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Assessing the Home Range, Foraging Pattern and Roost Fidelity of Greater Short-nosed Fruit Bat (*Cynopterus sphinx*) in a Semi-Urban Environment

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Radio telemetry is a method used in wildlife ecology to examine the movements and behaviours of animals, as well as to define their home ranges and habitat preferences. Bats, a highly diverse group of mammals, are recognized for their essential contributions to ecosystems, including seed

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dispersal, pollination, and pest control through their foraging activities. This study utilised radio telemetry to explore the basic foraging behaviours, range of movement, and roosting flexibility of the *Cynopterus sphinx* species. A total of 15 bats were equipped with compact, hand-wired, two-stage transmitter radio devices, including two harem males, nine harem females, and four non-harem males. Three groups used TRX-1000S receivers and collapsible 5-element Yagi antennas to track these radio-tagged bats. Our findings indicate that the radio-tagged female bats were the first to leave their roosts, with emergence times between 18:15 and 19:18 hrs. In contrast, harem males emerged last, following the quicker departure of non-harem males. The harem males covered an average foraging distance of 2.4 km (±0.3 km), whereas non-harem males travelled further. Both male and female bats visited multiple feeding sites nightly, with females travelling an average distance of 4.5 km (±0.9 km). Time spent at foraging sites varied among individuals. Males show higher roost fidelity than females, who frequently move between harems and roost sites. The study highlighted gender-specific differences in emergence times and distinct foraging behaviours, underlining the importance of understanding these patterns for conservation and habitat management efforts, which are crucial for supporting bats' roles as providers of ecosystem services.

Keywords: Cynopterus sphinx; ecosystem; emergence; roost fidelity; foraging distance.

1. INTRODUCTION

Bats belong to Order Chiroptera, one of the most varied mammalian groups, comprising 18 families, 202 genera, and 1,440 species, accounting for 25% of all mammal species globally [1, 2]. Molecular phylogenetic research has categorized these 18 families into two primary suborders, Yinpterochiroptera, which includes the families Pteropodidae, Rhinolophidae, Megadermatidae, and Rhinopomatidae; and Yangochiroptera, which encompasses Emballonuridae, Furipteridae, Molossidae, Mormoopidae, Mystacinidae, Myzopodidae, Natalidae, Noctilionidae, Nycteridae, Phyllostomidae, Thyropteridae, and Vespertilionidae [3].

Bats showcase significant diversity with 18 families. These families exhibit various distribution patterns across the globe, highlighting the adaptability and resilience of bats. Some families, such as Pteropodidae, Rhinopomatidae, Nycteridae, Megadermatidae, Rhinolophidae, Hipposideridae, Myzopodidae, and Mystacinidae, are restricted to the Old World. Conversely, families like Noctilionidae, Phyllostomidae, Desmodontidae, Natalidae, Furipteridae, and Thyropteridae are found only in the New World. Three families Emballonuridae, Molossidae, and Vespertilionidae have members in both hemispheres, underscoring their extensive adaptability [4,1]. This varied distribution reflects the historical and ecological dynamics influencing bat evolution.

Bats play essential roles in ecosystems as key service providers. Plant-visiting bats are crucial in seed dispersal and pollination processes, while insectivorous bats help control nocturnal insect populations, aiding agricultural pest management significantly [5]. Their activities illustrate the intricate interactions within ecosystems, emphasizing their importance in maintaining ecological balance.

Fruit bats, in particular, are fascinating due to their diverse and specialized diets. They rely on plant resources throughout the year, with each species exhibiting specific preferences for certain plants. A notable aspect of their foraging is the quick germination of seeds once processed by the bats. For example, Pteropodid bats pollinate around 168 plant species across 100 genera and 41 families, while Phyllostomid bats are known to pollinate approximately 360 species in 159 genera and 44 families. This extensive pollination and seed dispersal are crucial for the reproduction of many plant species and the sustainability of habitats [6].

Radio telemetry has become indispensable in wildlife ecology, especially in studying bat behaviour. This technique allows researchers to track animal movements and activities, helping them to understand the size of their home ranges and how they utilize their habitats. By using radio telemetry, researchers have been able to expand our knowledge of chiropteran behaviours significantly. Studies conducted by some authors [7-9] are examples of how radio telemetry has contributed to our understanding of chiropterans. For instance, radio tracking has provided insights into the activities of *Nyctalus noctula, Rhinolophus ferrumequinum, Plecotus auritus,* *and Eptesicus nilsonii*, revealing patterns in roost selection and fidelity [10-13]; mating success [14] and resource defence [15]. Such studies help enhance our understanding of bat ecology, which is vital for effective conservation strategies and habitat management.

