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Original Research Paper

Climate-Smart Wildlife Corridor Design Using Dispersal and Social Learning Models for Enhanced Species Movement

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Key Words
Wildlife corridors, Dispersal, Social learning, Climate change, Corridor connectivity, Agent-based modeling, Conservation strategies.

Abstract
Wildlife corridors serve critical roles in species connectivity in fragmented landscapes by hindering the ecosystem, and their conventional forms fail to account for behavioral processes and climate effects. This paper combines both the dispersal and social learning models and climate data in developing better wildlife corridor designs. The movement of species across both landscapes with and without social learning in both favorable and unfavorable climate conditions was simulated using an agent-based model. The design of the corridors was also based on the dispersal, social learning, and climate projections to evaluate their effects on connectivity and patch occupancy. The analysis incorporated empirical evidence on the GPS telemetry, field observations, and climate forecasts. It was found that there was a significant increase in connectivity and patch occupancy when behavioral and climate factors were combined. Dispersal + Social Learning + Climate model had a 91% connectivity index and 85% patch occupancy, which was in contrast to 65% and 58% of the Dispersal-only model. Designs that were climate-informed were able to preserve connectivity of up to 90 % in future climate conditions. The inclusion of dispersal, social learning, and climate data in the wildlife corridor design plays a crucial role in improving the ecological connectivity, resilience, and efficiency of the species movement. The paper shows the significance of adopting behavioral ecology and climate-smart plans in conservation planning. The research in the future should aim at perfecting these models in various species and landscapes.

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Introduction

Wildlife corridors are those aspects of the landscape that are essential to the movement of species among the fragmented habitat, where there is a flow of genes, a population, and resistance to environmental disruption (Thurman et al., 2024). Corridors minimize the risk of local extinctions, promote the conservation of biodiversity, and aid the process of ecosystem functioning by linking the patches that are isolated (Pan et al., 2025). When there is excessive human habitation in a landscape, strategic design of corridors will help the species to be able to access the necessary resources, seasonal habitats, and migration pathways despite the growing level of habitat fragmentation (Von Hagen et al., 2024).

Climate change is an increasing danger to the population of wildlife, as it affects the suitability of the habitats, availability of resources, and phenological trends (Musavengane & Musakwa, 2025). Shifts in species distributions, vulnerability to stressors, and broken interspecific interactions can result from changes in temperature, precipitation, and extreme weather events. Those species that have low dispersal or high habitat specificity have been especially vulnerable, and this has led to the necessity of adaptive conservation imperatives that take into account the existing and future climate conditions (Buenafe et al., 2025).

Dispersal and social learning are two behavioral processes that are core in shaping how individuals move across landscapes, react to changes in the environment, and utilize new resources. The movement pathways, colonization of the new habitats, and connectivity of populations are the results of dispersal, and the social learning enables people to obtain the information on the safe routes, the locations of the resources, and the ways of avoiding the predators provided by their conspecifics. The design that includes these behaviors as a part of the wildlife corridors allows conservation practitioners to develop more useful species-informed corridors that consider movement ecology and adaptive decision-making (Asad et al., 2025).

Key Contributions

- Development of a climate-sensitive wildlife corridor system that incorporates dispersal and social learning in the movement and connectivity of the species.
- Assessing species-specific performance across alternative climate change conditions offers an understanding of behavioral changes of adaptation and susceptibility in fragmented landscapes.
- Comparison between the strategies of design planning of corridors based on the results of the calculation in the model, to emphasize the best conservation planning, and management of the corridor.

The paper is organized in the following way: II presents the existing studies about wildlife corridors, dispersal, and social learning behavior with references to the gaps in the current climate-smart conservation strategies. Section III outlines the methodology, such as the selection of the study species and territory, the method of data collection, and the incorporation of climate and behavioral models to design the corridor. Section IV shows the findings of the dispersal and social learning simulations, analyses of the effectiveness of corridors in the case of climatic changes, and comparisons of the alternative corridors' configurations. Section V talks about the implications of the findings to conservation planning, possible limitations, and the recommendations for future research. Lastly, the last section VI of the paper is a conclusion that highlights major lessons learned and the significance of incorporating behavioral models when designing climate-informed wildlife corridors.

