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Seasonal Influence on Roosting Ecology of Short-Nosed Fruit Bat, *Cynopterus sphinx*

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Abstract: The current study was conducted to determine the potential impact of microclimate on the roosting ecology of short-nosed fruit bat, *Cynopterus sphinx,* between plants and building roosts in the Lucknow region. The microclimatic parameters, population, roost preference and roost shifting in both the roosting habitats at regular intervals were analysed. The roost preference was severely affected by extreme summer (46.70 °C) and the average population of plant-roosting bats declined from 46.8 in April to 29.4 in June. The building roosting bat population remained unaffected by the same weather conditions from April (11.1) to June (13.6). However, the population of building-roosting bats increased due to newborn pups. The extreme summer temperature forced the tent-roosting bats to vacate and shift to safer locations such as abandoned buildings/heat-tolerant plant roosts that were not normally inhabited by this species. Thus, *C. sphinx* is likely to respond to climate changes at plant roosts by migrating to more suitable areas. Therefore, the current study identified the habitat risks associated with roost selection of *C. sphinx* at high temperatures, and this study suggests further research is required on fruit-bat roost management.

Keywords: Chiroptera, Habitat conservation, Roost, Microclimatic parameters

Bats are one of the most speciose and ecologically diversified mammalian order, constituting 22% of all mammalian diversity living today about 1,474 species (Simmons 2005, Simmons and Cirranello 2024), next to rodents, and distributed across the world except Antarctica (Simmons, 2005). The pteropodids observed consuming food on 1072 plant species from 493 genera and 148 families. Sixteen pteropodid species have been validated as pollinators for 21 plant species and 29 pteropodid species act as seed dispersers for 311 plant species, potentially benefiting the ecosystem by long-distance pollen and seed dispersal services (Aziz et al., 2021) and maintain the plant kingdom's genetic diversity in tropical and sub-tropical ecosystems (Muscarella and Fleming 2007, Kunz et al., 2011). The short-nosed fruit bat *Cynopterus sphinx* (Vahl 1797) is an ubiquitous frugivorous bat widely distributed throughout the Indomalayan region. *C. sphinx* occupies a variety of roosts and alters different types of tree foliage, modifying it into 'tents'. Several studies suggest that *C. sphinx* also roosts in man-made structures, such as the ceilings of abandoned or unused buildings and partially enclosed porches, either individually or in harems (Hasnim et al., 2020). The use of modified roosts was recorded for 21 bats in neotropical and paleotropical regions (Kunz and Lumsden 2003, Dechmann et al., 2005). In bats, the variety of roosts used for shelter typically reflects both functional and social attributes of the species, in which mating and rearing of young ones take place and selection of optimal shelter may also have profound survival fitness consequences for the species (Campbell et al., 2006).

The roost's physical condition such as temperature, humidity, light intensity, wind velocity and roost characteristics play a significant role for bats in their reproduction, stabilizing the social structure and protection from adverse weather conditions, predator attacks, as bats spend a maximum time in their roosting environment (Kunz 2013). Many factors, such as microclimate, structural characteristics of the roost, surrounding habitat, human disturbance and risk of predation, may influence roost selection by bats (Doss et al., 2018). The majority of studies of roosting ecology of tent-making bats behaviour have been focused mainly on the physical properties and functional value of the modified roost (Stoner 2000), while relatively little attention has been paid to the relationship between roost selection concerning the microclimatic parameters. Likewise, comparative studies for *C. sphinx* opportunistic in their use of modified roosts in plants and buildings are lacking. The proper knowledge of the roosting ecology of bats is absolutely important for their conservation. Therefore, the current study was planned to understand the seasonal influence on roost preference of *C. sphinx* between building roosts and plant roosts by examining the bat population size, harem size, roost longevity, roost diversity, and roost characteristics of *C. sphinx* concerning the roost's microclimatic factors.

MATERIAL AND METHODS

Study species: *Cynopterus sphinx* is a medium-sized fruit bat listed as least concern and characterized by a deep emargination between the projecting nostrils, a short and broad muzzle structure with an average wingspan of 380 mm. It shows a socially polygynous mating system and is more agile on the wing than larger fruit bats (Garg et al., 2018, Kumar et al., 2025).

Study site: Observations on the roosting ecology of *C. sphinx* were conducted during the day time from January to June 2024 at roosting sites within Babasaheb Bhimrao Ambedkar University (80°55'10” E, 26°46'18” N) on alternate days. Additionally, three other roosting sites in the Lucknow district were monitored to study their roosting ecology (Table 1). These sites, including the National Bureau of Fish Genetic Resources, Maharaja Bijli Pasi Degree College, and Sisandi Kothi, are located in Lucknow, Uttar Pradesh, India (Fig. 1). Lucknow, positioned at an elevation of 123 meters above sea level, lies between 26.30°–27.10° North latitude and 80.30°–81.13° East longitude. The city experiences an extreme continental climate, with hot summers, cold winters, and approximately 75% of its total annual rainfall occurs during the monsoon season.

