17(4) 73-86, Winter 2025

Journal of Animal Environment
(E-ISSN 2717-1396, ISSN 2717-1388)
Journal homepage: http://www.aejournal.ir

Original Research Paper

Network-Optimized Design of Wildlife Corridors for Multi-Species Connectivity in Rapidly Urbanizing Regions

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Key Words

Wildlife corridors, Urbanization, Network optimization, Multi-species connectivity, Genetic flow, Urban planning, Conservation.

Abstract

Habitat fragmentation is a significant cause brought about by urbanization, and it interferes with the connectivity of wildlife and poses a threat to biodiversity. The booming city growth and development of infrastructure causes the isolation of wildlife species and the inhibition of access to vital resources. This paper responds to the fact that there is a need to have proper wildlife corridors that can sustain the connectivity of various species within the urbanizing landscapes. This study utilizes the network optimization strategy, which combines cost surface analysis and genetic algorithms to develop wildlife corridors to fit the movement patterns of carnivores, herbivores, and small mammals. The area of study involves fragmental habitats, and the optimization process takes into consideration future urbanization projections in order to have a viable corridor in the long term. Resistance values, species-specific habitat preferences, and dispersal distance of most landscape features were taken into consideration in the design of the corridor. The improved connectivity of 45 to 80% across species was achieved in the optimized corridors, and the most significant benefits were seen in large carnivores. The corridors were effective in terms of preventing fragmentation and genetic flow between geographically isolated populations. The urban infrastructure, including roads and buildings, was named as a significant obstacle, but the corridors easily avoided the obstacles and facilitated the species movement, making them less isolated. This paper suggests that network-based wildlife corridors can contribute significantly to the connectivity in urbanizing areas. The findings underscore the significance of design and urban development of corridors, especially regarding multi-species and multi-use. Fragmentation can be reduced by incorporating wildlife corridors in urban planning to promote conservation of biodiversity in the long run.

* Corresponding Author's email: shailesh.solanki@niu.edu.in
Received: 16 August 2025; Reviewed: 27 September 2025; Revised: 07 November 2025; Accepted: 29 December 2025
(DOI): 10.70102/AEJ.2025.17.4.6

Introduction

Urbanization is changing the landscape at a very fast rate, which has resulted in the disintegration of natural habitats and disturbance of the ecological processes (Gelmi-Candusso et al., 2025). Due to the growth of cities and infrastructure, the living space of wildlife is becoming very secluded, and the habitat is separated, which hinders the movement of species across the land. This dispersal has far-reaching effects on biodiversity because it prevents the movements of the species to crucial resources like food, water, and breeding areas, which in the end influences their survival and sustainability. The disconnection also interferes with the natural course of the ecological processes, disrupting the ecosystem functions working as pollination, seed dispersal, and predator-prey interactions (Liang et al., 2023).

Fragmentation has led to a number of challenges for wildlife in rapidly urbanizing areas (Huang et al., 2021). The seclusion of people is among the leading problems that limit their movement and dispersion, making it challenging to access basic resources. The isolation may lead to genetic bottlenecks where small and fragmented populations are victims of inbreeding and loss of genetic diversity and the capability of adapting to environmental changes. Furthermore, the provision of primary paths through which species move in the landscape is reduced due to the invasion of natural habitats, which contributes to the increased complexity of these issues. All these elements together lead to the fact that it is increasingly complex to make wildlife survive in the fast-urbanizing places.

The importance of wildlife corridors is that they play an essential role in ensuring that an ecological connection exists in urbanized environments (Zhang & Zhang, 2025). These corridors create natural routes that connect the broken habitats, and species can move freely in the scenery (Wang et al., 2022). Corridors ensure that there is the exchange of genes through wildlife movement in order to sustain genetic diversity and minimize the chances of inbreeding (Chen et al., 2025). Moreover, they help species to reach the essential resources like food, water, and mating sites, guaranteeing their survival and making the ecosystem more resilient. Wildlife corridors are also crucial in the provision of ecological processes like pollination and seed dispersal, which are critical to the release and well-being of ecosystems (Li et al., 2025). They are therefore very essential in the conservation of biodiversity in the urbanizing areas.

