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Roost site selection and seasonal dynamics of the Indian flying fox (*Pteropus medius*): Influence of environmental and anthropogenic factors

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This study examines the roosting site selection and seasonal dynamics of the Indian flying fox (*Pteropus medius* Temminck, 1825) in relation to environmental and anthropogenic factors. Fifteen roosting sites located in Okara, Kasur and Lahore districts, Punjab, Pakistan were investigated over a two-year period from July 2022 to June 2024. A total of 202 trees were used by *P. medius* as roosting sites representing 28 species, 23 genera and 10 families. Roosting sites with higher bat populations were dominated by *Bombax ceiba* (16.3%), *Eucalyptus* sp. (9.9%), and *Pinus strobus* (8.4%) during winter whereas *Syzygium cumini* (7.9%), *Swietenia mahagoni* (6.4%) and *Ficus benjamina* (6.4%) were more frequently occupied during summer. Significant seasonal fluctuations in bat numbers were observed with protected sites showing minimal changes while non-protected sites had higher bat populations in winter. Protected areas, such as Changa Manga Forest provided more stable environmental conditions, leading to higher and more stable bat populations. The correlation matrix revealed that permanent roosting sites were more strongly associated with higher bat populations. Additionally, bat abundance was positively correlated with canopy cover (r = 0.499), tree diameter at breast height (r = 0.501) and tree height (r = 0.122). Principal component analysis (PCA) highlighted temperature, humidity, and vegetation as key environmental factors influencing roost site selection. The analysis also revealed that anthropogenic activities such as tree cutting and hunting negatively affect bat populations. According to PCA, protected permanent roosts in natural habitats with minimum human interference scored highest followed by permanent protected sites in urban areas, with temporary non-protected sites scoring lowest. A 1.7% decline in bat numbers was recorded over the study period, particularly at non-protected sites due to human-induced disturbances. The findings highlighted the critical need for conservation of roosting habitats, particularly in light of the ongoing threats posed by human activities and climate change.

Keywords: *Pteropus medius*; habitat suitability; seasonal fluctuations; PCA; bat conservation.

Introduction

Bats are a diversified group of mammals from the order Chiroptera found on every continent except Antarctica and a few marine islands and have inhabited on the earth for more than 50 million years, making them one of the oldest mammalian orders (Russo & Fenton et al., 2023; Bat Conservation International, 2024). Overall, bats are represented by 1,460 species globally as the second-largest group of mammalia (Simmons & Cirranello, 2023). Few mammals can glide however, bats are the only flying mammals that have the ability of active flight (Vengust et al., 2018; Anderson & Ruxton, 2020). Bats are cosmopolitan in distribution and in temperate regions these species have behaviors like migration and hibernation (Hutterer et al., 2019). Alteration in natural habitats driven by human activities, climate change and habitat loss has raised concern for bats (Lambert et al., 2018; Frick et al., 2020). Change in precipitation patterns, increased temperatures and the intensification of extreme events have been observed as consequences of climate change and directly affect the global biodiversity (Fowler et al., 2021). Bats live in close proximity to human populations as well as being reported across a wide range of habitats, including desert areas, woodlands and oceanic islands, making them an ideal taxon for study of the impacts of climate change (Ramirez-Francel et al., 2021). Bats control the many pests, help in pollination, seed dispersal, and are used in education and research (Boyles et al., 2011; Ramírez-Fráncel et al., 2022; Deshpande et al., 2022). Habitat requirements of bats must be known for conservation of these environmental friendly creatures (Gulraiz et al., 2015; Gao et al., 2023). However, human induced environmental stresses has resulted in extensive deforestation of roost trees, habitat loss and fragmentation casing major concern (Mickleburgh et al., 2002).

Pakistan is represented by 50 bats species, making them 28% of all the cuntry's mammalian species (Roberts & Bernhard 1977). This includes four species that feed on fruit ; the Indian flying fox (*Pteropus medius*), greater short-nosed fruit bat (*Cynopterus sphinx*), Leschenault's rousette (*Rousettus leschenaultii*), and Egyptian fruit bat (*Rousettus aegyptiacus*) (Mahmood-ul-Hassan et al., 2010). Old world fruit bats are recognized for their vital contribution to seed dispersal, contributing to the regeneration and maintenance of forest ecosystems (Aziz et al., 2021). Indian flying foxes play a vital role as pollinators, seed dispersers and contribute to ecosystem functioning on whole (Devi & Kumar, 2024). The Indian flying fox is the largest species of mega bats in South and Southeast Asia and has the wingspan up to 1.5 meters and weight around 1.7 kg (Wilson, 2015; Rahman & Choudhury, 2017). *P. medius* is reported from Bangladesh, India, the Maldives, Myanmar, Nepal, Pakistan, Sri Lanka and possibly extant in Bhutan and classified as Near Threatened (NT) (IUCN, 2024; Ahmed et al., 2025). *P. medius* is facing many threats such as habitat loss, fragmentation, hunting and culling, and climate change (Dey et al., 2015; Roy et al., 2020; Tella et al., 2020; Murugavel et al., 2023). Despite its ecological importance, the current knowledge regarding its population dynamics, behavior, habitat preferences, spatial distribution and seasonal scattering patterns as well as the associated risks and benefits it brings to ecosystems and human health is limited (Masood et al., 2024). Roost site selection of fruit bats is often complex and associated with biotic and abiotic factors of site (Russo, 2024).

Understanding the factors that influence the spatial and seasonal scattering patterns and roost site selection is important for effective conservation planning and management. Previous research indicates that roost availability, microclimate conditions and proximity to foraging areas plays a vital role in roost selection by bats. Additional factors are seasonal variations in food availability, temperature, humidity and rainfall impact on behavior, reproduction and seasonal movement patterns of *P. medius*. Therefore, assessing the factors affecting the selection of roosting sites by *P. medius* and their seasonal distribution patterns is crucial for the effective conservation strategies for this species and ensuring maintenance of a healthy ecosystem.