Roost characteristics and microclimatic conditions measurement: Roosting sites were identified by the presence of bolus and faecal droppings beneath roost trees or in abandoned buildings designated as roosting locations (Chan et al., 2021). The main focus was given to plant species frequently used by *C. sphinx* for roosting, including palm, creepers, mast trees, and artificial structures (Nagarajan-Radha et al., 2024). The roost characteristics include roost height (in feet), canopy area, number of roosting trees, availability of feeding trees, and proximity to water bodies. The roost microclimatic parameters, like the roost's temperature (°C) and humidity (%), with the help of a thermo-anemometer (Neumann & Miller-9818), were recorded at every roost site. Roost's light intensity was measured with a Lux meter (KUSAM – MECO- LUX-99) by placing it below the roost. The GPS coordinates of all the sites have been taken by a hand-held GPS (Montana 680, Garmin). The GPS coordinates, details of roosting sites, population, availability of food and water resources, along with roost characteristics of all the study sites were recorded (Table 1).

Bat roost observation: The roosting behaviour of *C. sphinx* was studied across five different sites at regular intervals. Of these sites, three were tree roosts, while two were located in abandoned buildings (Table 1). At each roosting site, the bat's harem size and total roost population were counted using a manual counter machine. The identification of the sex of roosting individual bats was approached with binoculars to observe the individual sex (Aculon- A211 NIKON). Roosting individuals at static positions within the roosting tents were photographed using a camera (Nikon, D5200). In harem condition, identifying the sex of individual bats is quite difficult because they typically cluster closely at the apex of tent cavities in the diurnal roosting groups (Balasingh et al., 1995), where the pelage colour of adult males can be easily distinguished from females (Bates and Harrison 1997, Storz and Kunz 1999). The population size of the roost site was used across the study months to check the impact of season on roost preferences of bats in both types of roosting habitats. The interpretations were made with the recorded microclimatic variables. Average population size was used to explain the behavioural responses through graphs and tables using Microsoft Excel.

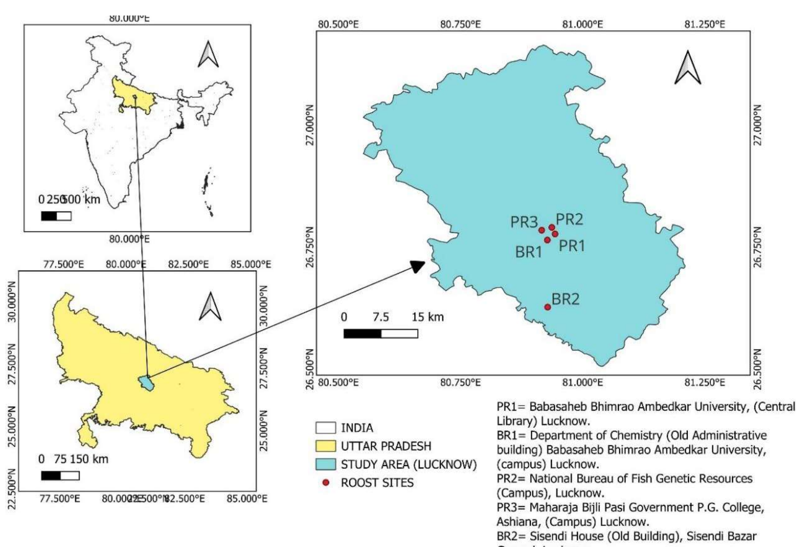

Fig. 1. Study sites at different places in plant roosts (PR) and building roosts (BR) in Lucknow district, Uttar Pradesh, India

Table 1. *Cynopterus sphinx* roost locations, details of roosts, population, available food tree, and distance from water sources