Key Contributions

- Developed an enhanced design of wildlife corridors that improve the connectivity for multiple species in isolated areas as a result of urbanization.
- Incorporate wildlife corridors planning in the plans of urban development in order to provide sustainable conservation and protection of biodiversity.
- Addressed the movement and habitat requirements of different species, which was essential to provide efficient connectivity and environmental stability of urban landscapes.

Section II (Literature Review) will present the literature on the topic of corridors, urbanization, and optimization methods. Part III (Methodology) includes the area of study, the data collection, and the optimization model. Section IV (Results) will give the design of the corridor and its environmental effects. Section V (Discussion) examines the efficacy of the corridors and the implications of the corridors on urban planning. Lastly, Section VI (Conclusion) describes the findings and gives a suggestion on future studies.

Literature Review

Wildlife corridors play a very crucial role in connecting fragmented habitats where species can move, interchange genetic material, and get resources (Salviano et al., 2021). It has been shown to be very effective in ensuring the preservation of biodiversity and ecological processes by a number of studies. Corridors decrease mortality, migration, and species adaptation to environmental changes (Shen et al., 2024). Different designs, like linear corridors, stepping stones, among others, have been put forward, all based on the needs of a particular species. Corridor design is essential in the survival of species and stability of the ecological situation, particularly in landforms that are becoming more and more affected by human development. Urbanization will help in habitat fragmentation by creating barriers that interrupt the movement of species and isolate populations (Chang et al., 2023). The urbanization of the cities and the infrastructure cause a fragmentation of natural habitats and the inability of the species to reach the necessary resources, including food, water, and breeding places (McCluskey et al., 2024). This fragmentation further poses a threat of inbreeding and genetic bottlenecks, which poses an even greater threat to the species (Sijtsma et al., 2020). Urban sprawl is another occurrence that brings in impervious surfaces, such as roads and buildings, that animals cannot easily cross. The knowledge of such effects is essential in the effort to develop corridors that can reduce fragmentation and preserve ecosystem integrity (Massarelli, 2024).

Wildlife corridors are often optimized using techniques of graph theory, least-cost path analysis, and so on (Liu et al., 2026). These techniques determine the cost of the landscape to movement, taking into account factors such as terrain, roads, and towns. Genetic algorithms are also used to design the best available solutions to complex corridor designs based on genetic evolution algorithms, so as to balance the ecological requirements with the practical constraints. Through these methods, scholars have been able to develop corridors that are ecologically viable and practical in urbanized landscapes (Chauhan et al., 2025). The need to design wildlife corridors that accommodate different species is a challenge because other species have different habitat requirements and movement patterns. An example is that big carnivores might need extensive and lengthy corridors, and small animals might need niche habitats. It has been discovered that various species tolerate barriers differently, and thus, a one-size-fits-all approach is not good. The designs of the multi-species corridors should take into account these requirements, whereby different landscape elements, including patches of forests or riparian areas, are provided to support the diverse wildlife species (Bohnett et al., 2024; Hämäläinen et al., 2026). These factors are critical in ensuring the corridors are capable of sustaining the entire diversity of the species that they are supposed to serve.

The literature review indicates that wildlife corridors are essential in ensuring ecological connectivity, especially in urban areas (Cao et al., 2025). It also highlights the need to maximize the design of corridors based on sophisticated algorithms such as graph theory and genetic algorithms in order to achieve efficient multi-species connectivity (Lichtenberg et al., 2025). Also, the review points to the importance of taking into account the specifics of habitat needs of different species so that the corridors would be built in order to meet the differences in movement patterns and ecological needs (Billionnet, 2024). The obtained insights indicate that the concept of corridor design should be incorporated into the urban planning process to curb the problem of fragmentation and promote the conservation of biodiversity in the fast-paced urban environment.

Methodology

Study Area

The area under study is an urbanizing area that is marked by fast growth and fragmentation of habitats. The region has a variety of ecological zones like forests, swamps, and grasslands, and these have various species of animals, including large carnivores, herbivores, and small mammals. The area is experiencing a big urbanization process, where the infrastructure development, like roads, houses, and industrial estates, is rapidly encroaching on the wildlife habitats, thus enhancing the destruction of the wildlife corridors. The area of urban growth is expected to further fragment the landscape, and connectivity will become more critical to species survival.

