



Original Research Paper

Road Mortality and Traffic Volume Affecting Gene Flow and Behavioural Adaptation of Large Carnivores

Dr. Deepti Patnaik^{1}, Rakshak Bharti²*

^{1}Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.*

Email: ku.deeptipatnaik@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0009-6421-5418>

²Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.rakshakbharti@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0009-6629-7189>

Key Words

Abstract

Large carnivores,
Road mortality,
Traffic volume,
Gene flow,
Behavioral
adaptation,
Landscape
connectivity,
Wildlife
conservation.

Linear transportation infrastructure structures are detrimental to the existence of macro-ecosystems in two main ways, causing mortality of the organisms and imposing limitations on the spatial processes of top predators. This study explores the consequences of roadkill mortality and vehicular disturbance for genetic connectivity and behavioral adaptation to roads in apex predators. By employing a descriptive approach through landscape synthesis, the present work analyzes both the impact of roadkill mortality leading to a reduction in local populations and the influence of vehicular disturbance creating a behavioral barrier for the passage of apex predators across roads. The proposed methodology involves the combination of fieldwork observations, non-invasive genetic analyses, and GPS telemetry tracking in order to assess the effects of small-scale displacement processes and fragmentation of the genetic gene pool in highly mobile apex predators. It is found that despite the capacity of large carnivores to adjust their activity rhythms and cross linear barriers in periods of decreased traffic, extremely trafficked highways serve as complete obstacles for migration. Such a road impact leads to increased allelic isolation and inbreeding depression.

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

Received: 13 December 2025; Reviewed: 21 January 2026; Revised: 06 February 2026; Accepted: 13 April 2026

(DOI): [10.70102/AEJ.2026.18.1.22](https://doi.org/10.70102/AEJ.2026.18.1.22)

Introduction and Ecosystem Dynamics

The fast development of transportation networks is an important factor in the process of habitat fragmentation and affects the ecological stability of top predators. Road kill, which is the direct death of animals due to their contact with motorized vehicles, is one of the main causes of unnatural mortality for large carnivores that have extensive home ranges, making encounters with infrastructure networks almost inevitable. On the other hand, gene flow, or the exchange of genetic information between isolated populations through dispersal, is a key process that retains the evolutionary fitness of large carnivores, ensures heterozygosity, and prevents genetic disorders from fixing into the population. Thus, studying the behavior of large carnivores within this multifaceted anthropogenic environment becomes crucial.

It is imperative to comprehend the correlation between large carnivores, road kill incidents, and different levels of traffic volume in present-day wildlife management. Due to apex predators' high positions on the food chain, their populations are characterized by slow reproduction rates, low densities, and large territorial requirements to provide energy and reproduction demands. All of the mentioned biological features create susceptibility to demographic fluctuations within the studied species. Moreover, traffic volume serves as an invisible acoustic and behavioral barrier, which can limit animals' movements regardless of the presence of physical barriers. With a continuous rise in the number of vehicles beyond critical levels, the area will become impermeable,

causing transport roads to change into total barriers to wildlife movements.

For centuries, the study of ecology was based mainly on measuring the numbers of animals found dead along rights-of-way. Nevertheless, current theories in conservation biology acknowledge that measuring deaths is only a partial approach towards understanding the overall effects that roads have on wildlife. As previous theories postulated, there is strong evidence supporting the idea that roads create an avoidance response for large mammals, which often varies according to their plasticity behavior and the presence of man-made structures. In recent decades, efforts have been made to move away from purely spatial considerations, combining disciplines like landscape genetics with behavioral studies.

This paper offers a descriptive analysis of the impact of transport infrastructure on the genetic and behavioral profiles of large carnivores. This study integrates spatial demographic losses with micro-evolutionary adaptations to chronic traffic stress to elucidate the mechanisms behind genetic drift and nocturnal shifts. Section 2 analyses road mortality variables. Section 3 analyses gene flow and plasticity. Section 4 details non-invasive methods. Section 5 synthesizes species results. Section 6 discusses mitigation. Section 7 summarizes conservation priorities.

Anthropogenic Road Pressures and Traffic Intrusions

The occurrence of large carnivore deaths on roads is influenced by the interplay between topographic features of the habitat, road layout, and predator-specific hunting habits (Grilo et al., 2015). Large carnivores often tend to be attracted to roadside areas because of high concentrations of prey attracted to the increased availability of food along the edges, or for the convenience of patrolling territories. This makes these predators vulnerable to collisions with vehicles. The combination of road layouts having high speed limits, low visibility in the undulating terrain, and the absence of continuous exclusion fencing makes the matter even worse, turning the sinks into death traps. Furthermore, seasonal changes in behavior, such as the dispersal period of juveniles and long-distance movement of adults looking for mates, contribute to the problem.