Materials and methods

Investigative field surveys were conducted to find out the roosting sites of the Indian flying foxes (*Pteropus medius*) in the districts Okara, Kasur and Lahore, Punjab, Pakistan (Fig. 1). The roosting sites were visited on a monthly basis from July 2022 to June 2024 for two consecutive years. Possible bat habitats such as old and high trees in the grounds of old buildings, farm houses, gardens, forest plantations and trees along bank of rivers or canals were carefully visited and GPS locations of roosting sites were noted and categorized into urban or rural area roosting sites. Selected roosting sites were also classified into protected or non-protected roosting sites on the basis of their presence in protected areas (located in government properties and managed by official authorities) or in non-protected areas (present in public properties and not managed by anyone). Total estimated area of the selected roosting sites with their elevation was noted (Table 1) and the direct roost count method was also used to count the bats at the selected roost sites (Kunz et al., 1996; Mwinyi, 2020). The bats were counted on a monthly basis. Then for each roosting site, the averaged number of bats was calculated for each season viz., spring, summer, autumn and winter.

The data, such as history of roosting sites as per knowledge of local communities, the condition of the trees (dead or alive), tree height, tree diameter at breast height (DBH), canopy cover, solar exposure, location in relation to other trees, spatial relationship to water sources, nearest human settlement, nearest road, nearest industry/factory, nearest railway track and fruit orchard was recorded in a field notebook (Table 2). The number of trees present at each roosting site was recorded as well as the tree species. Tree height was measured using the stick method and a sextant device. To measure the percentage of canopy cover for each roosting site, the following formula was used:

$$\text{Canopy Cover (\%)} = \frac{\text{Total Canopy Cover (Shaded Area)}}{\text{Total Ground Area}} X\ 100$$

Moreover, tree diameter was measured at breast height (DBH) for each tree and later average diameter at breast height (DBH) of all the trees was calculated for each roosting site.

$$\text{DBH} = \frac{\text{Circumference}}{\pi} \qquad (\pi = 3.1416)$$

$$\text{Average DBH} = \frac{\text{DBH1+DBH2+ ....+DBH(n)}}{n}$$

Average temperature (minimum and maximum) on a monthly basis and humidity level was recorded at 08:00 AM and 05:00 PM, Illegal and harmful activities such as hunting, killing or culling of bats, cutting of trees, loud sounds, fire smoke or other causes of disturbance to roosting sites and major changes at roosting sites with their reasons were also noted after observations and questioning of residents living near roosting sites. Environmental attributes such as temperature and humidity were obtained from the Regional Meteorological Center (RMC) in Lahore, following the approval of the application by the Pakistan Meteorological Department.

GPS coordinates of roosting sites along with photographs were taken. The distances between the species' roosts and the nearest water body, nearest human settlement, nearest road, nearest industry / factory, nearest railway track and fruit orchard were measured using GPS Essentials mobile app and Google Earth Pro (Table 2). A GIS-based distribution map of bats was constructed using R software (R 4.4.3) and ArcGIS 10.1 (ESRI, 1996) in the GIS and Remote Sensing Lab, Department of Wildlife and Ecology, UVAS, Ravi Campus.

The collected data was analyzed using time series analysis and repeated measures ANOVA to identify seasonal trends in bat numbers at all selected roosting sites. Correlation analysis was done to explore the relationship between bat numbers and environmental factors like temperature, humidity and other roost site characteristics. Furthermore, the multivariate analysis with principal component analysis (PCA) was used to find the patterns in the best roosting sites and environmental factors to understand how bats choose their roosts during different seasons. All statistical analyses were conducted using R software.

