



THE DIURNAL ACTIVITY PATTERNS AND FORAGING BEHAVIOUR OF THREE-STRIPED PALM SQUIRREL *FUNAMBULUS PALMARUM*

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Abstract: The three-striped palm squirrels (*Funambulus palmarum*) are arboreal and opportunistic animals. They are diurnal and exhibit various activities in the daytime followed by a period of inactiveness in the night. The squirrels are omnivores and show wide range of food preferences and feeding strategies. The diurnal activity patterns, food preferences and feeding strategies exhibited by the three-striped palm squirrels were studied using focal animal sampling method across different seasons in Anna Nagar, Madurai for a duration of three months from December 5, 2021 to March 4, 2022. From the results it is seen that the squirrels showed bimodal patterns of diurnal activities which had two distinct peaks in the morning and the evening. The squirrels highly preferred the foods provided by humans rather than natural vegetation and insects which describes the boldness or risk-taking behavior of the squirrels. Gnawing of foods was frequently opted as a feeding strategy. The squirrels were found to adapt to the available resources irrespective of the seasonal changes.

Keywords: Physiological adaptations, diurnal activities, running, climbing, jumping, resting, natural vegetation, supplemented food, gnawing, caching, scavenging.

1.0 INTRODUCTION

The Indian Palm Squirrel or Three-striped Palm Squirrel or the Common Palm squirrel, *Funambulus palmarum* are rodents that belong to Family Sciuridae. The word 'palmarum' refers to the palm trees where it is generally spotted. It is endemic to southern India and Sri Lanka. They range in size from 220 to 400 mm in length and weigh about 100 to 120 g (Menon, 2003). They have rounded ears, dark rounded eyes, brownish grey dorsum, a bushy tail which measures 7 to 9 inches, and three yellowish-white stripes on its ventral side. They breed in autumn and their gestation period is about 42 to 45 days. A female can have two to three litters per year of one to six pups (Seebeck, 1989).

F. palmarum builds nests from leaves, twigs, and other plant-based fibres at a height of about 25 feet from the ground. The nests are usually lined with twigs and filled with dry leaves that serve as a bedding material for the young ones (Thurston and Brittingham, 1997). By 5 weeks of age, the pups fully develop a coat of fur and by 10 weeks of age, the young ones are completely weaned and no longer depend on the mother. Palm squirrels in the wild live for about 2 to 3 years. *F. palmarum* is commonly found in dry tropical habitats that include grasslands, scrublands, plantations, and all urban ecosystems (Long, 2003). They are generally arboreal and burrow in tree cavities. Palm squirrels are opportunists, and they exhibit a wide range of food preferences. They are omnivores and hence feed on plants, fungi, insects, and other animal-based foods. When their population peaks at a particular location, they chew tree barks and other animal matter (Thurston and Brittingham, 1997).

Diurnal activity of an animal can be best described by the activities that are exhibited during the day which is followed by the state of inactivity in the night (Lima, 1998). The study of diurnal activity rhythm is essential to note the response of the animal to climatic changes (McCain and King, 2014).

Darwin's theory of natural selection emphasizes on two terms in his Origin of Species- the struggle for existence (determines the variations that provides advantages in the environment which alters the species through a selective reproductive rate) and survival of the fittest (the organisms that are most adapted to their environment are the most successful in surviving and reproducing) (Claeys, 2000). Boldness or risk-taking behaviour of an organism determines its rate of surveillance in the environment (Tinkle, 2016). Natural selection produces various foraging strategies like food selection, location, time, and duration of feeding which balances the energy gains. It favours the selection of those that can be easily foraged and consumed which can provide higher net energy intake (MacArthur and Pianka, 1966; Pyke *et al.*, 1977). This is determined by energy cost to benefit ratio (Stephens and Krebs, 1986). Squirrels have well-developed sharp claws to hold the tree trunk firmly as they climb and leap over trees in search of food. Tree squirrels have a longer tail that helps them to run across the branches (Thorington and Ferrell, 2006). Generally, squirrels prefer to eat in trees than on the ground as they are more prone to predation. Their sharp curved claws and the flexibility in joint between talus and calcaneus provides the ability to rotate their hind feet to due to 180 degrees make them excellent climbers and to leap larger distances using their hindlimbs (Campbell, 1999). Various sounds of vocalization include high-pitched squeaks, low-pitched chatter, and harsh rough calls accompanied by changes in posture and tail flicks (Thompson, 1977). Squirrels are excellent model organisms to study the

ecological and behavioural differences in urban and rural wildlife as they are diurnal, easy to observe, can be individually marked and studied for longer time periods (Thorington *et al.*, 2012).

