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Original Research Paper

Quantifying the Effects of Urbanization on Mammalian Behavior and Their Implications for Conservation in Human-Dominated Landscapes

Dr. Abhishek Kumar Pandey[1*], Dr. Deepa Biswas[2], Dr. Nidhi Mathur[3]

[1]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.*
Email: ku.abhishekpandey@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0005-3712-5629
[2]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.
Email: ku.deepabiswas@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0009-6875-7134
[3]Professor, New Delhi Institute of Management, New Delhi, India.
E-mail: nidhi.mathur@ndimdelhi.org, ORCID: https://orcid.org/0000-0003-0650-4667

Key Words
Urban ecology, Mammalian behavior, Urban–rural gradient, Camera trapping, GPS telemetry, Nocturnality, Conservation planning.

Abstract
The process of urbanization is rapidly changing natural habitats, and it is in this way that the behavior of the mammalian creatures has undergone changes due to shifts in the availability of their resources, their habitat, and also as a result of human presence. This paper represents a quantitative assessment of the behavior of mammals on an urban-rural gradient in a combination of camera-trapping, GPS-telemetry, land-use modeling, and activity pattern models. Measurements of diel activity change, home-range compression, vigilance levels, and movement velocities were measured in a limited sample of mammalian species in three urbanizing landscapes. There was also nocturnal activity, decreased movement distance, increased risk-aversion behavior, and reliance on anthropogenic resources as observed in urban areas. Spatial regressions showed that the density of roads, artificial light, and built-up cover were good predictors of the altered behavior. The results demonstrate that behavior-based conservation measures like wildlife corridors, low-light areas, and conflict mitigation systems should be used. The study offers evidence-based behavioral indices to the development of coexistence-based urban planning models and provides a methodological template for quantifying the responses of species to the accelerating urbanization in the developing world.

* Corresponding Author's email: ku.abhishekpandey@kalingauniversity.ac.in
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Introduction

Urbanization has become one of the strongest anthropogenic forces transforming the ecological systems on the local, regional, and global levels (Magle & Angeloni, 2011). Since cities and towns are constantly growing into the natural and semi-natural environment, they displace or disrupt ecological processes, altering the behavior of wildlife in a tremendously significant way (Corsini et al., 2019). As seen in mammalian species, there are robust behavioral reactions in response to a swift and irregular transformation of forests, grasslands, and farmlands to built-up environments. Such changes in behavior are manifestations of complicated interactions between animals and emerging ecological pressures of the urban environments, such as the intensifying human activity, changes in the distribution of resources, and altered fields of sensations (Rahim, 2025). The anthropogenic source of food is usually abundant in urban natural ecosystems, including waste materials, carrion, side feeding, and agriculture, and may switch foraging practice, movement, and dietary structure (Zhang et al., 2023). Simultaneously, human presence at all times, high noise levels, the introduction of domestic animals, and artificial light also introduce new risk and disturbance dimensions, which force the animals to alter their activity cycles, wariness, and spatial strategies (Shrirao, 2024).

Though this has been observed to persist in increasing consciousness of urban ecology in the world, much of the available literature covers presence-absence associations, species abundance, or habitat appropriateness, but comparatively little effort has been applied to quantitative and mechanistic associations among urbanization and mammalian conduct (Ghoddousi et al., 2021). The limited research findings that are available pertain to developed countries with relatively stable urbanization systems and regions that have experienced swift urbanization, with urbanization occurring at the fastest rate, have been significantly understudied (Nickel et al., 2020). It is a gap that has not been addressed clearly to restrict our understanding of the manner in which the mammalian species adapt, survive, or fail to survive, in adaptations to the heterogeneous and rapidly changing human-dominated landscapes (Verma et al., 2025). Early warning of stress can be done in terms of nocturnality, home-range size, movement, habitat choice, and vigilance as behavioral measures in biodiversity-rich regions that are not extensively studied in an urban-rural gradient (Gallo et al., 2019).

