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Original Research Paper

Influence Of Urban Expansion on Bat Diversity Roosting Patterns and Foraging Behaviour in Metropolitan Areas

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Key Words

Urban ecology, Chiroptera, Species richness, Echolocation, Artificial light, Green infrastructure, Roost selection.

Abstract

Urban growth is one of the main contributors to biodiversity losses around the world, but their influence on bat communities is still not well known within metropolitan environments. In this study, bats' diversity, roosting preference and foraging behaviour were assessed in five different habitats from a gradient ranging from urban to rural, in one of the largest metropolitan regions. Acoustic sampling took place in 45 different sites during 24 months, using full spectrum bat detectors. A total of 16 different species of bats were identified, showing that species richness decreases significantly from peri-urban reserves (13 species, Shannon index $H' = 2.18$) to urban core (3 species, $H' = 0.62$; $p<0.001$). Roost surveys have demonstrated a change from natural structures (hollow trees and cracks of rocks) in less urbanized zones to artificial ones (building cracks and bridges). The foraging behavior, measured by echolocation pass rates, showed that foraging behavior was highest in green corridors (47.3 ± 6.8 passes/hr) but lowest in urban core (18.4 ± 3.1 passes/hr). The regression analysis found artificial light at night and noise as significant negative predictors of bat activity ($R^2 = 0.74$). This study proves that urbanization is filtering out bats, retaining only ecologically plastic generalists while habitat specialists are being excluded from the ecosystem. Bat species richness and activity are high where there is more greenery such as riparian corridors and trees. From this study, it is evident that it is necessary to reduce light and noise pollution, and conserve green space to ensure the survival of diverse bat populations. These approaches will contribute significantly towards biodiversity and maintenance of foraging habitats in urban environments.

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Introduction

Urbanization is considered one of the most extensive and widespread ways of landscape transformation globally and will increase the coverage of impervious surfaces by more than two-fold by 2050 (Jung & Threlfall, 2018). Expansion of cities changes habitat architecture, microclimate conditions, acoustical and lighting conditions, thereby creating a novel ecological filter. The group of bats (order Chiroptera), the second most diverse order of mammals characterized by being obligate nocturnal echolocating hunters, serves as a representative indicator group that reflects the influence of urbanization on ecosystems.

Bats are affected by urbanization in several aspects. Species diversity and functional diversity of bats usually decrease with an increase in urbanization, but the impact varies depending on the particular species and their specific traits like body mass, frequency of echolocation call, wing morphology and roosting preferences (Jung & Threlfall, 2018). Species with a high-aspect ratio, open-space foraging behavior, e.g., genus Tadarida, are more tolerant of urbanization, whereas species that use low-frequency echolocation and forage in cluttered vegetation, like forests, suffer from habitat losses due to tree cover and complexity reduction (Starik & Göttert, 2022).

Urbanization causes similar disruption within the field of roosting ecology. Roosting substrate, such as holes in trees, crevices in rocks, and caves, is reduced in availability due to deforestation and the sealing of geological features under layers of impervious surfaces (Law et al., 2015). While some synanthropes adapt to roost in structures such as buildings, bridges, and underground infrastructure, this adaptation limits colony size, thermo-regulation, and vulnerability to human presence (Threlfall et al., 2011).

Among the two most important stresses facing bats in urbanized environments, one can note anthropogenic light and anthropogenic noise. Anthropogenic light disturbs the beginning of activity periods and prevents light-sensitive chiropterans from feeding on insects around lights, while also altering the foraging dynamics throughout the course of night (Rowse et al., 2015). On the other hand, traffic and industrial noises may disturb echolocation of prey at detection ranges, thus increasing the effort associated with successful hunting (Starik & Göttert, 2022).

In spite of increasing awareness regarding these issues, most studies related to urban bat ecology have been carried out in the temperate environments of Europe and North America, while few comparative studies exist regarding cities in Asia, Africa, and South America that are rapidly becoming urbanized (Ait-Abdesselam et al., 2025). In addition, the predominant trend of most of the research is to focus on one aspect of bat ecology such as species diversity, roosts, and foraging, whereas an integrative analysis of all three ecological variables is crucial for investigating the filtering process of bats through urban environments (Carlier et al., 2019; McCabe, 2023).

