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Understanding the Ecological Impacts of Roads on Wildlife: A Focus on the Mudumalai Tiger Reserve, India

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Abstract
The rapid expansion of road networks presents significant challenges to wildlife, particularly in biodiversity hotspots like the Mudumalai Tiger Reserve (MTR) in Tamil Nadu, India. This study evaluates the ecological impact of roads on wildlife within the MTR by analysing roadkill data collected over ten months across three road segments: an interstate highway, a state highway, and a secondary road. A total of 343 roadkill incidents were recorded, spanning 42 species, with reptiles (30.32%) and amphibians (27.41%) being the most affected groups. Among the road segments, the interstate highway exhibited significantly more roadkills compared to the state and secondary roads, especially for reptiles and amphibians. Roadkill rates were higher in Dry Deciduous Forest habitats than in Dry Thorn Forests. Notably, the Three-striped Palm Squirrel, Jungle Babbler, and Garden Lizard were identified as the most susceptible species in their respective taxa. This study underscores the urgent need for targeted mitigation measures, such as wildlife crossings and speed restrictions, to reduce road-related mortality in MTR and similar landscapes across India, thereby contributing to biodiversity conservation efforts.

Keywords: Habitat types; Mudumalai Tiger Reserve Road mortality; Roadkill patterns: Wildlife conservation.

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INTRODUCTION

Roads are a ubiquitous feature of modern landscapes, providing essential connectivity for human activities but posing significant challenges to wildlife. The issue of wildlife roadkill—where animals are injured or killed due to collisions with vehicles—is a global concern that has intensified with the expansion of road networks (Schwartz et al., 2020). The rapid growth of these networks is one of the most widespread human activities, fundamentally altering natural landscapes worldwide. While roads are crucial for economic development by facilitating the movement of people, goods, and services, their construction and use have significant environmental impacts (Forman & Alexander, 1998; Samson, 2023).

Roadkill leads not only to the direct loss of individual animals but also contributes to broader ecological disruptions, including habitat fragmentation, altered animal behavior, and declines in vulnerable species. These impacts are particularly severe in biodiversity hotspots where roads intersect with critical wildlife habitats, resulting in frequent and often fatal interactions between animals and vehicles (Grilo et al., 2018; Samson et al., 2016). The consequences extend beyond the physical footprint of the road, affecting surrounding ecosystems and wildlife in multifaceted ways.

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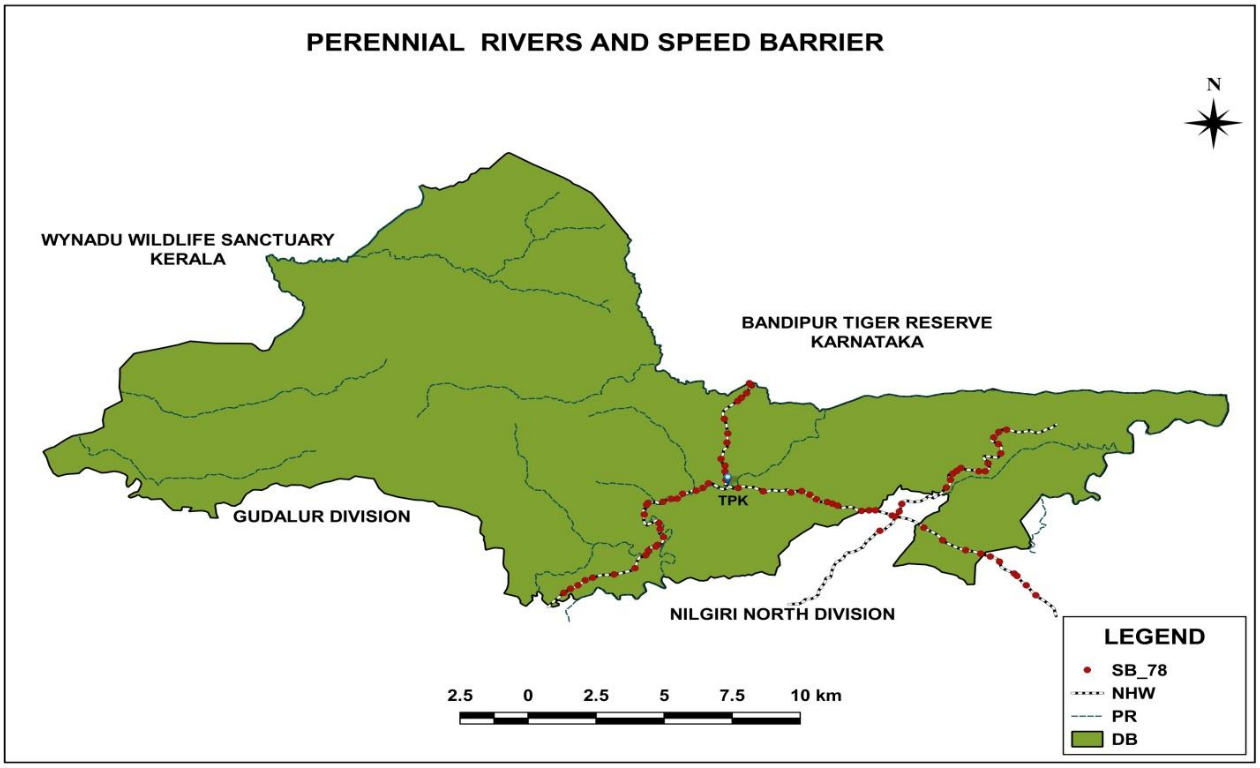

FIGURE 1. Road connectivity for the Mudumalai Tiger Reserve.

