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Behavioral adaptations and coexistence of the five-striped palm squirrel (*Funambulus pennantii*) in urban Kathmandu, Nepal

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Abstract

The coexistence between humans and wildlife began since their origin sharing foods and habitats. Urban areas are human-dominated, non-natural, and non-protected environments where wildlife struggles to survive. Despite life-threatening issues persisted in these places, five-striped palm squirrel (*Funambulus pennantii* Robert Charles Wroughton) inhabit in dense human dwellings. Therefore, we aimed to study nine types of behaviors (i.e. adaptive, aggressive, avoidance, cognitive, feeding, grooming, reproductive, social and aestivation) in Shahid Gangalal Heart Centre (SGHC), HAMS Hospital and their surroundings at Kathmandu by visual observation (VO) and hearing sound calls (HSC). During study, visits were made twice in each site in all seasons (i.e. winter, spring, summer, and autumn), and documented every sign or signal that offers value for survival. Food availability rather than food variety, temperature and precipitation was the major determinant factor for occurrence in the habitat. Although agnostic behavior shaped their hierarchies within the species, avoidance and adaptation were the key behaviors to keep them survive in human dominated expanses. The most preferred nutrient was the leaf buds (27.9%, n=12) and insects as the least (4.7%, n=2). Although tree branches and trunks were the most preferred substrates (51.8%, n=29) for roosting and safety, their diurnal activities and vocalization drew human attention and provoked nearby stray dogs creating risks. Conclusively, squirrels were found to co-exist under prominent conflicts with humans and dogs in shared territories. So, further study is recommended to understand effects of pollution in reproduction and transmission of zoonotic diseases.

Key words: Behavior, Mammals, Pollution, Urban ecosystem, Wildlife

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Introduction

Globally, over 1687 species with 380 genera of the Family-Sciuridae and Order Rodentia have been reported (Jones *et al*., 1984). However, nearly 300 species are squirrels and marmots (Thorington *et al.,* 2012). Squirrels are small arboreal mammals with body weights less than five-kilogram (Wauters and Dhondt, 1989) which can well adapt in urban areas (Parker and Nilon, 2008; Chaudhary, 2018). In Nepal, the number of squirrel species have reported differently in various studies. Eleven species were reported by Amin *et al.,* (2018), 12 species by Baral and Shah (2008), 14 species by Shrestha (1997), Thapa (2014), and six species by Budhathoki *et al*., (2023).

Five-striped palm squirrel (*F. pennantii*) live in variety of habitats such as grasslands, forests, patchy gardens, urban areas, slopy lands, under tin roofs etc., (Jones *et al*., 1984; Perodaskalaki *et al.,* 2023). The squirrels mainly feed on fruits, seeds, roots, barks, and leaf buds (Keith, 1965; Yarborough *et al.,* 2015) of fruiting and/or non-fruiting trees. Scarcity of foods and species competition in the forest distract them to human dwellings to get variety of crops as foods.

The squirrels scurry during the day time and perform different behaviors to mitigate problems shaped from human activities, predators, and stray dogs. Avidly feeding and avoidance behaviors keep them safe from unpredicted threats where sound signaling (chirping sound) play additional role in protection. Their arboreal characters resting most of the time on tree trunks and branches (Perodaskalaki *et al.,* 2023) also reduces ground threats. Potentiality of making nests in upper branches of trees (Cudworth and Koprowski, 2011; Halloran and Bekoff, 1994), under tin roofs, tree-holes and branches, and in broken pipe supplies of houses ensures to survive in the urban areas (Chaudhary, 2020 and 2021).

People's activities in urban areas impact significantly in squirrel survival. Hunting for meat and skin, disrupting natural habitat by cutting down of trees and demolishing tall concrete substrates exacerbate living in harmful environments. These challenges may lead to nutritional deficiency and could reduce the rate of breeding declining population. So, further research is required to investigate whether accumulated problems and deficiency of food variety effects on reproduction and behaviors of squirrels or not in the cities.

Researches related to squirrel behaviors are little (Perodaskalaki *et al.,* 2023) in compare to occurrence and distribution (Amin *et al.,* 2018; Shrestha, 1997; Thapa *et al.,* 2016) due to diminutive sources of funding and less prioritized in study than larger mammals in Nepal. The small mammals such as squirrels have significant roles in seed dispersal of plants and urban ecosystem interactions (Nyhus, 2016; Chaudhary, 2018). However, the roles of their behaviors in survival, maintaining population status, species diversity, genetic variability, impact of pollution and climate change along chances of zoonotic disease transmission (Chaudhary, 2021; Mushtaq *et al.*, 2024) remain to investigate. In addition, the knowledge on urban mammals is essential during preparation of development plans and to reduce harm in urban ecosystem (Chaudhary, 2018).

