ECOCYCLES
ISSN 2416-2140

OPEN ACCESS
Scientific journal of the
European Ecocycles Society

Ecocycles, Vol. 10, No. 1, pp. 105-114 (2024)
DOI: 10.19040/ecocycles.v10i1.439

RESEARCH ARTICLE

Roost characteristics of Indian flying fox along urban noise gradient: A case study in Sallaghari Forest, Kathmandu Valley, Nepal

Sandhya Hyongaju[1#], Asmit Subba[1,2#], Madhu Maharjan[1], Laxman Khanal[1]
[1]Central Department of Zoology, Institute of Science and Technology, Tribhuvan University, Kathmandu 44618, Nepal
[2]Conservation Himalaya, Chandragiri-14, Kathmandu 44619, Nepal
[#]Contributed equally
Corresponding author: Laxman Khanal. Email: laxman.khanal@cdz.tu.edu.np

Abstract – The Indian flying fox, *Pteropus medius* is a fruit bat that contributes significantly to seed dispersal and pollination services. These bats face serious threats from the loss of roosting trees due to urbanization and deforestation. This study aimed to assess the roost characteristics of Indian flying foxes and the effects of anthropogenic noise on roost tier selection in an urban forest patch. We carried out population surveys of Indian flying foxes in the Sallaghari Forest in Kathmandu Valley, Nepal by direct roost count method from July to November 2023. Further, we quantified the intensities of anthropogenic noise at every five-meter interval along the transects from the forest edge towards the main forest and recorded the minimum roosting heights at each point. Indian flying foxes were found to be roosting on trees belonging to six species. *Eucalyptus* sp. was the most abundant roost tree (50%) in the forest whereas the highest relative abundance of roosting Indian flying foxes was on *Populus ciliata* (40.1%). The regression analysis revealed that tree DBH and height and the combined interaction of height and canopy cover significantly increase the abundance of Indian flying foxes. The noise intensity at ground level and roosting height of Indian flying foxes showed a significant strong positive relationship indicating their roosting at higher tier under intense noise. We recommend measures for reducing anthropogenic noises and conserving large and tall trees to ensure the roosting habitat of Indian flying foxes in urban setups.

Keywords – Direct roost count, *Eucalyptus*, fruit bat, Indian flying fox, urban forests

Received: June 15, 2024 Accepted: August 21, 2024

1. INTRODUCTION

The Indian flying fox, *Pteropus medius* (Megachiroptera: Pteropodidae) is one of the biggest fruit bats in the world. They are native to the Indian sub-continent and are widely dispersed across Southeast and South Asian countries including Bangladesh, Bhutan, Maldives, Myanmar, Nepal, Pakistan, Sri Lanka, and Tibet Autonomous Region of China (Tsang, 2020). Indian flying foxes are frugivorous bats feeding on varieties of wild and cultivated fruits and flowers and playing a key role in forest rejuvenation because of their ability to preserve the seeds in their gut for many hours (Javid et al., 2017; Shilton et al., 1999). Their long-distance foraging behavior (Tidemann and Nelson, 2004; Epstein et al., 2009) plays an imperative role in seed dispersal and pollination (Nyhagen et al., 2005). However, due to extensive urbanization and clearing of tall trees, they are losing their habitats, especially in rapidly urbanizing areas like Kathmandu Valley (Ishtiaque et al., 2017; Chauhan et al., 2021).

Indian flying fox is a communal species that inhabits large day roosts (12–14 hours daily) close to water sources, forests, or agricultural lands (Pandian and Suresh, 2021; Tsang, 2020; Meade et al., 2021). They prefer to roost on well-exposed large trees such as *Mangifera indica*, *Eucalyptus globulus*, *Ficus bengalensis,* and *Tamarindus indica* (Chakravarthy et al., 2009; Katuwal et al., 2019), *Dalbergia sissoo*, *Cinnamomum camphora*, *Albizia procera*, *Cedrela toona*, *Celtis australis*, *Taxodium mucronatum*, *Diospyros peregrine*, *Kigelia pinnata*, *Manilkara hexandra*, *Pterospermum acerifolium* and *Putranjiva roxburghii* (Gulraiz et al., 2015). Bats roosting on trees generally favor large and tall trees that offer ample surface area for roosting and protection (Kalcounis-Rüppell et al., 2005). Roosting plays a central role in the daily lives and survival strategies of the Indian flying foxes. It primarily influences their behavior, reproduction, and overall population dynamics (Mildenstein et al., 2016). Selection of a suitable roost provides bats with the benefits of better maternal care, enhanced mating opportunities, and improved social interaction. They prefer isolated, elevated, and sheltered locations that offer protection from adverse weather conditions and predators (Kerth et al., 2003; Kunz et al., 2003; Pandian and Suresh, 2021).

Bats use echolocation for navigation and hunting, emitting high-intensity sounds and listening to the echoes bouncing off objects (Surlykke et al., 2008). Anthropogenic intrusions, such as urban development, traffic, or industrial activities, can interfere with these echolocation calls, disrupting the bats' ability to effectively navigate and perceive their environment (Siemers & Schaub, 2010). The ubiquitous rise in anthropogenic noise has led to the variation in noise levels across different areas within an urban environment (Blumstein et al., 2011). This could have particularly strong effects on obligate tree roosting fruit bats. High-intensity noises in urban vicinities can mask acoustic communication (Pearson and Clarke, 2019) and cause stress to the fruit bats triggering an increase in their cortisol level and even a spillover of viruses in their excreta (Edson et al., 2015; Walsh et al., 2017). Indian flying foxes exhibit a preference for roosting at higher heights within trees or structures that provide them with a quieter environment for resting and communication, away from the din of the city streets (Russo et al., 2018). This may cause them to shift their roosting habits and plausibly force them to thrive in suboptimal habitats with inadequate resources.