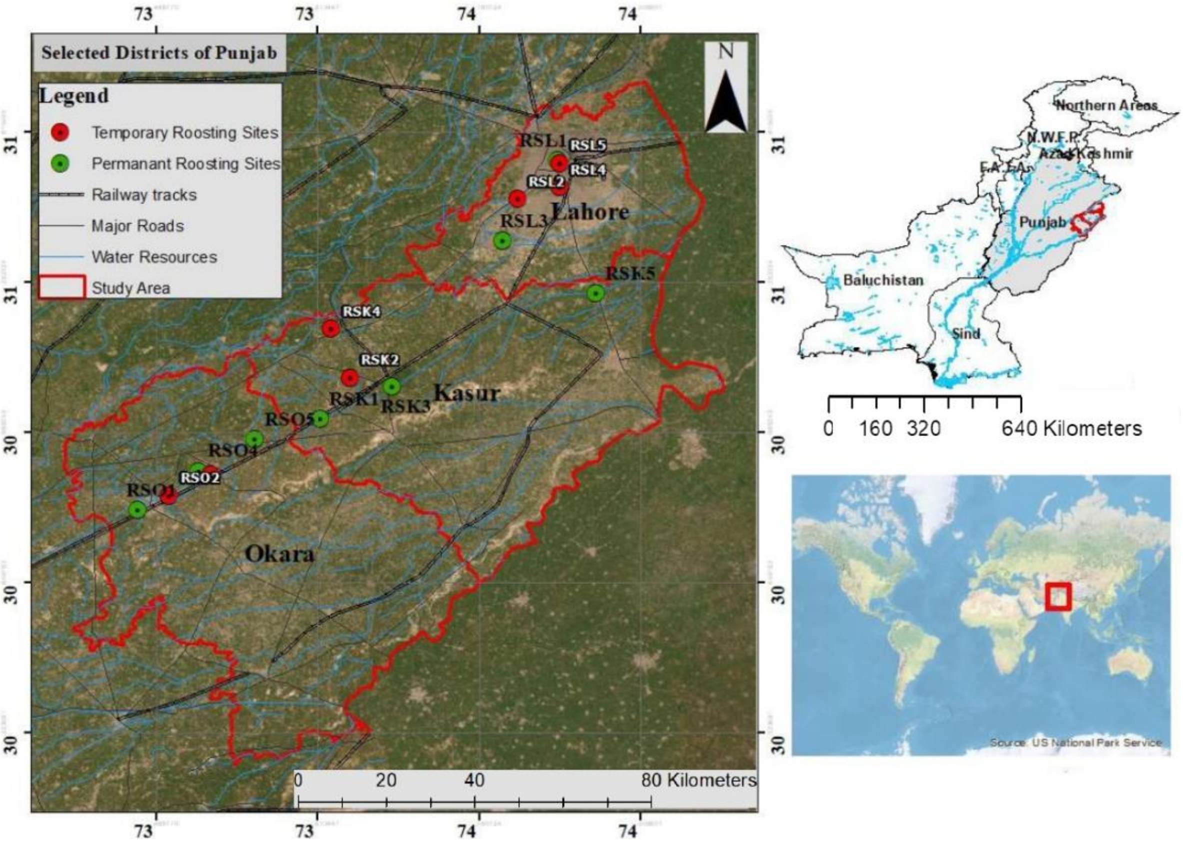

Fig. 1. GIS based map of the roosting sites of *P. medius* in the study area

Results

A total of 15 roosting sites of Indian flying fox (*Pteropus medius* Temminck, 1825) were identified across three districts, namely Okara, Kasur and Lahore in Punjab, Pakistan (Fig. 1). These sites varied in terms of location, roost type and protection status, these differences being essential in understanding how the species selects its roosting sites during different seasons. Table 1 and Table 2 summarize the details of *P. medius* roosting sites in the study area. Out of these 15 sites, 8 were located in rural areas and 7 were located in urban settings. All the roosting sites were totally isolated from each other at distances ranging from 0.8 to 15.2 km. The elevation range of the selected roosting sites was 593 to 774 feet.

Table 1
Details and characteristics of *Pteropus medius* roosting sites in the study area

Sr. No.	Site ID	Site name	GPS Coordinates	Roost type	Roost site area	Roost Categories	Roost elevation, f	Total no. of roost trees	Roost site area, m^2	Average no. of bats
1.	RSO1	DC Office Okara	30°48'4.84"N 73°25'31.94"E	permanent	urban	protected	593	12	1350	383
2.	RSO2	Sikandar Road, Okara	30°49'56.42"N 73°29'33.65"E	temporary	rural	non-protected	602	4	300	121
3.	RSO3	Mitchells Factory, Okara	30°52'38.48"N 73°35'2.81"E	temporary	rural	non-protected	631	3	280	36
4.	RSO4	Military Farm, Okara	30°53'8.54"N 73°33'27.81"E	permanent	rural	protected	630	6	800	424
5.	RSO5	Chak no. 7, Okara	30°57'15.48"N 73°40'44.20"E	permanent	rural	non-protected	663	7	600	365
6.	RSK1	Pattoki Nurseries II, Kasur	30°59'51.79"N 73°49'8.30"E	permanent	rural	non-protected	639	5	580	402
7.	RSK2	Arain Modal Farm, Kasur	31°5'11.33"N 73°53'0.49"E	temporary	rural	non-protected	675	7	160	220
8.	RSK3	Changa Manga Forest, Kasur	31°4'1.98"N 73°58'29.89"E	permanent	rural	protected	693	95	7100	9142
9.	RSK4	Sara e Mughal, Kasur	31°11'28.67"N 73°50'36.35"E	temporary	rural	non-protected	694	5	380	302
10.	RSK5	Mustafaabad, Kasur	31°16'5.10"N 74°24'44.82"E	permanent	urban	non-protected	772	8	450	442
11.	RSL1	Jinnah Garden, Lahore	31°33'14.99"N 74°19'44.15"E	permanent	urban	protected	774	25	8400	2496
12.	RSL2	Lalazar Park, Lahore	31°28'14.43"N 74°14'37.87"E	temporary	urban	protected	744	3	320	38
13.	RSL3	Safari Zoo, Lahore	31°22'52.61"N 74°12'40.50"E	permanent	urban	protected	718	11	3000	852
14.	RSL4	Modal Town Park, Lahore	31°29'47.29"N 74°20'1.46"E	temprary	urban	protected	772	3	400	140
15.	RSL5	Jillani Park, Lahore	31°32'53.04"N 74°20'1.79"E	temporary	urban	protected	744	6	425	93

Note: site ID: RSO (roosting sites in district Okara), RSK (roosting sites in district Kasur), RSL (roosting sites in district Lahore).

Table 2
Detailed characteristics of *Pteropus medius* roosting sites in the study area

Sr. No.	Characteristics	Roosting Site IDs														
		RSO1	RSO2	RSO3	RSO4	RSO5	RSK1	RSK2	RSK3	RSK4	RSK5	RSL1	RSL2	RSL3	RSL4	RSL5
1	History of roosting site, years	30	15	10	30	10	30	10	30	15	15	30	15	30	10	15
2	Condition of trees	alive	alive	alive	alive	alive	alive	alive	alive	alive	alive	alive	alive	alive	alive	alive
3	Average canopy cover, %	80	45	65	78	61	82	48	95	85	55	92	84	88	61	53
4	Average tree height range, m	15–23	12–22	16–24	17–25	12–21	16–25	15–23	18–22	15–21	17–25	14–22	15–18	12–18	18–23	18–22
5	Average tree DBH range, cm	75.9	40.1	49.7	71.2	63.9	78.3	41.6	84.8	50.2	81.7	69.9	59	64.3	52.1	42.8
6	Nearest water sources, m	1900	42	75	425	225	10	55	220	790	10	900	105	10	2145	32
7	Nearest human settlement, m	50	425	455	580	75	660	150	425	690	88	300	140	270	170	165
8	Nearest road, m	95	350	410	1500	990	100	50	700	1525	100	235	50	485	90	110
9	Nearest industry, m	1000	425	215	2540	3500	450	3180	2500	3000	265	680	560	750	250	1300
10	Nearest livestock farm, m	746	385	135	125	170	95	305	860	115	125	2885	2110	640	2950	3055
11	Nearest railway track, m	527	310	340	2490	3415	50	4600	2200	16000	11580	2640	230	7265	2125	2850
12	Nearest fruit orchard, m	625	475	600	400	300	240	450	930	75	315	6500	2960	280	9680	3220
13	Nearest public park, m	90	3050	220	300	5550	4800	7565	2750	3420	460	10	10	10	10	10
14	Nearest selected roosting site, m	7241	10075	2645	13440	13360	11660	8970	12160	15720	22120	830	9000	10400	5780	819

Protected vs non-protected sites. 8 roosting sites were located within protected areas (e.g., government managed forests) and permanent roosting sites while 7 were in non-protected areas (e.g., private properties and public lands), some of which were temporary roosting sites (Table 1). The protected sites (RSK3, RSL1, RSL2, RSL3, RSL4 and RSL5) generally had more stable environmental conditions which may contribute to the preference of *P. medius* for these areas.

