



Original Research Paper

Adaptive Behavioural Responses of Nocturnal Mammals to Urbanization and Light Pollution in Semi Urban Landscapes

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Key Words	Abstract
Nocturnal mammals, Urbanization, Light pollution, Behavioral adaptation, Semi-Urban landscapes, Wildlife ecology, Habitat disturbance.	Nocturnal mammals rely on darkness for their movement, foraging, predator avoidance, and shelter usage, and are now facing new challenges due to urbanization and artificial light at night, which are altering semi-urban habitats. The adaptations of nocturnal mammals in behavioral response to urbanization and light pollution in a semi-urban environment with agricultural fields, scrublands, forest edges, wetlands, village roads, settlements, and peri-urban extension areas were studied. The study area was divided into three artificial light zones (low, moderate, and high) from the perspective of light intensity, distance from roads, and settlement influence. Camera trapping, night transects, GPS-based habitat mapping, lux measurements, and satellite night-light data were all used to collect data. The behavioral observations were activity timing, movement frequency, foraging events, road-crossing behavior, avoidance of illuminated areas, and habitat-use intensity. Results indicated that the most detections occurred in low-light conditions (320 detections), moderate-light conditions (219 detections), and high-light conditions (102 detections). Activity patterns also changed in brighter habitats, with the peak time of activity at the high-light areas being predominantly after midnight, especially between 00:00 and 02:00. Sensitive species were more inclined to avoid illuminated areas, and the adaptable species were partially tolerant and flexible in their behavior. The results indicate the importance of providing dark refuges, vegetation corridors, reducing night lighting, directing lights away from wildlife, and planning semi-urban development in a wildlife-friendly way for the conservation of nocturnal mammals.

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Introduction

Urbanization is one of the primary causes of habitat loss in semi-urban landscapes, where natural habitats are being progressively lost to roads, settlements, agriculture, industry, and artificial lighting (Jasim, 2024). These alterations impact the wildlife's movements, feedings, breeding, and sheltering. Nocturnal mammals are particularly sensitive due to their ecological actions, which are primarily nocturnal. Small carnivores, porcupines, hares, bats, foxes, jackals, and civets are among the species relying on night-time foraging, movement, predator avoidance, and reproductive activities. Turning cities and towns into bright places with street lights, vehicle lights, buildings, and business activities disturbs the natural dark environment and puts pressure on nocturnal mammals in their behavior.

Nocturnal mammals' natural activity patterns may be disrupted by artificial light at night. Certain species may move only after the light level decreases at the end of the day, or may not venture into well-lit locations at all. Foraging efficiency may also be diminished due to light pollution, as animals may feel more vulnerable to predators or human disturbance in the lighted habitat. Mammals can move to areas of darker vegetation, to abandoned areas, or areas where agriculture is taking place, to boundaries of agriculture or water bodies that offer protection and movement corridors in some instances. Adaptive reactions are manifested as these behavioral changes, but in the face of long-term urban stress, habitat quality can diminish, and

ecological stresses can build up (Isaksson, 2015; Łopucki et al., 2021; Lin, 2024).

There are a few studies that have investigated wildlife in fully urbanized environments and protected forest settings; however, there is less research undertaken in semi-urban environments (Lowry et al., 2013; Mori et al., 2025; Ciach & Fröhlich, 2019). These areas are vital as they serve as the 'interface' between human settlements and natural ecosystems. For nocturnal mammals inhabiting such environments, there are opportunities and disturbance pressures. But little information is available regarding their activity patterns, habitat utilization, foraging patterns, and avoidance response to urbanization intensity and artificial light. Thus, the aim of this study is to investigate adaptive behavioral reactions of nocturnal mammals to urbanization and light pollution in semi-urban environments (Abad & Nejad, 2019; Schirmer et al., 2019; Isaksson et al., 2020).

This work aims at:

1. To measure the effect of urbanization intensity on night-time patterns of mammal activity in semi-urban environments.
2. To investigate how artificial light affects behavior, including movement, foraging, and avoidance.
3. To outline conservation actions that would help minimize light disturbance in semi-urban wildlife habitats.