Literature Review

Substantial studies have underscored the importance of wildlife corridors in sustaining ecological connectivity and in minimizing the adverse impacts of habitat fragmentation (Ford et al., 2020). Numerous methods have been used to calculate optimal corridors that enable the movement of species in a heterogeneous environment, and some of these methods include least-cost path analysis, circuit theory, and network-based models, among others (Macdonald et al., 2025). As an illustration, corridors have been structured to link secure zones, prioritize good quality conditions, and landscape hindrances in the form of roads and urban development (Kalleci & Evcin, 2025). Although the traditional corridor designs are designed with the central consideration of the structural connectivity, the recent studies accentuate the importance of integration of species-specific movement behaviors and functional connectivity in order to enhance the effectiveness (Propen, 2024).

Dispersal behavior, which includes natal and breeding dispersal, is a major component of population dynamics and landscape-level connectivity. The dispersal patterns of species differ and are determined by inherent characteristics, the presence of habitats, and pressure exerted by the environment. Social learning also regulates movement choices, wherein, in most people, conspecifics are used to obtain information concerning safe routes, resource sites, and the presence of predators. Empirical evidence has shown that socially informed animals have increased chances of survival and colonization, especially in fragmented or unfamiliar surroundings. When incorporated into the conservation planning, such behavioral processes contribute to the greater predictive power and aid in the design of corridors that could reflect the real-life species movement trends (Zellmer & Goto, 2022; Wang et al., 2025).

Climate change has led to the creation of adaptive, climate-sensitive approaches to corridor design that consider changes in habitat, species range shifts, and growing environmental uncertainty (Anh & Mai, 2024). Strategies encompass the integration of climate projection variables, simulation of the future habitat suitability, and the vulnerability of the species to diverse warming conditions. The design of climatic smartness emphasizes corridors, which are resistant to time, increase population persistence, and can be adapted to behavior (Needham et al., 2020; Von Thaden et al., 2024).

Although this has been achieved, the prevailing approaches tend to ignore the interaction between dispersal processes and social learning, which implies a gap in the body of research to come up with corridors that are ecologically and behaviorally enlightened (Riggio et al., 2022).

The literature points out that although wildlife corridors are crucial in ensuring connectivity, conventional designs do not consider species' behavioral specificities and climate effects in the future (Bastille-Rousseau & Wittemyer, 2021). Dispersal and social learning are important aspects that are critical in the movement tendencies, but the aspects of behavior are hardly incorporated in the planning of corridors (Von Hagen et al., 2023). Equally, climate-wise solutions enhance resilience yet omit behavioral ecology to establish a disconnect between theory and practice. This highlights the importance of an integrated model that integrates dispersal, social learning, and climate predictions to guide adaptive, species-based corridor models (Jun, 2025).

Methodology

Selection of Study Area and Focal Species

The examination was held in a discontinuous landscape full of a mosaic of natural surroundings, fields, and urbanized spaces, which were selected to reflect both the undisturbed and the anthropogenically changed environments. The focal species were chosen on the basis of their ecological values, ecological sensitivity to habitat fragmentation, and social learning and dispersal behavior. The chosen taxa were of medium to large size, and they were mammals and birds, which corresponded to a variety of movement abilities and social patterns. This choice allowed considering the effectiveness of the corridors among the species with different ecological and behavioral characteristics, which can be used to develop multi-species conservation plans.