Although their general biology is known, specific knowledge of their natural feeding behaviour, oral anatomy and physiology are essential (Mancinelli and Capello., 2016). The dental adaptation in squirrels is necessary, as it is used to crack open hard-shelled foods and for self-defence from animal predators and humans. The incisors are a special dental feature in this order.

Squirrels spend their daytime foraging and also depend on food provided by people in urban areas such as parks and homes (Magris and Gurnell, 2002) and on bird feeders as well (Reher *et al.*, 2016). Therefore, if supplemented food is an important source of food for the squirrels, people in the urban environment can be made aware or educated on what foods can be offered to squirrels to have a varied and balanced diet (Shuttleworth, 2000).

The main aim of the study is to observe, understand and analyse the diurnal activity rhythm, food preferences and feeding patterns of three-striped palm squirrels (*Funambulus palmarum*). This study was done in Anna Nagar, Madurai for a period of three months in three different phases which corresponded to three different seasons in South India- the early winter (Phase 1), spring (Phase 2) and summer (Phase 3)

2.0 MATERIALS AND METHODS

2.1 Selection of study site

The study was carried out from 5th December 2021 to 4th March 2022 in Sathamangalam, Anna Nagar, Madurai, Tamil Nadu, India ($9^{\circ}55'11''N$ $78^{\circ}08'43''E$) in eight different sample points which includes Aalamaram bus stop, Shenbagam hospital, YWCA school, Shenbagam school of nursing, Sarveshvarar temple street, Velankanni Shrine, Reliance Super Market and Mall Super Market. The study site is a highly urbanized area bordered by busy roads and covers an area of 0.4 km². The study period was divided into three phases- Phase-1 (5th December 2021 to 4th January 2022), Phase-2 (5th January to 4th February) and Phase-3 (5th February to 4th March) which corresponds to the seasons in South India such as winter, late winter and spring. In each phase, four three-hour observations were done from 6 AM to 9 AM (early morning), 9 AM to 12 noon (late morning), 12 noon to 3 PM (afternoon), and 3 PM to 6 PM (evening).

