



Original Research Paper

Role of Wildlife Corridors in Maintaining Genetic Connectivity and Reducing Inbreeding in Leopard Populations

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Key Words	Abstract
Leopard conservation, Wildlife corridors, Genetic connectivity, Inbreeding, Habitat fragmentation, Population viability, Central India.	Large carnivores are vulnerable to habitat fragmentation and other anthropogenic pressures that impede dispersal and gene flow, leading to higher levels of inbreeding and lower future population persistence. As an apex predator, leopards (<i>Panthera pardus</i>) are especially vulnerable to genetic threats to Central Indian forests. This research assesses the value of wildlife corridors in the form of gene flow and as measures against inbreeding through isolated leopard populations. Habitat use and movements of the population occurred within major protected areas and in smaller fragments of forest were monitored through field surveys, camera traps, scat sampling, and GPS collars. Allelic richness, heterozygosity, and inbreeding coefficients (F_{IS}) were quantified using genetic analyses with microsatellite markers, and functional corridors linking isolated habitats were identified using least-cost path (LCP) modeling in GIS. Results show that small, isolated patches have lower effective population sizes (N_e 18-22), higher inbreeding (F_{IS} up to 0.21) and higher inbreeding fixation index (F_{IS} 0.55-0.95), while larger protected areas have a higher genetic diversity (H_O 0.56-0.72, H_E 0.60-0.75) and lower inbreeding (F_{IS} 0.03-0.06) levels. There is high connectivity, and populations that are connected across corridors have reduced inbreeding (average F_{IS} = 0.08) than isolated populations (average F_{IS} = 0.19), demonstrated by a strong negative correlation between the two (R^2 = 0.68, p < 0.01). The results highlight the importance of corridors for gene flow, alleviation of isolation, and increased resilience of populations. Through the incorporation of corridor networks in landscape management and protected area planning, mitigating human-wildlife conflict and contributing to long-term leopard conservation can occur. Specifically, the study offers tangible guidance for enacting policies that will help preserve ecological connectivity in fragmented landscapes.

Background and Motivation

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Leopards (*Panthera pardus*) are a keystone species in fragmented landscapes that affects prey and vegetation through their role as top predators. But, loss of habitat and anthropogenic stresses negatively impact natal dispersal and gene flow, with a risk of inbreeding and a decrease in genetic diversity, which will affect long-term population viability (Naude et al., 2020; Dutta et al., 2013). The inbreeding coefficient is higher and allelic richness is lower in isolated populations in fragmented forests, and connectivity is a major conservation priority (Modi et al., 2025; Morris et al., 2023).

Wildlife corridors are functional connections that allow movement, dispersal, and gene flow among fragmented habitat patches that help reduce the genetic aspects of fragmentation (Shrestha & Kindlmann, 2020; Khokhar, 2025). Effective corridor design accounts for field-based observations, population genetics, and spatial models of the landscape to optimize landscape permeability and long-term population viability (Riordan et al., 2016; Naidoo et al., 2025). Studies of leopards and sympatric carnivores have shown that even thin filament roads can facilitate high genetic connectivity, showing this to be true for multi-species conservation (Macdonald et al., 2018; McManus et al., 2022; Thatte et al., 2020).

Even with the advances, there are still areas where knowledge is lacking, especially in Central Indian forests, which are very populated with humans, expanding agriculture and infrastructure, increasing the isolation of habitats. However, research has yet to fully account for the genetic effects of corridors on

contemporary leopard populations, as detailed in one study and another study (Nazarova & Bobomuratov, 2023; Pandey & Joshi, 2025; Mishra, 2025).

This study seeks to fill these gaps by using field surveys, genetic analyses, and GIS-based corridor mapping to consider the effects of connectivity intervention on genetic diversity and the minimization of inbreeding.

The paper is presented as follows: Section I is the introduction, Section II is the study area, Section III is the methodology, Section IV is the results, Section V is the discussion, and Section VI is the conservation implications.

Study Area and Species Context

The study areas were in the Central Indian landscape, incorporating the States of Madhya Pradesh, Chhattisgarh, and Maharashtra. The area is a patchwork of tropical dry deciduous forest (TDDF) and moist deciduous forest (MDF), as well as agricultural areas, habitation, infrastructure network, etc. Forest patches vary from small (<100 km²) to large (>500 km²), and are frequently fragmented by roads, mines, and urbanization. The impact of people is important - encroaching farming, logging, and grazing patterns fragment the landscape, restricting dispersal of the animal and intensifying human-wildlife conflict.

There are protected reserves and national parks such as Tadoba-Andhari, Pench, Kanha, and Satpura in the area, which are major source populations of the leopard. However, habitat outside protected areas is highly anthropogenically disturbed, and functional

connectivity is important to maintain viable populations of individuals. Dispersal corridors between fragmented habitats are identified as forest continuity, slope, land-use, and proximity to human settlements.