Cynopterus sphinx is a medium-sized (mean body weight: 40 g – 60 g) plant-visiting bat in the old-world tropics. *C. sphinx* is characterised by a harem-forming social structure. It is a tent-making bat, the males modify and construct tents in the flower/fruit clusters of kittul palm (*Caryota urens*), the area beneath the stems of climbing vines (*Vernonia scandens*), the foliage of mast tree (*Polyalthia longifolia*), the drooping fronds of desert palm (*Washingtonia filifera*), Palmyrah palm (*Borassus flabellifer*) and artificial structures [16] and defend it as a resource to attract females. It shows seasonal polyoestry, having two distinct reproductive periods per year [17]. The first breeding phase occurs from March to April, and the second occurs from October to November [18].

Studying the foraging behaviour of bats like *Cynopterus sphinx* is challenging due to their nocturnal and quick-flying nature, which complicates direct observation. Key aspects of their foraging ecology, such as the maximum distance travelled for food, duration spent at foraging sites and social interactions within and between species, are critical for understanding their ecological roles and for conservation efforts. This investigation seeks to gather basic foraging information on the Greater short-nosed fruit bat. It aims to document their emergence and return timings, night roost usage, foraging patterns, social interactions within the colony, alternate roost sites for females, and roost fidelity among both male and female bats. Such information is vital to developing effective conservation strategies and understanding the ecological dynamics of this species.

2. MATERIALS AND METHODS

A radio telemetry study was performed in the semi-urban region of Tirunelveli, focusing on tracking the *Cynopterus sphinx*, a species known for its distinct breeding cycles. The study was divided into two phases, aligning with the bat's breeding seasons. The first phase of the radio-tracking experiment took place in October 2020, while the second phase occurred from mid-February to March 2021. This timing was strategic, allowing researchers to observe and record behaviours and movements specific to each breeding period of the *Cynopterus sphinx*.

2.1 Study Area

The study was conducted in Rajagopalapuram, a semi-urban area within Tirunelveli, India, located at coordinates 08°41.465' N, 077°45.619' E (Fig. 1). This region, situated on the southern coastal plains of peninsular India, lies in the rain shadow region of the Western Ghats. The focal species, *Cynopterus sphinx*, is abundant here, utilizing the Palmyrah palm trees (*Borassus flabellifer*) as day roosts. These bats form harems within the modified bell-shaped leaves of these palms, providing ideal roosting conditions amidst the agricultural landscape of paddy fields and banana plantations.

Surrounding the area are various fruit-bearing trees such as neem (*Azadirachta indica*), Manila tamarind (*Pithecellobium dulce*), country almond (*Terminalia catappa*), Singapore cherry (*Muntingia calabura*), and various species of *Ficus*, along with orchards of guava (*Psidium guajava*), sapota (*Achras zapota*), and mango (*Mangifera indica*). These serve as opportunistic foraging sites for the bats.

During the first breeding season, telemetry studies involved nine bats—comprising one harem male with six females and two non-harem males. In a subsequent phase of the study, six bats were tracked, including one harem male with three females and two non-harem males. Bats were captured using a hoop net mounted on extendable aluminium poles just before their evening emergence. Recorded data for each individual included sex, relative age, tooth wear class, and reproductive condition. Morphometric measurements such as forearm length and body mass were precisely measured.

Following data collection, each bat was fitted with a small, hand-wired 2-stage transmitter (model SOM2011, Wildlife Materials Inc, Illinois, USA), weighing 0.9 g, with a range of approximately 900 meters. The transmitters were attached to plastic collars covered in reflective tape of different colours to facilitate easy identification during nighttime activities, such as foraging or roosting. The combined weight of the transmitter and collar was about 3.6% of an adult bat's body mass, adhering to the recommended maximum of 5% [19]. Bats equipped with these radio collars were released within two hours of capture, ensuring minimal disruption to their natural behaviour. Three tracking groups monitored the radio-tagged bats using two TRX-1000S receivers and collapsible three and 5-element Yagi antennas (Customs Electronics, Urbana, Illinois, USA and Wildlife Materials Inc, Illinois, USA). Each day, two groups tracked two bats in the foraging area, while the other group was stationed near the day roost, monitoring the bat activity there. The single bat was tracked for a maximum of 5 or 7 days. A change in pulse rate according to the antenna's orientation allowed us to determine whether the bat was flying or roosting. The constant beep signals were considered 'rest', and variable singles were considered 'flying'. Foraging time is defined as the period between emergence from the roost at dusk and return to the roost at dawn. 'Foraging bouts' were defined as when a bat flew continuously between leaving the roost and returning to the same roost. The distance travelled by each individual was calculated by using an area map.

