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Original Research Paper

Functional Connectivity Assessment of Urban Green Spaces for Wildlife Movement

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Key Words

Functional connectivity, Urban green space, Wildlife movement, GIS and remote sensing, Landscape fragmentation, Ecological corridor, Urban biodiversity Conservation.

Abstract

Urbanization has dramatically changed the natural habitats, causing fragmentation and loss of biodiversity in urban areas. The paper assesses the functional connectivity in urban green spaces to determine how they help with the movement of wildlife in the city of Chennai, India. The selection of the six representative green spaces was based on size, ecological nature, and space location, such as the Guindy National Park, Pallikaranai Marshland, and Semmozhi Poonga. Data on the land use, vegetation density (NDVI: 0.20.7), presence of wildlife, and anthropogenic disturbances were collected through a multi-method combination comprising Geographic Information System (GIS), remote sensing, and field-based ecological surveys. The Least-Cost Path Analysis, Graph Theory, and Circuit Theory models were used to measure connectivity to determine movement corridors, ecological hubs, and permeability of the landscape. The findings showed that the larger green land areas, such as Pallikaranai Marshland (connectivity index: 0.88) and Guindy National Park (0.84), had strong connectivity, whereas smaller areas, such as Semmozhi Poonga (connectivity index: 0.49), had weak connectivity because of high urban resistance. The statistical results showed that vegetation density ($r = 0.72$, $p < 0.001$) and patch size ($r = 0.65$, $p < 0.01$) had a positive impact on connectivity, whereas road density and human disturbances negatively affected wildlife movement. The findings have indicated the role of habitat quality and spatial organizational structure in maintaining ecological networks. The research arrives at the conclusion that conservation of biodiversity requires improvement in connectivity by means of ecological corridors, higher vegetation cover, and fewer urban barriers. The suggested framework will contribute to the development of evidence-based urban planning models that will result in resilient and wildlife-friendly cities.

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Introduction

With urbanization, natural landscapes are quickly being converted to build environments, and hence habitat fragmentation and reduction of biodiversity are high (Hugh, 2024). Urban green areas like parks, gardens, wetlands, and urban forests are significant in this dynamic environment to ensure ecological balance (Bolliger & Silbernagel, 2020). The green spaces serve to provide refuge to wildlife and also play the role of stepping stones, facilitating the movement of species across fragmented environments in the urban areas (Xun et al., 2014). With the ever-growing urban areas, the ecological value of the green areas is becoming very vital in ensuring the sustenance of species, ecosystem services, and the sustainability of the environment (Lv et al., 2019).

The capacity of a landscape to support or inhibit the movement of wildlife among the patches of habitat is known as functional connectivity (Guo et al., 2018). Functional connectivity is in contrast to structural connectivity, which only addresses the physical structure of habitats, but not the behaviour of species or preferences of habitats, or movement. This method is more realistic in explaining the interaction of wildlife with urban landscapes (Zhou et al., 2023). It is necessary in the study of dispersal of wildlife, gene flow, and long-term stability of the population. When studying functional connectivity, researchers are able to locate ecological corridors, identify barriers in roads and developed areas, and identify important habitats that may be needed to support biodiversity.

Even though it is an essential issue, there has been a research gap in the knowledge on how various urban landscape elements contribute to the movement of wildlife, especially in fast-developing areas (Jamil et al., 2024). There are several existing studies with most emphasis on structural connectivity measures, but only a small number of studies that deal with species-specific movement responses and behavioural adaptations to urban environments. This is one of the limitations that limits the success of conservation planning in urban areas (Braaker et al., 2014). This article is relevant because it will have a holistic evaluation of functional connectedness in urban green space and its contribution to wildlife movement (Aleixo et al., 2024). The results are some of the evidence-based urban planning measures to improve the ecological networks, minimize habitat fragmentation, and support sustainable urban development without losing biodiversity (Zhang et al., 2019).