Despite diversified ecological and economic values, Indian flying foxes are often least prioritized in conservation and management plans due to the lack of knowledge about their population status and habitat requirements (Francis, 2008). The limited available studies on Indian flying foxes in Nepal have been focused on population status and behavior (Koju, 2008; Manandhar et al., 2017; Katuwal et al., 2019). Roosting colonies of Indian flying foxes in several districts of Nepal have shown dramatic population declines in recent decades due to tree felling and hunting for bushmeat (Katuwal et al., 2019). Few studies in India (Gulraiz et al., 2015; Kumar and Kanaujia, 2017) elucidate the effect of roost characteristics on their colony size, however, information regarding the roost tier preference of Indian flying foxes in urban setups is still scanty. Anthropogenic noise in rapidly urbanizing areas might pose behavioral, physiological, reproductive, and survival challenges to the fruit bats inhabiting fragmented forest patches (Francis and Barber, 2013; Bunkley et al., 2015). Animals might tend to avoid such noises by modifying their roosting behavior (Ditchkoff et al., 2006). With increasing anthropogenic pressure, the noise level in Kathmandu has reached beyond the permissible limit of WHO and the National Sound Quality Standard of Nepal, 2012 (Chauhan et al., 2021). The effects of anthropogenic noise on the roosting site selection of Indian flying foxes have not been analyzed yet. Bats colonies have been observed in several places of Kathmandu Valley such as Godawari, Nagarjun, Pharping, Panimuhan, Nagarkot, Chobhar, Sundarijal, Sankhu, Bajrabarahi, Kesharmahal, Sallaghari, etc (Thapa et al., 2010). Sallaghari Forest is one of the potential roosting sites for fruit bats. However, the area is currently experiencing a great deal of physical transformation which in turn affects the bat population. Hence, this study intends to provide knowledge on the roosting preference of Indian flying foxes and the effect of anthropogenic noise on their roost tier selection in Sallaghari, Bhaktapur, Nepal. We hypothesized that i) roost characteristics (such as canopy cover, height, etc.) influence the colony size of Indian flying foxes (taller trees and higher canopy coverage provide a safer roost); and ii) anthropogenic noise intensity affects their roosting height selection (at higher intensity of noise, they roost on upper tier). To test these hypotheses, we identified the population status, major roost trees, and roosting habitat characteristics of Indian flying foxes in Sallaghari Forest and analyzed the roost tier preference in response to anthropogenic noise intensity.

2. Materials and Methods

2.1 Study area

This study was conducted in the Sallaghari Forest of Bhaktapur Municipality in the Kathmandu Valley (Figure 1). The precise geographical location of the site is between 27º26' to 27º44' northern latitude and 85º21' to 85º32' eastern longitude and has an elevation of around 1,332 m above sea level (masl). The core forest covers approximately an area of 0.16 km^2. The study area experiences a mild and moderate climate with an average annual temperature of 20–25 °C and an average annual rainfall of 2596 millimeters (DDC, 2020). The forest is dominated by *Pinus roxburgii*, however, *Eucalyptus* sp. *Populus ciliata*, *Grevillea robusta*, *Celtis australis*, *Cinnamomum camphora*, *Morus alba*, etc. are also common in the area. The study site is located within the premise of Sainik Aawasiya Mahavidhyalaya of Sallaghari, Bhaktapur, and is surrounded by agricultural lands, roads, and buildings.

2.2 Population count

The population surveys were done from July to November 2023. Indian flying foxes were counted on each roost using the direct roost count method (Kunz et al., 2009). Counts were done by enumerating the number of Indian flying foxes on individual trees which was considered as a colony (Kunz et al., 2009), and then summed across all trees to get the total population at a time. A colony was defined as a discrete group of Indian flying foxes that formed a social unit on each roosting tree at the time of observation and the sum of all individuals from all the colonies formed the population (Kunz et al., 2009). Only the trees with more than two individuals were considered for counting. The Indian flying fox count on each tree was done with the consent of two observers' simultaneous estimates. Binoculars (Nikon Monarch M7 10×42) were used to spot the Indian flying foxes. Counts were made during day hours between 11:00–16:00 when most of the Indian flying foxes were on rest (Koju and Chalise, 2010; Kumar et al., 2019; Htun, 2021).

2.3 Roost survey

Different species of roost trees occupied by Indian flying foxes were identified and marked. Roost characteristics such as Diameter at breast height (DBH), tree height, and canopy cover were measured. Circumference of the roosting trees was measured approximately 4.5 feet above the tree base using measuring tape and DBH was calculated by dividing the tree circumference by 3.141. For the measurement of roost heights, a laser rangefinder (REVASRI NK600, magnification 6.5×, range 5–600m) was used to find out the perpendicular distance from the observer to the base of the tree (b) and the angular distance to the tree height (h), and then the tree height (p) was calculated using Pythagoras's theorem ($h^2 = p^2 + b^2$). Canopy cover was measured using Canopy capture application version: 1.0.2. A sound level meter (Mengshen Decibel Meter of the range 30 dB to 130 dB with an accuracy of ±1.5 dB) was used to record intensities of noise along a transect (n = 15, length 20 – 75 m) noted at every five-meter interval from the forest-road edge towards the main forest. The noise intensity was measured for two minutes (repeated at least three times to get a steady reading and then averaged) at every spot from morning 8:00 to 11:00 AM when flying foxes were typically present in the roosts. The instrument was held 1.2 meters above the ground surface to avoid the degradation of sound from reflection (Hanafi et al., 2019). All the variables in the field, except the population survey, were collected by a single observer (SH).

2.4 Data analysis

Tree species that were identified as roost were numbered consecutively and visited twice every week (eight visits per month) and the colony of Indian flying fox on the roost was recorded on each visit. Counts were avoided during heavily rainy days. The total population of Indian flying fox on each month was analyzed quantitatively and averaged. The relative abundance of each roost tree and the mean relative abundance of the Indian flying fox were calculated using the formula:

$$\text{Relative abundance of each roost tree species (\%)} = \frac{\text{number of individual roost tree species}}{\text{total number of all roost trees}} \times 100$$

$$\text{Relative abundance of Indian flying fox in each roost tree species (\%)} = \frac{\text{number of Indian flying fox in individual roost tree species}}{\text{total number of Indian flying fox in all roost trees}} \times 100$$

Before the statistical analysis, a multicollinearity test was done with Variance Inflation Factor (VIF) values after the variables were scaled. The VIF values for all the variables were < 3, so all the variables were considered for the analysis. Generalized linear mixed modeling (GLMM) with Poisson distribution was conducted to examine the effect of roost characteristics on the colony size of Indian flying foxes. Backward elimination was conducted to choose a suitable model. We considered variables DBH, tree height, and canopy cover, height: DBH, and height: canopy cover are fixed effects, and tree type was considered as random effects. Linear regression analysis was performed to analyze the relation between noise intensity and roost height selection. All the statistical analyses were done in R statistical tool v.4.2.1 using the ‘lme4, ggplot2, sjplot, ggeffects packages (R Core Team, 2023). The QGIS version 3.24.0 (QGIS Development Team, 2024) was used to create a map of the study area (Figure 1).