In this study, we attempted to fill in these gaps by analyzing species diversity, roost site choice, and foraging behavior of bats in five zones characterized by the degree of urbanization.

Objective of the Research

- To estimate species richness and diversity within habitat zones.
- To analyze habitat preferences for roosting in relation to urbanization gradient.
- To evaluate temporal and spatial distribution of foraging activity.
- To determine main environmental determinants of bat activity within the metropolitan area.

The structure of the paper is as follows. In Section 2, the results of research concerning urbanization effects on bat communities will be reviewed with respect to species richness, roosting behavior, foraging behavior, and other ecological processes. Materials and methods used in this research will be described in Section 3. These include the description of the study area, selection of habitat zones, acoustic monitoring of bat activity, roost analysis, measurement of environmental variables, and statistical methods. The obtained results will be presented in Section 4. They cover species richness, estimates of diversity indices, changes in preferred roost substrates, foraging activity, and influence of environmental factors such as light pollution and anthropogenic sounds. Finally, these results will be discussed in Section 5, considering ecological consequences for bat communities in the context of habitat loss, habitat specialization, and presence of green corridors.

Materials and Methods

Study Area

This study was carried out in an urbanized environment covering a total of about 1,200 km² with a concentric zone gradient of varying levels of urbanization density from highly urbanized central core to the peri-urban fringes, where areas are semi-natural. This particular area consists of five different habitat zones that have been determined on the basis of land cover classes obtained through high-resolution remote sensing images and city planning documents. These zones were classified into: (i) Urban Core, (ii) Suburban Matrix, (iii) Green Corridors, (iv) Peri-urban Fringe, and (v) Peri-urban Reserves. Imperviousness varied between 91% in the Urban Core to 12% in Peri-urban Reserves.

Bat Acoustic Surveys

Acoustic surveys were conducted from May 2022 to April 2024 through the use of 45 fixed listening stations (nine per habitat type) employing full-spectrum bat detectors (AudioMoth v1.2, Open Acoustic Devices), with recordings made at a frequency of 384 kHz. All 45 sites were set to record throughout each night, starting 30 minutes prior to sunset until 30 minutes after sunrise, on at least four nights during each month of the survey. Files were processed in BatExplorer Pro (v3.1) and manually cross-checked against a regional library of echolocation calls. Species were determined using acoustic identification criteria, and ambiguous calls were classified to complex level. Foraging activity was calculated as the total number of echolocation passes per hour of monitoring (station-hour) and included differentiation between foraging and commuting calls based on the presence of feeding buzz sequences. Nocturnal activities were analyzed for three time periods: early night (from sunset to three hours after sunset), middle night, and late night (from two hours pre-sunrise to sunrise).

Roost Surveys

Roost survey was carried out on a quarterly basis for all sampling stations, through a combination of transects, building inspections, hollow tree surveys, and radio telemetry for selected trapped bats. A total of 14 bats from six different species were tagged using a 0.4 g Pip tag radio transmitter (Biotrack Ltd.), and the bats' roosting sites were then found using hand-held receivers. The types of roost were categorized into either:

- Natural roost (tree hollows, rock crevices, cave entrances)
- Anthropogenic roost (crevices on buildings, roof spaces, bridges, drainages).

Environmental Variables

The variables of interest at each site included the following environmental measurements: percent cover of impervious surfaces within 250 m and 1 km radiuses (based on satellite image analysis); percent vegetation cover (within 250 m); distance from nearest waterbody (m); sky brightness (using Sky Quality Meter, Unihedron); sound intensity between 20–80 kHz (passive bat detector in noise monitoring mode); and mean temperature (°C).