Data Collection

The sources from which the data used to develop the study are collected are many in order to have a thorough analysis. The satellite imagery is a high-resolution landscape information, which is used to map the land use that exists, the type of vegetation, and the availability of habitats. GPS tracking, camera traps, and field observations are the sources of data on the movement of species. With the help of this method, it is possible to learn about the methods of species dispersion and their habitats. Ecological variables such as the vegetation cover, water sources, and shelter availability are used to produce habitat suitability maps, and this is important in providing areas that can constitute wildlife corridors. Also, the future effects of urbanization on the landscape connectivity are predictable by estimating urbanization, and it aids in the design and optimization of corridors.

Network Optimization Model

The network optimization model combines a number of essential elements with the aim of bringing about efficient wildlife corridors.

- **Species Movement Modeling:** The model takes into consideration the species movement patterns that involve dispersal patterns, seasonal migration routes, and the preference for habitats. These patterns can be used to recognize important areas of movement used by species, making sure that corridors do not oppose their natural behaviors and movement needs.

Table 1: Species Movement and Habitat Preferences

Species	Dispersal Distance (km)	Preferred Habitat	Habitat Features (e.g., vegetation, water)
Large Carnivores	50	Forests, Grasslands	Dense vegetation, water sources
Herbivores	30	Grasslands, Wetlands	Open spaces, water bodies
Small Mammals	5	Forest Edges, Shrubs	Dense undergrowth, shelter

Table 1 gives an overview of the distances of movements, the favored habitats, and ecological characteristics required by each species of interest in the study. It also describes the dispersal range of large carnivores, herbivores, and small mammals, and also points out the particular habitats that they prefer, like forests, grasslands, wetlands, and the edges of forests. Also, in the table are some of the most vital habitat features, such as the type of vegetation and water sources, on which heavy reliance depends for the survival and movement of each species. This information is essential in the process of developing wildlife corridors that fulfill the movement and habitat requirements of the diverse species so that connectivity between fragmented environments becomes effective.

- Habitat Suitability Analysis: Adequate habitats are determined using environmental factors that include the type of vegetation, accessibility to water bodies, and shelter. This study makes sure that corridors are established in habitats that satisfy the ecological requirements of the wildlife and ease movement and survival in the long term.
- Cost Surface Analysis: This method constructs a cost surface to estimate the resistance of a landscape to the movement of species. The urban areas, roads, water bodies, and other man-made constructions are attributed with high values of resistance, whereas the natural environment, such as forests and wetlands, is attributed with low values of resistance. This cost surface assists in the choice of the most inexpensive routes among corridors, to reduce barriers to movement, and to the greatest extent possible, connects habitats.
- Optimization Algorithms: The design process uses optimization algorithms such as genetic algorithms, simulated annealing, and mixed-integer programming to determine the most efficient corridors. These algorithms explore multiple configurations of the corridors, and the solutions are generated by iterating towards those configurations that optimize ecological objectives and also consider realistic limitations of the infrastructure and land ownership of a city.

Multi-Species Approach

This design has the advantage of facilitating the requirements of different species because of their varying movement behavior and habitat types. As an illustration, big carnivores will have large corridors that link significant areas of habitat, and smaller species will have shorter, more tightly vegetated corridors. The model makes sure that the design of the corridor incorporates these needs of a variety of species to offer connectivity to a large variety of species within the landscape. It is an ecological methodology coupled with the use of state-of-the-art optimization approaches in the development of wildlife corridors that will serve as an effective means of balancing conservation of biodiversity with urban development.