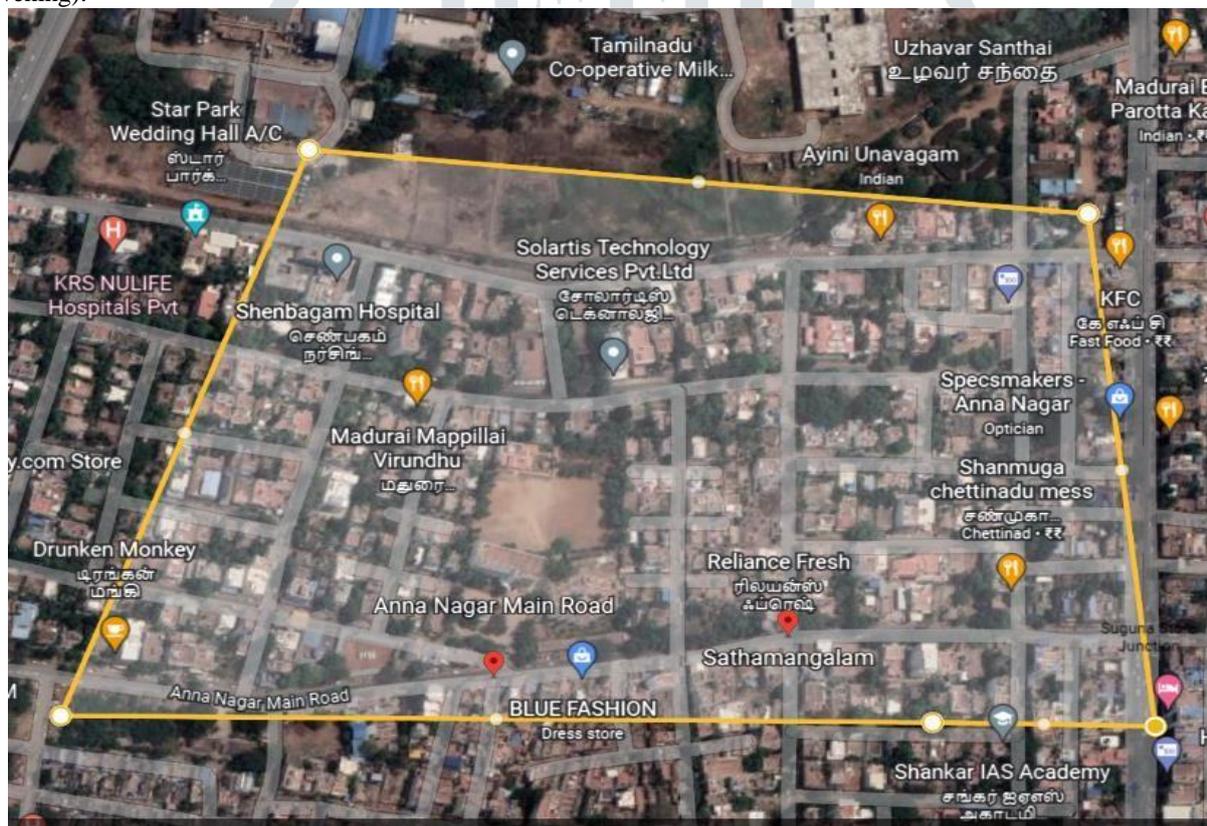


Figure 1: Study site- Sathamangalam, Anna Nagar, Madurai, Tamil Nadu, India

2.2 Calculation of population abundance of three-striped palm squirrels

Time-area survey (Goodrum, 1940) was used to define the richness and abundance of the three-striped palm squirrels, *Funambulus palmarum* in each zone. This method is commonly used to survey tree squirrels. Eight sample points (each point 100 m away from the other) were chosen at random in each zone, and all the squirrels sighted at a point were observed and counted for 15 minutes. The number of squirrels recorded in all the eight sample points in a zone was averaged. The population size estimated in each zone was estimated using the formula mentioned below.

$$N = \frac{A \sum x}{n \Delta \pi r^2}$$

where, N = Population abundance

A = Area of zone

$\sum x$ = Number of squirrels seen

n = Total number of points sampled in a zone

Δ = average sample effort in terms of portion of circle observed

r = average radial distance between two points in a zone

The population abundance is tabulated in table 1 in the form of Mean \pm Standard Deviation ($\bar{x} \pm SD$) and percentage.

2.3 Diurnal activities of three-striped palm squirrels

Diurnal activities of the squirrel such as climbing, creeping, and foraging strategies such as food preferences, handling time (was counted using a stopwatch and denoted in minutes), caching, and instant consumption of food were also recorded using a camera. Focal animal sampling (Altman, 1974) was used to assess the diurnal activities which involves observing an animal for a determined sampling period and recording all the performed activities.

2.4 Food preferences and feeding strategies of three-striped palm squirrels

Feeding and Food Preferences was studied by providing supplemented food like peanuts, dry red chilies, and cooked rice were placed on the ground at 2 meters from the observer to note the choice of food selection without direct human contact.

3.0 RESULTS AND DISCUSSION

The distribution, diurnal activities and foraging strategies of the three-striped palm squirrels (*Funambulus palmarum*) were recorded and statistically analyzed in eight different sample points at Sathamangalam, Anna Nagar, Madurai, Tamil Nadu, India.

3.1 Estimation of population abundance of *F. palmarum* using time-area survey (Goodrum, 1940) from December 5th, 2021 to 5th March, 2022

The number of three-striped palm squirrels (*F. palmarum*) were counted in four different time of observations viz., early morning (6 AM- 9AM), late morning (between 9 AM-12 noon), afternoon and evening (between 3 PM-6 PM). The squirrels were counted for 15 minutes by stopping at each sample point. The highest number of squirrels were recorded during the late morning and evening in phase 1; during the early morning (between 6 AM-9 AM) and evening (between 3 PM-6 PM) in phases 2 and 3. Least number of squirrels were recorded in the afternoon in all the three phases (Table 1). The average number of squirrels was calculated for each phase and represented as Mean \pm Standard Deviation ($\bar{x} \pm SD$). The population abundance of *F. palmarum* was calculated using the time-area survey (Goodrum, 1940). The population of *F. palmarum* was found to be abundant in phase 1 when compared to phase 3 (Table 1)