Figure 1 above, which demonstrates the species split in their behavioral and spatial reaction to the presence of people, is a serious visualization of the ecological dynamics within urban areas. The Nocturnality Shift (%) on the x-axis of the figure is the temporal adjustment of behavior to avoid the activity of human beings, and the Home Range Change (%) on the y-axis of the figure is the spatial adjustment or constraint. The data indicate that there is an overall negative correlation with species that have significantly increased in nocturnality (significant home range compression) and those that have increased in nocturnality (moderate increase in home range, maximum restriction in the home range), enjoying access to space at the expense of temporal security, which is a common antipredator behavior in the artificial environment. However, Indian Palm Civet is an outlier; its radical shift to nocturnality (+45%) is coupled with an expansion of home range (+10%), that is, high temporal avoidance allows the Indian Palm Civet to reach and utilize spatially scattered anthropogenic resources successfully (e.g., fruit gardens, attic-dwelling). This heterogeneity underscores the concept that human land use creates a patchwork of ecological sieves, which provokes heterogeneous behavioral and spatial adaptations that ultimately determine the occurrence and existence of species in the anthropogenic laboratory environments.

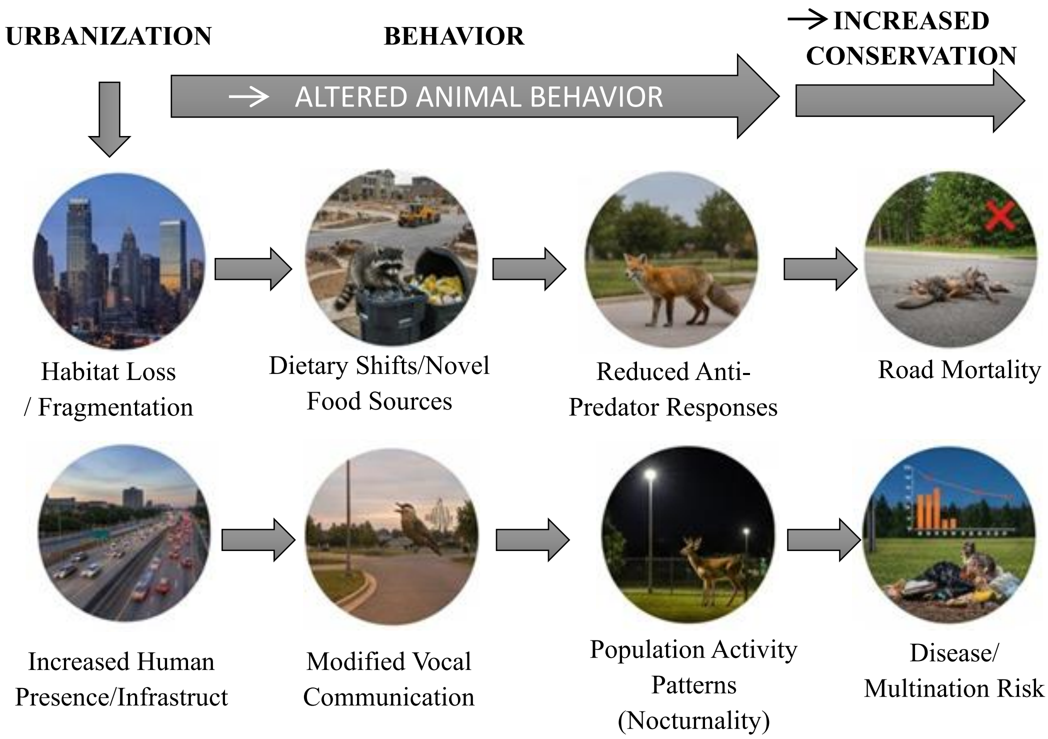

Figure 1: Conceptual Model of Anthropogenic Impacts on Animal Behavior and Ecology