Key Contribution

- The current study presents a full-scale evaluation of green spaces in Chennai in terms of functional connectivity using a combination of GIS, remote sensing, and ecological data collected in the field.
- It uses an integrated framework of modelling through least-cost path, graph theory, and circuit theory to determine ecological corridors, movement pathways, and important habitat centers.

- The paper learns the major forces behind the movement of wildlife, with vegetation density and patch size being good forces, and urban disturbances as deterring forces, providing useful information on conservation and planning of urban biodiversity.

The paper is organized in the following way: Section I covers the concept of functional connectivity and its significance in the conservation of urban biodiversity. Section II is a literature review of relevant connectivity modelling methods and issues that affect wildlife movement. Section III provides the methodology, which involves the selection of the study area, data collection techniques, tools of connectivity assessment, and statistical analysis. Section IV reflects the findings in the connectivity index, statistical results, and comparative results amongst the urban green spaces. Section V also addresses the consequences of the results, gives recommendations on how the connectivity can be improved, and outlines future research directions. The last and final section VI of the study is the conclusion, where the main findings are summarized, and their implications for sustainable urban development and wildlife conservation are given.

Literature Review

The most common analytical tools that have been used previously to study functional connectivity in urban landscapes include graph theory, circuit theory, and the least-cost path analysis to simulate the movement patterns of wildlife (Bourgeois et al., 2024). The techniques are useful when defining ecological corridors, stepping stones, and barriers in fragmented urban habitats (Tannier et al., 2016). Graph theory is concerned with network geometry and connectivity of nodes, whereas circuit theory computes many possible movement paths over landscapes. Least-cost path analysis, however, is an analysis that recalculates the best routes based on the resistance value it has attached to various types of land-use types. The results of the research have shown that connectivity is species-specific, and small mammals, birds, and insects are sensitive and have varied movement behaviours to the environmental conditions in cities (LaPoint et al., 2015).

There are various other factors that have a major impact on the movement of wildlife in urban ecosystems (Liu et al., 2022). Quality of habitat is one of the most critical factors since more species are found in areas with high vegetation cover and the availability of resources. Patch size is also important, and larger green patches will tend to facilitate more biodiversity and movement. The distance separating the patches of habitats influences the ease of movement, with the closer patches facilitating connectivity. On the other hand, the low speed of the road network and dense built-in infrastructure impede movement. There are also human-made disturbances such as noise, pollution, and recreation, which further influence the behaviour of wildlife (Saidova et al., 2024). Also, artificial lighting has been cited as one of the major causes that interfere with the nocturnal species and distort the natural movement patterns.

The functional connectivity is key to the healthy population of the wildlife and a sustainable ecological state in the long term (Kiran et al., 2025; Khyade & Jagtap, 2019). The exchange of genes between populations is made possible by connectivity, hence minimizing the chances of inbreeding and genetic isolation. It also increases the resilience of species to environmental change, including climate variation and habitat loss. Urban ecosystems have ecosystems that are well-linked green spaces that provide essential ecosystem services such as pollination, pest control, and stabilization of microclimates (Gelmi-Candusso et al., 2025). Though these are known to be the advantages, the ecological connectivity is not fully taken into account in the urban planning practice, which is more concerned with the development of the infrastructure rather than the environment (Gelmi-Candusso et al., 2025). Such oversights result in more habitat fragmentation, loss of biodiversity, and ecological networks, which underscores the urgency of considering the connectivity-based strategies in sustainable urban planning (Lynch, 2019).

On the whole, it is evident in the literature that functional connectivity is a very significant consideration for the movement of wildlife and biodiversity in urban environments. Although more sophisticated methods of modelling, including graph theory and circuit theory, have enhanced the knowledge base, wildlife movement is very specific to species-response as well as landscape features. The quality of the habitat, patch size, and human disturbances are some of the important conditions that influence connectivity patterns. Nevertheless, the fact that these insights are not thoroughly implemented in urban planning points to a loophole, underscoring the fact that connectivity-oriented planning should be used to facilitate sustainable urban conservation of biodiversity.