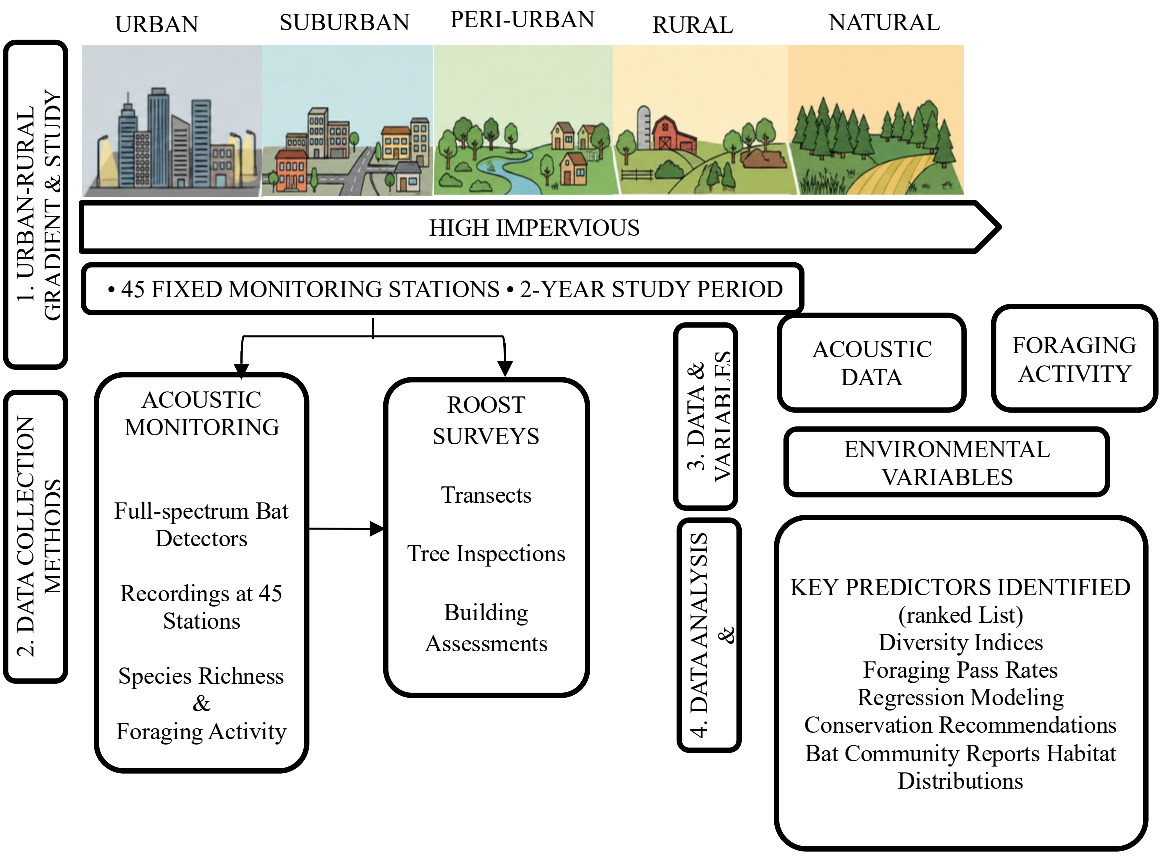

Figure 1: Conceptual Workflow of Bat Monitoring Across Urban–Rural Gradient

As shown in figure 1 below, the study methodology consisted of evaluating the bat community composition in five different habitat zones within the urban-rural continuum. Acoustic surveys were performed for two years using full-spectrum bat detectors installed at 45 permanent stations in order to capture species richness and foraging behavior of local bat populations. Roost surveys involved the use of transects, inspections of trees and buildings, and tracking using radiotelemetry of captured bats. Environmental parameters measured at the site included the amount of impervious surfaces, canopy cover, distance to water bodies, light pollution, noise, and temperature.

Data Analysis

Diversity of the species assemblage in each habitat zone was calculated using species richness (S) and Shannon-Wiener diversity index (H'). One-way ANOVAs with Tukey's HSD post-hoc comparisons were performed in order to compare diversity and foraging metrics among zones. Multiple linear regressions were applied to test for associations between bat passes and environmental factors using an Akaike information criterion (AIC) approach to predictor selection. All statistical analyses were performed using R software (v.4.3.0; R Core Team, 2023) with statistical significance determined at $p < 0.05$.