Study sites	Roosts	Study site code	GPS location	No. of roosting trees with tents	Total available bats in the roosting site (n)	Available food trees at study sites (number of trees)	Water sources distance	Study site description
Babasaheb Bhimrao Ambedkar University, (campus) Lucknow.	*Polyalthia longifolia (n=257) Caryota urens(n=2)*	PR1	26°46'168''N 080°55'597''E	28 roosting trees, with tents (n=68). 2 roosting trees of *Caryota urens* with tents (n=3)	115	*Mangifera indica* (10), *Ziziphus mauritiana* (62), *Morus alba* (120), *Syzygium cumini* (20), *Fucus racemosa* (26), *Ficus bengalensis* (10), *Ficus religiosa* (8), *Azadirachta indica (250+), Psidium guajava (50), Musa acuminata* (6), *Neolamarckia cadamba (18).*	5 water ponds Average distance 250 m.	The site comprises many trees (roosting & feeding trees), water bodies, grasslands, buildings, and a big part of the forest within the campus, spread over about a 250-acre University campus, situated in a semi-urban area.
Department of Chemistry (Old Administrative building), Babasaheb Bhimrao Ambedkar University, (campus) Lucknow.	In the old Building (n=1)	BR1	26° 45'856''N 080°55'627''E	(At fused tube light sockets and building ceiling) (n=3)	8			
National Bureau of Fish Genetic Resources (Campus), Lucknow.	*Polyalthia longifolia (n=156) Caryota urens(n=4)*	PR2	26°47'228''N 080°56'208''E	74 roosting trees with tents (n=42). 4 roosting trees of *Caryota urens* with tents (n=12)	96	*Mangifera indica* (8), *Musa acuminata* (5), *Fucus racemosa* (6), *Psidium guajava* (10), *Syzygium cumini* (11), *Azadirachta indica* (5), *Neolamarckia cadamba* (18)	12 water ponds with an average distance of 120 m.	The campus comprises several trees (roosting & feeding trees), water bodies, buildings, and agricultural fields near the campus, spread over about a 52-acre campus, situated near the Indian Institute of Sugarcane Research campus area, 186.5 ha in a semi-urban area.
Maharaja Bijli Pasi Government P.G. College, Ashiana, (Campus) Lucknow.	*Caryota urens(n=6)*	PR3	26°75'335''N 080°93'183''E	12 roosting trees with tents (n=8).	78	*Neolamarckia cadamba* (20), *Mangifera indica* (10), *Ziziphus mauritiana* (12), *Psidium guajava* (5).	2 water ponds with an average distance of 450 m.	The roosting site is present inside the college campus, on palm trees that are surrounded by buildings. Where a regular human presence is observed and the foraging routes are constantly exposed to artificial light illumination at night in semi-urban areas. Near the roosting tree, a good numbers of vegetation were observed in the nearby park areas.
Sisendi House (Old Building), Sisendi Bazar Ground, Lucknow.	Old Building	BR2	26°69'664''N 080°87'199'E	The ceiling of the well without tents occupied by bats as a harem.	20	*Mangifera indica* (20), *Ficus religiosa* (10), *Ziziphus mauritiana* (6), *Psidium guajava* (8).	3 water bodies with an average distance of 350 m.	The roosting sites were present at the ceilings of old wells near the old unused buildings. The roosting site had no other roosting tree found like *Polyalthia longifolia*, or *Caryota urens,* while several feeding tree presences were recorded near the roosting sites at agricultural fields and gardens. This roosting site was surrounded by a dense human colony in a rural area.

PR= Plant roost, BR = Building roost; n= 1,2,3… Roost serial number

RESULTS AND DISCUSSION

Roosting Ecology

Behaviour of tent-roosting bats: The roosting ecology of *C. sphinx* was surveyed in a total of 413 *P. longifolia* plants. Of these, 102 had tent structures built by male bats. Similarly, all surveyed *C. urens* plants contained bat-constructed tents, with a total of 15 tents recorded (Table 1). These findings suggest that *C. sphinx* primarily prefers *P. longifolia* for roosting, followed by *C. urens*. Despite the presence of diverse plant species, only these two tree species were predominantly used as roosting sites. In *P. longifolia*, bats modify leaves and twigs to create canopy tents, which vary in shape, size, and group size, ranging from 2 to 14 individuals per tent, with each tree usually hosting a single tent and rarely 2–3 tents per tree (Fig. 2 A, B). In *C. urens*, bats alter floral structures by carving out a bell-shaped cavity in hanging flower or fruit clusters, chewing and discarding central portions. The group sizes varied from 2 to 20 individuals per floral tent, with each tree typically supporting 3–8 tents, depending on the number and size of floral clusters (Fig. 2 C, D). Previous studies show that *C. sphinx* may utilize more than 80 species of vascular plants as their diurnal roost worldwide (Kunz et al., 1994; Balasingh et al., 1995), such as *P. longifolia*, *Musa acuminata, Borassus flabellifer, Corypha umbraculifera, Livistona chinensis, Roystonia regia, Persea gratissima,* and *Philodendron giganteum* (Garg et al., 2018). Roost tents are typically used for weeks or months, depending on ecological conditions. Bats frequently construct new tents when existing ones no longer provide adequate shelter and relocate to nearby trees to establish fresh tents. During the day, *C. sphinx* roosts in groups of around 20 individuals, though smaller groups (1–3 bats) were also observed roosting inside tents on *P. longifolia* and *C. urens*. Throughout the day, bats engage in social interactions or rest quietly in the shade, preferring well-hidden, secure roosting spots (Fig. 2 B, D). The roosting behaviour of *C. sphinx* is influenced by different types of roost characteristics, including greater transfer of information between groups, access to many mates, familiarity with diverse roost sites, easy entrances to roost sites, and the ability to limit predator attacks and parasite infections (Rajasegaran *et. al.,* 2018). However, environmental changes play a primary role in determining roost stability, often prompting bats to abandon unsuitable tents and seek alternative sites. Similar findings observed among the five studied sites; bats switch their roost destinations based on the closest availability of food and water resources from daytime roosts in plants and building roosts. Greater food resource sites possess larger populations than those with fewer food resources (Table 1). Roost structure and other physical characteristics of the roosting sites play an important role in roost selection (Digana et al., 2003).