Fig. 1. Google Earth image showing the study area

Fig. 2. Photograph showing the palmyrah palm that provides a roost site for *C. sphinx*

Fig. 3. Study animal *C. sphinx*

Fig. 4. A radio transmitter fitted to a bat

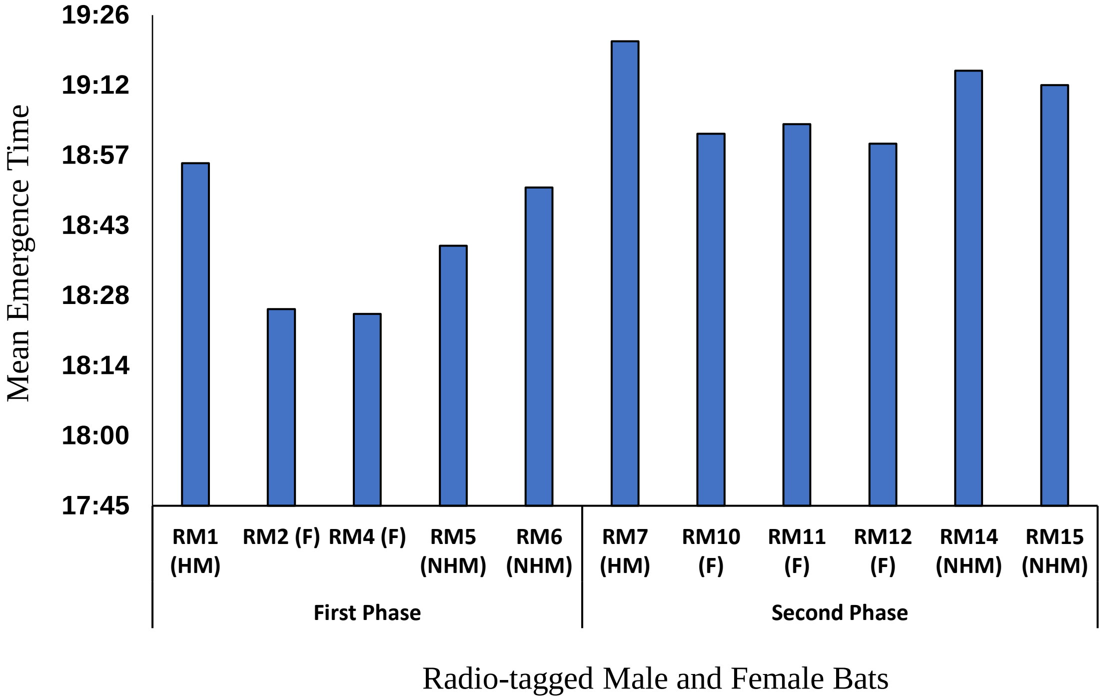


Fig. 5. Average emergence time of male and female bat

3. RESULTS

Of the 15 bats involved in the study, three female bats (identified as RM3, RM8, and RM13) left their designated roosting sites; one was transmitter failure. The remaining 11 bats were successfully tracked throughout the study. The radio-tagged bats provided valuable data that allowed researchers to determine critical aspects of bat behaviour. This included the timing of their emergence from and returns to roosting sites, their foraging patterns, the use of night roosts, interactions among the bats, and the identification of alternate roost sites used by female bats. These insights are essential for understanding the spatial and social dynamics of the bats, as well as for future conservation efforts.