Results

Species Richness, Diversity, and Activity Across Habitat Zones

The total number of 16 species of bats from five families were observed in the five habitat zones within the span of 24 months of monitoring. There was a dramatic decline in species richness and diversity as the urbanisation intensifies (Table 1).The Urban Core had three species, all in the genus Pipistrellus, with a Shannon diversity index of $H' = 0.62$. The Peri-urban Reserves had the most diverse community with 13 species from four families ($H' = 2.18$). A one-way ANOVA showed significant differences between zones regarding species richness ($F_{4,40} = 38.7$, $p < 0.001$) and foraging activities ($F_{4,40} = 29.4$, $p < 0.001$).

Table 1: Bat Diversity and Activity Across Habitat Zones

Habitat Zone	Species Richness	Diversity Index	Dominant Roost Type	Primary Foraging Sites	Activity (passes/hr)
Urban Core	3	Low (H′ = 0.62)	Building crevices (89%)	Street lamps & park edges	18.4 ± 3.1
Peri-urban Fringe	9	Medium (H′ = 1.74)	Tree hollows (61%)	Woodland patches & wetlands	34.7 ± 5.6
Suburban Matrix	7	Medium (H′ = 1.43)	Mixed (52% buildings, 48% trees)	Riparian corridors & gardens	28.2 ± 4.9
Green Corridors	11	High (H′ = 2.01)	Tree cavities (73%)	Water bodies & insect-rich margins	47.3 ± 6.8
Peri-urban Reserves	13	High (H′ = 2.18)	Natural caves & old trees (81%)	Forest edges & agricultural margins	53.6 ± 7.4

The Green Corridors and Peri-urban Fringes were more diverse compared with the former two zones (H′ = 2.01 and H′ = 1.74, respectively) due to the presence of medium-frequency guild members such as Myotis daubentonii (Daubenton’s bat) and Eptesicus serotinus (Serotine bat). The Tukey HSD test results show a significant difference of the Urban Core from the remaining zones ($p < 0.05$ in all pairwise tests), but there is no significant difference between Peri-urban Reserves and Green Corridors ($p = 0.34$).

H′ = Shannon–Wiener diversity index. Activity data represent means ± standard error pooled across all survey nights per zone.