Roost tree availability and preferences. A total of 202 trees were used by Indian flying fox (*Pteropus medius*) as roosting sites representing 28 species, 23 genera and 10 families (Table 3). Roosting sites in protected areas tended to have more trees, larger tree sizes (higher DBH), and greater canopy cover, which provide better roosting conditions for bats. Results revealed that during winter, roost sites with higher numbers of bats were dominated by *Bombax ceiba* L. 1761 (16.3%), *Eucalyptus camaldulensis* Dehn 1832, (9.9%) and *Pinus strobus* L. 1761 (8.4%). However, *Syzygium cumini* L. Skeels 1761 (7.9%), *Swietenia mahagoni* L. Jacq 1761 and *Ficus benjamina* L. 1767 (each at 6.4%) were more frequently occupied by *P. medius* in summer. Only single tree species were used by *P. medius* in non-protected roosting sites in rural areas: *Eucalyptus camaldulensis* (n = 4) at RSO2, *Bombax ceiba* (n = 5) at RSK1 and *Eucalyptus camaldulensis* (n = 7) at RSK2. While at temporary protected roosting sites in urban areas RSL2, *P. medius* used *Syzygium cumini* (n = 3) and *Pinus strobus* (n = 6) at RSL5 was used by *P. medius*. All other roosting sites were with more than one tree species used by *P. medius* especially at the permanent protected roosting site in Changa Manga Forest (RSK3); n = 95 trees representing 19 different tree species.

Tree characteristics. The tree species preferred by *Pteropus medius* varied slightly by region, with larger trees being preferred at all the roosting sites specifically in rural areas on non-protected sites. The average DBH ranged from 40.1 cm at Sikandar Road, Okara (RSO2) to 84.8 cm at Changa Manga Forest, Kasur (RSK3). This difference may reflect the availability of suitable trees for roosting in these areas.

Seasonal trends in bat populations. The time-series analysis was done to check the *P. medius* population across various seasons on selected roosting sites during study period. Bat populations were monitored from July 2022 to June 2024, showing seasonal fluctuations at different roosting sites (Table 4). The highest bat populations were recorded during summer and the lowest populations were recorded during winter at protected and permanent roosting sites. The summer months, particularly from June to August, recorded the highest bat populations, with an average of 9,142 bats observed at the Changa Manga Forest site (RSK3), while during the winter months, December to February, an average of only 18 bats was observed there. In contrast, the bat population significantly decreased at non-protected and temporary roosting sites during summer and increased in winter. The roosting sites like Sikandar Road, Okara (RSO2) and Arain

Modal Farm (RSK2) had lower populations in summer (average 53 and 216 respectively and higher in winter (RSO2 = 228 and RSK2 = 481). During the study period, an overall a 1.68% decline was observed in the bat population on selected roosting sites. The major decline was at sites like RSO2 (35.1%), RSO3 (24.4%), and RSK2 (61.1%) due to killing and cutting of specific roost trees (Table 4).

Table 3
Tree species availability and preference of roost trees by *Pteropus medius* across selected roosting sites in Punjab, Pakistan

Sr. No.	Roosting site ID's	Total no. of roost trees (N)	Tree species and their number			Plant species percentage occupied by *P. medius*	
			common name	scientific name	no. of trees	name	%
1.	RSO1	12	Teak	*Tectona grandis*	1	*Bombax ceiba*	16.3
			Banyan	*Ficus benghalensis*	1	*Eucalyptus camaldulensis*	9.9
			Neem	*Azadirachta indica*	2		
			Copachi	*Aspidosperma sandwithianum*	2	*Pinus strobus*	8.4
			Chhatim	*Alstonia scholaris*	2		
			False Banyan	*Ficus altissima*	1	*Syzygium cumini*	7.9
			Ashoka	*Saraca asoca*	3		
2.	RSO2	4	Safeda	*Eucalyptus camaldulensis*	4	*Swietenia mahagoni*	6.4
3.	RSO3	3	Safeda	*Eucalyptus camaldulensis*	1		
			Simbal	*Bombax ceiba*	2	*Ficus benjamina*	6.4
4.	RSO4	6	Peepal	*Ficus religiosa*	1		
			Simbal	*Bombax ceiba*	5	*Cedrela toona*	4.5
5.	RSO5	7	Neem	*Azadirachta indica*	2		
			Safeda	*Eucalyptus camaldulensis*	2	*Heterophragma adenophyllum*	4.5
			Simbal	*Bombax ceiba*	3		
6.	RSK1	5	Simbal	*Bombax ceiba*	5	*Bischofia javanica*	3.5
7.	RSK2	7	Safeda	*Eucalyptus camaldulensis*	7		
8.	RSK3	95	Mango	*Mangifera indica*	4	*Pterospermum acerifolium*	3.5
			Bamboo	*Bambusa arundonisi*	2		
			Jamun	*Syzygium cumini*	8	*Ficus retusa*	2.9
			Sukh chain	*Pongamia galabra*	3		
			Safeeda	*Eucalyptus citrdora*	5	*Azadirachta indica*	2.5
			Toona	*Cedrela toona*	9		
			Toog	*Bischofia javanica*	7	*Albizia lebbeck*	2.5
			Bahera	*Terminalia bellirica*	3		
			Catalpa	*Catalpa bignonioides*	2	*Putranjiva roxburghii*	2.5
			Kanak Champa	*Pterospermum acerifolium*	3		
			Arjuna	*Terminalia arjuna*	4	*Ficus religiosa*	1.9
			Gul e Nishter	*Erythrina blakei*	2		
			Peepal	*Ficus religiosa*	3	*Mangifera indica*	1.9
			Shareen	*Albizia lebbeck*	3		
			Simbal	*Bombax ceiba*	5	*Terminalia arjuna*	1.9
			Mahagni	*Swietenia mahagoni*	13		
			Bohri	*Ficus benjamina*	11	*Saraca asoca*	1.5
			Chir	*Pinus strobus*	8		
9.	RSK4	5	Simbal	*Bombax ceiba*	1	*Pongamia galabra*	1.5
			Neem	*Azadirachta indica*	1		
			Bohri	*Ficus benjamina*	1	*Terminalia bellirica*	1.5
			Jamun	*Syzygium cumini*	2		
10.	RSK5	8	Bohri	*Ficus benjamina*	1	*Aspidosperma sandwithianum*	1.0
			Simbal	*Bombax ceiba*	6		
			Safeeda	*Eucalyptus camaldulensis*	1	*Alstonia scholaris*	1.0
11.	RSL1	27	Nag phalli	*Heterophragma adenophyllum*	9		
			Bohri	*Ficus retusa*	6	*Bambusa arundonisi*	1.0
			Putajan	*Putranjiva roxburghii*	5		
			Kanak Champa	*Pterospermum acerifolium*	4	*Catalpa bignonioides*	1
			Tun	*Cedrela toona*	3		
12.	RSL2	3	Jamun	*Syzygium cumini*	3	*Erythrina blakei*	1
13.	RSL3	11	Simbal	*Bombax ceiba*	4		
			Jamun	*Syzygium cumini*	2	*Tectona grandis*	0.5
			Shareen	*Albizia lebbeck*	2		
			Chir	*Pinus strobus*	3	*Ficus benghalensis*	0.5
14.	RSL4	3	Jamun	*Syzygium cumini*	1		
			Simbal	*Bombax ceiba*	2	*Ficus altissima*	0.5
15.	RSL5	6	Chir	*Pinus strobus*	6		