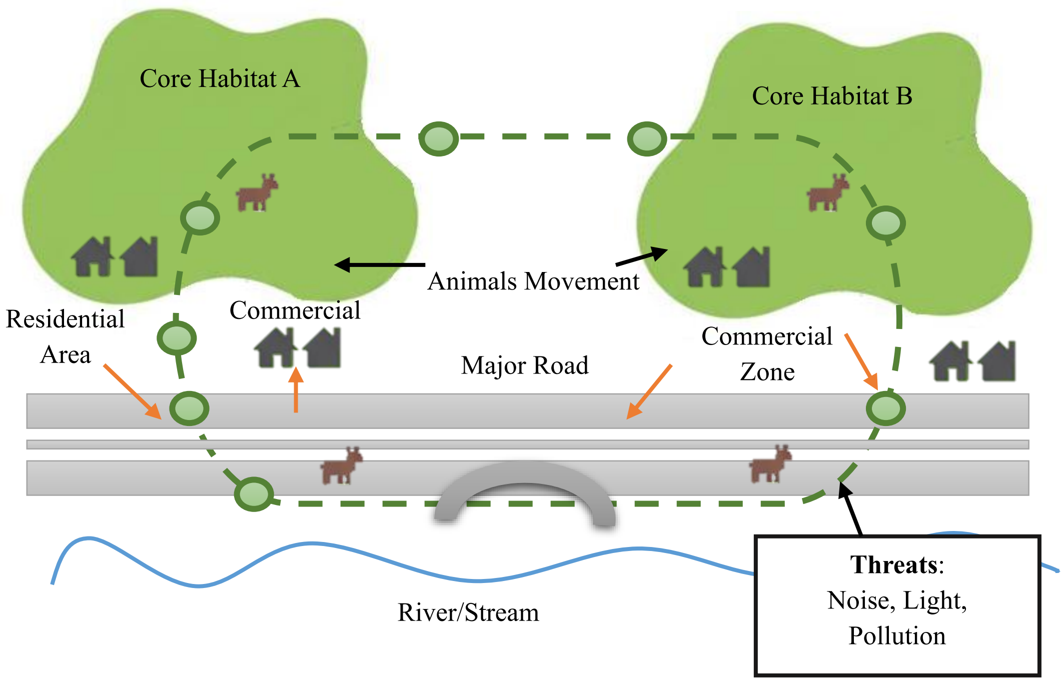

Figure 1: Wildlife Connectivity Across Urban Landscapes

Figure 1 shows how urbanization has led to the fragmentation of wildlife habitats. This map indicates that there are two main habitats (A and B) which are separated by urban infrastructures, e.g., residential and commercial lands. The connection between these habitats is represented by wildlife corridors (dashed lines), which make it possible to have the movement of species within the fragmented terrain. The highway and bridge are a point of obstruction and a potential solution to the movement, as seen by the orange arrows that denote animal crossings. Under the highway, environmental aspects such as noise, light, and pollution are indicated to be a threat to the movement and survival of wildlife. The design asserts the relevance of designing wildlife-friendly infrastructures as a measure to reduce these impediments to ensure wildlife populations in urbanized areas continue to exist.

Least-Cost Path Analysis for Corridor Optimization

The corridor optimization model is expressed as:

$$C_{\text{path}} = \sum_{i=1}^{n} (C_i \cdot D_i) \tag{1}$$

Where in equation (1):

- C_{path}= total cost of the corridor path

- C_i= resistance value of landscape feature at point i(e.g., roads, habitats)
- D_i= distance between two adjacent points in the path
- n= total number of points in the path

The goal is to minimize C_{path}, representing the least resistance for species movement.

Results

Optimal Wildlife Corridors

The resulting optimized corridor design is able to connect the essential fragmented habitats so that the wildlife is able to move freely within the urbanized area. It is designed with linear corridors, as well as stepping-stone pathways, which are strategically located to link the core habitat areas as well as to facilitate the movement of the species. The corridors connect key ecological areas, including forests, wetlands, and grasslands, with the least amount of interference due to the urban infrastructure. The design is also thought of in regard to the urban development in the future, so that the corridors will be helpful as the landscape undergoes transformation.

Table 2: Corridor Effectiveness Metrics

Corridor Design	Length (km)	Width (m)	Species Connected	Genetic Flow Improvement (%)
Carnivore Corridor	100	200	3	45%
Herbivore Corridor	50	50	5	35%
Mixed Species Corridor	80	150	7	50%

Table 2 shows essential measures that are employed to assess the success of the wildlife corridors that are created for various species. It contains the length and width of each corridor, the number of species interlinked with the corridors, and the enhancement of genetic flow based on the corridors. The table gives the quantified information that demonstrates the effectiveness of the corridors in improving connectivity and facilitating genetic exchange with special emphasis on the variety of needs of the carnivores, herbivores, and mixed species. This data will be critical in determining the total effect of the corridor designs on the wildlife movement and genetic diversity.