Beyond direct conflicts, the density and speed of vehicular traffic generate a sensory barrier that affects the behavior of large carnivores and influences the connection between different carnivore populations (Moore et al., 2023). High traffic density results in an area of constant acoustic disturbance, light pollution, and emission of various chemicals, which extends far beyond the immediate road area. The sensory impact of such traffic requires that highly sensitive carnivores keep a safe distance from transportation corridors. Once certain threshold levels of traffic density are exceeded on any given road, the latter becomes not only dangerous for animal crossings but also turns into an impenetrable barrier for carnivore migration and

dispersion. Animals are forced to either avoid such transportation corridors or leave their traditional territories altogether. High traffic density is associated with low rates of animal crossing, while low traffic density is associated with high crossing and mortality rates.

Studies conducted within different geographic locations have provided evidence of the differences in the behavior of different carnivore guilds in response to the threat posed by the construction of transportation corridors. In this regard, wide-ranging felids such as the Florida panthers experience heavy mortality rates in the form of collisions as their movement routes overlap with fast-growing road networks in suburbs (Schwab & Zandbergen, 2011). On the other hand, wide-ranging ursids and large canids are characterized by high behavioral flexibility, where their movement patterns change to move away from dense road networks, especially when traffic activity is at its peak (Basille et al., 2013). It is evident that some species view roads as sources of mortal danger, while others view them as absolute barriers to movements.

Disruption of Gene Flow and Behavioral Adjustments

Habitat fragmentation by large traffic barriers is another major factor affecting the gene flow patterns of continuous populations of animals (Bendegúz et al., 2020). If the animals are not able to migrate across the transportation corridor, there will be very little or no exchange of genes between the separated populations of animals. Over several generations, a lack of gene flow will cause depletion in the number of alleles in the

population, and the population becomes highly susceptible to genetic drift. With the decrease in effective population size, the chances of inbreeding increase, causing the undesirable traits to become manifest.

In order to adapt to such landscapes dominated by humans, many large carnivores have had to modify their behavior in order to adapt to the presence of road systems and changing traffic flow (Jacobson et al., 2016). The most typical modification involves adapting a nocturnal lifestyle, in which animals engage in activity and foraging during dark periods, during which there is much less traffic on the roads. This type of behavior requires that animals modify their movements to move along the highway parallel for very long distances before discovering any rare underpasses or quieter zones. Such behavioral modification carries high energetic costs, as animals have to travel through unfavorable terrain and suffer from increased conflict between predators due to smaller territories.

The presence of linear transportation infrastructure leads to demographic dysfunction as a result of increased deaths and loss of breeding individuals, as well as spatial displacement, such as the adoption of a nocturnal habit and substandard feeding sites. As a result, both factors combined lead to habitat fragmentation, interfering with genetic interchange in the process.

These continual interferences in the genetic links and behaviors of these animals have grave consequences for the long-term persistence of these large carnivores (Carvalho et al., 2018). In

situations where an animal has to put more emphasis on day-to-day survival and avoiding roads rather than foraging and mate selection, the base-level resilience of its population is reduced. Populations that are fragmented become highly susceptible to stochastic events leading to their extinction, such as diseases and reductions in prey numbers, due to the fact that individuals are unable to immigrate into the area from adjacent source populations.

Analytical Methods and Empirical Frameworks

The assessment of effects caused by traffic and roadways on the populations of large carnivores entails a combination of different field methods (Grilo et al., 2018). Typically, road kill studies are conducted, in which spatial coordinates, the type of animal killed, and the time of year are recorded. For understanding how road kills relate to wider movements, GPS collar tracking devices are attached to the animals for the collection of high-frequency spatial data around transportation routes. The data provides an understanding of the movement pattern of the animal when close to the highway, whether there are certain crossing spots or areas where the animals clearly avoid.

Figure 1 illustrates a combination of movement paths and crossing hotspots using GPS telemetry combined with noninvasive genetic collection of hair samples and scat analyzed for microsatellites.