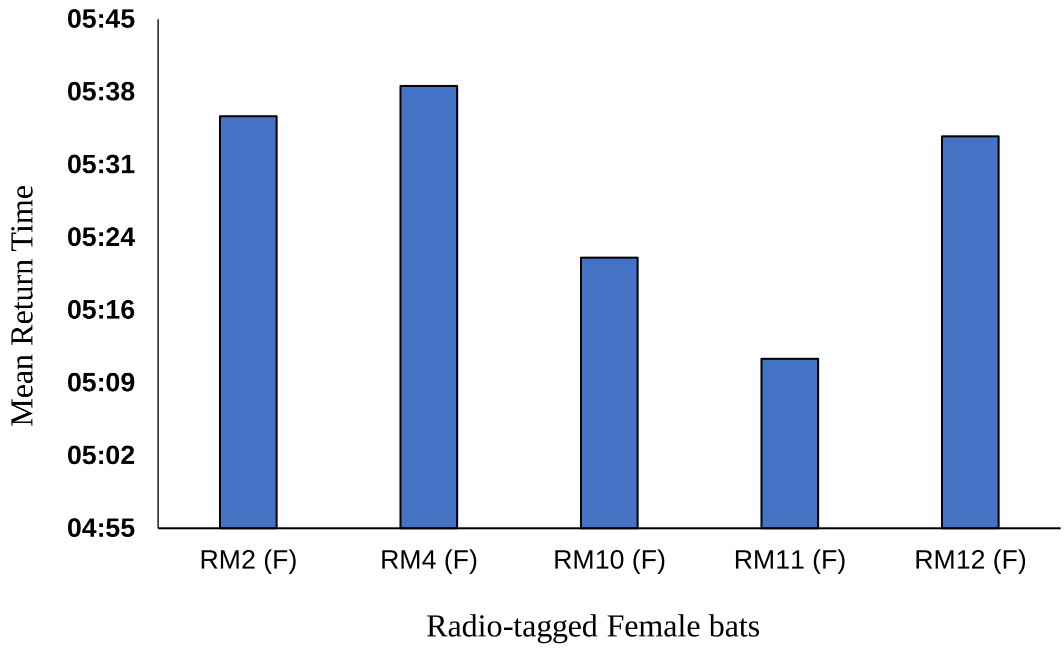


Fig. 6. Average return time of the female bat

3.1 Dispersal from the Roost

Our study provided valuable insights into the behavioural patterns of *Cynopterus sphinx*, particularly focusing on their emergence and return timings. We found that the radio-tagged female bats were consistently the first to leave their roosts, with emergence times spanning from 18:15 to 19:18 hours. In contrast, harem males were the last to emerge, preceded by non-harem males. The mean time interval between the emergence of females and harem males was recorded at 31 minutes and 19 seconds during the study's first phase and shortened to 19 minutes and 9 seconds in the second phase. The gap between the emergence of females and non-harem males also varied, averaging 20 minutes and 9 seconds in the first phase and reducing further to 8 minutes in the second phase. These temporal patterns are depicted in Fig. 5, with a significant correlation (Spearman's rs = 0.738, $P < 0.001$, $n = 68$) between the emergence times of females and non-harem males.

Regarding their return behaviour, female bats typically returned between 4:45 to 6:02 hours, as shown in Fig. 6. Intriguingly, about 90% of the radio-tagged females did not return to their initial roosting tent or colony during the nighttime. This contrasts sharply with male bats, which often revisited their tents throughout the night. Observation of male behaviours suggested they would quickly travel to their foraging areas after emerging, undertake a short foraging bout, and then return to their roost. These observations highlight clear distinctions in nocturnal activities and social interactions between male and female bats within this species, providing a deeper understanding of their ecological roles and behaviours.

3.2 Foraging Pattern of Males

During the study, notable differences were observed in the foraging behaviour and distances travelled by harem and non-harem male *Cynopterus sphinx* bats. Harem males travelled an average distance of 2.4 km (± 0.3 km) for foraging, as documented for two individuals. In contrast, non-harem males ventured further, with an average maximum distance of 3.4 km (± 0.4 km) recorded for four bats.

Regarding foraging behaviour, harem males typically carried the collected food, which included fruits, leaves, or flowers, back to their roosting tents. The time spent in the foraging grounds was notably different among individual bats. For instance, harem male bat #1 spent an average of 190.0 minutes (± 47.8 minutes) over five days in the foraging grounds, while harem male #7 spent approximately 169.3 minutes (±

26.8 minutes) over six days. Among the non-harem males, bat #5 spent the most time foraging, averaging 334.0 minutes (± 38.5 minutes) over five days, indicating a more extended foraging period than the harem males.

The study also documented the roosting habits of the males. Harem males typically roosted at night in the same tents used during the day. Harem male #1 spent an average of 362.6 minutes (± 43.9 minutes) inside the tent over five days, while harem male #7 spent about 342.2 minutes (± 40.9 minutes) over six days. The frequency of commuting flights between the tent and foraging grounds for these harem males was 7.6 times (± 3.9 times) and 8.5 times (± 2.7 times), respectively, over the observed days.

Non-harem males, on the other hand, chose day roosts or trees close to fruiting trees for their night roosts. These locations, primarily used for feeding and resting, saw varied durations of stay. For instance, bat #5 spent the most time at night roosting locations, averaging 131.8 minutes (± 21.1 minutes) in places with tree species dominated by coconut trees (*Cocos nucifera*) and *Albizia lebbek*. In contrast, bat #15 spent the least time, averaging 84.5 minutes (± 34.9 minutes) over five days.

Additionally, the behavioural activities observed at the tent during night hours included feeding, resting, tent construction, marking, and cleaning, highlighting the complex and dynamic nature of their nightly routines. These findings provide a deeper understanding of the behaviour of male *C. sphinx*. That is essential for effective conservation and management strategies.