Methodology

This study's research methodology has a systematic approach used in evaluating functional connectivity in urban green spaces used by wildlife. It entails the sampling of the representative study sites, and the spatial, ecological, and wildlife data are collected through field surveys, remote sensing, and GIS tools (Suresh Kumar & Rajan, 2026). The most important landscape characteristics, like vegetation, land use, and human disturbances, are studied in order to understand the condition of the habitats. The methods of connectivity assessment are then used to test the movement pathways and ecological connections among the habitat patches. Lastly, statistical analysis is done to determine the important factors that determine the movement of wildlife. This general strategy provides a holistic assessment of the urban landscapes to promote or limit wildlife connectivity.

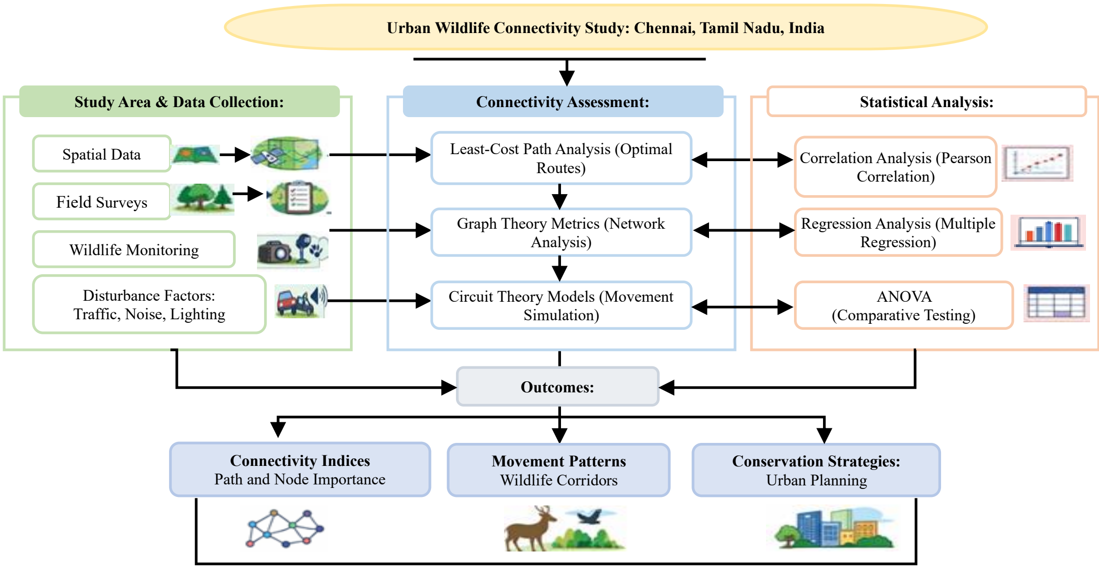

Figure 1: Architecture Diagram for Functional Connectivity Assessment in Urban Green Spaces

Figure 1 presents the general outline of the work, which combines the selection of the study area, multi-source data collection (the spatial, ecological, and disturbance data), methods of connectivity assessment (least-cost path, graph theory, and circuit theory), and the statistical analysis. It emphasizes the interaction of these components to assess the movement patterns of wildlife and generate indices of connectivity, movement pathways, and conservation strategies to enhance urban ecological networks.

Study Area Selection

The work was carried out in the urbanizing, fast-growing metropolitan area of Chennai, where green spaces were different, and the habitat fragmentation grew. Six sample areas were chosen in terms of size, spatial distribution, and ecological features such as Guindy National Park (2.70 km^2), Adyar Eco Park (0.58 km^2), Theosophical Society Gardens (1.08 km^2), Semmozhi Poonga (0.08 km^2), Nanmangalam Reserve Forest (3.20 km^2), and Pallikaranai Marshland (6.00 km^2). These locations are core, buffer, and isolated habitats, which allow connecting them on multiple scales. Spatial analysis was conducted in the 10 km buffer, and the inter-patch distances were in the range of 1.5 km to 12 km. The functionality of the analysis was developed by a value of the resistance of land-use categories (1 through 10) applied on the GIS-based least-cost modelling scales. There was also an NDVI value (0.21) applied in the measurement of the vegetation density to give solid analysis on the movement of wildlife.