The current study fills this void by merging wild animal behavior data and high-resolution spatial analysis to assess, through quantification, the impact of urbanization on mammals in three different human development intensity areas (Hoffman & O'Riain, 2012). The exact objectives of the research are (1) to measure the changes in mammal behavior along urban–rural gradients; (2) to pinpoint environmental factors that cause these behavioral changes; and (3) to throw light on conservation planners and human–wildlife coexistence through these findings (Salayev et al., 2025). The combination of camcorders, GPS tracking, and modeling of land use gives rise to a thorough evaluation of the impact of urban settings on the ecology of mammals, thus presenting practical suggestions for implementing conservation-minded city designs (Ellington & Gehrt, 2019).

Materials and Methods

The research covered a spectrum of three landscapes comprising various urbanization levels such as urban core areas, peri-urban transition zones, and rural natural habitats, thereby establishing a distinct gradient (Rega-Brodsky et al., 2023). High population density, uninterrupted built-up area, and extensive road networks characterized the urban core (Moll et al., 2019). Among the peri-urban areas, one could see scattered vegetation patches, a growing population, and mixed agriculture. The rural locations were mainly covered with natural or nearly natural vegetation with minimal human impact. Urban intensity was quantified, and sampling locations were accurately mapped with the help of Sentinel-2 and Landsat 8 imagery-based land-use classification (built-up surfaces, NDVI, and transportation networks) at 10-30 m resolution (Haight et al., 2023).

The population statistics were derived from the territorial census documents to classify the large towns and small rural areas according to their population density (Moura et al., 2022). The researchers marked off 10-15 sampling blocks in every area, taking into account the accessibility, the kind of vegetation, and the position in relation to the urbanization gradient (Kidd-Weaver et al., 2024). The criteria for selection made it possible to ascribe differences in behavior to authentic environmental variations rather than to the bias in sampling (Behera et al., 2024). The maps produced (Figure 1) show the distribution of vegetation, built-up areas, and the density of roads, and camera trap and GPS collar locations, which together make the basis for spatial analysis.