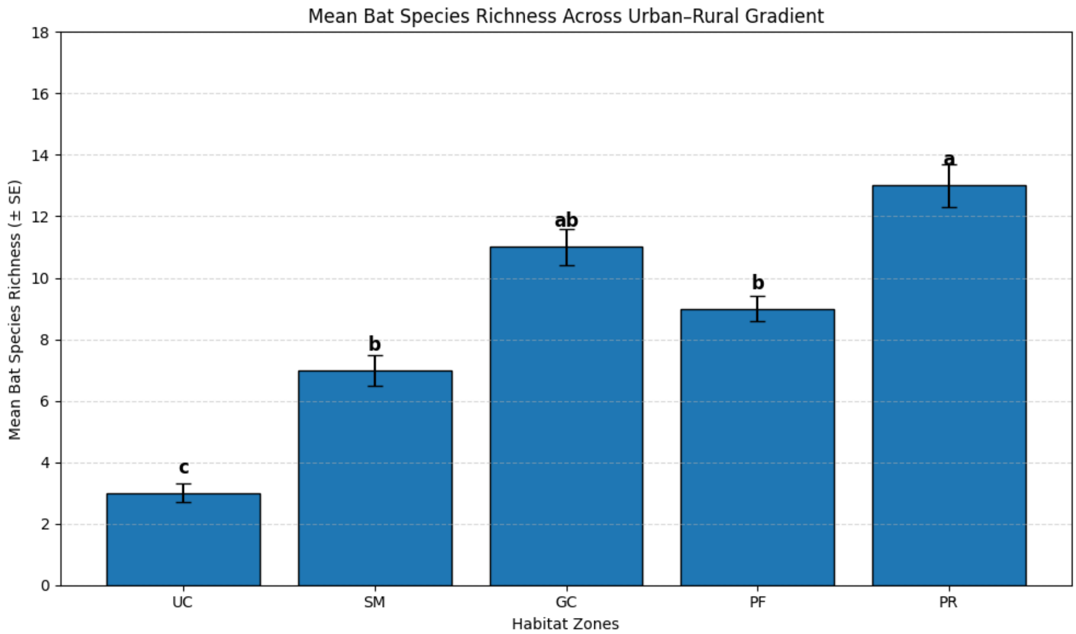

Figure 2: Mean Bat Species Richness Across Urban–Rural Habitat Zones

Bat species richness (± SE) mean values for different habitat zones within an urban-rural gradient are shown in figure 2. There is a negative relationship between bat species richness and the level of urbanisation in the zone. Species richness was found to be 13 in the Peri-urban Reserves and 3 in the Urban Core. The letters on top of the bars represent differences among the habitat zones that were significant at the Tukey HSD test, $p < 0.05$.

Roosting Substrate Preferences

A significant change in roosting substrate preference along the urbanization gradient can be noted (see table 1). In the urban core, the vast majority of roosting sites (89%) were found in man-made habitats, i.e., in crevices in brick walls of buildings and expansion joints in bridges. The mean size of roosting colonies (18 ± 6 individuals) was relatively small due to limited opportunities for cavity nesting in the built habitat. In peri-urban reserves, almost all the roosts were in natural substrates (hollow trees and cave openings), with the roosting colonies up to three times larger than in urban habitats.

The radio tracking results clearly demonstrated that the most plastic roosting habits were shown by Pipistrellus (common pipistrelle):

the species equally used the building crevices in the urban setting and tree hollows in less disturbed areas without the preference for one substrate type over another. On the contrary, Rhinolophus ferrumequinum (greater horseshoe bat), recorded only in peri-urban reserves, strictly preferred to roost in caves and hollow trees, which corresponds to high roost site fidelity of this species (Law et al., 2015).

Foraging Behaviour and Temporal Activity

The differences between zones were pronounced regarding the amount of foraging activity performed by bats, with the highest average pass rate being registered in Peri-urban Reserves (53.6 ± 7.4 passes/hr) and Green Corridors (47.3 ± 6.8 passes/hr), and the lowest in the Urban Core (18.4 ± 3.1 passes/hr). In addition, the bats' activity during nighttime also depended on the location, with bats in urban zones showing activity only during the first third of the night and bats in peri-urban zones being active during all three-time intervals. Stations located close to water bodies attracted considerably higher pass rates (on average 2.3 times more) than the farther locations.

A multiple linear regression revealed four factors that significantly influenced the level of foraging activity: sky brightness ($\beta = -0.61$, $p < 0.001$), ambient noise level ($\beta = -0.43$, $p < 0.001$), impervious surfaces within 250 m ($\beta = -0.38$, $p < 0.001$), and canopy cover within 250 m ($\beta = 0.52$, $p < 0.001$). In total, the model accounted for 74% of variation in activity ($R^2 = 0.74$, $F_{4,40} = 28.9$, $p < 0.001$). Among the variables, sky brightness turned out to be the strongest negative predictor of bat activity.