Table 1- Population abundance of *F. palmarum*

Population abundance of <i>F. palmarum</i> in different time of observations at Sathamangalam, Anna Nagar, Madurai			
	Phase 1	Phase 2	Phase 3
Average no. of squirrels observed ($\bar{x} \pm SD$)	6 \pm 1.29	5 \pm 0.95	4 \pm 1.70
Population abundance (%)	60%	50%	40%
$N = \frac{A \sum x}{n \Delta \pi r^2}$			

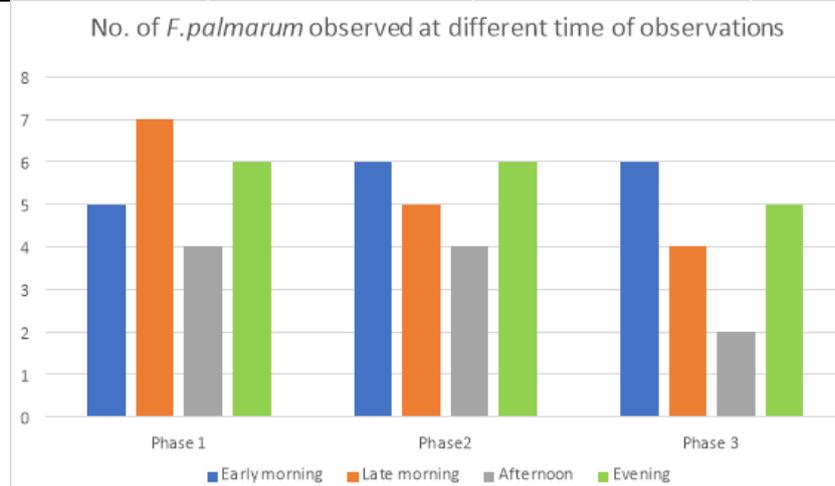


Figure-2 Number of *F. palmarum* observed at different time of observations at Sathamangalam, Anna Nagar, Madurai. (Early morning- 6 AM to 9 AM, Late Morning- 9 AM to 12 noon, Afternoon- 12 noon to 3 PM, Evening- 3 PM to 6 PM)

3.2 The frequency of diurnal activity in three striped palm squirrels (*F. palmarum*)

The diurnal activity (daily activities) of *F. palmarum* were studied based on the following ethogram (Table 2).

Table-2 Defining the daily activities and the average daily activities of *F. palmarum* in all the 3 phases

Diurnal activities	Description of the Activity	Phase 1	Phase 2	Phase 3
Running	Running on the tree branches, ground, and power lines	9	9	7
Climbing	Climbing the tree, buildings	7	7	7
Displacement	Jumping from one place to the other	5	6	4
Feeding	Eating and drinking	6	6	7
Resting	Body lies in contact with the ground, with eyes closed or Open	9	1	2

In the present study two defined peaks were observed in phase 1, in the early morning (between 6 AM-9 AM) and evening (between 3 PM-6 PM) i.e., two defined peaks in the daily activity frequency were observed for different time of observations at each phase (Figure 3, 4, 5). The three-striped palm squirrels were highly active during two distinct time periods of the day. The squirrels were found to be less active in the afternoon. In Phases 2 and 3 the animal showed longer activity period in the morning compared to other two phases and the beginning of the activity occurred earlier in the morning (began at 6 AM) in phase 1 (began at 6:30 AM). Hence the squirrels showed bimodal pattern of frequency (Bordignon and Filho, 2000) in the diurnal activities. Previous studies on the foraging behaviour of squirrels reveal that peak foraging activity of squirrels was observed to be in the morning after two hours from sunrise and before two to five hours from sunset (Halloran, 1999). This bimodal activity may be due to the fact that the temperature is moderate in the mornings and evenings. Squirrels avoid foraging in the afternoon to prevent exposure from extreme heat (Bryce *et al.*, 2001). Squirrels remain less active in the afternoon to escape highest temperature of the day (Tonkin, 1983). As the Phase 1 corresponded to the month of December which marks the winter season in India there was a delay in sunrise and drop in temperature that could have affected the activity of the squirrels in the morning.

