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A review on "mitigating road killed animals in India: A scientific approach to diverse faunal groups"

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Abstract
The rapid expansion of India's road network has led to significant ecological consequences, including habitat fragmentation and a surge in wildlife vehicle collisions the present study delivers an inclusive review concerning the mitigation of road kill in India, with a specific focus on mammals, Birds, Reptiles and invertebrates. the current findings from various landscapes such as western Ghats, Himalayas and central Indian parts brings lights on susceptible species prone to vehicular collision and effective mitigation strategies.
We noticed amphibians and reptiles shows highest roadkill rates, particularly during the monsoon seasons, when they show increased activity levels. Large mammals, such as tigers, elephants face significant threats in highways bisecting critical wildlife corridors. Birds, including endangered species like forest owlet, are also frequent victim during specific seasons. Information on invertebrates remains relatively less, although studies have documented mortality incidences of these insect groups, highlighting critical research gap.
In this study mitigation strategies like structural interventions, underpasses, overpasses, artificial canopy bridges to traffic management measures such as speed limits, speed breakers were discussed along with advanced technological solutions including AI-based animal detection, IoT enabled sensors. This review emphasizes the necessity of incorporating road kill mitigation into early stages of infrastructure planning to ensure the sustainability of India's biodiversity conservation.

Keywords: Vehicular collision, wildlife, corridor, roadkilled, biodiversity conservation

Introduction
The growth of linear infrastructure, particularly roads and highways, is primarily driver of biodiversity loss and habitat fragmentation globally. In India, a country characterized by its immense biological diversity and rapidly developing economy, the intersection of wildlife habitats and transportation networks has created a critical conservation challenge [23]. Roadkill, or the mortality of animals due to vehicle collisions, not only threatens the survival of numerous species but also poses significant risks to human safety and leads to economic losses [18, 22]. Wildlife mitigation measures economic loss after the EPR in Tamilnadu ranges increases, and beehives also implemented near forest fringes to reduce wildlife entry into fields [31, 32]
This review examines the current state of research on roadkill mitigation in India. It covers a wide range of taxonomic groups, including invertebrates, reptiles, birds and mammals, to provide a holistic understanding of the impact of roads on Indian fauna. By synthesizing findings from diverse geographic regions from the rainforests of the Western Ghats to the mountains terrains of the Himalayas. This report aims to identify effective strategies and highlighting areas where further research and policy integration are urgently needed.

Methods
Study on roadkill animals in our country operates a variety of methodological approaches in assessing the mortality levels and evaluating mitigation techniques.

Road Surveys and Carcass Analysis: Systematic surveys along highway transects are frequently done to document roadkill incidents. These studies often record species identification, geographical locality, seasonality of occurrence to categorize mortality hotspots and temporal patterns of road kills [1, 7, 8, 16].
Modeling and Spatial Analysis: Advanced techniques such as mapping and mathematical equations are employed to predict wildlife movement and mortality locations in recent studies conducted in wildlife reserves. These models help in the optimal employment of crossing structures [3, 25].
Monitoring of Mitigation: Studies evaluate the effectiveness of existing infrastructure, such as underpasses. This done by monitoring their usage by different species using camera traps or surveys [15, 20]. Periodical transect surveys in the highways near forest edges exhibit insect mortality rates in Coimbatore forest division of Tamilnadu. [34].
Meta data inquiry: Large-scale reviews produce data from multiple studies, which bring essential data on road kills animals. His also helps to plan mitigation strategies and conservation planning [14, 18].
Technological Prototyping: Development and testing of innovative systems, such as AI-driven animal detection and IoT-based warning systems, represent a growing field in roadkill research [24].

Findings and Comparative Analysis
The impact of roads varies significantly across different animal groups, influenced by their behavior, movement patterns, and ecological requirements.

Mammals

Mammals are often get into road accidents due to passing in protected area networks. Most of the papers focus on bigger mammals, due to its size, visibility, and conservation status. Large mammals, particularly ungulates and carnivores, are highly susceptible to vehicular collisions on highways passing through dense forest ranges [2].

Species like Chital (Axis axis), Sambar, and Wild Pig are among the most frequent victim groups when compared to others in Western Ghats and Central India [2, 16, 20]. They live in groups and more susceptible to road accidents, shows highest risks [2]. Key stone species such as Tigers and Leopards are also shows significance risk. Even though their overall collision probability may be lower than abundant species, the impact on their populations is severe due to their low density and less reproductive rates [2, 13, 15]. Smaller species also surveyed in roadkilled studies, such as Jungle Cat, Indian Palm Civet, and Black-naped Hare, are commonly recorded in roadkill surveys in southern regions [10, 16]. Habitat fragmentation by roads is one of the major threat to primates such as Golden Langur in Assam [5] and Gray Langur in Maharashtra [3]. Artificial canopy bridges have been employed in Assam to facilitate safe movement for the Golden Langur [5].