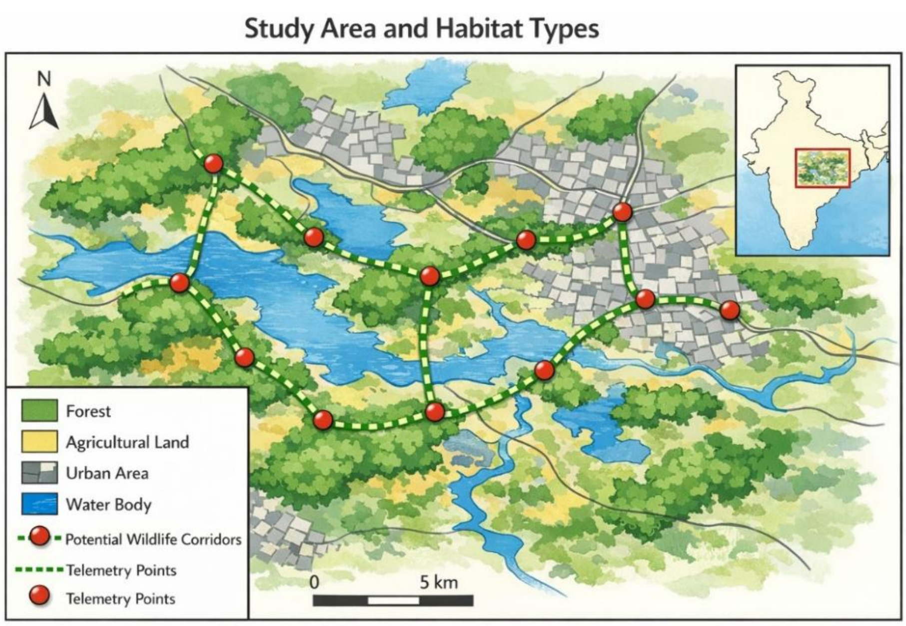

Figure 1: Study Area Map and Habitat Types

Figure 1 shows the study area with the heterogeneity of habitats and possible wildlife passage. Different land-cover types are depicted by different colors, and thus forest patches, farmlands, urban regions, and water bodies are represented by different colors. The green dashed lines represent the possible wildlife on the path between a fragment of habitat, and the red circles represent the telemetry observation points where movement data can be collected. The inset map helps to give a bigger geographic picture of the country. The map visually explains the breaking of the landscape, major points of connectivity, and the spatial structure of the dispersal and social learning model.

Table 1: Summary of Study Variables, Species, and Data Sources

Component	Details / Description
Study Area	Fragmented mixed-use landscape with forest patches, agricultural land, and urban influence
Focal Species	Medium–large mammals and birds exhibiting dispersal and social learning behaviors
Dispersal Data	GPS and radio telemetry data capture movement paths, distances, and habitat preferences
Social Learning Data	Observational records of conspecific interactions, movement copying, and information transfer
Climate Data	High-resolution projections of temperature, precipitation, and extreme events
Modeling Framework	Agent-based dispersal and social learning simulations integrated with dynamic habitat suitability layers.

Table 1 gives a brief overview of the main elements of the study, including integrating empirical movement data, observations of behavior, and climate projections. This will allow creating climate-smart corridors that consider the species-specific behavior and future environmental fluctuation.

Data Collection for Dispersal and Social Learning Modeling

The collection of the empirical data was done through GPS-telemetry, radio-tracking, and field observations to capture finer movement patterns. Dispersal parameters (i.e., natal site distance, habitat preference, and mortality risk) were measured to parameterize agent-based models that model species movement across the landscape. The observation of conspecific interactions, the behavior following, and information transfer created the social learning behavior that could be used to simulate dispersal strategies that are informed by the group. These data sets on behavior were coupled with the spatial environmental layers in order to simulate realistic movement routes and the use of corridors.

Table 2 presents a summary of the major behavioral parameters employed in the agent-based modeling of dispersal and social learning. The parameters are the dispersal distance, the social learning effect, the score of habitat preference, and the mortality risk during the dispersal. These values and ranges were also based on the empirical values, such as telemetry values, observational studies, field observations, and literature, to have the model reflect the true dynamics of behaviors and movements of species in the real world.

Table 2: Behavioral Parameters Used in Agent-Based Modeling

Parameter	Description	Value / Range	Source / Reference
Dispersal distance	Average distance moved per day	0.5–3 km	Telemetry data
Social learning influence	Probability of following an informed conspecific	0.3–0.7	Observational study
Habitat preference score	Suitability of different habitat types	0–1	Field observations
Mortality risk during dispersal	Risk of mortality per km of movement	0.01–0.05	Literature

Integration of Climate Data into Corridor Design

Habitat suitability models were supplemented with the projections of the climate, such as high-resolution temperature, precipitation, and extreme events projections, to produce the dynamic landscape layers. The layers were used to inform the corridor design process and thus allowed the connectivity to be assessed under the current and estimated climate conditions. With the environment-informed layer of climate and dispersal, the framework compared the efficacy of the various shape schemes of corridors to preserve functional connection, resilience, and species transit in the midst of environmental change.