Discussion

The findings from this research show a reliable and statistically significant inverse correlation between the level of urbanization and bat diversity in the study area metropolis. In this regard, the drop in bat species diversity from 13 to three from Peri-urban Reserves to Urban Core translates to a loss of 76% of the bat community, a pattern which is congruent with previous global meta-analysis findings (Jung & Threlfall, 2018) and also corroborated by recent trends in quickly urbanizing cities across Africa (Ait-Abdesselam et al., 2025). Furthermore, the prevalence of Pipistrellus bats in the urban core region was predictable based on theoretical considerations regarding the traits favored by urban filtering effects. In this case, the presence of high-frequency echolocation adapted for cluttered environment, roosting behavior tolerant of anthropogenic structures, and diverse diets capable of supporting generalist feeders were factors that allowed their persistence in a habitat unsuitable for specialists (Lewanzik et al., 2022). The complete exclusion of Rhinolophidae from urban habitats stands out due to their long wavelengths prone to attenuation by noise and physical obstacles, and also their need for contiguous forest canopy to commute (Yantén et al., 2022). The colonization of buildings and bridges by the Pipistrellus species constitutes an additional roost site system that partially offsets the reduction of natural cavities, although this solution benefits only ecologically adaptable species (Müller et al., 2012). Such conservation strategies like the addition of bat boxes within urban architecture and the protection of ancient trees as potential substrates would provide sufficient habitat conditions for more species (Threlfall et al., 2011).

The conclusion that ALAN represents the sole significant predictor of bat activity suggests a critical point for consideration when designing policies related to urban planning and public streetlighting. The transition towards LED technology within public lighting systems in many cities leads to increased ALAN levels, since white-light LED modules produce light of the blue short wavelength spectrum, which is the most disruptive in terms of phototactic insect behavior and bat feeding activity initiation (Rowse et al., 2015). Dimming strategies, amber spectrum light sources, and motion detection lighting present effective solutions at relatively low cost (Gili et al., 2020). The green corridors proved to be particularly significant habitats for bats in terms of bat diversity and foraging activity in comparison with their area by recording 11 species and having second highest foraging activity despite being embedded in the continuous urban matrix. This observation is congruent with evidence of green corridors, parks, and trees in streets in an urban setting as means for connecting urban areas with forests, allowing forest-interior species to exploit urban foraging grounds (Li & Rudevdagva, 2024). Clearly, what matters for maintaining bat diversity in a cityscape is not only the total area covered by green corridors, but also their shape, width, and canopy cover (Printz et al., 2021; Becker et al., 2018). Among potential weaknesses of the current study are the uncertainties associated with using acoustic species identification and lack of measurements of prey abundance as a possible confounding factor (Pamije & Havalam, 2025; Kelm et al., 2025). Future research should consider the simultaneous use of acoustic bat monitoring and insect abundance data, which will help in determining the relative importance of prey abundance compared to habitat structural heterogeneity (Starik & Göttert, 2022). Multi-year studies would also help in elucidating how urban intensification interacts with other global trends like climate change.

Conclusion

This study shows that urbanization has an enormous impact on the structure of bat assemblages because of its simultaneous effects on species diversity, roosting behaviors, and foraging habits. The urbanization gradient serves as an ecological filter that allows generalist species capable of using versatile types of roosts and echolocating calls to exist in highly urbanized cores, whereas specialist bats do not survive within such environments. Based on acoustic observations, the diversity of bat species decreased dramatically from the peri-urban nature reserves towards the urban cores, while the survey of roosts indicated a clear trend of transitioning from natural habitats to anthropogenic substrates with urbanization. Foraging behavior was lessened in places characterized by intense illumination and noise pollution in the nighttime environment, rather than the absence of habitats. The provision of green corridors and peri-urban reserves were vital sources of refuge during foraging and commuting. This is why conservation efforts should be multidisciplinary and include such measures as protecting green corridors and restoring green spaces, protecting natural roosting substrates through urban forestry initiatives, and using spectrally sensitive lighting and time-controlled light exposure for public areas. In addition to promoting bat biodiversity, these conservation actions will facilitate greater nocturnal biodiversity which relies on the same environment. Urban development can continue while ensuring the survival of ecological communities of bats by protecting habitat, developing an urban plan, and mitigating sensory pollution. These results have important implications for biodiversity conservation in cities because they show that structural and functional diversity of urban ecosystems should be preserved.

Ethical Statement

All capture and tracking of bats were done with appropriate wildlife permits from the concerned country. Bats were handled according to ethical principles guiding bat research to reduce stress and ensure that the bats are released immediately after instrumenting.

Conflict of Interest

The authors declare no conflicts of interest.

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