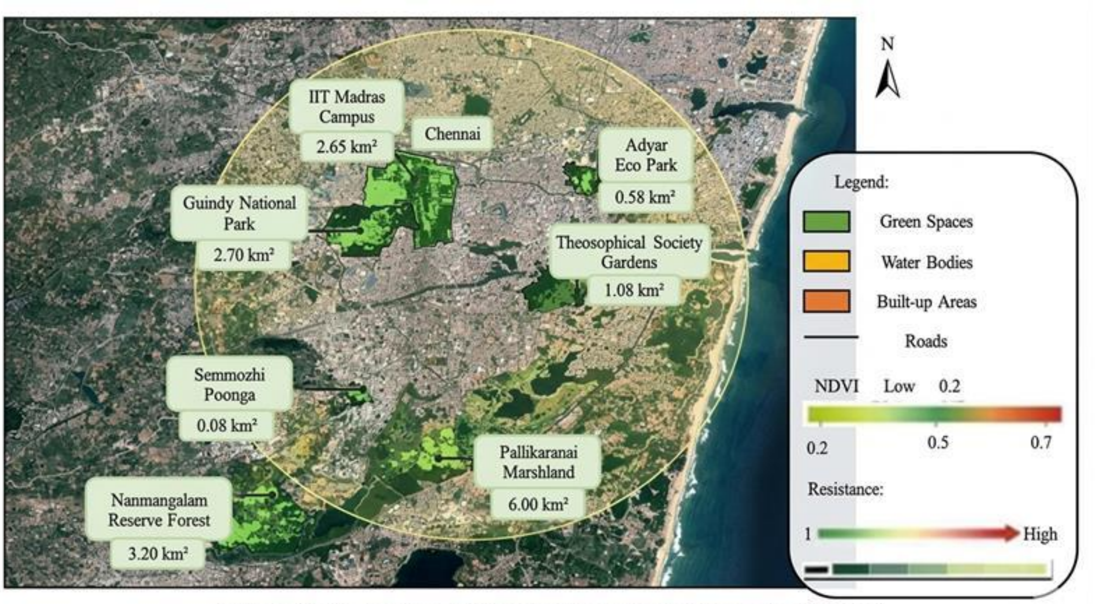

Figure 2: Study Area Map of Urban Green Spaces in Chennai

Figure 2: Study Area Map of Urban Green Spaces in Chennai

Figure 2 shows the spatial distribution of Guindy National Park, Pallikaranai Marshland, Nanmangalam Reserve Forest, Theosophical Society Gardens, Adyar Eco Park, and Semmozhi Poonga, some of the urban green spaces selected in Chennai. A 10 km buffer zone is indicated in the map to make connectivity analysis and shows the land-use characteristics surrounding the area, including built-up areas, road networks, and water bodies. The NDVI values have been used to express vegetation density, which is used to represent the quality of habitats in various regions. The figure substantiates the definition of ecological corridors, landscape resistance, and patterns of connectivity that are crucial in the evaluation of the movement of wildlife in urban systems.