The frequency of running behavior of palm squirrels on the ground, buildings, tree branches, and power lines was recorded to be the highest in all the three phases (Table 2). Running was observed during search of food and defending of available resources. Climbing on trees and jumping over electric powerlines was observed during gnawing, caching of food and to escape predation. Feeding involved various patterns, strategies and choice of food. The frequency of resting behavior was observed to be higher in summer (Phase 3) where the squirrel was found to lie on dense tree branches, switch boards and buildings with shade to prevent exposure from the sun. The squirrels ran rather than walking/leaping to save energy, time and protect them from predators (Hoyt and Kenagy, 1988). This decreases the net rate of ecological cost transport (Kenagy and Hoyt, 1989). The slower speed of running increases the average daily running time. Their flexible hind legs and sharp claws helped them to hold firmly and climb the tree thereby secure the available food resources from other individuals of their group (Thorington and Ferrell, 2006).

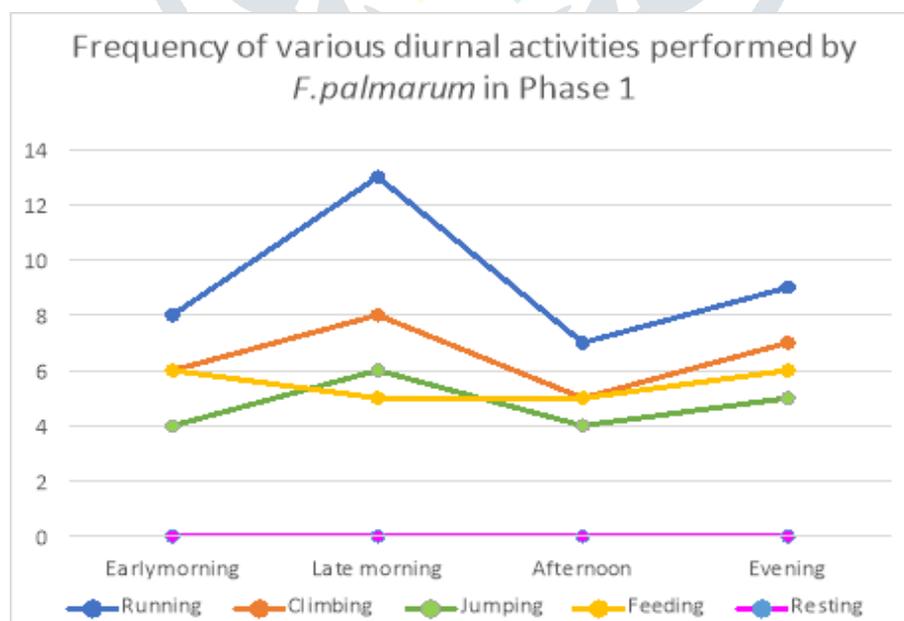


Figure -3 Frequency of various diurnal activities exhibited by *F. palmarum* in Phase 1

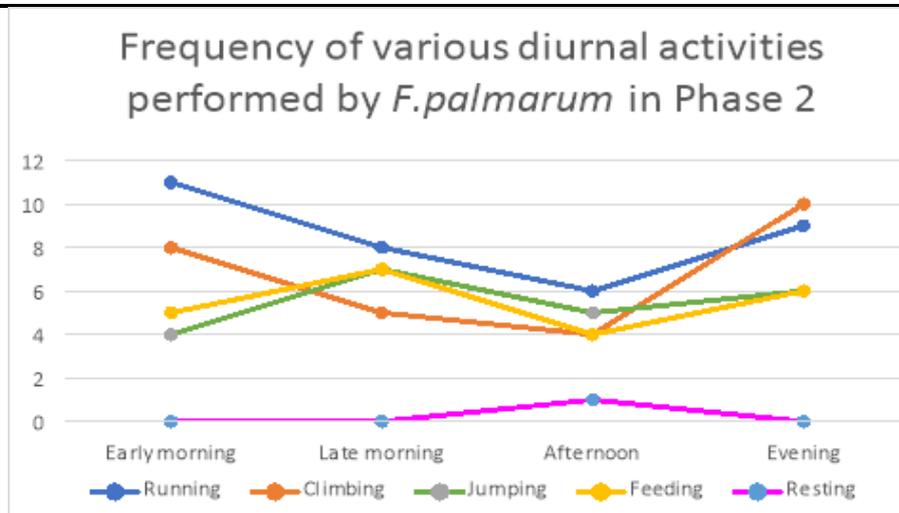


Figure -4 Frequency of various diurnal activities exhibited by *F. palmarum* in Phase 2