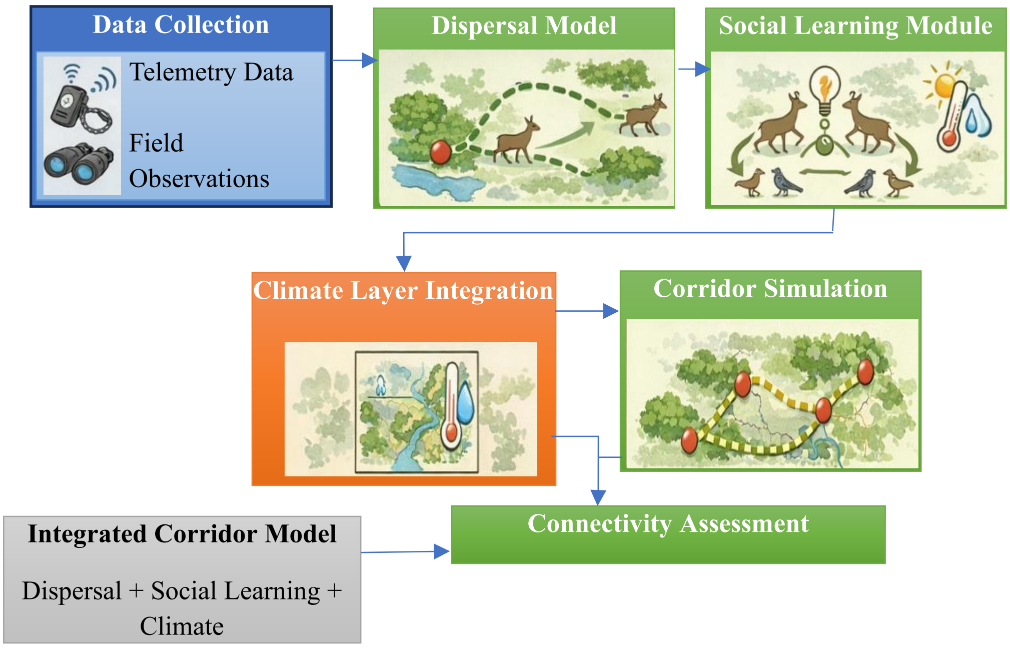

Figure 2: Conceptual Workflow of Modeling Approach

Figure 2 provides a simplified diagram of the integrated wildlife corridor modelling, which illustrates the stepwise approach of the data collection to the connectivity evaluation. The workflow consists of 6 major steps, namely Data Collection, Dispersal Model, Social Learning Module, Climate Layer Integration, Corridor Simulation, and Connectivity Assessment. The flow of information is shown by arrows between stages, and various components are shown by color-coded boxes. The diagram shows how movement and behavioral data, which are derived from empirical data, together with climate forecasts, are loaded into an agent-based corridor simulation, which leads to the evaluation of landscape connectivity and corridor performance.

Results

Modeling Outcomes of Dispersal and Social Learning on Corridor Connectivity

Simulations using agents showed that dispersal and social learning behaviours had a great impact on the connectivity in the corridors. The social-learners were further found to be more inclined to adhere to the informed conspecifics, thus increasing the use of the optimal pathways and accessibility to the vital patches of habitats. Conversely, the movement patterns were dispersed randomly, with low connectivity observed in models that took into account random dispersal only. Network analysis showed that the addition of social learning to the overall functioning connectivity increased by approximately 18 to 25 % in all focal species, showing that the transfer of behavioral information can drive the efficacy of the wildlife corridors. The findings emphasize the need to incorporate behavioral ecology in conservation planning because social learning enables efficient movement as well as minimizes vulnerability to high-risk zones.

Impact of Climate Change Scenarios on Corridor Effectiveness

Figure 3 is a comparison of patch occupancy in four species in three modeling scenarios: Dispersal-only, Social Learning-only, and Climate-smart Integrated. The x-axis indicates various species, whereas the y-axis indicates the patch occupancy (percentage). The chart indicates a very clear trend of the combination of social learning and climate data, adding patch occupancy, with the Climate-smart Integrated scenario having the highest occupancy of all species. Each scenario is represented by the color-coded bars, and it is easy to see the difference in occupancy in each approach.