3.3 Foraging Pattern of Females

Similarly to the male bats, the female *Cynopterus sphinx* also visited two foraging grounds each night, as indicated in Map 1. The females travelled an average distance of 4.5 km (± 0.9 km) from their day roosting sites, typically returning to the same foraging areas each night. Among the females tracked, bat #10 covered the maximum distance, travelling up to 6.4 km in a single night for foraging purposes. The time spent in the foraging ground varied among the individual female bats. Bat #11 spent the least amount of time foraging, averaging 204.8 minutes (± 37.9 minutes) over five days, while bat #4 spent the most time, with an average of 312.0 minutes (± 36.7 minutes) in the foraging ground, as detailed in Table 2.

Female bats used buildings and trees close to fruiting trees as their night roosts. These locations were typically protected areas, free from predators, enhancing their safety during rest periods. The females mostly navigated through the canopy layers to commute between their night roosts and foraging perches. The average time spent at the night roost varied among the females, and the maximum distance they commuted from the fruiting trees to their night roosting spots ranged from 9 to 21 meters, as shown in Table 2.

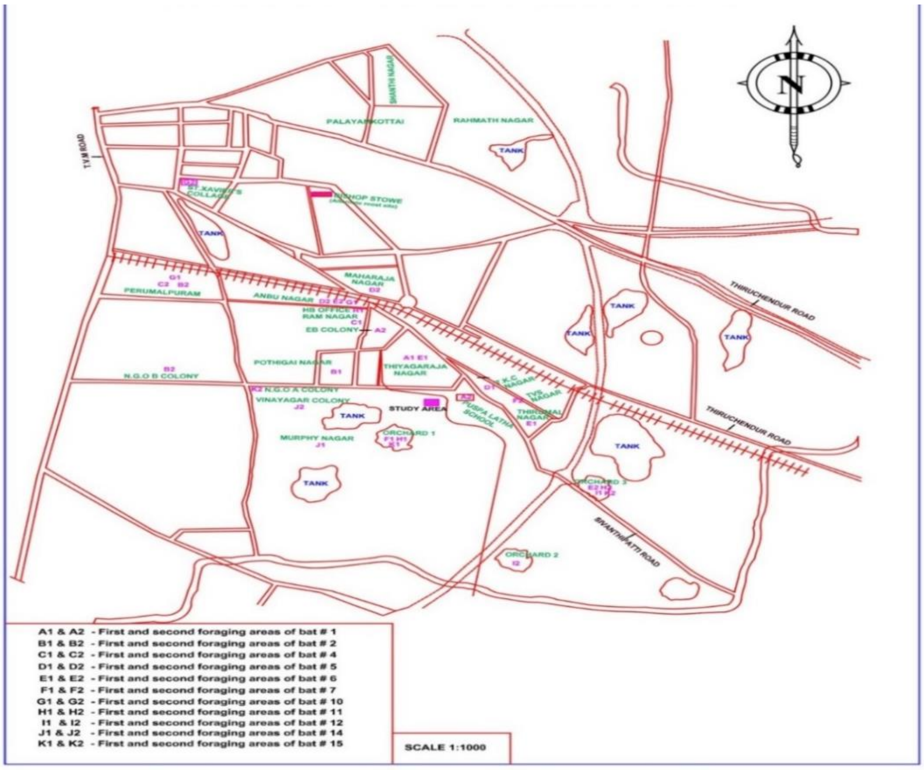
During their time at the night roost, the female bats engaged in various behaviours, including feeding, grooming, and resting. Notably, each female established separate night roosting sites, indicating a preference for individual roosting locations rather than shared sites. Observations of the debris collected beneath these night roosts revealed that the females typically selected a single type of fruit to consume during a given foraging period based on the availability of that fruit. This behaviour underscores the selective foraging strategies employed by female bats and highlights their adaptive responses to the availability of food resources in their habitat.

Table 1. Time budget of the harem and non-harem males

Bat No	Status	Tracking Days	Time spent by bats (minutes)			Number of commuting flights
			Day roost	Foraging ground	Other night roosts	
RM1	HM	5	362.0 ± 33.9	190.0 ± 27.8	Nil	14.6 ± 3.9
RM5	NHM	5	111.0 ± 29.6	334.0 ± 38.5	131.8 ± 21.1	7.5 ± 2.1
RM6	NHM	7	163.1 ± 27.9	311.2 ± 39.7	87.7 ± 19.5	8.6 ± 3.2
RM7	HM	6	342.2 ± 20.9	169.3 ± 26.8	Nil	16.5 ± 2.7
RM14	NHM	5	144.5 ± 11.5	282.3 ± 37.7	105.3 ± 44.2	6.0 ± 2.6
RM15	NHM	5	195.4 ± 45.4	265.0 ± 21.5	84.5 ± 34.9	9.7 ± 3.1