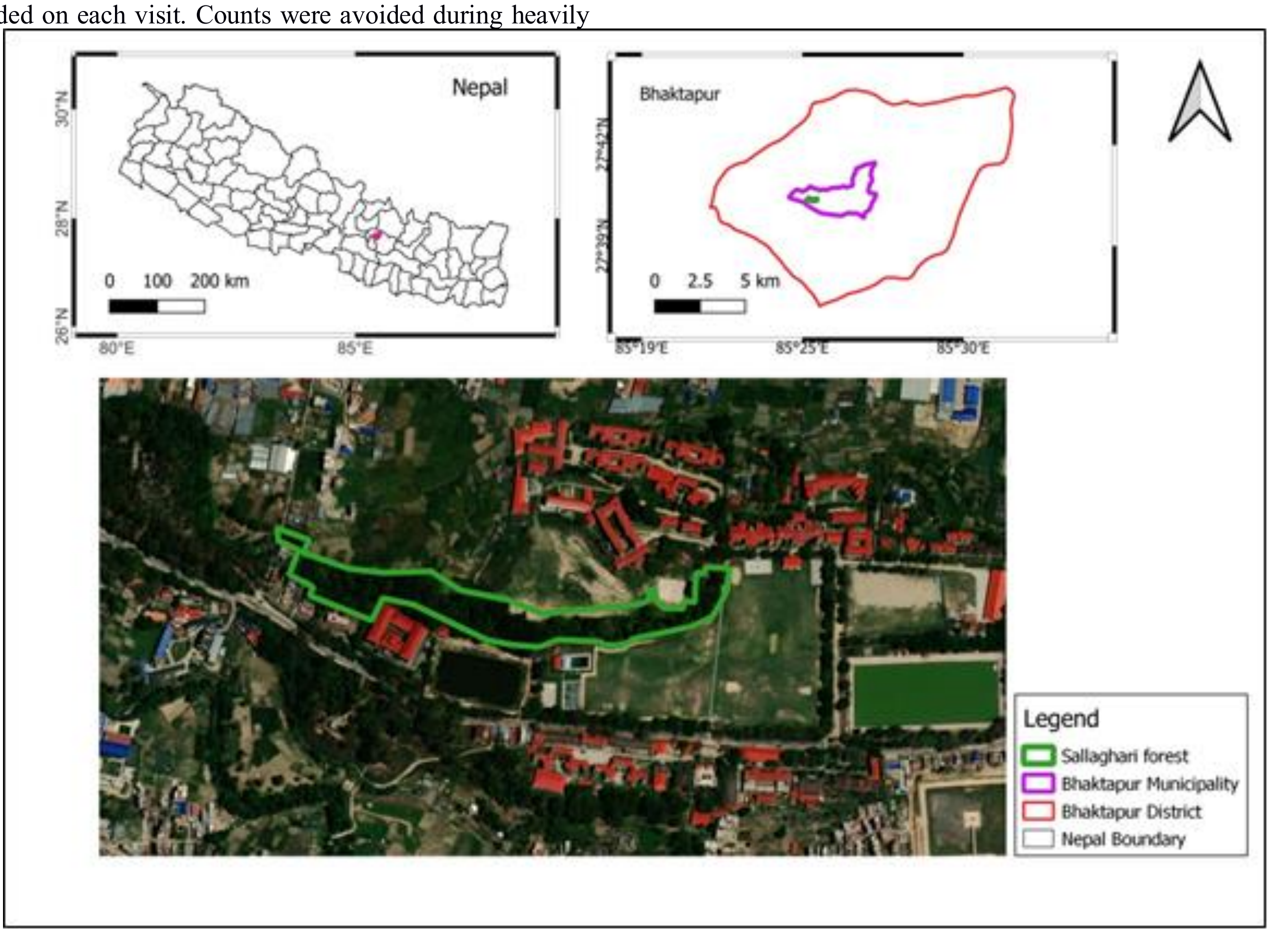

Figure 1. Map of the study area showing Sallaghari Forest in Bhaktapur, Nepal

3. RESULTS

The population size of Indian flying foxes in Sallaghari Forest differed among the study months (1,289 ± 199, n = 5). The highest number of individuals was observed in October (1,525 individuals) whereas the least was observed in July (1,020 individuals) (Figure 2). The population size of the Indian flying fox consistently increased from July reaching peak population in October whereas it started dropping with the onset of November (1,250).

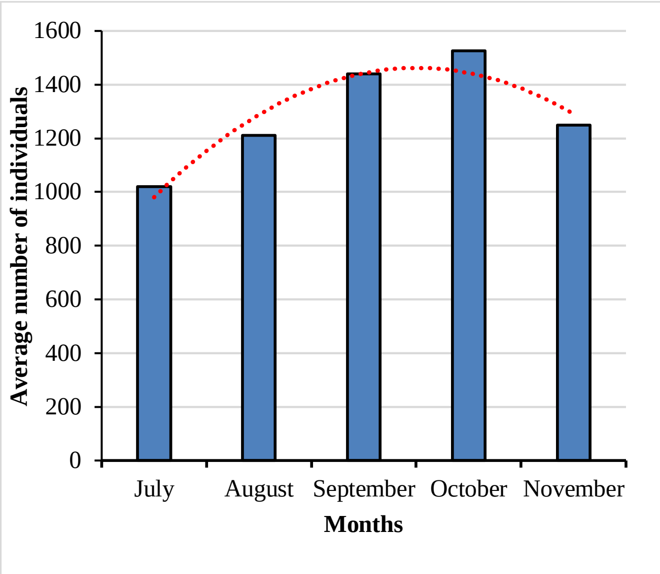

Figure 2. Average population of Indian flying foxes in Sallaghari Forest in different study months. The red dotted line indicates the monthly trend of the population

A total of 40 trees belonging to six species were used as roost trees by Indian flying foxes in the Sallaghari Forest (Table 1). *Eucalyptus* sp. was found to be the most abundant roost tree species accounting for a total of 50% (n = 20) of all roost trees whereas *Populus ciliata* exhibited the second most profuse species with the relative abundance of 18% (n = 7). The colony size of the Indian flying fox revealed the highest relative abundance in *Populus ciliata* (40.1%), followed by *Eucalyptus* sp. (26.8%). This indicates that *Populus ciliata* and *Eucalyptus* sp. are mostly preferred roost trees by Indian flying foxes compared to other roost tree species (Table 1).

The average DBH, tree height and canopy cover of the roost trees were found to be 57.67 ± 17.11 cm, 17.76 ± 7.77 m and 78.38 ± 12.3%, respectively. The average DBH ranged from a maximum of 62.5 cm (*Populus ciliata*) to a minimum of 34.9 cm (*Salix* sp.). The average height of the roosting trees varied between 8.8 m (*Salix* sp.) and 21.9 m (*Eucalyptus* sp.). The average canopy cover ranged from a minimum of 43% (*Salix* sp.) to a maximum of 85.1% (*Populus ciliata*) (Supplementary figures S1-S3). The tree DBH and height showed a significant positive effect outcome with the same estimate of 0.944 (both $p < 2\times10^{-16}$) on the colony size of the Indian flying fox (Table 2, Figure 3). However, the interaction between tree DBH and height (Estimate = -0.165, p = 0.00055) was significant and negative, indicating that the combined effect of increasing both DBH and height together was lesser than the sum of their individual effects (Figure 4). On the other hand, the interaction between tree height and canopy cover (Estimate = 0.186, p = 0.00013) was positive