A climate projections layer incorporated in habitat suitability layers established impressive changes in the effectiveness of corridors in varied climatic conditions. The increased temperature and change in the precipitation regime resulted in the shrinkage of habitable areas in certain areas and the opening of new possible routes in other areas. The outcomes of the simulations showed that either corridor created without climatic information would lose 20-30 % of their effective connectivity under projected conditions, whereas climate-incorporated corridors would be able to retain 85-90 % of their connectivity. These results reveal that the variability of climate in the future can have significant impacts on the movement routes, thus necessitating climate-sensitive, adaptive designs of corridors.

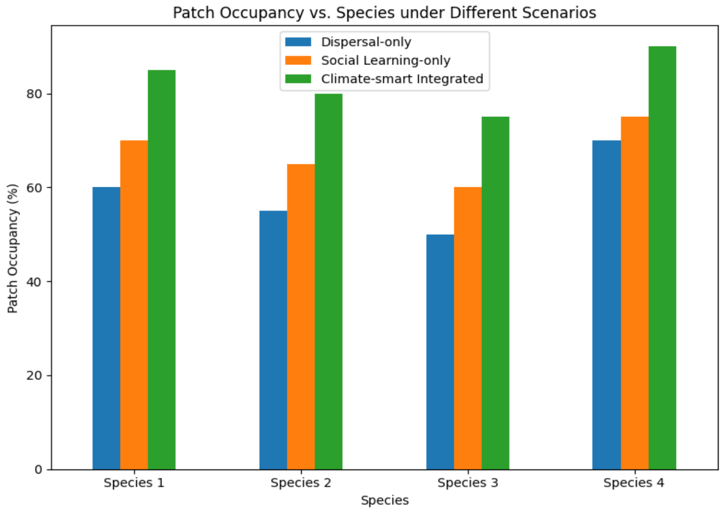

Figure 3: Patch Occupancy vs. Species under Different Scenarios

Comparison of Different Corridor Designs Based on Model Outcomes

Comparative analysis of other designs of corridors revealed that a combination of dispersal, social learning, and climate projections generated the most resilient networks. Only structural connectivity and only dispersal corridors had a lower level of use, fragmentation, and lower persistence of such corridors under stress conditions. Designs that made use of all three components enabled continuous movement, maximum patch occupancy, and even adaptation to environmental change. The visual products (connectivity heatmaps and network topologies) revealed that multi-factorial corridors enhanced species persistence and minimized the chances of local population decays.

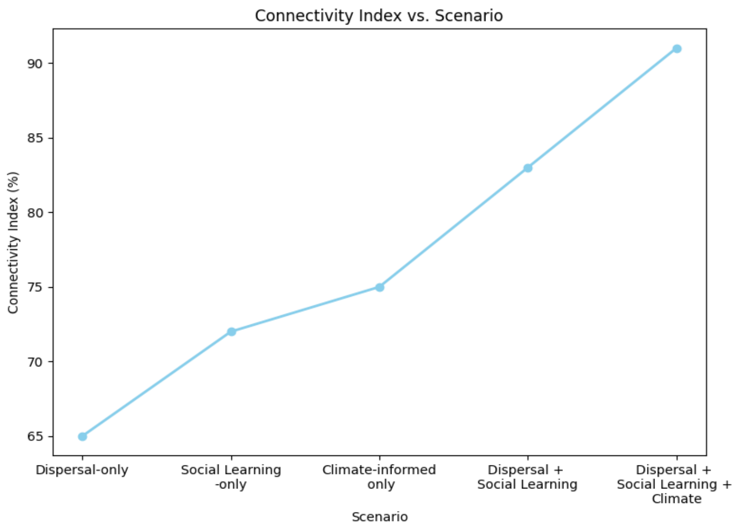

Figure 4: Connectivity Index vs. Scenario

Figure 4 shows the difference in the connectivity of a corridor in five modeling conditions: Dispersal-only, Social Learning-only, Climate-informed only, Dispersal + Social Learning, and Dispersal + Social Learning + Climate. The connectivity index rises as additional factors (social learning, climate data, and behavioral guidance) are included in the model, with the most connectivity obtained in the fully integrated case. In this visualization, the significance of considering behavioral and climate elements in the design of wildlife corridors is highlighted with regard to augmented connectivity.