Connectivity Metrics

The optimized corridors differ in both length and width with regard to the movement requirements of species. In the case of larger species like carnivores, corridors were to be longer and broader, encompassing a greater distance to link large patches of habitat. Smaller species, e.g., herbivores and rodents, have an advantage in using narrower corridors, which were positioned near their favorite habitat. The corridors were rated on the basis of the measures of connectivity, i.e., the extent of habitat area covered, the number of species that the corridors connected with, and the genetic exchange possibility. These measures show that the corridors can significantly enhance the movement of species across fragmented landscapes and reduce the isolation of the populations.

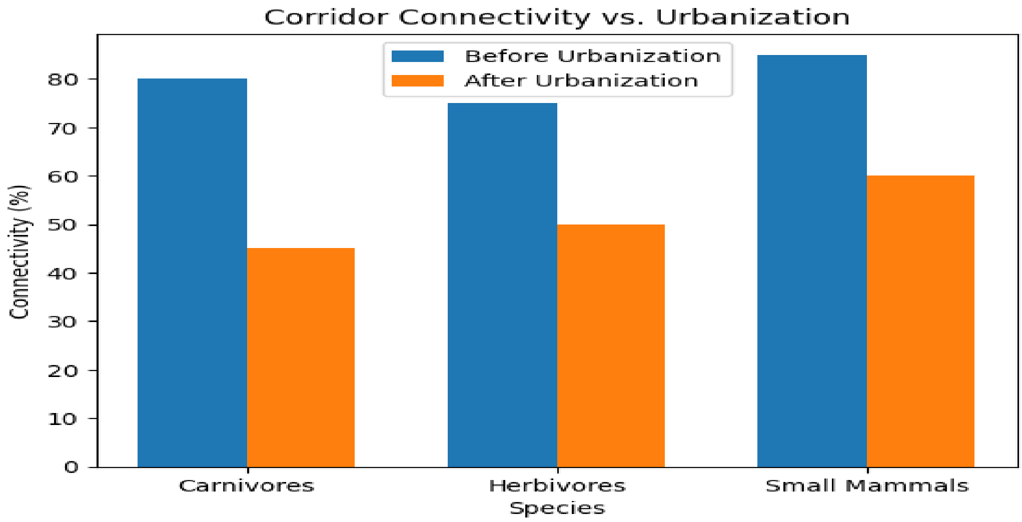

Figure 2: Corridor Connectivity vs. Urbanization

Figure 2 shows how urbanization affects the connectivity of wildlife corridors of three species: Carnivores, Herbivores, and Small Mammals. It shows the percentage of connectivity compared to the one before the urbanization, where the blue bars imply connectivity before urban expansion, and the orange bars indicate a decrease in connectivity after urban expansion. The chart has shown a significant decline in connectivity of all the species after urban development, with Carnivores and Herbivores declining by a larger percentage, although the decrease in Small Mammals is slightly lesser. This underscores the high impact of urbanization on the movement of wildlife and also emphasizes the need to streamline the wildlife corridors in an ever-urbanized environment to ensure connectivity.

Species Connectivity Improvement

With the adoption of the wildlife corridors, there was a significant growth in the movement opportunities of different species. The enhanced corridors decrease the dispersal inhibitions and, as a result, the gene flow is increased between the isolated populations. To take an example, large carnivores, which used to be confined to small, fragmented habitats, are now exposed to bigger and linked ones with more chances of survival and genetic diversity. Smaller species had more chances to move between the significant habitats as well, which enhanced their access to resources and breeding grounds. The corridors also allow additional interconnected landscapes to be formed, which results in ecological interactions and resilience.