Data Collection

The data collection in the determination of functional connectivity consisted of integrated field-based observations, spatial datasets, and remote sensing data to record the features of the habitat and possible movement of the wildlife. The GIS databases and satellite images were used to obtain spatial data concerning the green space boundaries, land-use classes, road networks, water bodies, and built-up areas to create landscape maps and resistance surfaces. Field surveys, NDVI values were used to evaluate the quality of vegetation and habitat, and sampling plots were used to note the canopy cover, shrub density, ground vegetation, and degree of disturbance. Camera traps, transect walks, face-to-face observations, and indirect indications like footprints and nests were used to study the occurrence of wildlife over 30-60 days to achieve a richness and pattern of activity in the species studied. Moreover, the intensity of traffic, the level of noise pollution, the movement of pedestrians, and artificial illumination, which are anthropogenic factors, were also measured. All the data were geo-referenced and combined into a GIS platform to allow examining the spatial and statistical patterns of wildlife movement and connectivity.

Connectivity Assessment Techniques

The functional connectivity was evaluated by merging the gathered spatial, ecological, and disturbance information into a GIS-based model of the urban green spaces of the chosen urban area, Chennai. According to the choice of the study area, the six sites were mapped as the habitat nodes, and the surrounding landscapes within a 10km buffer were classified with the help of the land-use data, NDVI (0.2-0.7), and field observations. This was done by creating a landscape resistance surface, assigning values to each type of land-use, namely: natural vegetation (1-2), semi-urban (3-5), and built-up areas, roads, and high human activity areas (6-10). The values were further refined using vegetation density, habitat quality data, and anthropogenic disturbance data to refine the values in the field.

The resistance layer was used to conduct the Least-Cost Path Analysis to determine the optimal movement paths between green spaces with respect to resistance and inter-patch distance (1.5km to 12 km). That was followed by Graph Theory Metrics, in which each green space would be presented as a node and movement paths would be presented as edges, hence the calculation of different connectivity indices and the identification of ecological hubs, including large and central patches. Also, the Circuit Theory Models were employed to simulate the various possible paths and test the total landscape permeability as alternative paths other than the single optimal paths.

Statistical Analysis

The statistical analysis has been conducted to compare the dependence of landscape features and wildlife movement in the green areas of choice within the city of Chennai. The variables, which were summarized using descriptive statistics, were patch size, NDVI, frequency of species, and levels of disturbance. Pearson correlation testing was conducted to test associations between the connection indices and the variables such as vegetation density, distance, and road density. Various linear regressions were used in determining the significant predictors of the functional connectivity, and ANOVA was used to compare the level of connectivity across various places. The level of statistical significance was deemed to be p below 0.05 and was analyzed in R/ SPSS so that the findings can be characterized accurately.

Results

Findings of Functional Connectivity Assessment in Urban Green Spaces

The functional connectivity analysis indicated that there was a great diversity in the chosen urban green spaces in Chennai. Greater and central positions of habitats like the Guindy National Park and Pallikaranai Marshland were more connected (as they had greater cover) and had lower values of resistance. On the contrary, smaller and remote green areas like Semmozhi Poonga had low connectivity because of high surrounding urban resistance and low habitat area. The analysis of Least-Cost Paths revealed the most suitable paths of movement, mostly on the banks of rivers, vegetated strips, and low traffic areas. A further observation, based on the model of circuit theory, revealed that there were various alternative routes in well-connected areas; on the other hand, fragmented areas exhibited limited movement flow. The findings of the graph theory showed that some of the green spaces were the crucial ecological centers of the urban network.

Table 1: Functional Connectivity Assessment Results Across Urban Green Spaces

Green Space	**Connectivity Index**	**Least-Cost Path Strength**	**Circuit Flow Value**	**Node Importance**	**Connectivity Level**
Guindy National Park	0.84	0.80	0.78	High	Strong
Pallikaranai Marshland	0.88	0.85	0.82	Very High	Very Strong
Nanmangalam Forest	0.76	0.72	0.70	High	Moderate
Theosophical Society	0.71	0.68	0.65	Medium	Moderate
Adyar Eco Park	0.66	0.62	0.60	Medium	Moderate
Semmozhi Poonga	0.49	0.45	0.42	Low	Weak

Table 1 indicates that the ecologically rich green spaces are larger and serve as the main ecological centers of movement, especially of wildlife. Minor and remote patches, on the contrary, have low connectivity since urban resistance is greater. The findings emphasize the significance of patch area, levels of vegetation quality, and the spatial positioning in favor of successful wildlife movement.