Materials and Methods

Study area

Two hospitals, Shahid Gangalal Heart Centre and HAMS Hospital of Kathmandu City, including their surrounding areas were study sites for five-striped squirrels. These sites were selected by spotting of squirrels during pilot survey. Altogether, four locational points were chosen for observation in the diameter of about 200 meters. Of these locational points, two were inside hospitals and two were from the surroundings. The surrounding points of

Sahid Gangalal Heart Center located at Khadka Tole, Bansbari-3, and Dhumbarahi Marga is the frontal surrounding of HAMS hospital, Kathmandu. The coordinates of Shahid Gangalal Heart Center is 27.747317ºN, 85.341962ºE. Similarly, HAMS Hospital locates at coordinates of 27.733585ºN, 85.345780ºE, and Dhumbarahi Marg locates in the frontal surrounding area of HAMS hospital at the coordinates of 27.7335ºN, 85.3458 E (**Figure 1**).

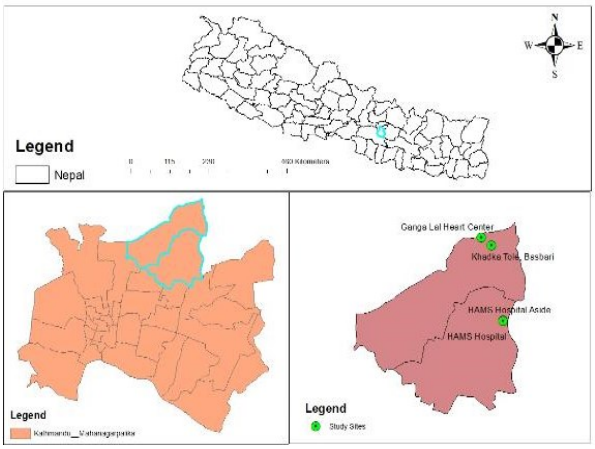

Figure 1. Maps showing study sites at Kathmandu with green spherical points.

These areas were intermingled with patchy forests of fruiting and nonfruiting tall trees such as peach, and pear trees, deciduous or non-deciduous broad-leaved trees, and lianas, etc. Human made concrete houses, walls, electric poles, wires etc., were also present which were used for safety from peoples and stray dogs. The landscapes were uneven near HAMS Hospital and almost all leveled at Gangalal Heart Center. The calm and less disturbed areas with thin traffic in the subways, favorable tall trees for resting and nesting, and the land slopes reduce the stray dog intrusion, which attract squirrels to live. So, these sites were suitable for squirrels as the annual rain fall, humidity and temperature were advantageous in Kathmandu. The annual temperature ranges from 4ºc in January to 24ºc in June, humidity ranges from 54% to 92%, and the precipitation from 26 to 778 millimeter annually. (https://en.climate-data.org/asia/nepal/central-development-region/kathmandu-1137/).

Methods

Data collection

The study was accomplished from first January to last December, 2024 by visual observation method (VO) and hearing sound calls (HSC). Through HSC the squirrels were followed to observe and to enlist the data in the data sheet. Four study sites were confirmed after spotting the squirrels in these places during pilot survey. The pilot survey was conducted over a week by riding a motorbike only once along the main and sub-roads inside, and 1 to 2 kilometers outside the Ring Road, driving at a speed of 10 to 20 kilometers per hour, and stopping whenever squirrel sounds were heard or their activities were observed.

During the study, the selected sites were visited twice in each season- winter, spring, summer, and autumn, in the area of 100 meters radius. Total eight times were visited in each site in a year. During VO and HSC, the adaptative, aggressive, avoidance, cognition, feeding, grooming, aestivation, reproductive and social behaviors were focused to study.

In adaptative behaviors, the hibernation, aestivation, seasonal caching, and fur shedding were included. Aggressive behavior included chasing, biting, scratching and tail flicking, and avoidance included alarm calls, camouflage, freeze and running. Similarly, cognition included problem solving and curiosity whereas feeding behavior included foraging. Grooming behavior comprised sunbathing and self-grooming, aestivation behavior included day time rest, reproductive behavior included nesting, mating rituals and parental care, and social behavior included territorial, play, body language, and communication.