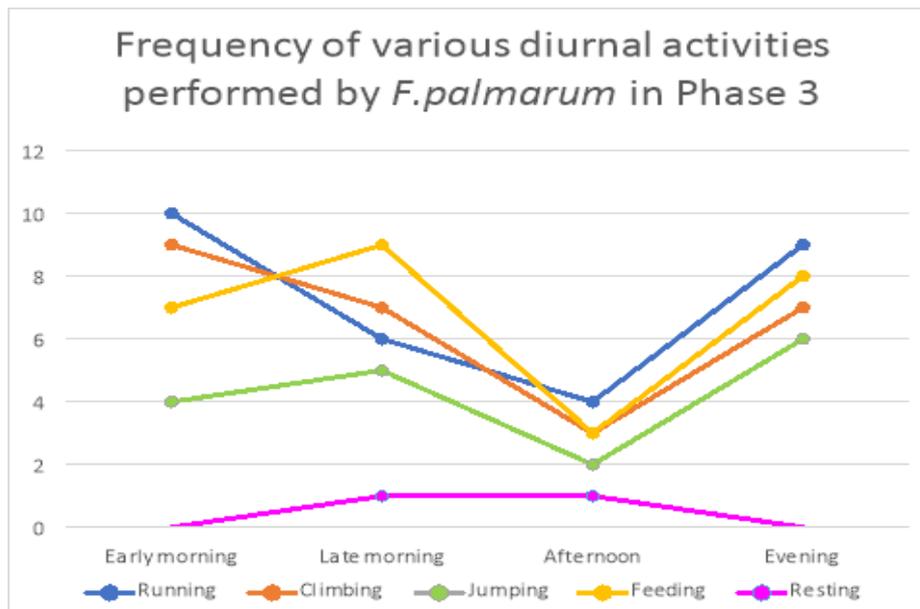


Figure -5 Frequency of various diurnal activities exhibited by *F. palmarum* in Phase 3

3.3 Food preferences in three-striped palm squirrels

Optimal Foraging Theory model (MacArthur and Pianka, 1966) explains that the most advantageous method is opted by the forager through natural selection. It states that the natural selection favours foraging strategies that optimizes the uptake of energy and nutrients from the food and the costs (challenges) of searching and obtaining the food such as expenditure of energy, quantity of food available and predation. This affects the organism's fitness, its rate of adaptability to the environment and successful reproduction. The three-striped palm squirrels highly preferred supplemented food such as cooked rice, red chillies and groundnuts over other food types in all the three phases. The squirrels fed on the mountain knot grass that was tied at the entrance of homes for Pongal (harvest festival of Tamil Nadu). The squirrels also practiced scavenging to a greater extent in Phases 1 and 2 where they fed on food remains from the disposed plastic bags and dustbins. The natural vegetation including the vilvah fruits and flowers from neem tree were also fed by the squirrels. Various insects such as *Oecophylla sp.* (Asian weaver ant) in trees and *Pholcidae sp.* (Cellar spider) under leaves were also fed by the squirrels. High temperature in phase-3 increased the requirement of water for the three-striped palm squirrels. Based on Optimal Foraging Theory (MacArthur and Pianka, 1966), the squirrels opted for the most advantageous method of foraging depending on the food sources that were available in each phase. The supplemented food such as cooked rice and red chillies were provided by the people in the community every day at the same place. Hence this reduces the expenditure of energy, search time for the food and increases the quantity and quality of food consumed (higher benefit and lower cost) (Brown and Morgan, 1995). Urban squirrels are more likely to travel around the anthropogenic habitats and forage human resources than wild squirrels. This is because the squirrels in the urban environment have become habituated to human presence and have learnt that they pose less predatory risks (Tinkle, 2016). Hence, squirrels are dependent on humans for food and shelter. Urban squirrels exhibit a higher degree of boldness as they are found to interact constantly with humans and considered to be opportunists (Nowak *et al.*, 2018). The preference to supplemented food (Peanut, red chillies, rice) that was provided as a part of the study indicates the boldness or the risk-taking behavior of squirrels and their less fear towards humans (Tinkle, 2016). Although other food sources were available in Phase 2, the squirrels preferred human resources because they were easily available. This reveals the habituation of urban squirrels (urban adapters) to human presence and their dependence on man and man-made sources for food (Nowak *et al.*, 2018). The rate of scavenging depends on various factors like weather conditions, deposition, and quantity of remains and the length of exposure of food remains to sun and the rate of decomposition (Byard *et al.*, 2002). So, there was less rate of decomposition of food remains in Phases 1 and 2 due to the mild weather conditions (minimum length of exposure to sun). Scavenging in dustbins occurred at a higher frequency than scavenging at disposed plastic bags at roadsides. This is because the quantity of food remains was higher in dustbins than in disposed plastic bags.