Key Factor Identification of Wildlife Movement

The statistical analysis showed vegetation density, patch size, and anthropogenic disturbance as the strongest factors to determine the movement of wildlife. There was a high positive relationship between NDVI values and connectivity ($r = 0.72$), which shows that places with thick vegetation cover promote movement. Patch size also exhibited a positive relationship ($\beta = 0.65$, $p = 0.01$), and road density, together with human disturbance, displayed a negative association ($r = -0.68$ and -0.59, respectively). Regression analysis proved vegetation density and patch size to be the best predictors of functional connectivity, and built-up areas and traffic intensity are significant in limiting movement. These results emphasize the role of keeping the green cover going and diminishing urbanization.

Table 2: Statistical Influence of Landscape Factors on Functional Connectivity

Factor	Correlation (r)	Regression Coefficient (β)	p-value
Vegetation Density (NDVI)	0.72	0.68	<0.001
Patch Size	0.65	0.65	<0.01
Distance Between Patches	-0.52	-0.48	<0.05
Road Density	-0.68	-0.60	<0.01
Human Disturbance	-0.59	-0.55	<0.05

Table 2 shows the statistical impact of the landscape factors that are important on functional connectivity. The findings show that the density of vegetation and patch size have a strong positive influence on the movement of wildlife, whereas the density of roads, inter-patch distance, and human disturbance affect the connectivity negatively. These results bring to the fore the importance of the quality of the habitat and urban pressures on influencing wildlife movement patterns.

Comparative Analysis of the Connections of the Various Green Spaces

The level of connectivity comparing various urban green spaces shows that there is a great difference in terms of size, concentration of vegetation, and other urban conditions. The bigger green areas like Pallikaranai Marshland and Guindy National Park are more connected because of the high vegetation cover and reduced resistance that will allow free movement of wildlife. The Nanmangalam Forest and Theosophical Society Gardens are moderately sized zones with moderate connectivity, which is affiliated with partial fragmentation and disturbances around these zones. On the other hand, low connectivity is exhibited in smaller and isolated spaces like Semmozhi Poonga because the urban barriers are high, and the habitat is scarce. These disparities accentuate the need to have extensive green areas that are well-connected to allow the movement of wildlife.