Birds

Birds are also reported often roadkill surveys in highways near forest fringes. Many research findings report birds as a major victim in vehicular collisions. Majorly nocturnal birds show high amount of risks due to vehicular collisions, especially Nightjars and Owls are vulnerable, especially on forest roads where they may be blinded by vehicle headlights or forage on edges of roadways [10]. The mortality of endangered species like the Forest Owlet has been documented in Central India [10]. The Black Kites are attracted to roadkill during discard of waste near roadsides, which puts them at risk of being smash by vehicles [9]. The Common Myna (*Acridotheres tristis*) has also reported with high mortality rates in certain urban and agricultural landscapes in Bihar [27].

Reptiles and Snakes

Reptiles, especially snake's shows high mortality rates compared to other vertebrates [4, 8]. Snakes are highly vulnerable due to their slow movement and they often use road surfaces for thermoregulation purposes. Noteworthy roadkill incidents have recorded through various habitats in the Western Ghats and Central India [11]. Common Wolf Snake and Common Garden Lizard [16] are get affected often. Reptile mortality accelerate during the monsoon season, which coincides with their breeding season and dispersal durations [12, 26]. Higher mortality recorded during the nighttime for many reptilian species [26]. Their reliance on specific microhabitats and also slow movements on roads mark them susceptible to the "barrier effect" of highways [4, 11].

Invertebrates and Insects

Studies on road-killed invertebrates is much less when compared to vertebrates. However, the available data suggest substantial impacts. In Anamalai Hills of the Tamilnadu, study records a rate of invertebrate roadkill 7.6 ± 1.81 kills per 10 km [12]. This shows the vulnerability of invertebrates having high risk due to road infrastructure. Another study emphasis on arachnida groups exhibits incidences of roadkill, signifying that these invertebrates are also subject to mortality from vehicular traffic [6, 38]. There is a less amount of studies on invertebrates documented in relation with vehicular collision in the recent times. These highlight the significant gap in the current understanding of road ecology in India [34].

Mitigation Strategies

A range of strategies has been proposed or implemented in India to reduce wildlife mortality and maintain habitat connectivity.

Structural Interventions

Structural modifications bring small scale solutions by providing safe passage for animals across or under roads. Studies recommend Underpasses and Overpasses, which are widely implemented in critical wildlife corridors, such as the Pench Tiger Reserve and along National Highway 44 [2, 20]. Monitoring has shown that ungulates like Spotted Deer and Wild Pig are frequent users of underpasses [20]. Artificial Canopy Bridges (ACBs) specifically designed for arboreal species, have effective in dropping road accidents for the Golden Langur in Assam by restoring connectivity across linear infrastructure [5]. Fencing is often used to direct animals towards safe pathways. However, the design and maintenance of fences are critical, as failures can compromise the effectiveness of ecopassages [16, 21]. Insect diversity also shows high in the forests protected without any roadways and interceptions [35, 36].

Traffic Management and Awareness

Management-based measures focus on altering human behavior and traffic flow. Speed limits, speed breakers are frequently recommended to lower the impact of collisions, especially in ecologically sensitive zones, reserve forest and biogeographic zones [1, 7, 10, 16, 19]. Employing signboards to alert drivers on wildlife crossing areas is a common and relatively low-cost intervention. Hence drivers may take care of the animals during journey inside forest zones [1, 10, 16, 23]. Outreach activities and Community awareness programs are essential for fostering a culture of conservation and encouraging drivers to be more attentive in wildlife-core areas [7, 9, 18, 23]. Regulation of time for heavy vehicle and small vehicles can minimize traffic, can also help reducing species mortality [2].

Technological and Innovative Solutions

In every period, science and innovation brings solutions for modern issues ecosystem face in our country. Recent trends in technology offer new ways to mitigate roadkill. Systems like "PawSense" use AI-equipped cameras for detecting animals and notify drivers or automatically adjust vehicle speeds [24]. Integrating IoT sensors for real-time monitoring and animal detection can significantly enhance road safety for both wildlife and humans. Elephant deaths are reduced in Coimbatore forest division by implementing this AI camera, which detect and sense elephant movements and alert Forest officers. Automatic obstacle revealing systems are being developed specifically for Indian road conditions to assist drivers in avoiding collisions [37].

Conclusion

Vehicular collision in roads near forest fringes reduce the biodiversity wealth of our country. Mitigating roadkill in India is a multifaceted duty collectively to be carried out by all sectors. It is essential task for preserving the country's unique biodiversity. Combining different strategies such as structural interventions, traffic management, and modern technological solutions offers the best hope for reducing wildlife-vehicle collisions. However, the success of these measures depends on rigorous scientific planning, long-term monitoring, and the integration of conservation objectives into the core of infrastructure development. Invertebrates and Vertebrates shows more victim to roadkilled animals in the wildlife rich areas. Collective efforts towards the conservation of biodiversity is important for sustainable and wildlife-friendly road network in India.

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