Table-3 Food preferences in *F. palmarum*

Type of food	Rate of food preference in <i>F. palmarum</i> (in percentage)		
	Phase 1	Phase 2	Phase 3
Insects (Ants, Spiders)	10%	10%	8%
Natural vegetation (Fruits, flowers,leaves)	20%	25%	20%
Food remains	25%	25%	20%
Supplemented food (Cooked rice, red chillies, Groundnuts,Mountain knot grass)	35%	30%	32%
Water	10%	10%	20%

3.4 Search time and Handling time of various foods by *F. palmarum*

Search time is the time taken by the squirrel to access the food and handling time is the time required by the squirrel to feed on the food (Nowak *et al.*, 2018). An organism looks for a larger food item with short time of search, short time of handling and higher nutritional value. When organisms choose to assess one of these strategies, fewer errors during foraging are made (Schmidt and Brown 1996). Therefore, the food with minimal search time and handling time favoured the three-striped palm squirrels in order to minimize their energy costs. The supplemented food had less search time and handling time. This was because the supplemented foods were available in surplus and easy to feed without the need to break open. The food remains were easier to search but it took more time to feed. This was because the food remains were also easily available, but more effort was taken to choose the food of higher energy content. The natural vegetation and insects took longer searchtime and handling time which is due to the seasonal availability. Search for water also increased gradually across the phases to withstand high temperature.

Table-4 Search time and handling time of food sources by *F. palmarum*

TYPE OF FOOD	Average search time (in minutes)	Average handling time (in minutes)
Insects (Ants, spiders, bugs)	5	5
Natural vegetation (Fruits, Flowers, Leaves)	3	7
Food remains	0.5	6
Supplemented food (Cooked rice, red chillies, groundnuts, mountain knot grass)	0.5	4
Water	3	1

3.5 Feeding patterns/strategies used by three-striped palm squirrels

Foraging begins with the search of food in the ground or in the tree, walking forward with its tail held straight (Thompson and Thompson, 1980). Squirrels often carry their food from the ground to a lower branch on the tree by rotating their hind limbs, holding on to the tree with their sharp claws and finally consumes the food by holding it between the two forelimbs and keeping an eye on the ground to avoid predation (Lipske, 1997). Gnawing is the biting/chewing of food with the sharp chisel-like incisors of the squirrels. Gnawing of food was found to be higher in all the three phases. Scavenging is a feeding pattern where the animal forages among waste and left-over food. The rate of scavenging in dustbins and wastes gradually decreased across phases.

During gnawing, the animal was found to hold firmly to the tree trunk with its hind limbs and hold the food with its front limbs. Gnawing was the easiest feeding strategy for the squirrel as it instantly met the energy requirements. Scatter hoarding is a behavioural trait where an animal hides the stored food from the members of its own species and others (Thorington *et al.*, 2012). Scatter hoarding can be either long-termed (caching food items seasonally for later consumption) or short-termed (caching food items and consuming within one to five days). Scatter hoarding in squirrels can occur in two phases. The first phase is 'Caching', where the animal finds food to store, carries the food in its mouth and buries it in a self-dug hole or hides it in leaf litters. The second phase is the 'recovery' where the animal recovers the buried food with its forepaws, takes it to its mouth with its tail held straight or slightly curved. After the recovery phase, recaching (reburial of the recovered food in another location) may occur or the animal eats the recovered food i.e., consumption. The decision on whether to cache the food or to consume immediately depends on the rate of pilferage and energy absorption (Lima *et al.*, 1985). Caching was the least used strategy by *F. palmarum* in phases 1 and 3 where the squirrel hid red chillies in the burrow at tree trunk. This was a short-termed caching where the squirrel fed/recovered the red chillies after 2 hours (Vander Wall and Jenkin, 2003). The short-termed caching was performed by the squirrel to secure its food resources from other squirrels and avian predators as well.