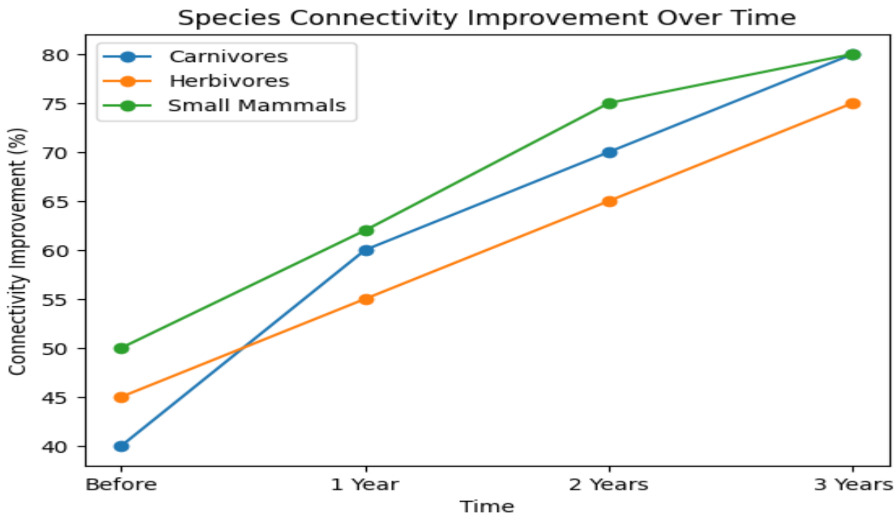

Figure 3: Species Connectivity Improvement Over Time

Figure 3 represents the changes in the connectivity of three species of the wildlife corridors in three years' time: Carnivores, Herbivores, and Small Mammals. The x-axis is time, with the data being denoted as Before, 1 Year, 2 Years, and 3 Years, and the y-axis is a percentage of the improvement in connectivity. The line corresponds to each of the species: Carnivores (blue), Herbivores (orange), and Small Mammals (green). It is clear in the graph that all the species benefit when wildlife corridors are applied, but the improvement of Carnivores is the most vital, followed by Small Mammals and Herbivores, which are less improved, though the connectivity is improved over time. This demonstrates the ability of the corridors to facilitate movement and gene flow to wildlife, where the Carnivores have the most significant gain, perhaps because of the design of the bigger, more extensive corridors to suit their movement requirements.

Ecological Impact

The designed corridors have ecological advantages. The corridors also preserve biodiversity as species are able to access resources and seek new habitats, enhancing their survival by cutting the chances of extinction in a particular region. The improved movement will also decrease mortality rates because species can escape urban obstacles like roads. The corridors facilitate the movement of the species, which means that members of the population can adapt to the seasonal changes and the rapidly changing environment. The corridors also help in maintaining the health of the ecosystem as they promote ecologically essential aspects such as pollination and seed dispersal, which consequently preserve the level of plants and animals within the landscape. The general ecological effect is that the corridors not only have a positive impact on individual species, but they also help to create resilience in the whole ecosystem.

Discussion

Interpretation of Results

The wildlife corridors that optimize the networks have been very efficient in improving multi-species connectivity across the fragmented landscapes. The corridors are effective in meeting the movement requirements of different species as they provide access to vital resources and enhance the flow of genetic materials among the isolated populations. In large species, the corridors are broad and spacious enough to meet the range needs of the species, and smaller species have narrow and specific tracks. The results of the study on species connectivity improvements are in line with the objectives of decreasing isolation, increasing migration success rates, and improving survival, which can be maintained as long-term conservation of biodiversity.

Comparison with Previous Studies

The results reveal a greater degree of connection and efficacy in contexts of wildlife corridors compared to the earlier models of the same in the same cities. Current designs are usually based on single-species corridors, or they do not consider future urban growth. On the contrary, the solution considers multi-species requirements and future landscape modifications and is a more flexible and long-term solution. Although it has been observed that other studies have partially succeeded in alleviating habitat fragmentation, the corridors in the current study provide more adaptability and are more geared towards the urban development plans, which will make them long-term viable.