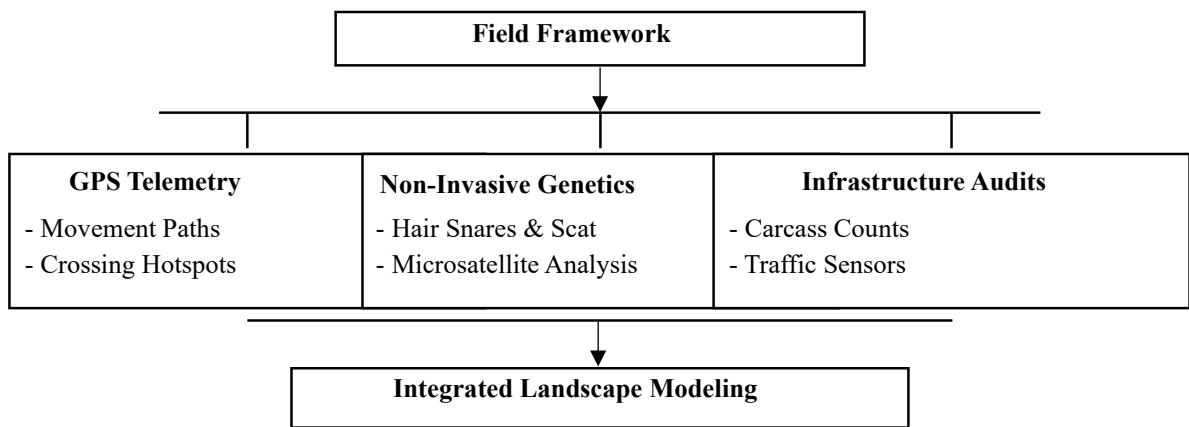


Figure 1: Integrated Field Methodology Framework

This is complemented by the assessment of infrastructure involving carcasses and traffic data. These data contribute to landscape modeling to measure the influence of transport infrastructure on the ecology of large carnivores.

For the purpose of quantifying changes in gene flow and genetic isolation, much of the work is done through non-invasive sampling of genetic material (Kimmig et al., 2020). This entails obtaining hair samples using special wire snares installed on game trails and collecting fecal samples in habitat fragments. Genetic material obtained from such samples will then be used for genotyping via microsatellites and single-nucleotide polymorphisms (SNPs) to ascertain the individual identity, gender, and kinship of each sample. Spatial distribution of genetic differentiation and genetic assignments will be undertaken in order to estimate current migration rates around highways.

Despite the advantages offered by these integrated approaches, there are some important factors that should be considered while conducting such studies, especially due to some biases associated with sampling (Creel et al., 2019). For example, the rate of carcass collection during road kill surveys can greatly differ depending on search intensity, presence of scavengers, and abundant growth at roadsides, resulting in understated mortality levels. Moreover, telemetry results may be biased towards the sampled animals, since they might not fully represent the age structure, sex ratios, and behavior of the entire population. Finally, genetic study results will take into account the long-term impacts of habitat change, as a new highway built today will not affect genetic differentiation immediately.

Synthesis of Carnivore Responses

Table 1: Species-Specific Carnivore Responses to Transport Infrastructure

Carnivore Guild / Species	Primary Landscape Threat Profile	Observed Behavioral Adaptation	Measurable Genetic/Demographic Consequence
Wide-Ranging Felids (e.g., <i>Puma</i> , <i>Panther</i>)	Expanding high-velocity highway networks intersecting core territorial ranges.	Absolute spatial avoidance of road edges; rare crossings attempted during minimal traffic.	Severe demographic losses via direct mortality; high genetic isolation in small sub-populations.
Large Ursids (e.g., <i>Brown Bear</i> , <i>Black Bear</i>)	Secondary development roads and localized highway corridors cut through foraging zones.	Pronounced shift toward nocturnality; select crossing points with dense roadside vegetative cover.	Restricted maternal gene flow; localized skewing of sex ratios near high-density infrastructure.
Mobile Canids (e.g., <i>Gray Wolf</i> , <i>Coyote</i>)	High-density road networks and perimeter highway fencing systems.	Use of landscape drainage culverts; parallel patrolling along transit rights-of-way.	Fine-scale genetic differentiation across barriers; high territory fragmentation.
Forest Meso-Carnivores (e.g., <i>Marten</i> , <i>Wildcat</i>)	Motorways and local connector routes bisect a continuous canopy cover.	Micro-habitat avoidance; complete refusal to cross wide, deforested multi-lane rights-of-way.	Immediate fragmentation of local matriline; high vulnerability to localized genetic drift.

Table 1. Descriptive synthesis outlines specific threat profiles, behavioral changes, and genetic or demographic impacts across different carnivore guilds under road pressures.