Behaviour of abandoned building-roosting bats: In addition to plant-based roosts, *C. sphinx* was also observed utilizing old, unused buildings, the ceilings of water wells, and non-functional ceiling tubes at two roosting sites, BR1 and BR2 (Table 1, Fig. 3). Building roost provides relative flexibility and specialization in roost choices and the comprehensiveness of roost modification among closely related species has been reported in two of the seven

Fig. 2. Plant roosts (tents) of *Cynopterus sphinx* (A) *Polyalthia longifolia* tent shown in red circle, and yellow circle indicates bats' harems. (B) *C. sphinx* harem resides in the tents on *P. longifolia*. (C) *Caryota urens* a roosting plant preferred by *C. sphinx,* inside the flower cluster, each red circle indicating a harem inside the flower cluster. (D) Clear view of the harem inside the flower cluster

species of genus *Cynopterus* recognized by Simmons (2005). *C. sphinx* consistently preferred relatively enclosed roosts (well ceiling), securing themselves using their toes and claws on roof crevices, clay tiles, eaves, and other structural gaps. Bats prefer roosting in dimly lit (6.96 Lux), moderately high humidity (25.20 %), and low temperatures (28.3°C), than plants roost in undisturbed areas (Table 2). They were generally found in a harem, consisting of adult males, females, sub-adults, and pups. The social structure in harems ranged from 2 to 18 individuals, forming stable groups without tent construction. Compared to plant roosts, *C. sphinx* spends more time in man-made structures, which often serve as long-term maternity roosts, used consistently for a long period. Buildings provide stable microclimatic conditions, particularly in terms of temperature and humidity, making them ideal for maternity colonies. Female bats select specific areas within buildings to raise their young, ensuring a secure and sheltered environment for pup development. Consequently, building roosts exhibit greater longevity than plant-based roosts. At both roosting sites, BR1 and BR2, *C. sphinx* did not share roosting habitats with other bat species and predominantly occupied dark, enclosed spaces, which offered protection from predators. These bats preferentially use abandoned buildings in humid, low-light conditions near food and water sources, particularly when suitable roosting trees are unavailable in the foraging area (Table 1). Titley *et al.* (2021) observed that animals may relocate to more favourable locations, including previously unoccupied places, in response to environmental changes. This scenario is more severe in tropical nations (Kingston 2010), and estimated that the loss of bat species along this zone would approach 40% in the subsequent decades (Lane et al., 2006). The effects of global climate change indirectly influence the microclimate of their roosts (Welbergen et al., 2008), which could result in an eventual change in bats' choice of roost sites. The studies on the roosting ecology of human-associated bat species in primitive and abandoned anthropogenic habitats should be recommended to ensure the effectiveness of human-associated bat conservation programs and to facilitate human-bat conflict-solving problems (Hasnim et al., 2020).

Impact of Microclimatic Factors on Bat Roosts

Temperature: The roost temperature was measured in both types of habitats, i.e., plant roosts and building roosts. The lowest temperature was in January at both types of roosting sites, in the plant roost (12.6°C) and the building roost (9.6 °C). In winter seasons, from January onwards, roost temperature rises and reaches the highest temperature in plant roosts (46.7 °C) and building roosts (42.2 °C) in June. The plant roost's average temperature (31.1°C) was slightly higher across the study period than the building roost's (28.3 °C) (Fig. 4 A). The plant roost's higher temperature forced bats to vacate the plant roost as a result population of plants inhabited bats goes down from 46.8 in April to 29.4 individuals at site in June. The building-roosting bat population remains unaffected by the same environmental changes. Although building roosting bat populations increase from 11.1 in April to 13.6 individuals at the site in June due to the addition of newly born pups of the gravid females (Table 2, Fig. 5). Direct observations indicate a population increase associated with the parturition of newborns among bats roosting in building roost. In contrast, plant-roosting bats tend

Fig. 3. (A) Bats roosting on the ceiling of a dome above the well. (B) Bats harem inside view under well ceilings (C) Individuals of *C. sphinx* roost in an abandoned tube light frame (D) Capturing of individual bats by hoop net at roosting site. (E) *C. sphinx* captured individual bats

Table 2. Microclimatic parameters variables with the population size in both the roosting sites, building, and plant roost throughout the study periods (Mean ±SD).