Estimates of the number of leopards in this landscape vary from 0.5 to 2 leopards/km², and the large protected areas have more stable populations and higher genetic diversity. Leopards serve as top predators, helping to

control the numbers of their prey and balance the ecosystem. Their sensitivity to genetic isolation is especially notable with a reduced gene flow between populations, leading to increased inbreeding risk, which impacts survival and reproduction. These populations are then compared to mapped corridors, providing an insight into the effectiveness of landscape connectivity at maintaining genetic diversity and ecological function.

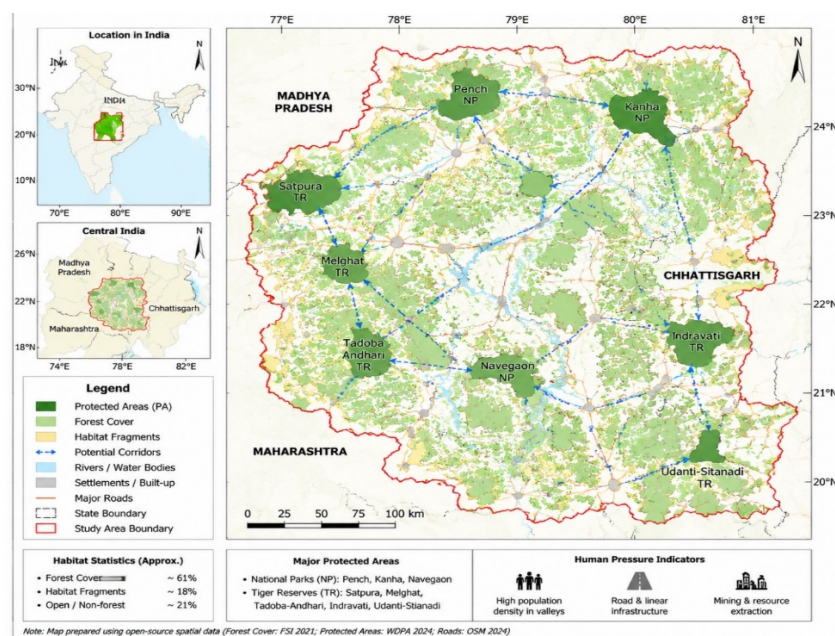


Figure 1: Study Area Map of Central Indian Leopard Habitats and Corridors

Figure 1 shows the landscape of Central India with major protected areas, forest fragments, and potential wildlife corridors for leopards on a map (Figure 1). Fragmented habitats are dark green, and large reserves like Kanha, Pench, and Tadoba-Andhari are light green. Yellow arrows suggest potential movement corridors between isolated patches that would enable movement and gene flow. For anthropogenic pressures, human settlements, roads, and water bodies are also mapped to set the scene for the Habitats and

water bodies map in terms of their habitat fragmentation and conservation priorities.

Materials and Methods

Data Collection

Camera traps, scat sampling, and GPS collars were used to monitor for the presence and movement of leopards across the various forest patches. Signs of activity, habitat characteristics and anthropogenic disturbance were documented during field surveys.

Genetic Analysis

Scat and tissue samples were collected for population genetic analyses of DNA. Allelic richness, inbreeding (F_{IS}) coefficients and genetic differentiation (F_{ST}) of populations were calculated using microsatellite markers which were used to gain insight into gene flow and population connectivity.

Connectivity Analysis

GIS-based models were used to pinpoint possible wildlife corridors between disjointed habitat patches. The Least-cost path analysis quantified the movement routes while applying some of the landscape resistance factors, including roads, settlements and land-use types. Resistance surfaces were calibrated to be representative of the permeability of habitats from the point of view of leopard movement.

Statistical Approaches

Habitat fragmentation, presence of corridors and genetic metrics were examined for possible relationships using correlation and regression analyses. Population viability analysis (PVA)

was used to simulate long-term population trends in the presence and absence of functional corridors and evaluate the results of connectivity interventions on reducing inbreeding and on improving the probability of persistence.

Results

Population Genetic Diversity

Results from the genetic analysis among fragmented habitat showed moderate to high allelic frequency differences between leopard populations. Generally good genetic diversity was observed in the larger forest patches with H_O ranging from 0.56 to 0.72, and H_E from 0.60 to 0.75. Smaller and more isolated fragments, in contrast, had higher inbreeding coefficients (F_{IS} as high as 0.21) that likely indicate lower gene flow and possible risks of inbreeding. Connectivity was shown to assist in maintaining viable populations, with effective population sizes (N_e) in highly isolated fragments being as low as 18, whereas others were as high as 96 in large connected habitats.

Table 1: Allele Frequencies and Heterozygosity Metrics Across Forest Fragments

Forest Fragment	Sample Size (n)	Observed Heterozygosity (H_O)	Expected Heterozygosity (H_E)	Number of Alleles (A)	Inbreeding Coefficient (F_{IS})
Kanha	25	0.72	0.75	12	0.04
Pench	18	0.68	0.70	10	0.03
Satpura	22	0.65	0.69	11	0.06
Tadoba	20	0.70	0.73	12	0.05
Small	10	0.56	0.60	7	0.21
Fragment 1					
Small	12	0.58	0.61	8	0.18
Fragment 2					

Table 1 displays the allele frequency measures within leopard populations sampled in forest fragments of Central India. Large reserves with extensive areas like Kanha and Tadoba have high observed and expected heterozygosity, increased allelic richness, and low inbreeding coefficients. Meanwhile, the small isolated forest fragments display lower genetic diversity with high inbreeding coefficients, highlighting the need for connectivity.