When analyzing empirical research conducted on wildlife in general, it is possible to state unequivocally that there exist correlations between structural features of roads, volume of vehicular traffic, and biological reaction of apex predators (Frangini et al., 2022). It appears from the collected data that the permeability of the landscape falls dramatically after traffic exceeds certain species-specific threshold values. According to GPS telemetry data, it becomes

evident that canids change their migration patterns and run along roads for quite a distance parallel to major transport routes. Such an approach consumes more energy and does not allow for reaching feeding grounds. Comparison of various species has shown that while some members of the canine family learn to cope with the human presence, changing their diurnal pattern, forest carnivores avoid roads at all costs.

Examining these characteristics reveals that the physical size, diet, and predatory behavior of carnivores make significant differences in how likely they are to suffer negative effects from roads (Mishra, 2025). Larger and wider-ranging

carnivores, which tend to travel over great distances in search of food at various times of year, will have far more exposure to transportation networks than smaller carnivores with less extensive ranges. On the other hand, while smaller carnivores that live in forests can be totally impeded by large highways due to the absence of an overhead tree canopy, they are susceptible to predation threats.

Conservation Interventions and Mitigation Frameworks

While examining the empirical results within the context of previous literature, it becomes evident that transportation systems are one of the major factors causing both demographic loss and population isolation (Leblond et al., 2013). Behavioral changes, such as becoming nocturnal animals and changing their routes, correspond well with existing ecological models of human disturbance. Nevertheless, this research emphasizes the notion that behavioral plasticity can have ecological boundaries when traffic levels are still quite high throughout the whole day. Under those conditions, behavioral plasticity becomes unable to counteract the impact of a barrier, resulting in serious constraints on gene flow.

In order to reduce vehicle kills and revive genetic flow that was once characteristic of this landscape, it is imperative to use structural approaches to connectivity restoration (Kiran et al., 2025). The optimal method includes creating special wildlife crossings, namely, wide and vegetated conduits and large underpasses, in conjunction with high-tensile fences, which

ensure that the animals cross the highways safely. Such crossings should be built based on the specific sensory needs of the target animal species; thus, natural substrates on the ground, acoustic insulation, and abundant protective coverings for the entry points should be included.

Design Features for Eco-Mitigation Corridors. The best design for eco-mitigation corridors involves designing an effective bridge deck structure built above the traffic on the road. This system makes use of constant soil substrates with vegetation planted in a way that connects the broken forest canopy coverage. The system uses a lateral shield mechanism to reduce the noise and light pollution coming from vehicles. It also uses exclusionary fencing on both sides of the traffic lanes to prevent animal access.

Road ecologists must consider the implementation of technologies involving real-time tracking and predictive modeling systems in the future (Almusawi et al., 2024). By placing such systems in areas with high wildlife risks through the use of sensor technology and video analysis with artificial intelligence, vehicles would receive automated warnings once animals were approaching the roadside. While this is going on, it is important for landscape managers to employ predictive resistance modeling to test the potential effects of future road construction activities on genetic connectivity in the region. Through the combination of behavioral and genetic monitoring, conservationists can improve mitigation design in order to prevent genetic isolation of predators due to infrastructure.

Conclusion

The present research paper will provide an all-inclusive insight into the relationship between road mortality and vehicle traffic volume as factors that influence gene flow and compel behavioral changes in the large carnivore population. Combining the information on the landscape and the behavior patterns of apex predators, one can determine that roads affect these animals in two ways: by causing them accidents and acting as sensory obstacles. Despite the considerable behavioral plasticity of the majority of the carnivores that allows them to change their activity period to nights when the traffic is minimal, the highways with heavy traffic constitute a significant barrier to the natural dispersal process. This, in turn, leads to the blockage of the historical routes, prevents allele exchange, and causes inbreeding depression. To combat such anthropogenic influences, a dual strategy should be adopted. It is critical that conservation approaches include the installation of large-scale wildlife crossing structures, appropriate to the species in question, including conductive facilities and underpasses, backed up with long stretches of directional fencing, to re-establish connectivity over roads already in place. In addition, future road-building efforts need to use landscape-genetic modeling in their early planning stages to ensure that core habitats will not be bisected.