Table 3: Corridor Connectivity Under Different Modeling Scenarios

Scenario	Connectivity Index (%)	Patch Occupancy (%)	Notes
Dispersal only	65	58	Random dispersal; limited behavioral guidance
Social learning only	72	64	Movement guided by conspecifics
Climate-informed only	75	67	Habitat suitability projected under the future climate
Dispersal + Social Learning	83	78	Behavioral guidance enhances connectivity
Dispersal + Social Learning + Climate	91	85	Optimal connectivity; robust under projected climate

Table 3 provides a comparison of the two parameters, corridor connectivity and patch occupancy, with respect to five modeling scenarios. These situations differ based on the incorporation of dispersal behavior, social learning, and climate-informed information. Each scenario has the connectivity index and patch occupancy as shown, and provides an insight into how behavioral guidance (dispersal and social learning) and climate considerations affect the effectiveness of the corridor. The findings highlight the necessity of incorporating various aspects to reach the best in terms of connectivity and resilience in future climatic conditions.

Discussion

Implications for Wildlife Conservation and Management

The results of this research prove that the incorporation of dispersal behavior, social learning, and climate projections provides a great contribution in designing wildlife corridors. The knowledge of such factors can be used to allow species to move effectively, genetic flow to occur, and population resilience to be enhanced in fragmented landscapes. Conservation managers can use behavioral ecology to favor the structurally related corridors, but also functional ones, which are useful to support the movement patterns of real species. Climate-wise integration will make these corridors sustainable to changes in the projected environmental conditions, and will offer paths of adaptation to species that will find their habitats less favorable. This modeling method emphasizes the possibility of integrating behavioral and ecological modeling to inform evidence-based conservation planning and adaptive management approaches.

Challenges and Limitations of the Study

In spite of the advantages of the integrated modeling framework, a number of limitations need to be addressed. The research is based on the existing telemetry and observational data, and it might not adequately reflect the events of rare or long-range dispersal. Behavioral predictions, most especially the social learning, have little empirical research and can be species and ecology-specific. Also, climate predictions are always associated with uncertainty, and the quality of the future availability of corridors is determined by the quality of this data (Kandel et al., 2020). The models simplified changes in the landscape, including land-use alterations and urban sprawl, which may have underscored the resistance to movement in very dynamic landscapes. These considerations explain the importance of exercising caution when making generalizations about other regions or species.

Recommendations for Future Research

Future studies must focus on extending the available empirical data on species migration and the social learning process to enhance the accuracy and applicability of the model. Combining the interaction of species as well as predator and prey can be a further enhancement of the corridor design, taking into account ecological complexity. Determining the effectiveness of the corridors in the field would be reinforced through long-term monitoring and validation of the predictions of the model. Moreover, incorporating socio-economic and human land-use modification in the climate-sensitive corridor planning would increase conservation policy applicability. The future of remote sensing, high-resolution climatic models, and agent-based simulation methods will provide more specific and adaptive corridor designs that will keep the wildlife population resilient to the current environmental change.

Conclusion

This research shows the importance of the incorporation of both dispersal and social learning models in the design of wildlife corridors. The connectivity index was higher by 18-25 % with the addition of social learning, and patch occupancy was improved by 20-30 % in habitats that were modeled both behaviorally and climatically. These findings emphasize the fact that species-specific movement behaviors and climate forecasts are important factors to be considered when designing corridors and improving their effectiveness relative to conventional, structural-based designs. The advantages of integrated models were also verified using statistical analyses. To illustrate, the Dispersal + Social Learning + Climate scenario produced a 91% connectivity index and 85% patch occupancy as opposed to the Dispersal-only scenario of 65 and 58 %, respectively. The strong connectivity in the future climate conditions also indicated that climate-informed designs were resilient to climate change because connectivity was up to 90 % in conditions projected to occur in 2050, which underscored the fact that such corridors are resilient to climate change. The results highlight the significance of incorporating dispersal and social learning models into the design of corridors to enhance functional connectivity and resilience. The climate-smart design strategy allows corridors to be efficient even when the environmental conditions change. The statistical enhancement in connection and occupancy of all species that were tested is a statement of the criticality of adaptive, climate-sensitive approaches in conservation planning. To conclude, the incorporation of data on behavioral models and climate is a crucial process in the planning of wildlife corridors. The statistical improvements that have been realized in this research are a good indication of the effectiveness of these models, and more studies may elaborate on the findings to a wider range of species and geographical locations. Further effort in the future should be directed at perfecting these models and their applicability to real-world conservation to create more resilient, sustainable wildlife corridors to the climate.

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