Parameters variables	Building roost							Plant roost						
	January	February	March	April	May	June	Mean	January	February	March	April	May	June	Mean
Temperature (°C)	12.9 ± 3.54	19.9 ± 4.64	26.6 ± 1.87	35.8 ± 2.65	36.7 ± 3.86	38.1 ± 3.11	28.33	15.3 ± 1.92	22.5 ± 1.92	28.3 ± 5.90	37.8 ± 2.12	40.9 ± 2.66	42.0 ±4.11	31.12
Humidity (%)	82.4 ± 8.65	42.1± 16.34	39.5± 29.62	21.0 ± 7.39	31.9± 11.22	27.4± 11.78	40.71	74.3 ± 8.81	35.2 ±8.70	36.9 ±11.42	21.0 ± 7.75	30.5± 11.95	30.5± 16.30	38.89
Wind speed (Km/h)	3.63 ± 0.92	5.63 ± 3.38	7.13 ± 4.91	12.63± 6.48	7.75 ± 3.69	11.88± 5.22	8.10	5.3 ± 2.12	8.1 ±5.74	9.6 ± 5.18	13.8± 6.54	14.9 ±3.60	12.9 ± 4.58	10.75
Light intensity (Lux 1x)	5.5 ± 0.53	5.5 ± 0.53	5.5 ± 0.53	5.6 ± 0.53	5.6 ± 0.74	5.8 ± 0.71	6.96	9.4 ± 0.92	10.5 ±1.41	12.0 ± 1.41	14.0 ± 0.76	14.1 ± 1.25	15.0 ± 0.53	12.50
Tent occupancy (n)	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.00	6.0 ± 2.51	6.6 ± 2.26	6.9 ± 2.53	7.3 ± 1.83	7.5 ± 1.93	8.3 ± 2.38	10.29
Available tents (n)	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.00	16.8 ± 7.78	17.3 ± 7.25	18.3 ± 8.31	18.8 ± 7.70	20.0 ± 8.85	20.8 ± 8.31	31.60
Population (n)	5.0 ± 4.07	6.1 ± 3.76	8.3 ± 4.43	11.1 ± 7.02	12.8 ± 7.78	13.6 ± 8.18	9.48	18. ± 10.82	32.3± 13.74	44.3± 14.01	46.8 ±2.76	43.3 ±7.72	29.4 ±10.32	35.77

to abandon their tents during this period and relocate to nearby, safer roosts, either newly constructed plant tents or building structures that provide suitable microclimatic conditions, particularly optimal roosting temperatures. Similarly, another study in bats reveals that behavioral thermoregulation is a coping mechanism used by bats in general, but high temperatures during heat waves can overwhelm them, resulting in thermal stress and dehydration (Welbergen et al., 2008). Thus, high temperature in the plant roosts leads to a higher chance of roost fidelity in plant roosts from April onwards, as persistent sunlight falls on roosting plants, as a result increase in plant roost temperature. The increasing rate of temperature creates a stressful situation within the tent and residing bats were forced to vacate the newly constructed tents (existing tents) from the plant roost to safe roosting places. In building, residing bats live more comfortably due to a negligible rise in building roost temperature and no stressful effect on the bat harem. Thus, building roosts provides good suitability and saves from direct (sunlight) heat stroke than plant roosts in summer. Therefore, building roost shows a poor chance of roost fidelity due to the negligible effect of roost temperature on harem size. The *C. sphinx* roost shifting is a survival strategy in which bats migrate to shaded or cooler microhabitats, such as dense foliage, or buildings with improved thermal insulation (Bronrier et al., 1999). This pattern of behaviors enables *C. sphinx* to escape the dangers of prolonged exposure to extreme heat, allowing them to discover more ideal microclimates that aid in thermoregulation. However, the current study shows that no deaths were reported at both types of roosting sites in extreme weather conditions. The building roosts adaptation and longer roost stability could facilitate the evolutionary approaches of roost-modifying behaviour in *C. sphinx* in extreme environmental changes. *C. sphinx* switch roosts for maintaining physiological balance and preventing heat-related mortality (Velpandi et al., 2024). Thus, the building roost's microclimate provides greater support to bats than plant roosts at extreme temperature to overcome summer temperature increasement.