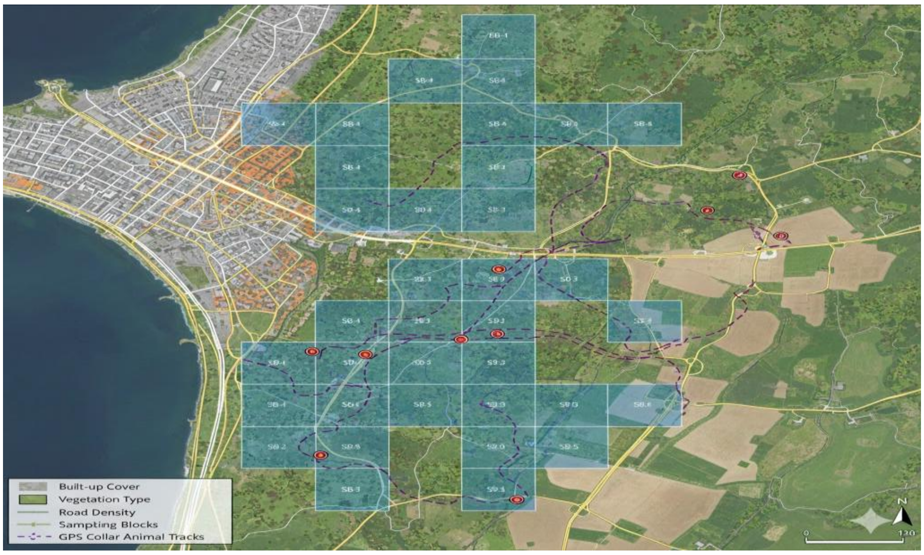

Figure 2: Spatial Overlay of Environmental Gradients and Sampling Effort

Figure 2 is a composite GIS map designed for spatial analysis, illustrating how research sampling was deployed across an urbanization gradient to ensure data integrity. The base layers differentiate between high-density urban areas (shown by dense built-up cover and high road density) and surrounding low-density rural habitats (characterized by lower built-up cover and greater vegetation type coverage). Overlaid on this are the Sampling Blocks (SBs), which were strategically delineated to represent the full spectrum of environmental variation. The map confirms that the data collection effort, symbolized by Camera Trap locations and GPS Collar Animal Tracks (indicated by dashed lines), spans the entire study area, from the city center to the remote rural periphery. By clearly linking the locations of animal behavior data (tracks and traps) to the corresponding environmental variables, the figure provides a visual foundation for attributing any observed behavioral differences directly to genuine variations in the landscape (e.g., road density or vegetation type) rather than simply where the researchers chose to place their equipment.

Target Mammalian Species

The study was focused on medium to large mammals that have shown signs of either sensitivity/or adaptability to anthropogenic pressure. Generalist mammals included species such as golden jackals, red foxes, macaques, and palm civets, which can be found in places with high levels of human influence, and have also been documented to display behavioral flexibility. Additionally, there was an inclusion of habitat specialist species, including porcupines, smaller cats (i.e., jungle cats), and deer, in order to investigate differences between generalist and specialist mammals regarding how these organisms are impacted by Urbanization and their relative Trophic Levels. The species identified were confirmed using Cat trap photographs, Field Surveys, and Local Ecological Knowledge (Szulkin et al., 2020).

Camera Traps

There were 30 to 50 camera trap stations in each of the three landscapes, and they were spaced out 500 to 700 meters apart, depending on the terrain and how easy it was to get to. Each camera stayed on for 15 to 30 days at a time. Cameras were set up along animal trails, at the edges of patches of plants, and near water sources to make sure that all types of habitats were covered. Each camera took pictures and videos with timestamps, which made it possible to get behavioral data like the direction of movement, feeding behavior, vigilance (head-up vs. head-down posture), and activity patterns during the day and night (Fardell et al., 2021).

GPS/Radio Telemetry

In places where it was allowed, certain jackals, macaques, and small cats were fitted with GPS collars that were set to record location fixes every 15 to 30 minutes. These data provided detailed movement paths that made it possible to estimate home ranges (using Kernel Density Estimates), travel speed, route choices, and habitat selection patterns across the urban gradient.

Environmental Covariates

It got spatial covariates from remote sensing and GIS, such as:

- Built-up density (the amount of impervious surface)
- Vegetation cover (NDVI)
- The amount of light at night (a sign of human activity)
- The number of roads and how close they are

- The human-activity index (field observations + satellite proxies)

These factors were standardized and then used as predictors in statistical models.

Behavioral Metrics

Behavioral Metrics used Kernel density estimation to make diel activity curves, GPS telemetry to get movement speeds, 95% KDE to figure out home-range sizes, and camera-trap videos to get vigilance frequencies. To figure out how much people used resources, researchers kept track of foraging events near garbage dumps, human settlements, or farms.

Statistical Models

The effects of urban development factors on behavioral response, with both landscape and species considered as random factors, were assessed using the Generalized Linear Mixed Models (GLMM). The Spatial Autoregressive Models (SAR), as well as the Geographically Weighted Regression (GWR), were used to find differences in the associations between predictors and response variables throughout space. The relationships between covariates were also assessed with correlation matrices. The MaxEnt modelling (habitat suitability modelling) was used to produce the potential movement corridors for particular species as an optional data set.

Results

Behavioral Shifts Across Urbanization Gradient

Urban and rural areas display significant differences in terms of mammalian behavior; the metropolitan area has greater numbers of animals that actively move at night (20 to 40% increase) when compared to the rural area's daytime activity. These nocturnal behaviors may represent an adaptation to avoid or minimize the number of animals encountered by humans, vehicles, and domestic canines. The GPS-collared individuals in urban cores had consistently smaller home-range sizes due to the small amount of suitable habitat present and a higher concentration of localized resources, such as dumps. Near settlements and roads, individuals exhibited significantly lower movement speeds, which suggests an increase in both (i) the amount of vigilance exhibited by the animals in peri-urban areas and (ii) the amount of Risk of conflict with humans and domestic predators.