Prompt response with human activities and dogs' chasings were also enlisted in the data sheet. These data were gathered sitting 1 to 2 hours continuously in a day in each site. The human traffics and vehicle numbers were principally regarded higher when the speed was slow and/or were in the que by congestion at the road during the time of observation. The photographs were taken using COOLPIX, 12X wide angle, 16-megapixel S6400 Nikon camera for identification of the squirrel species. *F. pennantii* species were identified using books written by Jones *et al*., (1984); Shrestha (1997); and Baral and Shah (2008).

Data analysis

The collected data were tabulated and statistically analyzed using MS-Excel and/or R software and the citation and referencing were completed using free version of Mendeley software. The categorical variables such as the association between five-striped palm squirrel occurrence and seasons, study sites and food preference, habitat and substrates used were analyzed using Chi-square test.

Results

Enlisted five-striped palm squirrels

During the study in four seasons of a year, total 56 five-striped palm squirrels were enlisted, and the Dumbarahi Marg (in front of HAMS hospital) had the highest individual count, 39.3% (n=22), followed by Sahid Gangalal Heart Center (SGHC) 35.7% (n=20), Khadka Tole 19.6% (n=11) and HAMS hospital 5.4% (n=3). In seasonal observation from winter, spring, summer and to the autumn, squirrels were recorded the highest 39.3% (n=22) in autumn, followed by winter 28.6% (n=16), spring 21.4% (n=12) and summer 10.7% (n=6). Among all, 8 individuals were juveniles (J) and 48 were adults (A). These juveniles were recruited in winter and autumn seasons from SGHC and aside of HAMS because of their biological growth time (**Table 1**). The occurrence was not significantly different ($p=0.0558>\alpha= 0.05$, at 5% level of significance) with seasons and the distribution was uniform.

Table 1. Season-wise recorded number of juvenile (J) and adult five-striped palm squirrels

Seasons	Observation Time	SGHC	Khadka Tole	HAMS Hospital	Aside of HAMS	Total	%
Winter	1st and 2nd	6(J=2)	3	1	6(J=1)	16	28. 6
Spring	3rd and 4th	4	3	1	4	12	21. 4
Summer	5th and 6th	2	1	0	3	6	10. 7
Autumn	7th and 8th	8(J=3)	4	1	9(J=2)	22	39. 3
Total		**20**	**11**	**3**	**22**	**56**	**100**
%		**35.7**	**19.6**	**5.4**	**39.3**	**100**	

Behaviors observed

Altogether nine types of single or multiple behaviors of all but not of an individual squirrel were enlisted by sitting continuously for 1 to 2 hours during visual observation (VO). HSC was used to access the squirrels for VO and photography (**Supplementary file, S1**). Feeding and avoidance behavior were recruited the highest percentage i.e. 20.8% (n=15), followed by adaptive behaviors 19.4% (n=14), cognitive 11.1% (n=8), grooming and aggressive behaviors 6.9% (n=5), reproductive and social behaviors 5.6% (n=4), and aestivation 2.8% (n=2) (**Table 2**)

Table 2. Multiple behaviors recorded during visual observation (VO)

Observation	Types of behaviors									Total
	Adaptive	Aggressive	Avoidance	Cognitive	Feeding	Grooming	Aestivation	Reproductive	Social	
1st	3	1	3	1	4	2	0	0	2	16
2nd	2	2	2	1	2	2	0	0	2	13
3rd	2	1	1	1	2	1	0	2	0	10
4th	2	1	2	1	1	0	0	2	0	9
5th	1	0	2	1	2	0	0	0	0	6
6th	2	0	1	0	1	0	2	0	0	6
7th	1	0	2	2	2	0	0	0	0	7
8th	1	0	2	1	1	0	0	0	0	5
Total	14	5	15	8	15	5	2	4	4	72
%	19.4	6.9	20.8	11.1	20.8	6.9	2.8	5.6	5.6	100

Location and substrate types

Squirrels were enumerated from four locations SGHC, Khadka Tole, HAMS hospital, and frontal surroundings of HAMS hospital. From the observation of each site, the number of squirrels were listed on the basis of types of substrates used. The substrates were tree trunks and branches, canopy, and ground where the squirrels were sighted. Among the varieties of substrates, habitually squirrels were using more to tree trunks and branches 51.8% (n=51), followed by canopy 25.0% (n=14) and the ground 23.2% (n=13) (**Supplementary file, S2**; **Figure 2**). However, there was not significant association between substrate types and location ($p=0.886 > \alpha=0.05$, at 5% level of significance).

