hardwickii* and found that they used open habitat and fed coleopteran insects which contributed about 51% of the diet. Heteropteran (order Hemiptera) insects were the second most commonly found food items and contributed 30.4% of the diet of *R. hardwickii* (Whitaker & Yom-Tov 2002). The diet selection of many insectivorous bats depends upon dental and cranial morphology, wing shape, and echolocation call (Neuweiler 2000; Altringham 2011; Weterings & Umponstira 2014). The results of faecal pellet analysis revealed that the legs and wings constituted more than 74% of the remnants isolated, while antennae, abdomen, and mouth parts contributed less than 15%. The highest percentage of legs and wings in the isolated remnants probably be due to the composition of chitin in legs and wings.

The Bundelkhand region of Uttar Pradesh comes under dry-arid zone wherein scarcity of water occurs except rainy season, while Lucknow and Barabanki are fertile Gangetic plains. The flora and fauna also vary naturally

among the regions; no difference was observed in the obtained remnants and food choices of *R. hardwickii*. Although, the food choices vary across roost sites (geographical regions) but did not differ significantly. The food choice of *R. hardwickii* was influenced by seasons. The earlier studies deduced that the prey availability and prey selection of most insectivorous bats were probably influenced by temporal, seasonal, and geographical factors (Whitaker 1995; Whitaker et al. 1996).

Arthropods destroy over 18% of the annual production of crops worldwide (Culliney 2014). The use of agricultural insecticides causes harmful impact on consumer and environment. Therefore, use of biocontrol agents for the suppression of insect pest is very important and the insectivorous bats are good source of insect pest suppressors as they consume a large number of insects of various orders. According to Boyles et al. (2013), insectivorous bats decreased the cost of pesticide about USD 22.9 billion a year and also reduced the development of pesticide resistance. Similarly, the current study revealed that the mouse-tailed bats consume a wide range of insects belong to eight orders across seasons, and geographical areas of Uttar Pradesh. Further, the food choice of *R. hardwickii* varies with seasons, and Coleoptera was the most preferred food item in summer, while Hemiptera and Orthoptera were preferred food items during winter and in monsoon seasons, respectively. Since, the mouse-tailed bats consume a lot of insects and play active role as insect suppressor, their roost sites and populations need adequate conservation for their sustenance and human welfare.

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