Humidity: The roost humidity was also an equally important parameter for understanding the roosting ecology of bat habitats. The highest humidity was in January, 82.4 %, and the lowest humidity in April, 21.0% in the building roost. Similarly, in the plant roost humidity in January was 74.3% and 21.0% in April, respectively (Fig. 4 B). In the summer, as warmth starts in March onwards, a negligible difference was recorded in the humidity at both the roosts. This was due to the roost being highly influenced by other physical parameters (roost canopy, tent type) and environmental conditions like high wind, temperature, etc. The mean variation in the roost humidity was a minor difference, 38.89 % and 40.71 % in the plants and buildings roost, respectively (Table 2). The persistent low humidity negatively affects the population size of the plant, inhibiting bats in the summer months (Fig. 5). Observation signifies that poor humidity leads to the instability of roosting bats in their habitats, resulting in roost population decline. Another study reveals that in the Mandore tunnel, bats actively select roosts based on microclimate conditions, including humidity. The observation shows a positive correlation between bat population and humidity, suggesting that bats prefer more humid environments. High fluctuation in roost humidity, due to factors like deforestation or building renovations, may lead to roost abandonment, reducing population density (Singh and Dookia 2021). In the present study building roost was mainly chosen in close proximity to water resources (well) that provide adequate humidity to the roosting harem (Fig. 3A). The high humidity in roosts helps bats to conserve water and maintain stable body temperatures. In contrast, low humidity can lead to increased water loss through respiration and skin, causing dehydration and higher energy expenditure (van Zuijlen and Groenendijk 2022).

The bats roosting in low humidity indicate that extreme temperature weather conditions show a negative impact on the population at the plant roost. Bondarenco et al. (2014). observed that fruit bat species were highly susceptible to heat-related mortality in these circumstances because their thermoregulatory systems can be rapidly overwhelmed by extended exposure to high temperatures. This is most likely because, despite their strong acclimatization capacity, bats have weak thermoregulatory approaches for dissipating heat at high temperatures due to the absence of sweat gland (Downs et al., 2012), resulting its more challenging for them to dissipate heat and making them vulnerable to high temperatures (Downs et al., 2012).

Wind: Wind speed was also recorded as an important parameter at both roosting sites (Fig. 4 C). The plant roosts were located in open areas, allowing bats to come into direct contact with the wind, which experiences higher wind velocities of 10.75 km/h compared to building roosts that are enclosed by walls and ceilings, resulting in lower wind speeds of 8.10 km/h (Table 2). In the plant roost, the highest wind speed occurred in May 14.9 km/h, while the lowest was in January, 5.3 km/h. In plant roosts, higher wind speeds combined with elevated temperatures (40.9°C) generate heat waves that adversely affect roosting individuals, prompting bats to leave the roosting tents associated with the roosting trees (Table 2). Direct observations in building roosts revealed no such impact from wind speed; bats maintain the same harem position for extended periods, and proper population growth was noted with the addition of newly born pups (Fig. 4 A, C). Furthermore, elevated wind speeds often correlate with cooler temperatures, influencing the energy balance of these thermoregulating animals, particularly during rest periods