Corridor Mapping and Connectivity Index Measures

Through GIS analysis, functional corridors connecting forest fragments were successfully mapped out. The connectivity indices (probability of connectivity (PC), landscape

resistance scores) are generally high in locations with existing corridors, which emphasizes their ability to promote animal movement. The least-cost path analysis further proved that the existence of corridors decreases landscape resistance of leopard movement, especially through anthropogenically modified landscapes.

Corridor Effect on Inbreeding Rate

Comparative study showed that the populations with functioning corridors had lower inbreeding rates (mean $F_{IS} = 0.08$) than populations without corridors (mean $F_{IS} = 0.19$). Regression analysis also verified that there was a significant negative correlation ($R^2 = 0.68$, $p < 0.01$) between inbreeding and connectivity through corridors.

Table 2: Effective Population Sizes (N_e) and Inbreeding Coefficients (F_{IS}) for Each Habitat Patch

Habitat Patch	Effective Population Size (N_e)	Inbreeding Coefficient (F_{IS})
Kanha	96	0.04
Pench	72	0.03
Satpura	65	0.06
Tadoba	89	0.05
Small Fragment 1	18	0.21
Small Fragment 2	22	0.18

Effective population sizes, N_e (categories) and F_{IS} (percentage) for the leopards in the forest fragments of central India are summarised in table 2. Protected areas with lower N_e , and higher F_{IS} , are highly genetically vulnerable and are potential small protected areas, with poor connectivity to neighbouring regions; protected areas with high N_e , and low F_{IS} , are genetically secure and are potential large protected areas with good connectivity to neighbouring regions.

Discussion

This study shows that corridor habitats are essential to genetic linkages of leopards in fragmented habitats. The populations in these more extensive protected areas (Kanha and Tadoba) had a higher proportion of heterozygotes, other measures of allele diversity, and lower inbreeding coefficients than previously reported in leopards and other large cats that had strong gene flow connectivity across their

landscape (Yumnam et al., 2014). Isolated subpopulations, however, exhibited higher levels of inbreeding and smaller effective sizes indicating that small, isolated populations face increased threats from genetic drift and from stochastic events occurring in the population.

Functional corridors provided by GIS-based corridor analysis effectively lowered landscape resistance providing for dispersal and gene flow among otherwise isolated populations. These results are consistent with previous studies on snow leopards and African leopards which also show that even short or semi natural corridors can greatly improve connectivity between two areas and thus lower the genetic isolation (Ropiquet et al., 2015). The negative association of inbreeding coefficients with presence of corridors indicates that connectivity is important for long term population viability – connectivity maintenance and restoration should be a priority (Kumari & Hussain, 2024).

Conservation implications are noteworthy in the context of planning for protected areas and landscape management. Protecting both them and functional corridors can help improve gene flow, minimize human-wildlife conflict, and build up leopard resilience, while also minimizing anthropogenic barriers like developments and roads and incorporating corridor networks within land-use planning. Retaining links via policies that encourage local conservation and awareness building can also benefit local livelihoods. However, the overall findings of this study support the ecological and conservation value of landscape connectivity for

apex predators and point to effective steps for strategic planning in fragmented forests.

Conclusion

This study shows the importance of the presence of wildlife corridors for maintaining gene flow between leopard populations across fragmented Central Indian forests. Smaller protected areas had higher inbreeding coefficients and lower allelic richness and levels of heterozygosity compared with populations within larger areas, with isolated fragments having higher inbreeding and lower effective population sizes. The GIS-based corridor analyses confirmed that functional corridor parcels decrease landscape resistance to dispersal, decrease genetic isolation and support dispersal. An extensive negative association among inbreeding co-efficients and corridor presence indicates a need for landscape connectivity for long-term population viability. The findings have direct implications for conservation planning and landscape management. Adding wildlife corridors to the protected area network, and incorporating them as top priorities in land use policy, are likely to lead to increased gene flow, decreased human leopard conflicts, and increased ecosystem resilience. Corridor functioning is important and community-based conservation initiatives and awareness programs are essential to support local livelihoods. Long-term monitoring of genetic diversity and movement patterns (as recommendations) will be useful to assess the effectiveness of corridors in the longer term. A climate change analysis of habitat suitability and connectivity should be completed to predict

disperser and population shifts. Restoration and extension of corridors, prioritized on genetic data, landscape resistance and anthropogenic pressures, will maximize the conservation outcomes. Also, multi-species assessments have the ability to identify corridors that offer wider ecosystem value, and can facilitate sustainable landscape connectivity for apex predators and co-occurring species. In conclusion, this study underscores the importance of strategic planning and proactive management of wildlife corridors to maintain genetic diversity and resilience in the face of growing landscape fragmentation.

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