Table 2. Time budget of females

Bat No	Tracking Days	Time spent by bats (minutes)		Distance from foraging ground (meters)
		Foraging ground	Night roost	
RM2	5	306.6 ± 40.2	262.5 ± 44.9	12
RM4	5	312.0 ± 36.7	246.0 ± 40.6	9
RM10	5	249.5 ± 43.2	259.1 ± 43.7	15
RM11	5	204.8 ± 37.9	271.8 ± 51.8	21
RM12	5	209.4 ± 30.2	264.9 ± 42.3	15



Map 1. Foraging area of ratio tagged males and female bats

3.4 Roost Fidelity and Alternate Roost Site

In the telemetry study involving 15 bats, we observed a 72% return rate to the original roost sites after being fitted with transmitters. This included all six tagged male bats and two of the nine tagged females. The return timings for the females varied: bat #10 returned on the second day, bat #2 on the fifth day, and bat #12 on the twelfth day. Our findings indicate that the radio-tagged female bats frequently moved between different harems within the colony.

All male bats with transmitters successfully returned to their roost sites. Specifically, five of the six male bats returned to their original tents, while one male bat (bat #15) shifted to an alternate tent on the twelfth day of the study, as detailed in Table 3.

We also successfully identified alternate roosting trees for two of the female bats. These alternate roost sites, which were *Polyalthia longifolia* trees, were located on the campus of Bishop Stowe, approximately 4.8 km away from their original roosting site. Notably, during the night-time of the ninth day of tracking, bat #11 was observed foraging on the Bishop Stowe campus. Early in the morning at 5:10 hrs, this particular female moved to and joined a well-established harem male's tent in tree no 8. Furthermore, on the fifteenth day of tracking, female #10 left her previously occupied tent and joined the tent of a non-harem male located on the same campus (tree no 22).

These observations highlight the dynamic nature of roosting and social behaviour among *Cynopterus sphinx*, particularly females, who exhibit more fluidity in roosting preferences and social associations than males.

3.5 Female Recruitment

During the study of non-harem male bats, three out of four maintained their status throughout the observation period. In contrast, one bat experienced a notable change in behaviour and status on the 13th day. Specifically, bat #15, a non-harem male, exhibited significant changes starting on the 12th day. After completing its first foraging session, this bat did not return to its original roost (tent no RP4/1) but moved to an adjacent, unoccupied tent (tent no RP4/2) within the same tree. Throughout that night, the bat made five visits to this new tent, spending considerable time there and engaging in activities such as tent marking, wing shaking, and tent maintenance.

On the morning of the 13th day, this non-harem male began to frequent a nearby well-established harem male's tent (tent no RP6/2), where it persistently disturbed the returning harem females. This behaviour resulted in a total of seven visits to the harem male's tent during that day. The interactions escalated when the non-harem male succeeded in recruiting three untagged females from the harem tent, forming a new harem in his newly occupied tent.

This transition had a noticeable impact on the bat's daily activities. Before the recruitment of females, the average time the male spent in the day roost was recorded at 195.4 minutes (± 45.4 minutes) over five days. Following the formation of the new harem, this duration significantly increased to 337.7 minutes (± 22.9 minutes) over three days. The statistical analysis ($F1, 7 = 24.48$, $P < 0.05$) confirms a significant difference in the time spent at the day roost before and after the recruitment of females.

These observations underscore a pivotal behavioural shift in the non-harem male. This shift altered the male's roosting preferences and social dynamics as it transitioned from solitary to harem leader, thereby affecting his daily routines and interactions within the bat colony.

Table 3. Roost site fidelity of radio-tagged bats

Days	Bat number											Return rate (%)
	RM1 (HM)	RM2 (F)	RM4 (F)	RM5 (NHM)	RM6 (NHM)	RM7 (HM)	RM10 (F)	RM11 (F)	RM12 (F)	RM14 (NHM)	RM15 (NHM)	
1	OT	NR	AT	OT	OT	OT	NR	OT	NR	OT	OT	72
2	OT	NR	AT	OT	OT	OT	NR	OT	NR	OT	OT	72
3	OT	NR	AT	OT	OT	OT	NR	AT	NR	OT	OT	72
4	OT	NR	AT	OT	OT	OT	NR	AT	NR	OT	OT	72
5	OT	OT	AT	OT	OT	OT	OT	AT	NR	OT	OT	90
6	OT	OT	AT	OT	OT	OT	OT	AT	NR	OT	OT	90
7	OT	OT	AT	OT	OT	OT	AT	OT	NR	OT	OT	90
8	OT	AT	AT	OT	OT	OT	AT	OT	NR	OT	OT	90
9	OT	AT	AT	OT	OT	OT	AT	OT	NR	OT	OT	90
10	OT	AT	AT	OT	OT	OT	AT	ARS	AT	OT	OT	90
11	OT	AT	AT	OT	OT	OT	OT	ARS	AT	OT	OT	90
12	OT	AT	AT	OT	OT	OT	OT	ARS	AT	OT	AT	90
13	OT	OT	OT	OT	OT	OT	OT	ARS	AT	OT	AT	90
14	OT	OT	OT	OT	OT	OT	OT	ARS	AT	OT	AT	90
15	OT	AT	OT	OT	OT	OT	ARS	ARS	AT	OT	AT	81
16	OT	OT	OT	OT	OT	OT	ARS	ARS	AT	OT	AT	81
17	OT	OT	OT	OT	OT	OT	ARS	ARS	AT	OT	AT	81