Section I includes an overview of urbanization, light pollution, nocturnal mammal ecology, research gaps, and aims. Section II

provides background information on the study area, the target species, the sampling design, camera trapping, light measurement, and statistical analysis. The species occurrence, activity changes, behavioral reactions, and light-intensity relationships are presented in

tables and figures in Section III. Ecological meaning, comparison to previous studies, conservation value, and limitations are discussed in Section IV. The study is completed in Section V, and future directions for wildlife-friendly semi-urban planning are discussed.

Materials and Methods

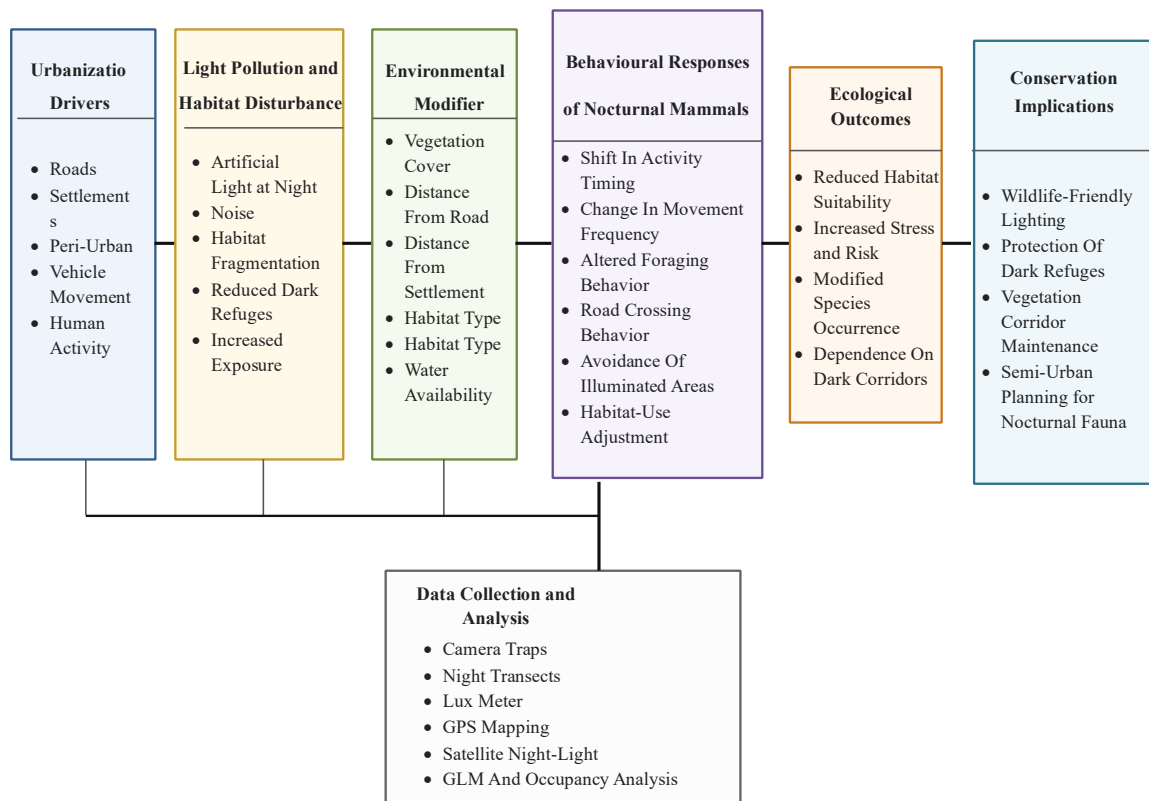


Figure 1: Conceptual Framework of Urbanization, Light Pollution, and Nocturnal Mammal Behavior

In the semi-urban landscape, urbanization drivers like road infrastructure, settlements, transportation, and human habitation have led to higher light pollution and habitat disturbance, as seen in figure 1. Environmental factors (vegetation cover, road distance, settlement distance, food availability) affect nocturnal mammal behavior. The framework identifies important responses, including shifts in activity timing, foraging, road-crossing behavior,

avoidance of lighted habitat, and habitat-use adjustment, ultimately resulting in ecological outcomes and conservation planning needs.