Table 4
Number of bats *Pteropus medius* recorded on seasonal and yearly basis at selected roosting sites in the study area

Sr. No.	Season/ Year	RSO1	RSO2	RSO3	RSO4	RSO5	RSK1	RSK2	RSK3	RSK4	RSK5	RSL1	RSL2	RSL3	RSL4	RSL5
1.	Summer 2022	468	53	0	572	279	228	218	15617	39	305	3098	12	1288	0	0
2.	Autumn 2022	418	107	35	486	357	420	302	12290	331	459	2685	38	703	30	14
3.	Winter 2022	298	228	83	300	468	573	481	14	453	554	1950	52	537	347	223
4.	Spring 2023	340	201	46	393	397	441	268	8352	416	477	2353	48	842	229	149
5.	Summer 2023	462	48	0	525	255	217	199	15828	46	294	3008	18	1245	0	0
6.	Autumn 2023	433	112	31	470	336	392	295	12812	310	445	2631	43	845	17	12
7.	Winter 2023	290	222	71	281	451	555	0	21	432	546	1900	45	516	323	207
8.	Spring 2023	350	0	21	371	374	431	0	8200	392	453	2341	44	839	172	136
9.	Year 2022-23	1525	589	164	1752	1501	1662	1269	36272	1239	1795	10086	150	3370	605	387
10.	Year 2023-24	1534	382	124	1647	1416	1596	494	36861	1180	1738	9880	149	3445	513	355

Correlation of environmental factors and bat populations. Figure 2 shows the GIS based spatial mapping and analysis of bats based on environmental factors. Temperature and humidity were correlated with bat populations, with higher bat numbers observed at sites with more stable temperatures and humidity levels.

Effect of anthropogenic activities on rooting sites. During the study recorded anthropogenic disturbances at selected *P. medius* roosting sites varied across seasons from summer 2022 to spring 2024. Activities such as hunting (H), killing (K), culling (C), loud sounds (LS), fire and smoke (FS) and tree cutting (CT) were observed intermittently at multiple sites in rural and non-protected areas. Summer months showed higher incidences of culling, cutting and loud sounds, particularly at RSO3, RSO5 and RSK2. Winter seasons exhibited frequent hunting and fire/smoke disturbances, especially at RSK2, RSK3 and RSL2. Notably, autumn seasons recorded minimal or no disturbances. Overall, anthropogenic impacts were site- and season-specific, with hunting and culling representing the most common disturbances influencing *P. medius* roosting habitats.

Correlation matrix of bat abundance. A correlation matrix was conducted to assess the relationships between bat abundance with roost sites categories and roost tree characteristics. The matrix revealed several significant findings (Fig 3).

Correlation matrix of bat abundance and roost site categories. Permanent vs. temporary roosting sites. Roost sites were categorized as either permanent or temporary based on their stability and longevity over time. The correlation matrix revealed that permanent roosting sites were more strongly associated with higher bat populations. This finding aligns with the expectation that permanent sites provide a stable microclimate and consistent availability of resources such as food and shelter. For instance, the Changa Manga Forest site (RSK3) and Jinnah Garden, Lahore (RSL1), both were permanent roosting sites which consistently hosted higher bat populations, as compared to temporary sites like Sikandar Road-Okara (RSO2) and Sara e Mughal-Kasur (RSK4), which had lower numbers of bats. Statistically, correlation analysis (Fig. 3)r evealed that permanent roosting sites had higher bat populations ($r = 0.373$) as compared to temporary roosting sites ($r = –0.373$).

Rural vs. urban roosting sites. Rural roosting sites consistently showed higher correlation ($r = 0.165$) with bat populations compared to urban sites ($r = –0.165$). Sites like Military Farm-Okara (RSO4) and Changa Manga Forest (RSK3) which are located in rural and protected areas, hosted significantly larger bat populations. As compared to urban sites such as DC Office-Okara (RSO1) and Mustafaabad-Kasur (RSK5, Fig. 3). Roost sites in rural areas are generally characterized by larger, older trees, providing optimal conditions for bats. Urban roosting sites, on the other hand, are typically smaller, with more disturbances such as noise, pollution and higher human activity, which can deter bat populations.