OT - Bat roosted at an original tent, NR- Did not return, AT - Bat roosted at an alternate tent, ARS - Bat roosted at an alternate roost site

4. DISCUSSION

The central focus of this study was to investigate the fundamental foraging strategies of *Cynopterus sphinx*, particularly examining aspects such as the timings of emergence and return, night use patterns, and social interactions at foraging sites. Additionally, the study aimed to identify alternate roosting sites and assess the stability of roost preferences among both male and female bats. This research was conducted during October and March, aligning with the species' biannual breeding cycles to provide insights during critical periods of their natural behaviour.

In the observed behaviours, radio-tagged female bats consistently emerged first after sunset, followed by non-harem males, and finally, harem males. The timing of emergence generally coincided with sunset, with a slight delay observed during shorter days as opposed to longer days. Typically, females would leave their roosts 5 to 10 minutes after sunset, underscoring a possible link between sunset timing and bat emergence behaviour. This pattern of early emergence in females is associated with their need for long-distance travel to forage. This aligns with findings from other studies on different bat species, such as the Little brown bat (*Myotis lucifugus*), where females also emerged earlier than males [20]. Similar behaviours have been noted in other bat species like *Nyctalus noctula* [21], *Lasiurus cinereus* [22], *Myotis velifer* [23] and *Chaerephon pumila* [24].

The later emergence of harem male bats is particularly interesting and appears strategic; these males have the critical role of defending their roost from potential usurpers, suggesting that their delayed emergence is a calculated decision to maintain security and stability within their harem groups [25]. This behaviour suggests a significant evolutionary adaptation that enhances their ability to manage and safeguard vital reproductive resources. Kelm *et al.* [26] reported that bat species' presence in natural roosts is predictable from habitat and structural roost parameters but that the presence and abundance of other bat species further modify roost choice.

In this study, the behaviour of radio-tagged harem male *Cynopterus sphinx* bats was closely monitored to understand their foraging strategies and territorial habits. After the harem females emerged, harem males left the tent and travelled to nearby areas to forage, primarily seeking fruits, leaves, or flowers, which they then carried back to the tent. The data indicated that harem males typically travelled an average distance of 2.4 km (± 0.3 km). This supports the idea that they prefer shorter foraging trips to stay close to the roost, which is essential for maintaining their resources and defending the harem.

In contrast, non-harem males were observed travelling farther distances for food, with an average maximum distance of 3.4 km (± 0.4 km), suggesting a different strategy possibly due to less territorial commitment, which allows them greater mobility. The behaviour of these males indicates a strategy where the need to defend a territory or harem does not restrict their foraging range. Mate guarding has been known to incur costs and cause constraints for harem males in many polygynous species. However, the effect of female group size on the harem male's time budget in bats has received very limited attention. The Indian short-nosed fruit bat, *Cynopterus sphinx*, exhibits resource defense polygyny, in which the males construct tents and defend multiple female bats. Once females departed for foraging, harem males remained in their tents at night-time between intermittent foraging bouts and engaged in tent maintenance and guarding. Mahendren *et al*. [27] argued that time invested by harem male bats in tent maintenance and tent guarding was positively and significantly correlated with female group size. Harem males extended their presence in tents by utilizing tents as feeding roosts. Female group size also influenced the emergence time of harem male bats, where males with the largest group emerged later than did the smallest group.

The responsibility of the harem males to defend their tent and maintain resources within a close range is an important behaviour, as noted by Marimuthu et al. [28]. Such behaviours, including scent-marking and vigorous wing flapping during their stay in the tent, are crucial for communication and territory defence, as reported by Doss et al. [18]. These behaviours are not unique to *Cynopterus sphinx*. Still, they are also observed in other bat species, such as *Carollia perspicillata* [6] and bat species [29], where males stay within their territories to fend off intruders without the presence of females.

Furthermore, similar patterns of restricted foraging distances are seen in *Artibeus jamaicensis*, *Phyllostomus hastatus*, and *Carollia perspicillata*, which predominantly forage near their day roosts, highlighting a common ecological strategy across different bat species to optimize foraging efficiency while balancing territorial and reproductive duties [30-32].