Study Area

The study took place in a semi-urban environment with a variety of habitat types (agricultural fields, scrublands, forest edges, wetlands, village roads, scattered settlements, peri-urban expansion areas). The chosen landscape was a transitional zone between

human-dominated settlements and natural habitats, and so would be appropriate for the study of behavioral responses of nocturnal mammals to urban stress. The study area was split into three zones of disturbance: areas of light intensity, areas near roads, and settlements. Forest edges, non-permanent lighting areas (such as scrubland and agricultural margins), and other areas with low lighting were identified. Moderate-light zones comprised village boundaries, farm roads and partly lit margins of wetlands. High-light zones comprised close to roads, settlements, street lights, shops, and other artificial light sources.

Target Species

The nocturnal and crepuscular mammals commonly occurring in the semi-urban Indian landscapes were selected for the study. The species selected were the Indian fox, golden jackal, small Indian civet, palm civet, mongoose, Indian hare, porcupine, jungle cat, and fruit bat. These species were selected because they primarily use night or twilight hours for activity, and are expected to be very sensitive to artificial light, road movement, human disturbance, and habitat modification. Using camera-trap images and direct (night) observations, along with indirect information and local field records, species were identified.

Data Collection

Camera trapping, night transects, GPS habitat mapping, lux readings, and secondary satellite night light data were used to collect data. The camera traps were strategically positioned in animal trails, field margins, scrub areas, wetland

borders, and road crossing locations to document the presence and activity patterns of species. Mammal movement, foraging events, road crossings, and avoidance behavior were seen during night transects during early night, midnight, and pre-dawn. The intensity of artificial light was determined at all sample points using a hand-held lux meter. Points of GPS for camera traps, road networks, settlements, vegetation patches, and water sources were recorded. Field-based light measurements were supplemented with data from satellites, and light classifications were made at a landscape scale using satellite night-light data.

Environmental Variables

To increase understanding of the effect of several environmental and disturbance-related variables on nocturnal mammal behavior, several variables were recorded. Artificial light intensity, distance from nearest road, distance from nearest settlement, vegetation cover, habitat type, noise level, human activity index, water availability, food-resource availability. A field observation and habitat mapping with GPS were used to estimate vegetation cover. Human activity index determined by road traffic, pedestrian traffic, livestock, and presence at night. Signs of crop, presence of small prey, signs of waste disposal, and natural forage availability were used to gauge the availability of food resources.

Data Analysis

Collected data were analyzed to compare nocturnal mammal activity in the low light, moderate light, and high light areas. Changes in movement timing and peak activity periods were

determined using activity pattern analysis. Habitat use was estimated using occupancy models which accounted for detection probability. Generalized linear models were employed to analyse the effects of light intensity, road distance, settlement distance, vegetation cover and human activity on detection frequency and behavioural responses of mammals. The correlation between artificial light intensity and foraging, movement frequency, road crossing and avoidance behaviours were assessed. High use areas, dark refuges and movement corridors were identified through the use of spatial mapping. The conceptual framework figure can be added onto the end of this section to illustrate how urbanisation and light pollution lead to behavioural response and conservation outcome.

Results

Species Occurrence Across Light Zones

Nocturnal mammals were found in all three light levels, but did not occur regularly across them. The higher numbers of species and detection frequency were obtained in areas of low-light, suggesting that darker habitats offered more safe movement and foraging conditions. Moderate-light zones had intermediate mammal activity, primarily in the form of jackals, mongooses, palm civets and hares, which are more of an adaptable species. Areas with high lighting intensity levels had lower species richness and detection rates, indicating that artificial lighting, road traffic and human disturbance limited the detection of sensitive nocturnal mammals. Small Indian civet, jungle cat and porcupine were more common in low light and vegetated areas.