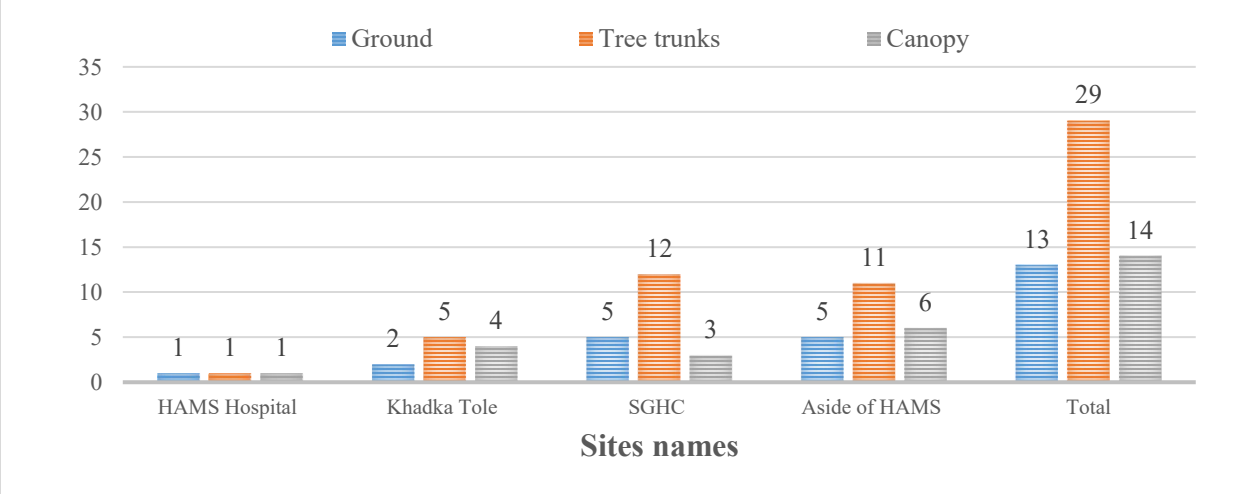

Figure 2. Location-wise substrates types used by five-striped palm squirrels

Food adoptions

The major food stuffs of *F. pennantii* were plant leaves, buds, barks, fruits, seeds, and insects. However, garbage of the houses and hospitals were opportunistic and additional feeds. Squirrels were enumerated feeding on leaves 27.9% (n=12), fruits and seeds 25.6% (n=11), barks 9.3% (n=4), insects 4.7% (n=2) and others 7% (n=3) (**Supplementary file, S3**). The 'others' foods category included garbage of houses and hospitals, and non-natural foodstuffs like discarded biscuits, noodles, etc. Nevertheless, there was not significant association between food types and location ($p=0.4506 > \alpha=0.05$, at 5% level of significance).