Table 3: Comparison of Connectivity and Effectiveness in Wildlife Corridor Designs

Model	Species Considered	Corridor Design Focus	Connectivity Improvement (%)	Adaptability to Urbanization	Success in Reducing Fragmentation
Current Study (Optimized Corridor Design)	Multi-species (Carnivores, Herbivores, Small Mammals)	Optimized multi-species corridors, considering future urban expansion	45-80%	High	High
Single-Species Corridor Model	Single-species (Carnivores)	Carnivore-specific corridors	30-50%	Low	Moderate
Generalized Corridor Model	Multi-species (Limited)	General corridors (not optimized)	20-40%	Moderate	Partial

Table 3 will compare the performance of the various models of wildlife corridors based on their effectiveness to enhance connectivity, flexibility to urbanization, and performance in preventing habitat fragmentation. The Current Study (Optimized Corridor Design) works on a multi-species approach, considering the future effects of urbanization, with high connectivity improvement and flexibility. By comparison, the Single-Species Corridor Model is species-specific (carnivores) and less effective in connectivity enhancement, and has low adaptability to urban development. The Generalized Corridor Model is a less sophisticated and optimized method for multi-species, but it demonstrates average success in connectivity and fragmentation minimization. The given comparison shows the benefits of an optimized multi-species corridor design to the problem of urban expansion and preservation of a wildlife connection.

Challenges in Corridor Design

These are some of the obstacles that arose in the process of optimizing the corridors. Conflict with urban infrastructure was one of the most significant barriers because roads, buildings, and other development forms tended to cut across the proposed routes of the corridor. The interests of landowners were also another challenge in gaining access to land to implement the corridors, where the rights of the property owners went against the conservation requirements. The budget constraints also made the design and construction of the corridors more challenging in the long term in terms of maintenance and growth. The nature of the ecological requirements in a city and the realism of the development demanded through an urban environment demanded a repetitive aspect of design correction and consultation with stakeholders.

Implications for Urban Planning

The paper has emphasized the need to incorporate wildlife corridor plans in the process of urban planning. The role of the urban planners can be critical in seeing that, in the initial development of the city, wildlife corridors must be taken into account, especially in zoning regulations, transportation planning, and environmental regulations. Planners can eliminate the impact of the urbanization process on wildlife by incorporating corridors into the city plan to uphold the ecological connectivity. The policies must support the maintenance of green areas, creation of buffer zones near urban areas, and facilitation of the infrastructure that supports corridors, e.g., wildlife crossings across roads.

Future Research Directions

Although this paper offers an all-encompassing method of designing efficient wildlife corridors, some of the fields need additional investigation. Future research ought to include the examination of the long-term efficiency of the corridors to facilitate the movement of the species and genetic exchange in a lasting way. It will also be essential to include the effects of climate change in the design of the corridors since the changes in environmental conditions can change the movement patterns of species and their habitat preferences. Also, the extension of the model to other areas with different ecological, socio-economic, and urban backgrounds would contribute to the optimization of the methodology and make it applicable to various landscapes. Another valuable insight area on which future research should be conducted is the role of the community and public awareness in designing and maintaining corridors.

Conclusion

This research highlights the role of optimization of the networks when building wildlife corridors, especially in urbanizing areas, to sustain the conservation of biodiversity. The most important findings showed that the optimized multi-species corridor design can significantly restore connectivity, and the connectivity was improved by 45 to 80 % between various species. The corridors not only lessen the fragmentation of the habitats but also enhance the genetic circulation among the isolated populations, thus enhancing the survival of the species in the long run. This study is more flexible and sustainable in its solution by taking into account the effects of future urban growth compared to the single-species or generalized corridor models. The combination of movement patterns and habitat needs of different species in the design has been found to be more helpful in conserving biodiversity amid urban development.

The implications of these findings on urban planning and management of wildlife have far-reaching practical implications. This study offers a guideline on how wildlife corridors can be included in urban development projects so that urban growth does not compromise biodiversity. Among the most essential pieces of advice are that the development of the corridors is planned to enable the connectivity of multiple species, that the wildlife crossings be considered in the infrastructure development, and that the networks of habitats should be preserved in the urban environment. The long-term sustainability of these corridors depends on constant accommodation to urban growth and the climate change processes, which would help in sustaining the urban development and conservation of wildlife in the swifter environments.

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