Table 1: Habitat and Light Characteristics of Study Zones

Study Zone	Light Intensity (lux)	Vegetation Cover (%)	Road Density (km/km ²)	Settlement Distance (m)	Human Activity Index
Low-light zone	0.8 ± 0.3	72.4 ± 5.6	0.9 ± 0.2	850 ± 110	1.8 ± 0.4
Moderate-light zone	5.6 ± 1.2	48.7 ± 4.9	2.1 ± 0.5	420 ± 85	3.9 ± 0.6
High-light zone	18.9 ± 3.4	26.5 ± 3.8	4.6 ± 0.7	160 ± 45	6.7 ± 0.8

The data in table 1 indicate that high-light zones had a high density of road and human activity and low-light zones had a high proportion of vegetation and distance from settlement. This suggests that the intensity of artificial light increased as urbanization pressure went up and natural habitat quality went down.

Table 2 shows that the most detections of total mammal were detected in the low-light zone and the least were detected in the high-light zone. Nighttime light had a negative impact on

nocturnal mammal occurrence as the percentage of detections in low-light was reduced from 320 to 102.

Table 2: Nocturnal Mammal Detection Frequency Across Light Zones

Species	Low-light Zone	Moderate-light Zone	High-light Zone	Total Detections
Indian fox	34	21	9	64
Golden jackal	42	35	18	95
Small Indian civet	38	19	6	63
Palm civet	31	24	11	66
Mongoose	29	26	17	72
Indian hare	46	33	14	93
Porcupine	27	13	4	44
Jungle cat	22	10	3	35
Fruit bat	51	38	20	109
Total	320	219	102	641

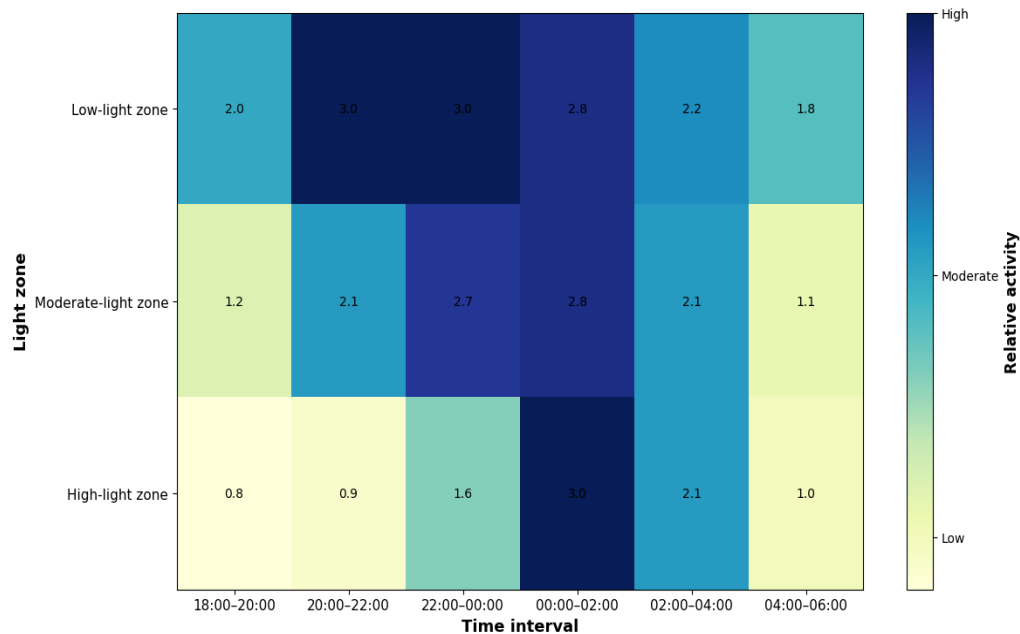


Figure 2: Night-Time Activity Pattern of Nocturnal Mammals Across Light Zones

The nocturnal mammal use was highest at low-light areas in particular, between 20:00 and 00:00, with peak values of 3.0 (Figure 2). The activities were low in early night (0.8–1.6) but rose after midnight (3.0 during 00:00–02:00) in high-light zones. This indicates that artificial light delays mammal movement towards later night hours.