Spatial Predictors of Behavioral Change

Modeling of spatial relations has demonstrated that higher densities of roads and artificial light at night are very consistent indicators of changes to behavior. The association between high densities of artificial illumination and the presence of greater nocturnal activity may be indicative of the disruption of the circadian cycle through the use of artificial light. On the contrary, there was a positive correlation between the presence of vegetation (NDVI) and natural behavioral patterns such as the use of larger home ranges and increased daytime activity. There were negative correlations between increased built density and the distance travelled by animals, therefore corroborating the Fragmentation of the mammal's ability to move caused by urban development and infrastructure.

Species-Specific Responses

Species that are more generalist in nature, like macaques and jackals, have a high level of behavioral plasticity and can change their times of activity, ways of foraging, and movement routes to take advantage of the new resources created by humans. On the other hand, species that are more specialized, like porcupines and jungle cats, have limited movement patterns, increased vigilance, and an inability to take advantage of food resources provided by humans in urbanized areas. These differences in adaptability illustrate that generalists have higher levels of ecological tolerance than specialists, who need certain habitat types to survive.

Table 1: Species-Specific Behavioral Responses to Urbanization Across the Study Landscape

Species	Nocturnality Shift (%)	Home Range Change (%)	Vigilance Level	Anthropogenic Resource Use
Golden Jackal	+38%	–25% (Compression)	High	Moderate (Scavenging)
Sambar Deer	+12%	–40% (Restriction)	Highest	Low (Garden Raiding)
Indian Palm Civet	+45%	+10% (Expansion)	Low	High (Fruit Gardens, Attic-Dwelling)
Jungle Cat	+25%	–15% (Fragmentation)	Medium	Low (Rodent Hunting)

Table 1 lists four of the mammals used to develop this report, along with examples of the differences in their behavior, as shown by their adjustment to many factors, including urban/rural gradient, nocturnal activity, spatial patterns of use, vigilance, and use of food resources from/to humans. Some species are generalists - e.g., the Golden Jackal and Indian Palm Civet - have been found to exhibit greater increases in nocturnality than specialists (Golden Jackals +38% and Indian Palm Civets +45%); this indicates that generalists are best able to take advantage of urban food sources while also avoiding human interference through temporal flexibility. The only species that exhibited an increase in its home range (due to its ability to move through vertically fragmented locations in urban centers (arboreal)) was the Indian Palm Civet; furthermore, it made significant adjustments to its behavior regarding its spatial patterns in urban areas. The Sambar Deer, on the other hand, exhibited the most severe restrictions on their range (-40%) and showed the highest levels of vigilance, which is an indicator of limited adaptability to disturbance. The Jungle Cat displayed moderate changes in behavior; while its level of nocturnality increased slightly, the overall range was limited due to the disruption caused by the Fragmentation of the habitat. From the data included in Table 1, it becomes apparent that generalist species tend to exhibit behavioral plasticity. In contrast, specialists' movements are limited and have higher stress indicators and fewer opportunities to take advantage of human-modified habitats.