In the present study, the behaviour of radio-tagged female *Cynopterus sphinx* bats was closely monitored, revealing that they consistently visited two specific foraging grounds each night. These females travelled an average distance of 4.5 km (± 0.9 km) from their day roosting sites and preferred to return to the same foraging areas regularly. This consistent travel pattern to established foraging sites can be attributed to the "trap-lining" behaviour, a strategy where bats follow a regular path to minimize commuting distance and energy expenditure, taking advantage of the constancy in resource availability [33].

The relatively longer distances travelled by female bats compared to some of their male counterparts might also reflect a strategic choice to access a broader range of foraging areas or to interact with potential mates. Such behaviours are not uncommon among bats and can be particularly pronounced in pregnant females, as seen in *M. myotis*, where increased foraging time is necessary to meet heightened energy demands [34].

Furthermore, female *Cynopterus sphinx* bats exhibit flexibility in their foraging patterns, often unpredictably changing their primary foraging areas, this behaviour was also noted in *Carollia perspicillata* [35]. This variability in foraging locations likely contributes to dietary diversity, as not every area contains the same quality or quantity of food resources. In contrast, male bats often show overlapping foraging areas, which could be due to the proximity of day roosts to rich food patches, allowing them to minimize the distance they travel and thereby conserve energy [33].

Commute distances in bats can vary significantly across species and even within a population, depending on ecological and physiological factors. Some species, like *Myotis myotis*, are known to travel up to 26 km to reach their foraging grounds [36], whereas others may forage near to their roosts, as documented in several studies [13,37,12]. This variation underscores the adaptability of bats to different environmental conditions and resource distributions, highlighting the complexity of their ecological dynamics and the need for tailored conservation strategies to ensure their survival and health.

In the observed behaviours of *Cynopterus sphinx* during our study, male bats demonstrated a higher degree of roost fidelity compared to females. The radio-tagged female bats frequently switched harems and roost sites. Notably, on the 9th day of tracking, bat #11 was observed foraging at the Bishop Stowe campus, which was identified as their second foraging ground. Rather than returning to their original roosting site early in the morning, they opted to join a well-established harem male's tent located within the foraging ground.

This pattern of higher roost fidelity among male bats can be attributed to their roles in harem formation and female recruitment. The need to maintain a stable roosting site is likely driven by the males' strategy to attract and retain females, thereby ensuring their reproductive success. This behaviour is consistent with findings in other bat species exhibiting strong roost fidelity due to similar social structures. For example, the tent-roosting bat *Artibeus watsoni* displays similar fidelity to roosts, which is integral to their social organization [38,39].

Additionally, the Jamaican fruit bat, *Artibeus jamaicensis*, known for its high roost fidelity, utilizes this trait to attract females and defend its roost, whether located in trees [40,41] or caves [42,43]. This behaviour underlines the importance of stable roosting sites in the social and reproductive strategies of male bats.

These observations highlight a fundamental aspect of bat behaviour where males often prioritize the stability of their roosting environment to enhance their attractiveness to potential mates and effectively defend their territory against competitors. This strategic fidelity is crucial in the context of harem maintenance and is a key factor influencing the social dynamics within bat populations [44,45]. Understanding these patterns is essential for conservation efforts, particularly in managing habitats that support these complex social structures.

Of the four radio-tagged non-harem males, three were solitary during the study period, and the remaining one bat changed their status on the 13th day by recruiting females. This is because the female *C. sphinx* tends to move from one roost to another. Our observation agrees with the study by Karuppudurai et al. (2008) which reported that the solitary males roosting near a harem started recruiting females by occupying the tent abandoned by a harem.

5. CONCLUSION

The prime intention of the study was to ascertain the social organisation and basic foraging strategy of the greater short-nosed fruit bat, *Cynopterus sphinx.* The foraging behaviour included the timings of emergence and return, the pattern of night use, social interaction in the foraging fields etc. Again, this study provided information about locating the alternate roost sites and roost lability of male and female bats. The long-term application of this study is twofold. Firstly, this animal plays a vital role in seed dispersal and pollinating various plants. Despite their importance, bats are still considered vermin, and their numbers continue to decline due to habitat loss. The present study provided the scientific database to protect the species and the habitat. Secondly, this type of study reveals the exclusive mating zones of bats, which is helpful for the conservation of bats. Further, the immediate outcome of this study is tent construction, tent defence, and harem formation were strictly male-biased behaviours, and females contributed to parental care entirely. The evolution of sex-biased social behaviours has contributed to considerable variation in sex-biased dispersal patterns, foraging patterns and spatial movement patterns.

ETHICAL APPROVAL

This study was conducted with ethical permission obtained from the Institutional Ethics Committee of Madurai Kamaraj University (Tamil Nadu, India).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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