References

- [1] Almusawi, Ali, Mustafa Albdaire, and Syed Shah Sultan Mohiuddin Qadri. "Assessing traffic performance: comparative study of human and automated HGVs in urban intersections and highway segments." *International Journal of Integrated Engineering* 16, no. 5 (2024): 409-427. <https://doi.org/10.30880/ijie.2024.16.05.031>
- [2] Basille, Mathieu, Bram Van Moorter, Ivar Herfindal, Jodie Martin, John DC Linnell, John Odden, Reidar Andersen, and Jean-Michel Gaillard. "Selecting habitat to survive: the impact of road density on survival in a large carnivore." *PloS one* 8, no. 7 (2013): e65493. <https://doi.org/10.1371/journal.pone.0065493>
- [3] Bendegúz, Mihalik, Wanjala George, Németh Zsolt, Stéger Viktor, and Kusza Szilvia. "Effects of natural and artificial barriers on the genetic diversity of wild animal species: A REVIEW." *Balk. J. Wildl. Res* 5 (2020): 1-18.
- [4] Carvalho, Filipe, André Lourenço, Rafael Carvalho, Paulo C. Alves, António Mira, and Pedro Beja. "The effects of a motorway on movement behaviour and gene flow in a forest carnivore: Joint evidence from road mortality, radio tracking and genetics." *Landscape and Urban Planning* 178 (2018): 217-227. <https://doi.org/10.1016/j.landurbplan.2018.06.007>
- [5] Creel, S., Spong, G., Becker, M., Simukonda, C., Norman, A., Schifftalier, B., & Chifunte, C. (2019). Carnivores, competition and genetic connectivity in

- the Anthropocene. *Scientific reports*, 9(1), 16339.
<https://doi.org/10.1038/s41598-019-52904-0>
- [6] Frangini, Lorenzo, Ursula Sterrer, Marcello Franchini, Stefano Pesaro, Johannes Rüdiger, and Stefano Filacorda. "Stay home, stay safe? High habitat suitability and environmental connectivity increases road mortality in a colonizing mesocarnivore." *Landscape Ecology* 37, no. 9 (2022): 2343-2361.
<https://doi.org/10.1007/s10980-022-01491-z>
- [7] Grilo, Clara, Daniel J. Smith, and Nina Klar. "Carnivores: struggling for survival in roaded landscapes." *Handbook of road ecology* (2015): 300-312.
<https://doi.org/10.1002/9781118568170.ch35>
- [8] Grilo, Clara, Guillem Molina-Vacas, Xavier Fernández-Aguilar, Juan Rodríguez-Ruiz, Victor Ramiro, Flávia Porto-Peter, Fernando Ascensão, Jacinto Román, and Eloy Revilla. "Species-specific movement traits and specialization determine the spatial responses of small mammals towards roads." *Landscape and Urban Planning* 169 (2018): 199-207.
<http://dx.doi.org/10.1016/j.landurbplan.2017.09.014>
- [9] Jacobson, Sandra L., Leslie L. Bliss-Ketchum, Catherine E. de Rivera, and Winston P. Smith. "A behavior-based framework for assessing barrier effects to wildlife from vehicle traffic volume." *Ecosphere* 7, no. 4 (2016): e01345. <https://doi.org/10.1002/ecs2.1345>
- [10] Kimmig, Sophia E., Joscha Beninde, Miriam Brandt, Anna Schleimer, Stephanie Kramer-Schadt, Heribert Hofer, Konstantin Börner et al. "Beyond the landscape: Resistance modelling infers physical and behavioural gene flow barriers to a mobile carnivore across a metropolitan area." *Molecular Ecology* 29, no. 3 (2020): 466-484.
<https://doi.org/10.1111/mec.15345>
- [11] Kiran, N. Chitra, Vinay Kumar Sadolalu Boregowda, Jayvadan Vaishnav, Swati Singh, Manpreet Singh, and Kanika Seth. "Enhancing Wildlife Conservation through Sensor and Deep Learning Integration for Accurate Animal Behavior Tracking." *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications* 16, no. 3: 261-280.
<https://doi.org/10.58346/JOWUA.2025.I3.015>
- [12] Leblond, M., Dussault, C., & Ouellet, J. P. (2013). Impacts of human disturbance on large prey species: do behavioral reactions translate to fitness consequences?. *PLoS One*, 8(9), e73695.
- [13] Mishra, Nidhi. "Forest-Landscape Connectivity under Climate Change: Modelling Species Dispersal, Genetic Flow, and Adaptive Capacity." *National Journal of Forest Sustainability and Climate Change* (2025): 31-37.
- [14] Moore, Lauren J., Silviu O. Petrovan, Adam J. Bates, Helen L. Hicks, Philip J.

Baker, Sarah E. Perkins, and Richard W. Yarnell. "Demographic effects of road mortality on mammalian populations: a systematic review." *Biological Reviews* 98, no. 4 (2023): 1033-1050.
<https://doi.org/10.1111/brv.12942>

[15] Schwab, Autumn C., and Paul A. Zandbergen. "Vehicle-related mortality and road crossing behavior of the Florida panther." *Applied Geography* 31, no. 2 (2011): 859-870.
<https://doi.org/10.1016/j.apgeog.2010.10.015>