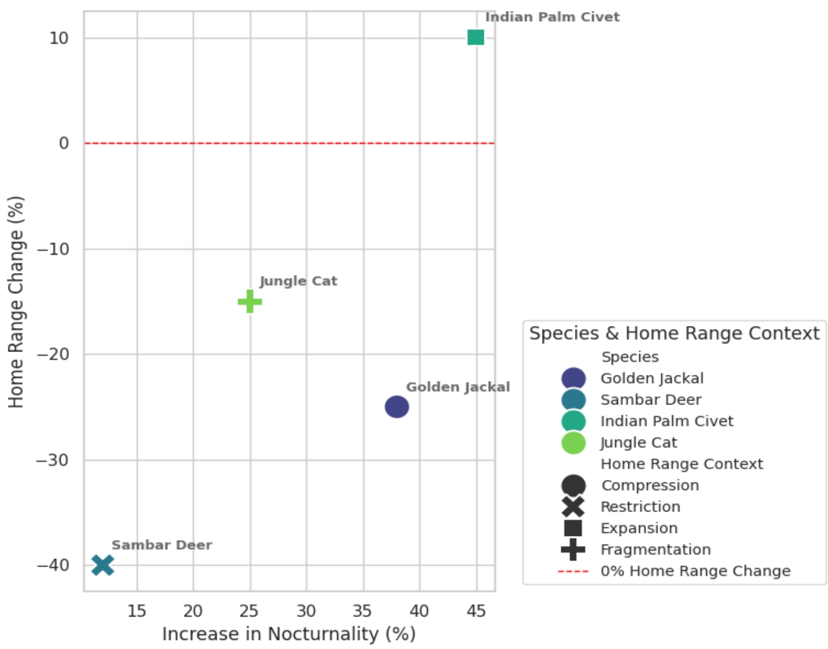

Figure 3: Nocturnality Shift vs. Home Range Change

Figure 3 shows that an animal's increased time spent awake during nighttime hours has affected how big its "home range", or area where it lives, becomes when moving from the countryside to the city Centre. Golden Jackals experience a 25% decrease in the size of their home range due to becoming nocturnal, whereas the Indian Palm Civet experiences a 10% increase in home range size due to being an arboreal (tree-dwelling) creature. On the other hand, the Sambar Deer was the least able to adapt to the changes created by urbanization. Sambar Deer had minimal change (12%) in the amount of time spent being awake during the nighttime hours. They showed the most dramatic (40%) decrease in the size of their home range, which suggests they were unable to tolerate humans and are highly sensitive to disturbance caused by humans. Jungle Cats were the only animal category between Generalist and Specialist behavior. They showed a 25% increase in the amount of time spent awake during nighttime hours and a 15% decrease in Home Range Size. The black dashed line represents the average home range size of mammals that increased in size as a result of urbanization, while the red dashed line represents mammals that decreased in size as a result of urbanization, illustrating how mammals adjust their NOCTURNAL/LIDAR behaviors to manage increasing urbanization pressure.

Discussion

One of the most interesting results of the research is that many different types of mammals are becoming nocturnal because of urban development. Many people think that becoming nocturnal is one way that animals are trying to avoid human interactions and the disruption that comes with it, such as walking their dogs, construction noise, and the presence of cars. By moving the times that they typically feed to the middle of the night, when there are no humans out and about, animals have less contact with humans, which in turn leads to fewer human-animal interactions. This behavior is not without its disadvantages, as moving from day to night to avoid contact with humans can decrease an animal's ability to locate food, communicate successfully with other individuals, and, because nocturnal predators can hunt them as well, provide a potential ecological trap. The relationships found with ALAN demonstrate how both behavior and physiology can be disrupted by urban light pollution and how animals using light are often restricted to their native habitats until the lights are turned down.

The compression and Fragmentation of urban and peri-urban home ranges are governed mainly by two opposing dynamics acting as the forces that influence them: resource concentrations and the perceived risks posed by barriers. A resource concentration (e.g., a steady landfill or a crop growing area that attracts wildlife) results in a high energy return for low energy expended traveling to it, limiting the area needed for the consumption of energy. On the other hand, the autoregulatory barriers of humans (e.g., highways or the sense of pervasive danger) diminish movement ability in both quantity and quality by creating barriers to movement that create a perception of Risk and consume energy. Thus, the concentration of core activity sites within remnant green corridors in urban matrices creates behavioral refugia for wildlife, while the pervasively hazardous nature of urban environments isolates wildlife populations, resulting in localized extinction even if total population size remains constant.