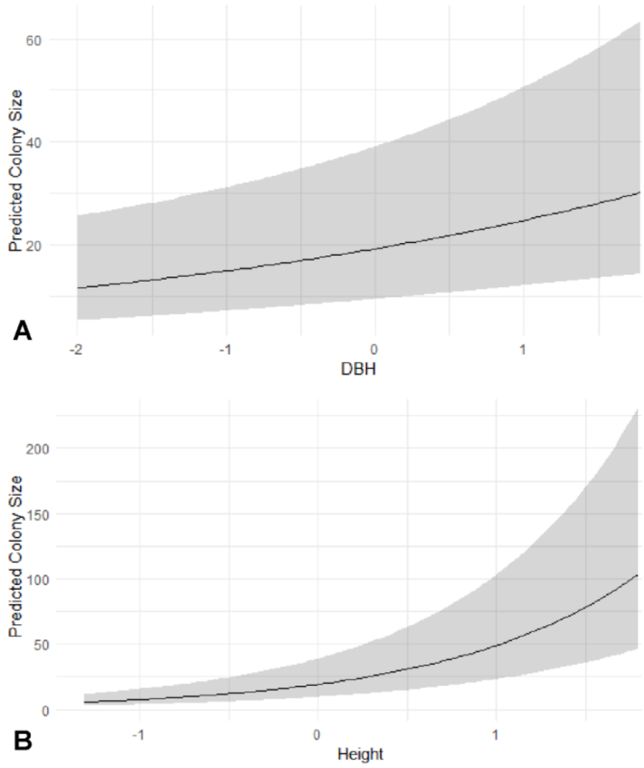

Figure 3. Relationship of Indian flying fox colony size with (A) tree DBH and (B) tree height

Table 1. Roost trees used by Indian flying fox in Sallaghari Forest showing the relative abundance of roost trees and roosting colonies

Roost tree species	Average DBH (cm)	Average height (m)	Average CC (%)	RA of roost trees (%)	RA of colonies (%)
Eucalyptus sp.	59.6	21.9	79.9	50	26.8
Populus ciliata	62.5	12.4	85.1	18	40.1
Grevillea robusta	59.3	15.3	82	10	9.6
Celtis australis	55.5	11.7	80.5	10	8.9
Persea sp.	57.3	25.3	81	5	12.1
Salix sp.	34.9	8.8	43	8	2.6

Note: CC- canopy cover, DBH- diameter on breast height, RA- relative abundance

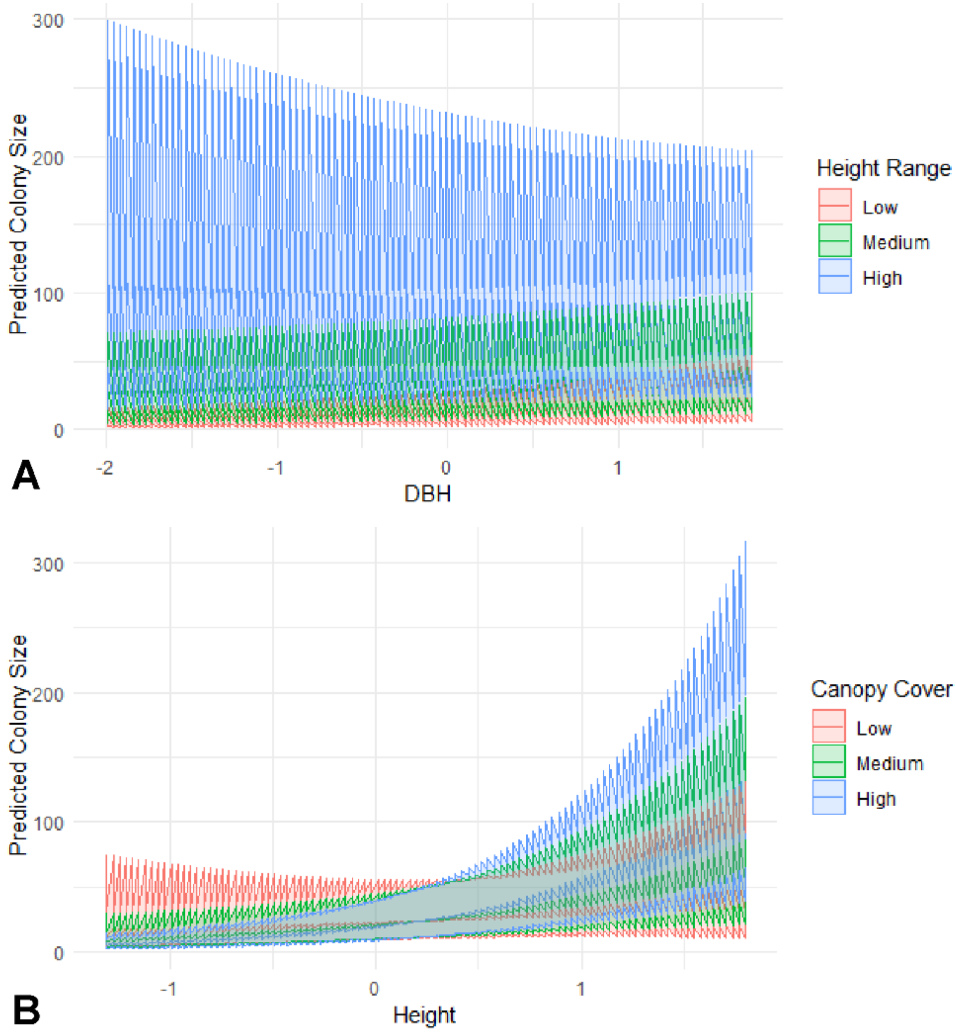

Figure 4. Effects of roost tree characteristics on the colony size of Indian flying fox. (A) the combined impact of tree height range (low: 7.59-15.64, medium: 15.64-23.69 and high: 23.69-31.74) and DBH with the colony size; (B) the combined impact of canopy cover percentage range (low:35-53.33%, medium: 53.33-71.67% and high:71.67-90%) and tree height with colony size

and significant, suggesting that the effect of height on the outcome variable was amplified when the canopy cover was higher (Table 2).

Populus sp., *Celtis* sp., *Salix* sp., *Persea* sp., *Grevillea* sp., and *Eucalyptus* sp. have positive random effects, with estimates centered around 5.2, 1.23, 0.61, 0.39, 0.83, and 0.86, respectively (Supplementary Figure S4). These values suggest that these species exhibit relatively high to moderate positive deviations from the overall model predictions. Compared to the other species, *Populus* sp. exhibits a distinct response that stands out significantly. This implies that *Populus* sp. provides a particularly favorable environment or conditions that lead to larger colonies. On the other hand, *Persea* sp. trees have the smallest impact on colony size, with an effect size of 0.39, suggesting that the colonies in these trees tend to be the smallest.