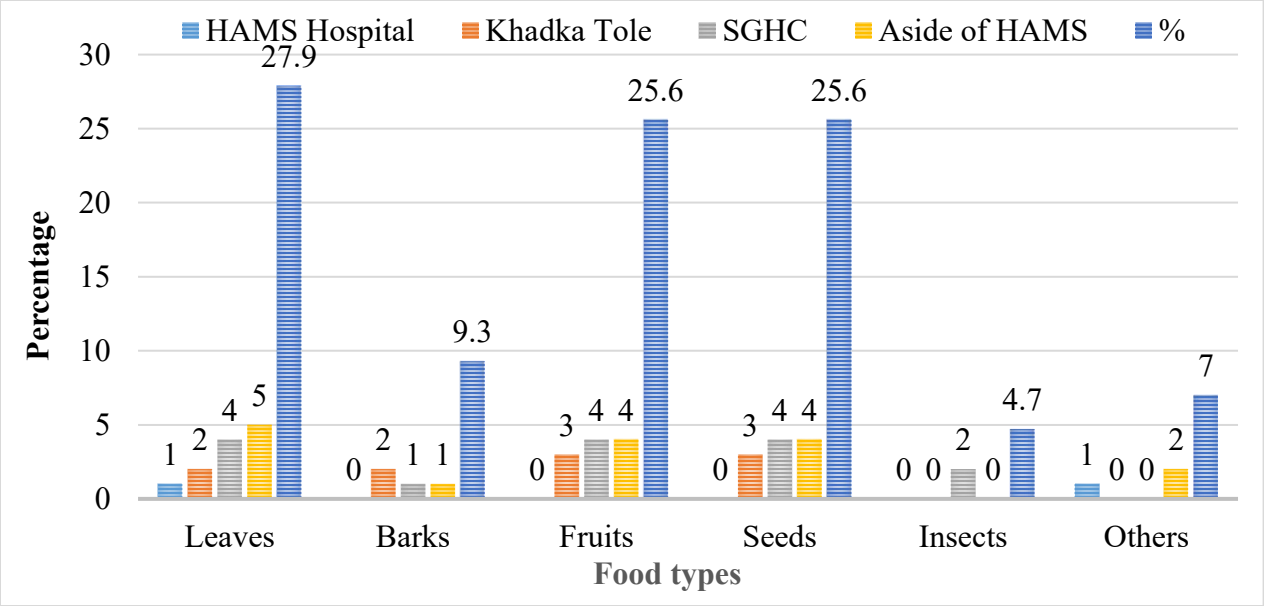

Figure 3. Location-wise feeding records of five-striped palm squirrels

Discussion

Coexistence of wildlife and humans has begun since the origin and civilization (Coelho, 1998; Ripple *et al.,* 2016). Sympatric association with humans and food competition with rodents have driven five-striped palm squirrels (*F. pennantii*) to adapt to perilous habitats in urban areas leading to co-evolution (Wong and Candolin, 2015). Changes in behavior, along with sharing of foods and habitats have created challenges and conflicts in acquiring favorable environment.

The *F. pennantii* species is primarily distributed in southern Asia and have remarkable adaptability to thrive in urban settings and numerous anthropogenic infrastructures.The urban, complex and mosaic habitats with different building heights, greenery of parks or gardens, and rivers and roads etc., makes natural habitats (Werner, 2011). The coexistence of rodents or squirrels in urbans indicates a crucial aspect of urban ecology, and illustrates how wildlife adapts in human dominated landscapes. Urbanization has significantly altered natural environment (Lowry *et al*., 2013), which drives many species to modify their behaviors, diets and nesting forms to survive in fragmented habitats

The behaviors studied of 56 five-striped palm squirrels in urban localities revealed significant information. Among four study sites, the enlisting of five-striped palm squirrels was found insignificant ($P=0.999>\alpha=0.05$ at 5% level of significance) in frontal area of HAMS hospital and the occurrence were uneven (**Table 1**). The site was less disturbed with human traffics, vehicles and stray dogs as lands were unevenly faced with bushes and trees during the period of observation. The seasonal number count was not significantly different in each site. The occurrence was 39.3% (n=22) in winter followed by autumn 28.6% (n=16), spring 21.4% (n=12), and summer 10.7% (n=6) due to amplified activity of breeding in first two seasons. Nevertheless, the increased human migration to the urban areas has driven to loss of biodiversity (Grimm *et al*., 2008). Consequently, the low density of squirrels locates in the urban areas (Parker and Nilon, 2008) and conflicts with humans (Saulsbury and White, 2015) and stray dogs can impact for living in the cities (Chaudhary, 2020). Despite the decrease of fauna, the urban biogeographic landscapes retain squirrel's

diversity in the local areas (Aronson *et al.,* 2014; La Sorte *et al*., 2014).

Out of many, nine substantial behaviors were studied where feeding and avoidance behaviors were listed the highest in percentage i.e. 20.8% (n=15) followed by adaptive behaviors 19.4% (n=14) and cognitive behaviors 11.1% (n=8), grooming and aggressive behaviors 6.9% (n=5), and reproductive and social behaviors 5.6% (n=4). However, the aestivation was recorded the lowest i.e. 3.6% (n=2) on a hot day (**Table 2**). Squirrels spent most of their time in feeding and foraging as well as responding to disturbances caused by peoples and stray dogs. Squirrels had developed behaviors that allow them to approach as close as two meters to humans. Their pace in running on the ground and climbing on the trees, walls etc., ensured to avoided enemies. Flickering of tails with vocalization signaled to warn conspecifics and hoodwink their attacks by stray dogs. The movements of tail with vocalization kept hierarchies enabling social interactions and minimizing direct confrontation to establish cohabitation that represents comparable to the findings reported by Nyhus (2016). The agile movement ensured avoidance of threats detecting the surrounding circumstances as it was similar to the findings of Amin *et al.,* (2018). The social gathering, and sound calls produced for signaling threats ensured safety living in urbans. The food availability, safety and suitable environments were crucial determinants for the terrestrial behaviors (Chaudhary, 2020).