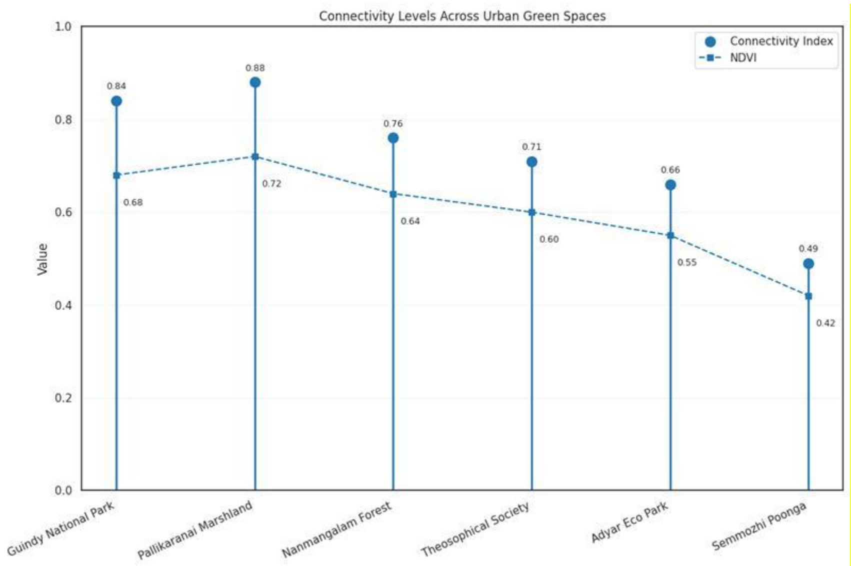

Figure 3: Connectivity Levels and Vegetation Density Across Urban Green Spaces

Figure 3 displays a lollipop chart of the values of start and NDVI of the selected city green spaces with respect to their connectivity index. The findings indicate that more dense vegetated areas depict stronger connectivity with Pallikaranai Marshland and Guindy National Park being the main ecological hot spots, and Semmozhi Poonga possessing the minimal connectivity in terms of urban limitation.

Discussion

The results of the present study show the importance of functional connectivity in facilitating the movement of wildlife in urban environments. The findings prove that larger areas of green space and higher vegetation density, i.e., the areas detected in Chennai, are important ecological centers that assist in the dispersal of species and access to habitats. Smaller and isolated patches, on the other hand, have limited connectivity as a result of greater resistance to urban environments and anthropogenic disturbances. These results highlight that conservation of urban biodiversity cannot be dependent on the availability of green spaces only, but on their connectivity and spatial distribution as well. Genetic exchange, habitat isolation, and ecosystem resilience in the fast-urbanizing world can be enhanced through enhanced functional connectivity.

Depending on the findings, it is possible to suggest a number of practical recommendations that can help to enhance connectivity in urban green areas. To connect the disconnected habitats, urban planners need to focus on ecological corridors in the form of green belts, roadside plantations, and riparian buffers. Safe movement across urban boundaries can also be enhanced through reducing landscape resistance by adopting infrastructure that is wildlife-friendly, which incorporates underpasses and green bridges. Habitat quality can also be improved by increasing vegetation cover through afforestation and urban greening projects. Also, it is important to regulate human disturbances like traffic, noise, and artificial light to reduce negative effects on wildlife movement.

Future studies ought to be aimed at the addition of species-specific movement information so that behavioural reactions to urban settings can be understood better. The connectivity modelling can be made more accurate with the help of the use of advanced technologies, including GPS tracking, remote sensing, and machine learning. The temporal changes in the connectivity and the efficacy of the applied conservation strategies are to be evaluated by long-term monitoring studies. Moreover, a more comprehensive perspective on urban wildlife conservation and sustainable urban planning can be offered by incorporating social-ecological variables and the involvement of people.

Conclusion

The paper offers an in-depth analysis of the topic of functional connectivity in urban green areas focusing on the impact of spatial structure, vegetation cover, and landscape resistance on animal movement in general. This is also evident in the results that bigger green spaces with an ecologically rich environment will be more connected and act as vital movement corridors whereas smaller green spaces are filled with multiple fragments or destroyed by urban barriers and, therefore, have less ecological flow. The statistical analysis was also used to establish that NDVI and patch size are some factors that have a positive influence on the connectivity, but road density and human disturbance have a negative influence on the movement patterns. These results support the need to embrace the idea of combining space and ecological aspects when planning urban areas to retain biodiversity. The research provides a very strong framework of evaluating and enhancing ecological connections in urbanized settings through integrating geospatial analysis, connectivity modelling methods, and statistical validation.

Functional connectivity evaluation would be the key to successful conservation of wildlife in the fast-urbanized regions because it would allow defining the ecological gaps and focus areas to be addressed. The urban green spaces are not based on leisure resources but are also essential ecological systems that facilitate the survival of species, reproduction and stabilization of the ecosystems. Enhancement of connectivity with ecological corridors, restoration of habitats and sustainable land-use planning can greatly increase the urban biodiversity. The paper highlights the fact that conservation and a smart management of urban greenlands is important to maintain the ecological balance and facilitate animal migration in urban areas. In sum, this study indicates the importance of evidence-based planning and monitoring in order to make sure that urban development does not proceed contrary to conservation objectives, and that the urban ecosystems can become resilient and wildlife-supportive.

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