The noise intensity in the Sallaghari Forest ranged from a minimum of 52.4 dB to a maximum of 89.3 dB. The highest intensity of noise (89.3 dB) was recorded at the forest edge towards the road. At the point of the highest noise intensity, the lowermost roosting height of Indian flying foxes from the ground was 23.9 m. The minimum roosting height of the Indian flying foxes was 8.8 m in an area with the least noise intensity (52.4 dB). Linear regression analysis showed a

Table 2. Summary of GLMM explaining the effect of the roost characteristics on colony size of Indian flying foxes

	Estimate	Std. Error	z value	Pr (>|z|)
Intercept	2.97964	0.34673	8.594	2×10^{-16} ***
DBH	0.94449	0.09239	10.223	2×10^{-16} ***
Height	0.94449	0.09239	10.223	2×10^{-16} ***
DBH: Height	-0.16493	0.04771	-3.457	0.00055 ***
Height: Canopy cover	0.18588	0.04852	3.831	0.00013 ***

significant strong positive relationship between noise intensity and roosting height of Indian flying foxes in the study area (r = 0.915, $p < 0.0001$) (Figure 5). This indicates that the Indian flying foxes prefer roosting at higher trees when the noise intensity increases.

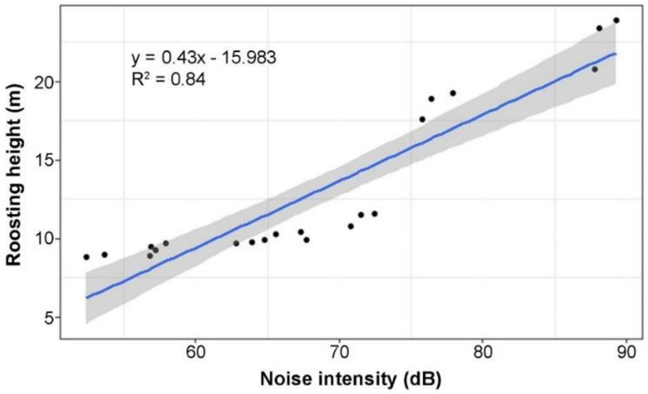

Figure 5. Relationship between anthropogenic noise intensity and roosting height, the grey area shows the 95% highest posterior density

4. DISCUSSION

4.1 Roost characteristics of Indian flying foxes

This study surveyed the population status of the Indian flying foxes in the Sallaghari Forest of Bhaktapur in Kathmandu Valley and assessed their roosting characteristics from July to November 2023. The highest count of Indian flying foxes (1,525 individuals) was in October. An increased population size of Indian flying foxes was observed from July to October whereas their number decreased with the onset of November as the temperature started to drop. This implies the probable local migration of flying foxes toward or away from the roost. The migratory pattern of highly mobile species like the Indian flying fox is poorly explored (Roberts et al., 2012) and knowledge of their behavior and ecology during migration is scarce (Mickleburgh et al., 2002). Indian flying foxes mostly depend on varieties of foods present nearby roost and travel a long distance in search of food (Tiwari et al., 2019). The availability or lack of food supplies might determine their migration (Acharya, 2006; Koju, 2008; Mishra et al., 2019).
The roost tree species in the Sallaghari Forest included *Eucalyptus* sp., *Populus ciliata*, *Grevillea robusta*, *Celtis australis*, *Persea* sp. and *Salix* sp. Vendan & Balasubramanian (2011) observed tress like *Albizia lebbek*, *Artocarpus integrifolia*, *Eucalyptus globulus*, *Eugenia jambolana*, *Ficus benjamina*, *Ficus glomerata*, *Tamarindus indica*, *Azadirachta indica*, *Mangifera indica*, *Polyalthia longifolia*, *Dilonex regia*, etc. served as roosts for Indian flying fox in Tamilnadu, India. *Tamarindus indica*, *Ficus religiosa* and *Madhuca latifolia* were identified as the most preferred roosting trees in Tamilnadu (Pandian and Suresh, 2021). The preference for different roost trees reveals the occupancy of diverse tree species by Indian flying foxes (Koju, 2008; Chakravarthy et al., 2009; Ali, 2010; Dey et al., 2013; Kumar & Kanaujia, 2017; Mishra et al., 2019).

Eucalyptus sp. was the most abundant roost tree in the study area with 20 individual trees (50%) of the species being used as roosts by the bats. *Populus ciliata* exhibited the highest value for relative abundance of Indian flying fox followed by *Eucalyptus* sp. Preference for *Populus ciliata* over other roosting trees might be because *Populus* trees often contain natural crevices or loose barks that secure their environment and are highly branched with suitable spacing that makes them desirable roosting sites for Indian flying foxes. Also, tall and large *Eucalyptus* trees provide ample space for the Indian flying foxes to get more sunlight for basking. Mishra et al. (2019) observed that *Terminalia arjuna* was the most favored species for roosting whereas *Bombax ceiba* and *Cassia fistula* were the least favored roost trees in Delhi, India. Thapa (2008) observed *Dalbergia sissoo*, *Mangifera indica* and *Bombax ceiba* as the major roosting trees in the eastern lowland of Nepal whereas Senthilkumar and Marimuthu (2012) found *Ficus benghalensis*, *Terminalia indica* and *Bassia latifolia* as dominant roost trees in southern India. These varied preferences in different areas indicate that rather than the plant species, the traits of available trees such as their height, canopy cover, etc. determine the roost preference of Indian flying foxes.

The colony size of Indian flying foxes roosting in a particular tree is influenced by roost tree characteristics such as roost height, DBH, and canopy coverage. Fruit bats prefer roosting in trees with greater DBH, height and canopy coverage (Kumar & Kanaujia, 2017). In the present study, DBH and the height of the roost trees collectively influenced the population size of Indian flying foxes. Numerous studies suggest that Indian flying foxes prefer to roost in trees with increased DBH and greater height that can accommodate huge colony sizes and provide protection (Gumal, 2004; Vyas & Upadhyay, 2014; Sharma & Rai, 2020; Madala et al., 2022). However, the findings of this study contradict Gulraiz et al. (2015) in which flying foxes preferred to roost on trees with small diameters. Pandian & Suresh (2021) observed that tree height does not necessarily influence the roost preference of Indian flying foxes. The GLMM indicated tree DBH and height as the significant roost characteristic imparting the major role in determining the colony size. This implies that the colony size increases with the increase in tree DBH and height of roost trees. However, the combined effect of increasing both DBH and height together is less than the sum of individual effects. Trees with a larger DBH are often durable and resistant to wind, rain and drought (Kumar & Elangovan, 2019). Trees having greater height are often found to have higher DBH (Metzger, 1893) that doesn't mean they largely signify the result. Tall trees with well-exposed greater canopy areas support the Indian flying foxes in flights during take-off and landing and serve as a protective refuge from threats.