The most preferred substrates were tree trunks and branches that were used by 51.8% (n=29) for safety from predators and ground enemies. Canopy were used by 25.0% (n=14) during feeding and sunbath for short period of time to avoid predators. The ground substrate was used by 23.2% (n=13) while less intruders were present, and during feeding on fallen seeds and fruits (**Supplementary file, S2**). The use of substrates was not significant in entire study sites ($p=0.886 > \alpha=0.05$ at 5% level of significance), and between substrate types and location. The preference of tree trunks and branches were reported higher by Perodaskalaki *et al.,* (2023), and Ramachandran (1992) although the squirrels visited to the ground frequently with care and nimble movements to escape from casualties. The spacious hospital grounds were visited to feed on or collect fruits and seeds when intrusions from human traffics and stray dogs were low. The calm and luminous hospital grounds attracted animals to stay few minutes to hours mainly in winter season.

One of the primary sources for survival of *F. pennantii* in cities were sufficiency of anthropogenic food sources, including discarded human foods, fruits bearing trees and ornamental plants that serve as alternative food supplies (Bateman and Fleming, 2012). Herein, the major foodstuffs of squirrels were leaf buds (27.9%, n=12), plant fruits and seeds (25.6%, n=11), barks (9.3%, n=4), insects (4.7%, n=2), and others like factory made biscuits, noodles, house and hospital garbage etc., (**Supplementary file, S3**). The types of foods consumed were not significant with respect to study sites ($p=0.796 > \alpha=0.05$, at 5% level of significance) and the food variety did not affect to the location-wise habitat use.

Therefore, the occurrence of five-striped palm squirrels was associated to food availability instead of food variety. The pollution besides organic garbage, human traffics and stray dog conflicts repelled them away. The temperature and precipitation were under compromised although these factors can play vital roles in regulating population in urban areas, maintaining food chain and balancing macro and microecosystem, which is yet to unveil.

Besides development of skills by squirrels to adapt in the urban spaces, *F. pennantii* has to cope with challenges and can depend on human-associated food materials competing with other rodents and birds (Oro *et*

al., 2013). Similarly, fragmented habitats like parks and roadside vegetations provides crucial microhabitats, foods, shelter, and breeding sites (Aronson *et al.,* 2014). Contrary to it, the anthropogenic disturbances limit the territory and foraging areas increasing risks and challenges (Chaudhary, 2020).

The innate skills of collecting and storing foodstuffs has ensured to survive during scarcity mainly in winter season. Producing sharp chirping sounds and signaling with flickering tails have substantial values to inform other members for safety. Their socialization and foraging behavior in groups increased survival even in harsh situations in patchy forests and gardens. The increased pollution and vehicle noise can distract them from natural habitats leading to casualties. Infrequent records near houses and hospital garbage indicated nutritional deficiency in the habitats although regular feeding on leaf buds, barks, fruits, flowers, seeds, and insects etc., can surplus the food deficiency. The squirrels may be surviving in under nutrition which can impact in reproduction. Among many discomfitures, low nutrition can diminish production of babies and reduces population. However, it is yet to reveal whether feeding behaviors affect in reproduction and genetic variations.

Conclusion

The enlisted five-striped palm squirrels demonstrated substantial coexistence and impacts in their multiple behaviors by seasonal changes, availability of foods, hiding places, and human encroachments. Food scarcity appears to reduce avoidance behavior, thereby increasing survival threats. The anthropogenic disturbances created by vehicle overloads, people's overcrowding and cumulative number of stray dogs added challenges in their survival although roosts in the canopy substrates of fragmented habitats reduces the terror. The surplus foods obtained from hospital garbage increases chances of human disease transmission to the animals which facilitates disease spreading in the surrounding environments. So, further research works are essential to conduct on squirrels as a model animal to explore their roles in balancing urban ecosystem, transmission of zoonoses, impact of urban pollution in reproductive behavior, trends in population, genetic diversity, and impacts of climate changes in overall urban ecological aspects.

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