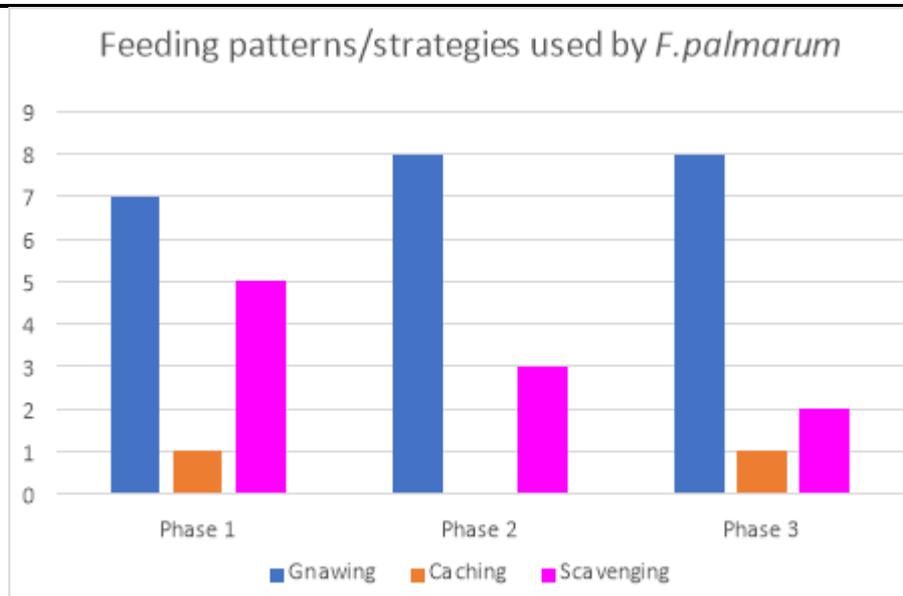


Figure-6 Feeding patterns/strategies used by *F. palmarum*

4.0 Conclusion

The existing study indicates that the three-striped palm squirrels *Funambulus palmarum* highly exhibited various activities in the morning and evening. The frequency of behaviors that were observed varied with seasonal changes (different phases). The peak activity period of the squirrels also coincided with the activity period of humans in the morning and evening. The squirrels adapted to the available food resources in every season and preferred foods with minimal search time, handling time and high nutritional value. Palm Squirrels were well-adapted to the foods provided by humans rather than feeding the natural vegetations and Insects. As they have emerged as urban adapters, they tend to depend on humans for basic resources like habitat and food. So, the squirrels occupy human habitats where their basic needs for survival are met. In India, the five-striped palm squirrel, *Funambulus pennantii* causes serious damage to important commercial crops apple, guava, mango, pomegranate, coconuts, palm trees, sugarcanes, and ground nuts by gnawing the crops from flowering to ripening stage (Barnett and Prakash, 1975). Squirrels also gnaw on telephone wires and feed on cambium causing potential damage to trees. They dig holes in gardens and enter buildings through the crevices for caching or building nests. Squirrels are found to carry parasites such as tularemia and ringworm that are easily transmitted to humans (Baldwin et al., 2015). It is very challenging to eliminate them from the urban and sub-urban habitats as they are widely distributed. The rate of dependence on human habitats by these squirrels will continue to increase across the development of urbanization gradient and there are chances for the squirrel to become a pest in the long run.

5.0 Future perspectives

With the knowledge on the diurnal activities, feeding strategies and food preferences of the three-striped palm squirrels, further studies can be done on the interspecific relationships on sharing the available resources with other species and on the reproductive behavior and fecundity of the squirrels.

6.0 Acknowledgement

The authors are grateful to Dr. Reginald Victor (Late), Retired Professor, Sultan Qaboos University, Oman for sharing his expertise on palm squirrels and to Lady Doak College, Madurai for providing an opportunity to take up this study as an academic project.

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