Protected vs. non-protected roosting sites. Protected roosting sites are those situated within government-managed areas, such as Changa Manga Forest-Kasur (RSK3) and Jinnah Garden-Lahore (RSL1), which are more likely to be shielded from human disturbances like killing of bats and cutting of roost trees. Non-protected sites, located on public or private lands, often face higher levels of human interference, such as hunting, tree cutting, or urban development. Protected roosting sites were found to positively correlated ($r = 0.317$) and host larger and more stable bat populations as compared to non-protected sites ($r = –0.317$). For example, the Changa Manga Forest (RSK3), a protected site, maintained large bat populations year-round, with an average of 9,142 bats in summer. On the other hand, non-protected sites were occupied by smaller bat populations such as Sikandar Road-Okara (RSO2 = 121), and Mitchells Factory-Okara (RSO3 = 36), especially during the winter months (Fig. 3).

Correlation matrix of bat abundance and roost tree characteristics. The correlation analysis for bat abundance and various roost tree characteristics revealed key insights into how different tree attributes influence the presence and number of *P. medius* at roosting sites. A correlation analysis revealed that bat abundance was positively correlated with canopy cover ($r = 0.499$), tree diameter at breast height ($r = 0.501$) and tree height ($r = 0.122$). The analysis indicates that canopy cover and tree diameter are more strongly associated with bat abundance than tree height. This suggests that *P. medius* preferentially selects roosts based on the availability of larger, mature trees with extensive canopy cover, which offer both better shelter and more secure roosting conditions. Tree height, while still having a slight positive correlation, seems to be a less critical factor for bat roosting behavior (Fig. 3).

Principal component analysis (PCA) was conducted to check the selection of roosting sites based on environmental factors, anthropogenic activities, roost tree characteristics and roost type. The PCA biplot identified two principal components (Dim1 and Dim2), which explained 35.3% and 30.8% of the total variance, respectively. Dim1 was positively correlated with favorable environmental factors such as higher canopy cover, larger tree diameter, and low anthropogenic disturbance. The biplot showed that sites with higher scores on Dim1 are associated with more favorable environmental conditions, lower anthropogenic disturbance, higher number of trees with greater canopy cover at protected and permanent sites associated with higher bat populations. However, roosting sites with lower Dim1 scores are associated with unfavorable environmental conditions, higher levels of human disturbance, lower number of trees with less canopy cover and lower bat populations. The ranking of roosting sites based on PCA scores identified RSK3, RSL1, and RSL4 as the best sites, while RSO2 and RSO5 were identified as the least suitable due to high level of anthropogenic disturbance (Fig. 4).

Discussion

The present study was planned to explore the factors that affect the roost site selection and seasonal dynamics of the Indian flying fox (*P. medius*) at selected sites of Punjab, Pakistan. The results have shown a complex interaction between these factors and give emphasis to the need for understanding the dynamics of bat ecology to conserve these species effectively.

The data revealed that *P. medius* prefer particular trees species for roosting sites. A total of 202 trees were used by the Indian flying fox (*P. medius*) as roosting sites representing 28 species, 23 genera and 10 families. Tall trees with large canopies such as *Bombax ceiba*, *Eucalyptus camaldulensis*, *Pinus strobus* and *Ficus benjamina* were preferred by *P. medius* as their roosts. These findings are consistent with earlier studies on other bat species, where large and mature trees with dense foliage were more used by bats. These attributes are linked to provision of shelter from predators and extreme weather conditions (Kunz, 2013; Lindenmayer & Laurance, 2017). Furthermore, the observations that *P. medius* only roost in living trees support the findings of several previous studies indicating that healthy trees are crucial for bat's roosting sites (Kunz et al., 2003; Mohsin et al., 2024).

The shifting of bats from one tree species to another during different seasons has been observed during the present study. A total of 19 tree species were used by *P. medius* as the roost in Changa Manga Forest (RSK3). This behavior is linked to the presence of diverse microhabitats within the site. *P. medius* showed preference for specific tree species across all selected sites, with the highest occupancy for *Bombax ceiba* (16.3%), *Eucalyptus camaldulensis* (9.9%), and *Pinus strobus* (8.4%), with higher bat numbers in winter. In contrast, the tree species *Syzygium cumini* (7.9%), *Swietenia mahagoni*, and *Ficus benjamina* (6.4%) were occupied by with a higher number of *P. medius* in summer. The variation in percentage of occupancy by bats is likely governed by the more stable temperature and humidity conditions for roosting during different seasons. These findings are in line with previous research; for example, Singh & Singh (2021) on *P. medius* in Ludhiana found a preference for *Eucalyptus globulus* (87.3%) and mulberry (24%) throughout the year. This study also observed a population increase from August to January (winter season) and a decrease from February to July (Summer season). Similarly, a study by Vyas & Upadhyay (2014) documented that *Syzygium*, *Eucalyptus* and *Ficus* genera of trees were reported as roost trees by *P. medius* and in the study by Prajapati et al. (2020), flying foxes were observed to roost primarily on *Eucalyptus* trees (58%), followed by *Populus* spp. (32%) and *Celtis australis* (5%).