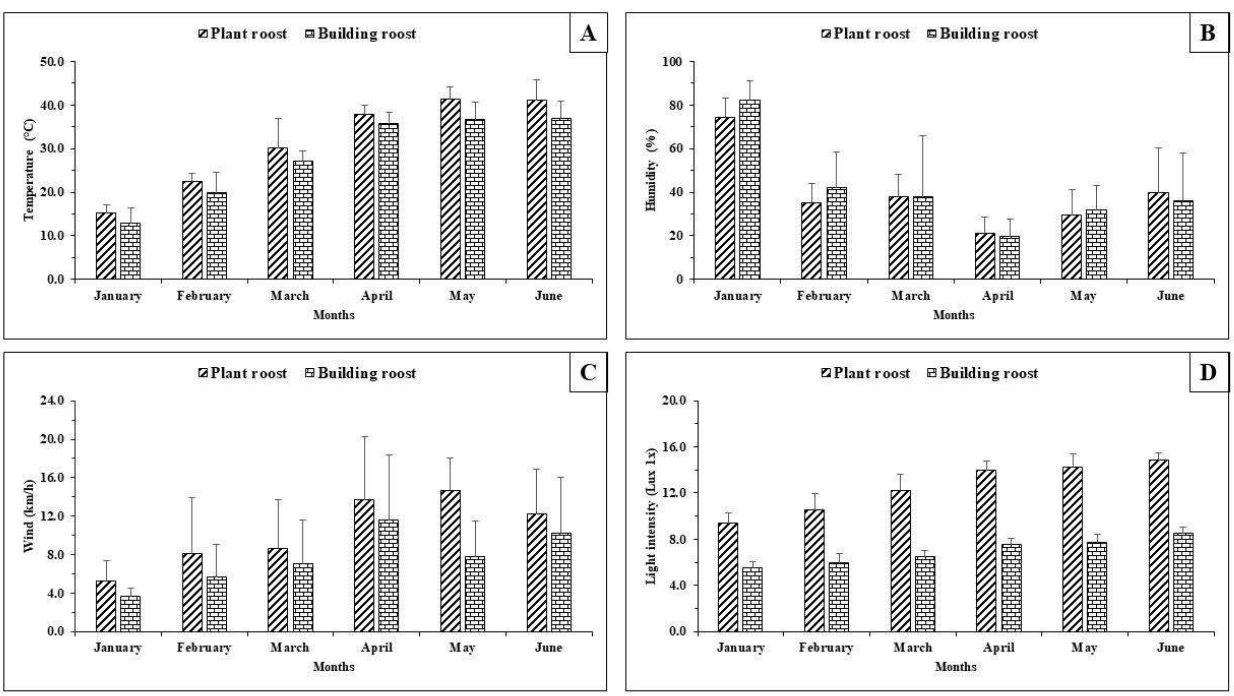

Fig. 4. *C. sphinx roost*'s microclimatic parameters in two different habitats, i.e., plant roost and building roost. (A) Temperature (B) Humidity (C) Wind speed (D) Light intensity

(Voigt and Kingston 2011). Current studies indicate that high wind conditions can lead to decreased roost site fidelity and increased movement between roosts as bats seek locations that reduce exposure to harsh environmental conditions (Kunz et al.,2003). To conserve energy and maintain thermal stability, *C. sphinx* may adjust its roosting patterns, favouring spots that offer windbreaks, especially during windy or cooler periods (Voigt et al., 2011).

Light intensity: The roosting tents were observed in both building and plant roosts. *Cynopterus sphinx* prefers to roost within the canopy region, which is altered by bats into a hollow space where the observed light intensity is consistently lower, 12.50 lx, than the normal light intensity level. During the daytime, light intensity within the tents ranges from 5-18 lx; plant-roosting bats experience an average of 9.4 lx in January and an average of 15 lx light intensity in June (Table 2, Fig. 4D). The light intensity gradually increases as the seasons change from winter to summer in all the observed roosting colonies. In extreme summer (June), increased sunlight adversely affects their roosting habitats and their population size within the plant roost. Tent-roosting bats leave the plant roost tent, leading to reduced roost fidelity due to extreme light intensity in summer. Conversely, in the building roost, bats experience an average of 5.5 lx light in January and 5.8 lx in June (Table 2). The building roost shows a slight increasement in roost light intensity, resulting in negligible changes, and no roost fidelity was observed due to light intensity. *C. sphinx* roosts in tents made of folding palm fronds and is exposed to intermediate light levels (10-15 lx within tents), while *R. leschenaultii* prefers caverns that are entirely shielded from daylight (< 0.1 lx) (Murugavel et al., 2021). Pteropodid bat species select different roosting locations based on ambient light levels. Some roost in trees with high sunlight exposure (>1000 lx), while others prefer dark caverns (< 0.1 lx) (Murugavel et al., 2021). They inhabit diverse environments; *Pteropus* and *Acerodon* roost in open trees well-exposed to strong daylight (>1000 lx), while *Rousettus, Eonycteris*, and *Latidens* prefer caves, houses, and tunnels with minimal daylight exposure (< 0.1 lx) (Bates and Harrison 1997). Previous studies projected an increase in global temperature, raising concerns regarding the frequency and intensity of extreme weather events for fruit bats (Masson- Delmotte et al., 2021). Light also influences roosting ecology by affecting the circadian rhythms of animals (Narendra et al., 2010).

Population: In winter, the presence of bats in the roosting sites was low at both types of roosting locations. Tracking hidden bats' presence in the canopy or dark buildings were highly difficult, making it challenging to determine the exact population due to mild foggy weather and low light intensity (Fig. 5). In the plant roost, the population increasement was recorded from February onwards. The rise in roost microclimatic temperature increasement results in improved visibility of bats within the roost tents. By the end of March, gravid females began parturition (March-April) of young ones (pups), consequently increasing the harem size per roosting tent, which also resulted in an increased number of bat records at both roosting habitats. The overall population peaked in April, coinciding with a rapid increase in population size, and the roost temperature rose quickly, reaching extremes of over 42°C (above the threshold). Suddenly, the plant' tent-roosting bats began vacating the roost tents or shifting to denser areas (safest places) within the canopy, close to their previous tent positions, disrupting the harem structure and causing the remaining individuals to leave the roost tents. Although the population in the plant roost declined, no bat deaths were reported due to the extreme heat, as temperatures continued to rise until June in the plant roost. Research on bat behaviour during heat waves has revealed similar patterns of roost shifting to mitigate thermal stress (Bondarenco et al., 2014). Several previous consecutive studies on bats have indicated that habitat specialist bat species are more sensitive to environmental changes than generalist species due to their narrower niche