4.2 Effects of anthropogenic noise on roosting height

The urban environment is often filled with anthropogenic noises arising from a multitude of sources. Traffic is a significant contributor to noise pollution (Bonsen et al., 2015) in urban areas. Noise pollution can disrupt the ability of Indian flying foxes to communicate, navigate, and locate prey, which can have negative impacts on their feeding habits, mating behavior, and overall survival (Bunkley & Barber, 2015; Lara-Nuñez et al., 2022). Noise frequency often overlaps with the sound frequencies of prey in urban settings which usually affects the foraging skill of some species like bats (Page and Bernal, 2020; Domer et al., 2021). To compensate for such effects bats may exhibit the preference to roost on upper tree tiers where the noise levels become comparatively lower and ease them with better communication and protection. The present study revealed that the lowermost roosting height of flying foxes was found to be 23.9 m at the edge of the forest close to the main road where traffic noise was dominant (89.3 dB) whereas the minimum roosting height was found to be 8.8 m at an area where the lowest noise intensity (52.4 dB) was recorded. A strong positive relationship between noise intensity and the roosting height of Indian flying foxes was revealed in the study area. This indicates that the roosting height of flying foxes ascends with the increase in noise intensity in their surroundings. The result suggests that the fruit bats in Sallaghari tend to avoid anthropogenic noise by roosting at higher heights on trees where noise levels become lower. Schaub et al. (2008) also observed that bats tend to avoid roosting in noisy areas. The Sallaghari area has been one of the peaceful habitats for Indian flying foxes as they have lived in comparatively peaceful and non-intruded environments for a long time. However, human encroachment has increased significantly in the area within these few years (Manandhar et al., 2017; Prajapati et al., 2020). Koju (2008) reported the presence of Indian flying fox colonies on either side of roads, but currently, they seem to have avoided roosting near the road. Only a few Indian flying foxes were found roosting in the southern part of the road where they were observed hanging comparatively at upper heights. Russo & Ancillotto (2015) mentioned that the Indian flying fox population may decline in areas with intense noise pollution, like busy roads or industrial zones.

Sallaghari Forest is one of the persistent habitats of Indian flying foxes in Kathmandu Valley. Thus, the conservation and management of large and tall trees that provide favorable roosting environments to the tree-dwelling fruit bats are of primary concern. Also, there is an urgent need to establish routine monitoring of the population and roosting habits of Indian flying foxes. Moreover, future studies should focus on the impact of anthropogenic noise on roosting behavior and a multitude of physiological aspects (communication, stress, reproduction, viral shedding, etc.) of Indian flying foxes. This endeavor will ensure the conservation of the species as well as attenuate the negative impacts of urbanization on them. Hence, we endorse the urban afforestation practice that will benefit the Indian flying fox and other species thriving in urban habitats.

5. Conclusions

This study provides insightful information on the population status, roost characteristics and roost tier selection of Indian flying foxes along noise gradient in Sallaghari Forest, Bhaktapur, Nepal. It is acknowledged that the study was conducted in a single forest patch in the Kathmandu Valley for two seasons only. A better understanding of roosting characteristics would have been obtained if multiple forest patches were surveyed year-round. We recommend a comprehensive survey of Indian flying foxes in potential habitats within the Kathmandu Valley covering all the seasons. Indian flying foxes were found to be roosting in tall trees including *Populus ciliata*, *Eucalyptus* sp., *Persea* sp., etc. and their colony sizes showed positive associations with the DBH, height, and canopy cover of the roosting trees. Results revealed a significant positive relationship between noise intensity and the roosting height of Indian flying foxes indicating avoidance of the anthropogenic noise. Therefore, anthropogenic noise mitigation strategies such as a declaration of 'no horn zone' along the adjacent road, roadside plantation, community awareness on fruit bats conservation, legal protection for roosting trees, etc. are recommended in the roosting habitats of the Indian flying foxes. This study signified the essence of conserving large and tall trees to promote the roosting habitat of Indian flying foxes.

Acknowledgements

We thank the Department of Forest and Soil Conservation, Government of Nepal and the Bhaktapur Municipality for the research permissions. We appreciate Dikpal Krishna Karmacharya, Rinzin Lama, Rabi Bati, Rosary Karki, and Madan Acharya for their support during fieldwork.

Authors' Contributions

L.K. conceptualized the study. S.H. and M.M. conducted the fieldwork; S.H., A.S. and M.M. analyzed the data. S.H. and A. S. prepared a draft of the paper. L.K. supervised the overall research. All authors read, gave their input and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Acharya, P. R. (2006). *Distribution of roosting and survival threats of bats in Pokhara Valley concerning species and population survey at Chamero Gupha* (MSc dissertation). Central Department of Zoology, Tribhuvan University, Kirtipur, Kathmandu, Nepal.

Ali, A. (2010). Population trend and conservation status of Indian flying fox *Pteropus giganteus* Brunnich, 1782 (Chiroptera: Pteropodidae) in Western Assam. *The Ecoscan*, *4*(4), 311–312.
DOI: 10.12691/aees-8-5-16

Bhaktapur District Profile. (2020). *Brief introduction of Bhaktapur.*
https://dccbhaktapur.gov.np/en/brief-introduction/ (Accessed on 26 September 2023)

Blumstein, D. T., Mennill, D. J., Clemins, P., Girod, L., Yao, K., Patricelli, G., & Cortopassi, K. A. (2011). Acoustic monitoring in terrestrial environments using microphone arrays: Applications, technological considerations and prospectus. *Journal of Applied Ecology*, *48*(3), 758–767.
DOI: 10.1111/j.1365-2664.2011.01993.x

Bonsen, G., Law, B., & Ramp, D. (2015). Foraging strategies determine the effect of traffic noise on bats. *Acta Chiropterologica, 17*(2), 347–357.
DOI: 10.3161/15081109ACC2015.17.2.010

Bunkley, J. P., & Barber, J. R. (2015). Noise reduces foraging efficiency in Pallid bats (*Antrozous pallidus*). *Ethology*, *121*(11), 1116–1121. DOI: 10.1111/eth.12428

Chakravarthy, A., Yeshvanth, H. M., Vijaykumar, L., & Prasannakumar, N. R. (2009). Giant Indian fruit bat *Pteropus giganteus* Brunnich roost in Karnataka, South India: A case for preservation as a heritage site. *Tiger Paper*, *23*, 25–31.