Discussion

The results suggest that nocturnal mammals are strongly adapted to urbanisation and artificial light at night in a semi-urban environment (Cronin et al., 2025). Zones with low light levels in which the number of detections was highest indicate that these areas may be safer for movement, foraging, and use of shelter.

Differences in detection rates between high-light and low-light areas, however, indicate that artificial light is an ecological stressor that reduces the use of habitat and influences normal night-time activities. The change of peak activity to a later schedule in high-light areas suggests temporal adjustment, in which animals shift to a later schedule where human activity, vehicle activity and light disturbance are relatively low. The results indicate that light pollution has a complex effect on nocturnal mammals (Candolin, 2024; Hoffmann et al., 2019). More sensitive species like civets, porcupines, jungle cats and hares were found to be more sensitive and avoided bright areas, while more adaptable species like jackals, mongooses, palm civets and fruit bats seemed to tolerate moderate disturbance. This implies avoidance, tolerance and behavioural flexibility. Avoidance was evidenced by decreased activity around roads and settlements, flexibility by the later timing of activity, and increased activity in vegetated corridors and movement in darker areas. This adjustment could, however, result in greater energetic costs, decreased foraging time and animals being more susceptible to mortality risk when crossing roads during a short safe time.

These results are similar to those found in previous studies of urban wildlife that have documented that nocturnal mammals will adjust their activity patterns and habitat use to minimize exposure to human activity and artificial light, especially traffic (Ritzel & Gallo, 2020; Selvakumar et al., 2025). Dark refuges, vegetated corridors, wetland edges, and agricultural boundaries are typical places where urban and

peri-urban mammals rely on dark refuges to move safely. In this study, an increase in vegetation cover was associated with an increase in mammal detections, suggesting that natural cover can help ameliorate disturbance effects and preserve ecological functioning in human modified landscapes (Mendes et al., 2020; Siddesh, 2024). Semi-urban planning must take into account the needs of nocturnal wildlife, from a conservation viewpoint. Minimizing unnecessary street lighting, using shielded and downward facing lighting, keeping corridors dark, preserving vegetation strips and restricting lighting along the edges of fields and forest, and near wetlands can help minimize disturbance. There is a need to balance the need to keep people safe with the need to protect biodiversity, and there are ways to do that through wildlife sensitive lighting policies. Some limitations of the study are the seasonality of species activity, a potential detection bias of camera-traps, the length of the monitoring period, and intra-specific differences. Longer monitoring periods, inter-seasonal comparisons, GPS monitoring and physiological stress indicators should be added to future studies to gain a greater understanding of the longer-term effects of urbanization of light on nocturnal mammals.

Conclusion

Semi-urban light pollution is found to have a significant influence on nocturnal mammal behaviour and habitat use. The number of detections of mammals was highest in low-light regions, with 320 detections, compared to 102 detections in high-light regions, thereby demonstrating that artificial light is not

favourable for mammal habitat use and limits mammal observations in disturbed areas. The results also showed a positive correlation between the different light times in different zones, with high-light zones having low activity during the early night hours but reaching maximum activity in the 00:00-02:00 light period. This means that nocturnal mammals will delay their movement when it is light, cars are moving, and humans are disturbing them. Sensitive species like civet, jungle cat, porcupine and hares were found to have a greater aversion to illuminated habitats, whereas adaptable species demonstrated partial tolerance by exhibiting behavioral flexibility. The results reveal the ecological stress caused by the artificial light at night, which leads to loss of safe foraging space, reliance on dark refuges, and a narrowing of the movement windows of animals. Thus, darkness should be considered as an ecological resource in conservation planning in semi-urban landscapes. Dark corridors between scrublands, forest edges, wetlands and agricultural margins can facilitate safe movement. Unnecessary night lighting is to be minimized in the vicinity of wildlife use areas and lights are to be shielded and directed downward, and of low intensity if lighting is necessary. Scrub patches, vegetated field margins, wetland edges and forest edge habitats are also critical for protection due to their role as refuge and movement corridors. In general, the policy of lighting for wildlife should be included in the design of lighting for semi-urban development so that human development and the conservation of nocturnal mammals can be achieved.

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