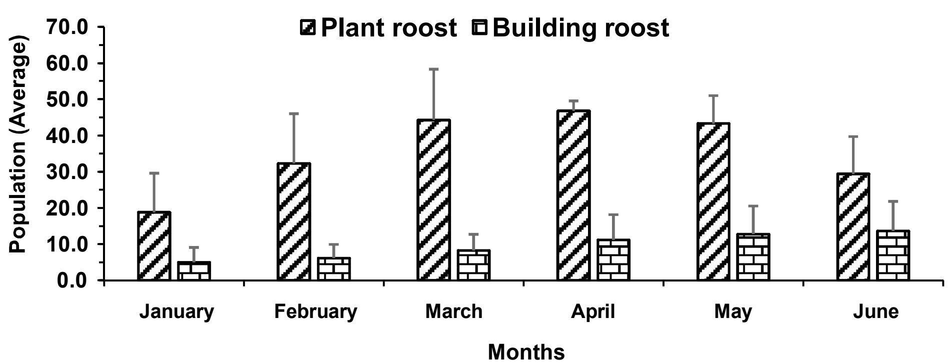

Fig. 5. Average population size in the plant and building roost throughout the study period

or stronger association with specific habitats (Novella-Fernandez et al., 2022). Larger fruit bats struggle to regulate their body temperature during extreme heat due to their roosting pattern in generally open plant roosts, which offer little protection from intense sunlight. Bats cope with extreme heat through various thermoregulatory strategies, such as increasing the area of their exposed wing surface, enhancing evaporative cooling by salivating and licking their wing membranes, and flapping their wings more during hotter afternoons than in the morning and evening, especially on sunny days rather than on cloudy ones (Anjum et al., 2024). Fruit bats are often vulnerable to high temperatures as they lack sweat glands (Downs et al., 2012).

The genus *Cynopterus* roosts in foliage, which is indeed more exposed to solar radiation and thus more prone to heat stress compared to those that roost in more sheltered locations like caves or buildings. Increased exposure to sunlight makes them more vulnerable to heat stress, which can lead to dehydration. Overheating can also elevate metabolic rates, leading to a higher demand for water and food, causing energy depletion and immune suppression, making them more susceptible to infections (Voigt and Kingston 2016, O'Shea et al., 2016). Such heatwave-related issues disrupt physiology, including thermoregulation and the reproductive cycle, and consequently may lead to mortalities. Earlier findings on bat mortality based on body size and roosting nature linked with large bat species like *P. medius* and *P. conspicillatus* show that are highly susceptible to extreme temperatures, resulting in mass mortality reported in different places in northern India and Australia due to their reliance on open, exposed roosting sites such as tree canopies, where they face direct sunlight (Dey et al., 2015; Diengdoh et al., 2022).

The current findings reveal that the disturbed harem structure of plant-tent-roosting bats due to climate change may be prone to the newly born young ones, which may cause the overall population decline in subsequent years. Previous studies report fruit bats suffer imminent dangers such as habitat loss and fragmentation, climate change, and extreme weather (Frick et al., 2018). These factors can cause fruit bat populations to decline, which can have serious ramifications for the environment, especially in areas where they are keystone species (Florens et al., 2017).

CONCLUSIONS

Cynopterus sphinx roosting pattern was influenced by various factors such as temperature, wind speed, humidity, light intensity, etc., contributing to the roost preference in the available building and plant roost with a large population size. Microclimatic factors can significantly impact the roosting behaviour of *C. sphinx* and cause them to change their plant roost to a safe plant canopy or building roost in extreme weather. These life-saving strategies reduce thermal stress and mortality and help them to survive better than other fruit bats. Therefore, important to study roost characteristics, roost microclimate, and availability of resources in roosting ecology for the conservation and management of bat roosts. Bat survival is a critical part of many ecosystems as they play a key role in pollination, seed dispersal of various plant species, and forest rejuvenation. Rapid climatic changes and roost-associated threats highlight the importance of protecting bats and their natural habitats by developing conservation strategies for sustainable biodiversity. Understanding the roosting behaviour is crucial to adopt region-specific conservation initiatives against climate change impact on their roosting habitats.

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AUTHOR'S CONTRIBUTION

Vijay Kumar: Writing original draft, formal analysis, software, data curation, methodology, review and editing. Shiv Shankar Pandey: Roost identification. Subham Acharya and Dinesh Gautam: Field observation and data collection. Vadamalai Elangovan: conceptualization, supervision, validation, review and editing of final manuscript.

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