Chauhan, R., Shrestha, A. & Khanal, D. (2021). Noise pollution and effectiveness of policy interventions for its control in Kathmandu, Nepal. *Environmental Science and Pollution Research*, 28, 35678–35689.
DOI: 10.1007/s11356-021-13236-7

Dey, S., Roy, U., & Chattopadhyay, S. (2013). Distribution and abundance of three populations of Indian flying fox (*Pteropus giganteus*) from Purulia district of West Bengal, India. *Taprobanica: The Journal of Asian Biodiversity*, *5*(1), 60–66.
DOI: 10.4038/tapro.v5i1.5664

Ditchkoff, S. S., Saalfeld, S. T., & Gibson, C. J. (2006). Animal behaviour in urban ecosystems: Modifications to human-induced stress. *Urban Ecosystem*, *9,* 5–12.
DOI: 10.1007/s11252-006-3262-3

Domer, A., Korine, C., Slack, M., Rojas, I., Mathieu, D., Mayo, A., & Russo, D. (2021). Adverse effects of noise pollution on foraging and drinking behaviour of insectivorous desert bats. *Mammalian Biology, 101*(3).
DOI: 10.1007/s42991-021-00101-w

Edson, D., Field, H., McMichael, L., Jordan, D., Kung, N., Mayer, D., & Smith, C. (2015). Flying-fox roost disturbance and Hendra virus spillover risk. *PLoS One*, *10*(5), e0125881.
DOI: 10.1371/journal.pone.0125881

Epstein, J. H., Olival, K. J., Pulliam, J. R. C., Smith, C., Westrum, J., Hughes, T., … & Daszak, P. (2009). *Pteropus vampyrus*, a hunted migratory species with a multinational home-range and a need for regional management. *Journal of Applied Ecology*, *46*(5), 991–1002.
DOI: 10.1111/j.1365-2664.2009.01699.x

Francis, C. M. (2008). *A Guide to the Mammals of Southeast Asia*. Princeton University Press.

Francis, C. D., & Barber, J. R. (2013). A framework for understanding noise impacts on wildlife: an urgent conservation priority. *Frontiers in Ecology and the Environment*, *11*(6), 305–313.
DOI: 10.1890/120183

Gulraiz, T. L., Javid, A., Mahmood-Ul-Hassan, M., Maqbool, A., Ashraf, S., Hussain, M., & Daud, S. (2015). Roost characteristics and habitat preferences of Indian flying fox (*Pteropus giganteus*) in urban areas of Lahore, Pakistan. *Turkish Journal of Zoology*, *39*(3), 388–394.
DOI: 10.3906/zoo-1401-71

Gumal, M. (2004). Diurnal home range and roosting trees of a maternity colony of *Pteropus vampyrus natunae* (Chiroptera: Pteropodidae) in Sedilu, Sarawak. *Journal of Tropical Ecology*, *20*, 247–258.
DOI: 10.1017/S0266467403001275

Hanafi, S., Chong, L. P., Maruthaveeran, S., & Yeong, K. L. (2019). Vocal response of Oriental Magpie Robin (*Copsychus saularis*) to urban environmental factors in Peninsular Malaysia. *Sains Malaysiana 48*(10), 2061–2069.
DOI: 10.17576/jsm-2019-4810-01

Ishtiaque, A., Shrestha, M., & Chhetri, N. (2017). Rapid urban growth in the Kathmandu valley, Nepal: monitoring land use land cover dynamics of a Himalayan city with Landsat imageries. *Environments*, *4*, 72.
DOI: 10.3390/environments4040072

Javid, A., Gulraiz, T. L., Ashraf, M., Nadeem, M., Hussain, S. M., Altaf, M., & Babu, I. (2017). Proximate analysis of Indian flying fox's (*Pteropus giganteus*) natural food, with a note on its roost variations in urban areas of Lahore, Pakistan. *Turkish Journal of Zoology*, *41*, 714–721.
DOI: 10.3906/zoo-1512-24

Kalcounis-Rüppell, M. C., Psyllakis, J. M., & Brigham, R. M. (2005). Tree roost selection by bats: An empirical synthesis using meta-analysis. *Wildlife Society Bulletin*, *33*(3), 1123–1132.
DOI: 10.2193/0091-7648(2005)33[1123:TRSBBA]2.0.CO;2

Katuwal, H. B., Kushwaha, S., & Quan, R. C. (2019). Indian flying fox *Pteropus giganteus* is declining in lowland Nepal: Need of conservation actions. *Journal of Bat Research and Conservation*, *12*(1), 60–63.
DOI: 10.14709/BarbJ.12.1.2019.08

Kerth, G., Almasi, B., Ribi, N., Thiel, D., & Lüpold, S. (2003). Social interactions among wild female Bechstein's bats (*Myotis bechsteinii*) living in a maternity colony. *Acta Ethologica*, *5*, 107–114.
DOI: 10.1007/s10211-003-0075-8

Koju, N. P. (2008). *Population status, general behavior and threats of flying fox (Pteropus giganteus) in Sallaghari, Bhaktapur, Nepal* (MSc dissertation). Central Department of Zoology, Tribhuvan University, Kirtipur, Kathmandu, Nepal.

Kumar, J., & Kanaujia, A. (2017). Roost characteristics and habitat preference of Indian Flying Fox (*Pteropus giganteus*) In Lakhimpur-Kheri, Uttar Pradesh, India. *International Journal of Recent Scientific Research*, *8*(7), 18101–18111.
DOI: 10.24327/ijrsr.0912.2946

Kumar, R., & Elangovan, V. (2019). Effect of tree characteristics on roost selection of the Indian flying fox, *Pteropus giganteus*. *Journal of Bat Research and Conservation, 12*(1), 100–106.
DOI: 10.14709/BarbJ.12.1.2019.13

Kumar, R., Prasad, D.N., & Elangovan, V. (2019). The effect of seasonal changes on emergence behaviour of the Indian flying fox, *Pteropus giganteus*. *Proceeding of the Zoological Society*, 72, 74–78.
DOI: 10.1007/s12595-018-0269-8

Kunz, T. H., Lumsden, L. F., & Fenton, M. B. (2003). Ecology of cavity and foliage roosting bats. In Kunz, T. H. and Fenton, M. B. (Eds.) Bat Ecology. University of Chicago Press, Chicago, Illinois. pp. 779.

Kunz, T. H., Betke, M., Hristov, N. I., & Vonhof, M. J. (2009). Methods for assessing colony size, population size, and relative abundance of bats. In Kunz, T. H. & Parsons, S. (Eds.). *Ecological and behavioral methods for the study of bats* (pp. 133–157). Baltimore: Johns Hopkins University Press.

Lara-Nuñez, A., Guerrero, J., & Rizo-Aguilar, A. (2022). Effect of anthropogenic noise on the echolocation pulses of the bats *Molossus sinaloae* and *Mormoops megalophylla*. *Therya*, *13*, 235–243.
DOI: 10.12933/therya-22-1168

Madala, M. F., Guna, C., Pradeepan, A., & Chalil, A. K. (2022). Roost tree characteristics of *Pteropus medius* (Chiroptera: Pteropodidae) in the midland laterite hillocks of northern Kerala, India. *Journal of Asia-Pacific Biodiversity*, *15*(4), 465–472.
DOI: 10.1016/j.japb.2022.04.011

Manandhar, S., Thapa, S., Shrestha, T. K., Jyakhwo, R., Wright, W., & Aryal, A. (2017). Population status and diurnal behaviour of the Indian flying fox *Pteropus giganteus* (Brünnich, 1782) in Kathmandu Valley, Nepal. *Proceedings of the Zoological Society*, *71*(4), 363–375.
DOI: 10.1007/s12595-017-0219-x

Meade, J., Martin, J. M., Welbergen, J. A., & Quinn, J. (2021). Fast food in the city? Nomadic flying-foxes commute less and hang around for longer in urban areas. *Behavioral Ecology*, *32*(6), 1151–1162.
DOI: 10.1093/beheco/arab078

Metzger, K. (1893). Der Wind als massgebender Faktor für das Wachstum der Bäume. *Mündener Forstliche Hefte*, *3*(1893), 35–86.