The study of generalist vs. specialist species illustrates how behavioral plasticity facilitates urban persistence. Behavioral plasticity refers to an organism's ability to change how, when, and where it feeds based on environmental cues. Generalists (e.g., jackals, civets) that quickly adapt to changes to food sources (diet) and the timings at which they feed exhibited tolerances well beyond expected levels. Generalists are able to exploit better the resource subsidies afforded by urban environments. The civet is an excellent example of a generalist lifestyle. The expansion of their home ranges likely reflects their ability to navigate urban landscapes using 'off-road' corridors (taking advantage of rooftops or trees), enabling them to access food sources (e.g., fruit from urban gardens) that are spatially dispersed by human activity. In contrast, specialists (e.g. sambar deer) exhibit more rigid behaviors characterized by increased risk aversion (high vigilance, more diurnal than nocturnal behavior), which are dependent on the quality of natural remnants that remain within urbanized areas of their range. Specialist deer are therefore susceptible to habitat loss, and may experience increased likelihood of high-stress encounters when crossing urban areas, which result in potential road mortality or direct conflict with other urban inhabitants.

Human-wildlife conflict is affected by these behavioral adaptations. Animals are not visually encountered during the daytime due to temporal avoidance (nocturnality); however, this behavior does increase the chance of nocturnal crop, livestock, and garbage raiding, leading to punitive actions taken by humans. Additionally, the reliance on anthropogenic food sources in small, compressed home ranges increases the potential for disease (zoonotic or reverse zoonotic) to be transmitted between domestic animals and wildlife. Traditional conservation efforts emphasize protecting significant, contiguous habitats; however, findings from this research indicate that urban conservation efforts need to place more emphasis on providing functional connectivity and quality to existing, fragmented habitats in order to promote behavioral resilience.

Conclusion

Through the utilization of data from camera trap observations, GPS tracking data, and a geospatial analysis, the research has shown that mammal behavioral changes correspond to urbanization, as quantified by a rise in urban intensity. The Nocturnal tendencies observed in Mammals were also noted to be Increased as well as reduced home range size, slower movement rates and an increased reaction to stress when located in Urban or Peri-urban environments compared to Non-Urban/Non-Peri-Urban areas. The above-mentioned behaviors are most likely an adaptation by the mammal to avoid contact with humans, human-associated animals and vehicles through the use of Artificial Light, Noise Pollution, Road Systems and Fragmentation of Habitats.

Species that are generalists have exhibited a great deal of behavioral flexibility and were able to exploit anthropogenic resources and persist in the heavily modified environment. On the other hand, Specialist Species tend to exhibit much less movement, increased stress behaviors and limitations in adapting to their environment, suggesting that they are significantly more prone to the ongoing encroachment of urban sprawl with less likelihood of adapting successfully. The spatial models indicate that road density, amount of built-up cover, and light pollution from developed areas is the most significant predictor of change in behavior for these species and suggests that the urban environments provide for significant impacts to wildlife ecology at all levels of their existing natural habitats.

Overall, the evidence suggests that when developing urban plans and conserving natural areas it is essential to consider Behavioral Indicators as part of them. In addition to providing opportunities for increased biodiversity through measures such as Creating Wildlife Corridors, Creating Dark Ecological Spaces, Creating Opportunities to improve Waste Management and Expanding Green-Blue Infrastructure, these Measures can help alleviate adverse effects caused by increasing levels of urbanization while enabling the Opportunity for coexistence of both people and wildlife. Further, by using behavioral Adaptation to Gain Understanding, it is possible to proactively identify species at Risk before they become severely affected by Population Decline. Taken together, the findings Support the need for Cities to include Ecological Considerations in the Development of Strategies and Supports the growing Movement to Design Urban Landscapes that Serve both People and Wildlife and to recognize that urbanization can Have Positive Impacts on Ecological Systems while also supporting human Health and Well-Being.

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