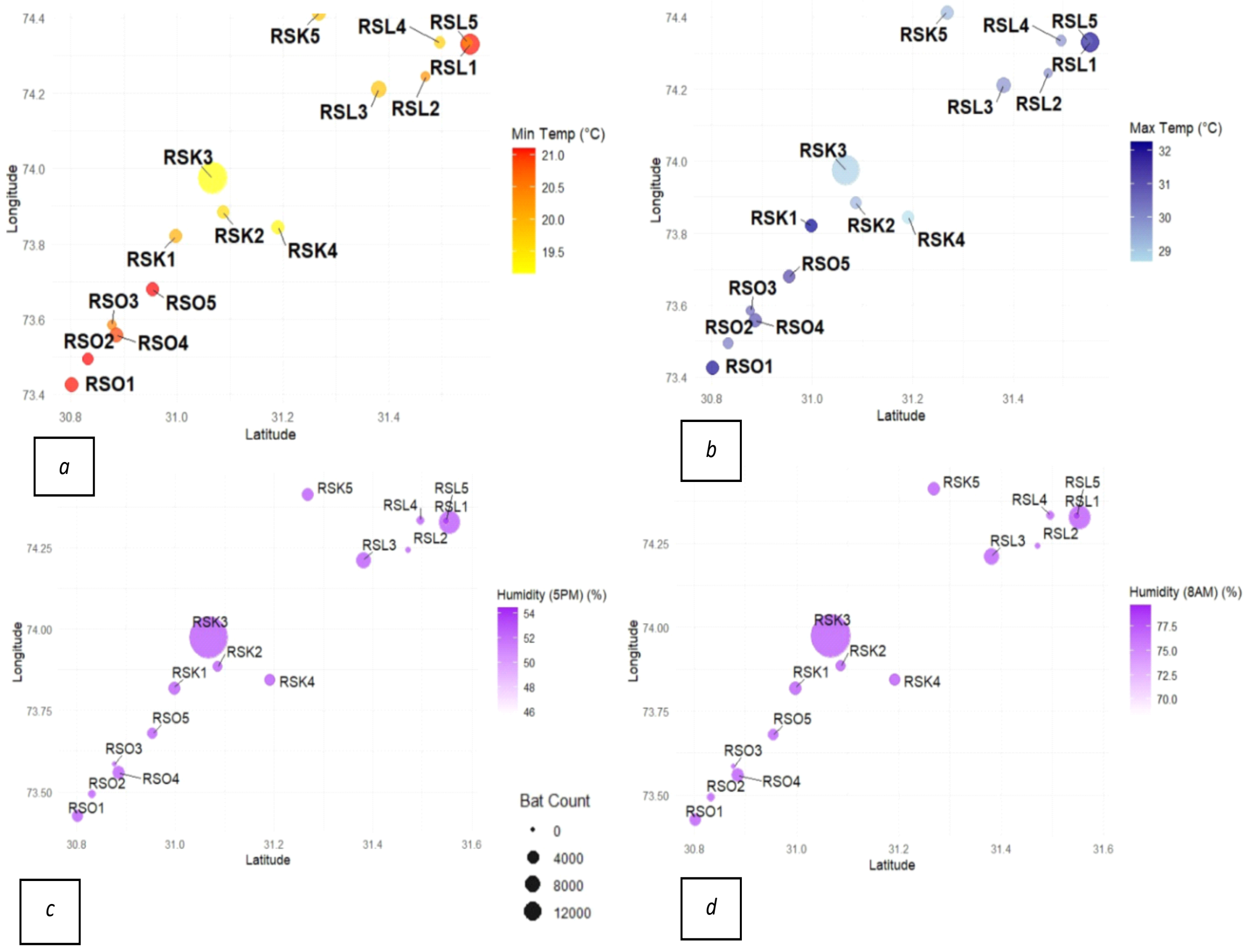

Fig. 2. GIS based spatial mapping and analysis of bats based on environmental factors: *a* and *b* plots on showing the minimum and maximum temperature at all roosting sites; *c* and *d* plots show the humidity level at 8AM and 5PM respectively at all roosting sites

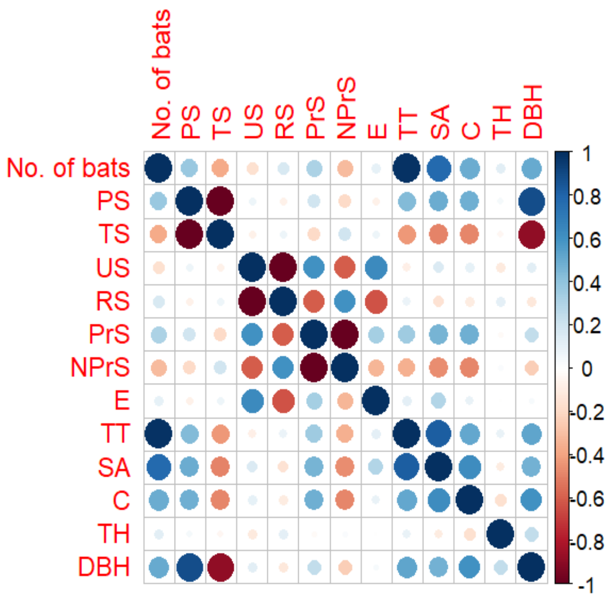

Fig. 3. Bat abundance correlation matrix with roost site characteristics: circle size and color intensity represent the strength and direction of correlations, with blue indicating positive correlations and red indicating negative correlations. permanent roosting sites (PS), temporary roosting sites (TS), urban roosting sites (US), rural roosting sites (RS), protected roosting sites (PRS), non-protected roosting sites (NPRS), elevation of roost site (E), total no. of trees (TT), roost site area (SA), canopy cover (C), average tree height (TH), tree diameter at breast height (DBH)

The seasonal changes in the populations of *P. medius* across different roosting sites, observed through time-series analysis, highlight the influence of environmental changes and human activities on bat behavior. A noticeable rise in bat numbers during the summer at protected sites like RSK3, followed by a significant drop in winter, aligns with the typical seasonal trends where bat activity peaks in warmer months and reduces during colder periods. Interestingly, an opposite pattern was observed at non-protected sites, where bat populations increased during winter and declined in summer, likely indicating seasonal movements influenced by factors such as food availability, temperature variations and roosting conditions (Mickleburgh et al., 2002). Ali & Singh (2023) also reported the migration of *P. medius* from selected roosting sites both in urban and agricultural areas during May–September and return in October–November. Interestingly, a 5.1% increase in the bat population was recorded in the preceding year (2018–2019) in urban areas while a 27.2% decrease in the bat population was observed at the roosting sites in agricultural areas, which was due to the formation of new human settlements. In the current study, a 1.6% decline in population was also noted and the major decline in bat populations was at non- protected roosting sites, over the course of the two years covered by the current study. Most often this was due to anthropogenic factors (hunting, culling and habitat destruction), which highlights the broader conservation challenges of our time (Frick et al., 2020). Previous studies have documented the detrimental effects of human-induced disturbances on bat populations, including habitat loss and direct human persecution. The marked difference in bat population stability between protected and non-protected sites further underscores the importance of conservation measures and highlights the vulnerability of non-protected roosting sites to anthropogenic threats. But management of protected areas alone is not sufficient to stabilise the bat population (Pessoa da Silva & De Marco, 2023).