Mickleburgh, S. P., Hutson, A. M., & Racey, P. A. (2002). A review of the global conservation status of bats. *Oryx*, *36*(1), 18–34.
DOI: 10.1017/S0030605302000054

Mildenstein, T., Tanshi, I., & Racey, P. A. (2016). Exploitation of bats for bushmeat and medicine. In *Bats in the Anthropocene: Conservation of Bats in a Changing World*, 325–375.

Mishra, R., Dookia, S., & Bhattacharya, P. (2019). Avenue plantations as biodiversity havens: A case study of population status of the Indian flying fox, *Pteropus giganteus* Brunnich, 1782 and implications for its conservation in the urban megacity, Delhi, India. *Proceedings of the Zoological Society*, *73*(2), 127–136.
DOI: 10.1007/s12595-019-00308-3

Nyhagen, D. F., Turnbull, S. D., Olesen, J. M., & Jones, C. G. (2005). An investigation into the role of the Mauritian flying fox, *Pteropus niger*, in forest regeneration. *Biological Conservation*, *122*(3), 491–497.
DOI: 10.1016/j.biocon.2004.08.012

Page, R. A. & Bernal, X. E. (2020). The challenge of detecting prey: Private and social information use in predatory bats. *Functional Ecology, 34*(2), 344–363.
DOI: 10.1111/1365-2435.13439

Pandian, M., & Suresh, S. (2021). Roosting habits and habitats of the Indian Flying Fox *Pteropus medius* Temminck, 1825 in the northern districts of Tamil Nadu, India. *Journal of Threatened Taxa*, *13*(12), 19675–19688.
DOI: 10.11609/jott.7468.13.12.19675-19688

Pearson, T., & Clarke, J. A. (2018). Urban noise and grey-headed flying-fox vocalisations: evidence of the silentium effect. *Urban Ecosystems*, *22*(2), 271–280.
DOI: 10.1007/s11252-018-0814-2

Prajapati, J., Chalise, M. K., & Karmacharya, D. K. (2020). Habitat and behavioral observation of Indian flying fox *Pteropus giganteus* (Brunnich, 1782) in Sallaghari, Bhaktapur, Nepal. *Journal of Natural History Museum*, *31*(1), 79–94.
DOI: 10.3126/jnhm.v31i1.39376

QGIS Development Team. (2024). QGIS Geographic Information System. Open-Source Geospatial Foundation Project. http://qgis.osgeo.org.

R Core Team. (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Roberts, B. J., Caterall, C. P., Eby, P. & Kanowski, J. (2012). Long distance and frequent movements of the flying-fox *Pteropus poliocephalus*: Implications for management. *PLoS One*, *7*(8), 42532.
DOI: 10.1371/journal.pone.0042532

Russo, D., & Ancillotto, L. (2015). Sensitivity of bats to urbanization: A review. *Mammalian Biology*, *80*(3), 205–212.
DOI: 10.1016/j.mambio.2014.10.003

Russo, D., Bosso, L., & Ancillotto, L. (2018). Novel perspectives on bat insectivory highlight the value of this ecosystem service in farmland: Research frontiers and management implications. *Agriculture Ecosystems & Environment*, *266*, 31–38.
DOI: 10.1016/j.agee.2018.07.024

Schaub, A., Ostwald, J., & Siemers, B. M. (2008). Foraging bats avoid noise. *Journal of Experimental Biology,* 211, 3174-3180.
DOI: 10.1242/jeb.022863

Senthilkumar, K., & Marimuthu, G. (2012). Tree roosting fruit bats (Chiroptera: Pteropodidae) in southern Tamil Nadu. *International Journal of Applied BioResearch*, *14*, 4–10.

Sharma, P., & Rai, M. (2020). Population status of Indian flying fox, *Pteropus giganteus* in urban Guwahati, Assam, India: A Case Study. *Applied Ecology and Environmental Sciences*, *8*(5), 287–293.
DOI: 10.12691/aees-8-5-16

Shilton, L. A., Altringham, J. D., Compton, S. G., & Whittaker, R. J. (1999). Old World fruit bats can be long-distance seed dispersers through extended retention of viable seeds in the gut. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *266*(1416), 219–223.
DOI: 10.1098/rspb.1999.0625

Siemers, B. M., & Schaub, A. (2010). Hunting at the highway: Traffic noise reduces foraging efficiency in acoustic predators. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1712), 1646–1652.
DOI: 10.1098/rspb.2010.2262

Surlykke, A., Pedersen, S., & Jakobsen, L. (2008). Echolocating bats emit a highly directional sonar sound beam in the field. *Proceedings. Biological Sciences / The Royal Society*, *276*, 853–860.
DOI: 10.1098/rspb.2008.1505

Thapa, S. (2008). Reporting *Pteropus* colonies and bat roosts from Eastern Nepal. *Bat Net Newsletter*, *9*(1).

Thapa, S., Suchita, S. and Dahal, S. (2012). Monitoring and conservation of bats in the Kathmandu valley, Nepal. *Asian Jouranl of Conservation Biology*, *1*(1), 1–4.

Tidemann, C. R., & Nelson, J. E. (2004). Long-distance movements of the grey-headed flying fox (*Pteropus poliocephalus*). *Journal of Zoology*, *263*(2), 141–146.
DOI: 10.1017/S0952836904004960

Tiwari, N., Koju, N. P., Acharya, P. R. & Dhamala, M. K. (2019). Diet composition of Indian flying fox (*Pteropus giganteus*) in Kathmandu valley. *Nepalese Journal of Environmental Science*, *7*, 25–30.
DOI: 10.3126/njes.v7i0.34412

Tsang, S. M. (2020). *Pteropus giganteus* (errata version published in 2021). The IUCN Red List of Threatened Species 2020: e.T18725A194134899.
https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T18725A194134899.en. Accessed on 02 Juney 2024.

Vendan, S. E., & Balasubramanian, K. (2011). Plant dispersal by Indian flying fox *Pteropus giganteus* in Madurai region, India. *Elixir BioDiversity*, *30*, 1810–1813.

Vyas, R., & Upadhyay, K. (2014). Study of the Indian flying fox (*Pteropus giganteus*) colonies of Jambughoda Wildlife Sanctuary, Gujarat, India: a record of largest roosting congregation at Targol. *Small Mammal Mail*, *6*(1), 1–8.

Walsh, M. G., Wiethoelter, A., & Haseeb, M. A. (2017). The impact of human population pressure on flying fox niches and the potential consequences for Hendra virus spillover. *Scientific Reports*, *7*(1), 8226.
DOI: 10.1038/s41598-017-08065-z