Table 5
Correlation matrix of bat abundance, roost characteristics and roost categories

Characteristics	No. of Bats	PS	TS	US	RS	Prs	NPrS	E	TT	SA	C	TH
PS	0.373*	1.000	–	–	–	–	–	–	–	–	–	–
TS	–0.373	–1.000	1.000	–	–	–	–	–	–	–	–	–
US	–0.165	0.071	–0.071	1.000	–	–	–	–	–	–	–	–
RS	0.165*	–0.071	0.071	–1.000	1.000	–	–	–	–	–	–	–
PRS	0.317*	0.196	–0.196	0.607	–0.607	1.000	–	–	–	–	–	–
NPRS	–0.317	–0.196	0.196	–0.607	0.607	–1.000	1.000	–	–	–	–	–
E	0.105*	–0.076	0.076	0.639	–0.639	0.334	–0.334	1.000	–	–	–	–
TT	0.987***	0.435	–0.435	–0.085	0.085	0.359	–0.359	0.114	1.000	–	–	–
SA	0.771***	0.491	–0.491	0.154	–0.154	0.465	–0.465	0.291	0.829	1.000	–	–
C	0.499**	0.489	–0.489	0.105	–0.105	0.489	–0.489	0.093	0.515	0.628	1.000	–
TH	0.122*	0.044	–0.044	–0.118	0.118	–0.029	–0.029	–0.025	0.091	–0.103	–0.167	–
DBH	0.501**	0.884	–0.884	0.126	–0.126	0.242	–0.242	0.039	0.528	0.470	0.605	0.249

Note: permanent roosting sites (PS), temporary roosting sites (TS), urban roosting sites (US), rural roosting sites (RS), protected roosting Sites (PRS), non-protected roosting sites (NPRS), elevation of roost site (E), total no. of trees (TT), roost site area (SA), canopy cover (C), average tree height (TH), tree diameter at breast height (DBH).

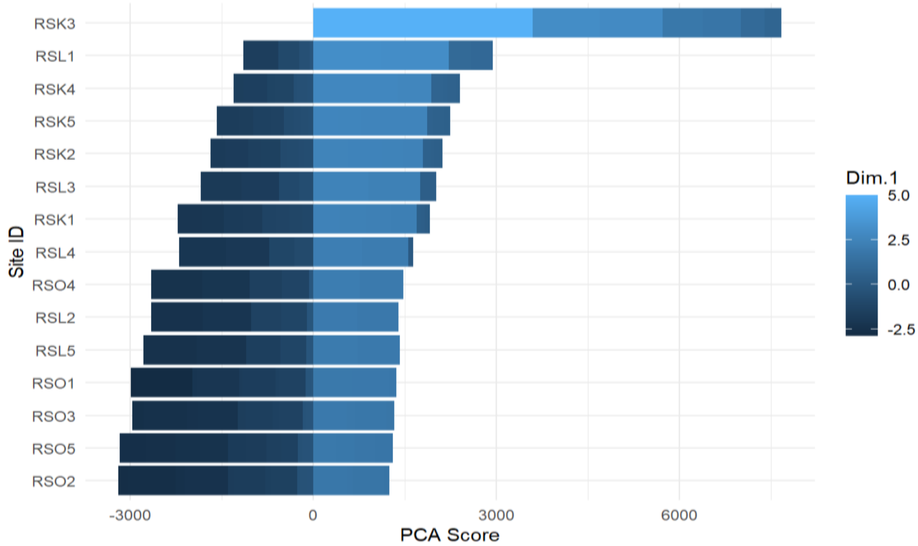

Fig. 4. Ranking of *Pteropus medius* roosting sites based on PCA scores: higher scores along dimension 1 (Dim1) indicate more favorable environmental conditions and lower anthropogenic disturbance; RSK3, RSL1, and RSK4 emerged as the best roosting sites, while RSO2 and RSO5 were identified as the least suitable roosting sites

The principal component analysis (PCA) highlighted the significant role of protected roosting sites in providing shelter to bats. A moderate positive correlation was found between environmental factors such as temperature, humidity and the preferences for roost sites by *P. medius*. These results of our study are in line with previous research suggesting that temperature and humidity are critical factors in bat roost site selection (Fenton & Barclay, 1980; Lacki et al., 2007). The PCA analysis also indicated that protected roosting sites, such as RSK3 and RSL1, provided more favorable environmental conditions as compared to non-protected sites. These observations are similar to those reported by Festa et al. (2023). This emphasizes the importance of conservation efforts aimed at preserving high-quality roosting habitats with stable environmental conditions for sustaining bat populations. Moreover, the study highlighted the negative impact of anthropogenic activities, particularly tree cutting and hunting, on roosting sites. Sites like RSO2 and RSO5, which are non-protected and temporary, had lower PCA scores, reflecting the adverse effects of human disturbances. This negative relationship between anthropogenic activities and roost site selection is consistent with other studies, where human activities like urbanization, deforestation and hunting have been linked to habitat degradation and displacement of roosting bats (Browning et al., 2021; Festa et al., 2023).

Conclusion

The results of the present study revealed that the bat populations fluctuate significantly during different seasons at all the roosting sites. Higher numbers of bats were observed during summer at protected, permanent roosting sites as compared to winter, particularly at non-protected and temporary sites. The statistical analysis identified key factors such as tree species, tree size, canopy cover and environmental factors such as temperature and humidity as critical for roost site selection. Among trees, *Bombax ceiba*, *Eucalyptus* sp., and *Pinus strobus* mostly preferred in winter while *Syzygium cumini* and *Ficus benjamina* were dominated during summer. The study also highlighted the negative effects of anthropogenic activities such as tree cutting, hunting, and urban development on bat populations. Protected roosting sites such as Changa Manga Forest had more stable environmental conditions, leading to higher and more stable bat populations. The correlation analysis and principal component analysis (PCA) further reinforced the importance of targeted conservation strategies to preserve roosting habitats particularly due to the threats posed by human activities and climate change. Future research should explore the impact of climate change on the species' behavior and further refine conservation strategies to mitigate the risks posed by human-induced habitat destruction.

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