The effects of road development include direct impacts such as habitat loss and roadkill, as well as indirect effects like pollution, noise, and barrier effects. The global proliferation of road networks has emerged as a critical concern for biodiversity conservation with profound implications (Spellerberg, 1998). The isolation of populations due to fragmentation can reduce genetic diversity, increasing susceptibility to inbreeding depression, genetic drift, and stochastic events—factors that elevate extinction risk (Harrison, 1994; Opdam, 1990).

Roadkill affects a wide range of species globally, from small reptiles and amphibians to large mammals and birds. Studies across various continents have documented alarming rates of wildlife mortality on roads, underscoring the pervasive nature of this issue (Santhoshkumar et al., 2017; Samson, 2023). In regions like Europe and North America, research indicates that roadkill is a major cause of mortality for species such as ungulates and large carnivores, often leading to significant ecological consequences (Colino-Rabanal & Peris, 2016; Santos et al., 2013). Furthermore, roadkill incidents are concentrated in specific areas known as hotspots, where high traffic volume coincides with critical wildlife habitats (Bager & Rosa, 2010; Jeganathan et al., 2018).

In India, the situation is particularly concerning due to its rich biodiversity and rapid road infrastructure expansion. The country is home to numerous endangered species at risk from road-related mortality. The expansion of roads into forested areas and protected reserves has resulted in significant wildlife roadkill affecting species such as tigers, elephants, leopards, and various smaller mammals and reptiles (Baskaran & Boominathan, 2010; Selvan et al., 2012). This problem is exacerbated by inadequate wildlife-friendly road designs and insufficient mitigation measures that lead to high mortality rates—especially where roads intersect with natural habitats or migratory routes (Saxena et al., 2019; Gubbi et al., 2012; Sur et al., 2022).

TABLE 1. The overall species frequency of road kills in MTR.

S. No	Wild animal categories	No. of kills	Relative Density (RD)	Encounter Rate (ER)	Mean ±SE
1	Mammals	63	18.37	0.063	6.3±0.34
2	Birds	82	23.91	0.082	8.2±0.78
3	Reptiles	104	30.32	0.105	10.4±0.92
4	Amphibians	94	27.41	0.094	9.4±1.20

Several studies have documented the impact of roadkill on India's wildlife, emphasizing the urgent need for effective mitigation strategies. Research in the Nagarjunasagar-Srisailam Tiger Reserve shows that roads can significantly increase mortality rates for mammals, leading to population declines and altered movement patterns (Behera & Borah, 2010). Similarly, in the Western Ghats—a global biodiversity hotspot—roadkill has been identified as a major threat to various species including reptiles and large mammals. These findings highlight the importance of implementing measures such as wildlife crossings, road signage, speed restrictions, and awareness campaigns to mitigate the impact of roads on wildlife (Bansal, 2020; Bhupathy et al., 2011; Kichloo et al., 2022).

The state of Tamil Nadu—particularly the Nilgiris district—presents a critical case study for understanding the ecological impacts of roads on wildlife. The Nilgiris region is home to exceptional biodiversity including species like the Asian elephant and Bengal tiger. However, road expansion through this area—including routes near the Mudumalai Tiger Reserve (MTR)—has led to significant wildlife mortality (Samson et al., 2020; Joshi & Dixit, 2012; Baskaran & Boominathan, 2010). Studies have documented seasonal variations in roadkill incidents within the Nilgiris, with higher mortality rates observed during certain times of the year such as the monsoon season when wildlife movement increases (Jeganathan et al., 2018).

The MTR—a key conservation area for tigers and elephants—has been severely impacted by road-related mortality. Baskaran and Boominathan (2010) noted high rates of roadkill in this area due to roads acting as major barriers to wildlife movement. A study by Samson et al. (2020) identified the three-striped palm squirrel as one of the most frequent victims of roadkill in the Sigur Plateau within the MTR landscape.

Beyond the MTR, roadkill has also been reported from other parts of Tamil Nadu including the Anamalai Hills where plantation roads intersect with natural forests creating significant wildlife-vehicle interactions (Jeganathan et al., 2018). Similarly, patterns of wildlife mortality have been observed in regions like the Kalaburagi-Chincholi corridor in Karnataka indicating that roadkill is a widespread issue across southern Indian states (Hatti & Mubeen, 2019).

These findings underscore the need for a coordinated approach to mitigate the impact of roads on wildlife across the Western Ghats and other critical landscapes in India. This research aims to contribute to understanding the ecological impacts of roads on wildlife by focusing on MTR. By analyzing roadkill data and assessing factors contributing to wildlife mortality in this region, this study seeks to identify key hotspots for roadkill incidents while understanding their seasonal and spatial patterns. Ultimately, it aims to inform policy and management strategies that can help reduce roadkill and enhance biodiversity conservation in MTR and similar landscapes throughout India.

MATERIAL AND METHODS

Study area

Mudumalai Tiger Reserve (MTR), located in the Nilgiris district of Tamil Nadu, is part of the Nilgiri Biosphere Reserve, a critical biodiversity hotspot in the Western Ghats (Fig. 1). Covering 321 square kilometers, MTR is contiguous with Bandipur National Park (Karnataka) and Wayanad Wildlife

Sanctuary (Kerala). The reserve hosts diverse ecosystems, including tropical dry thorn and deciduous forests, supporting species like Bengal tigers, Asian elephants, and numerous reptiles, birds, and mammals. The ecological diversity of the region, coupled with the presence of extensive road networks, makes the MTR an ideal site for studying the impacts of roads on wildlife. The vegetation types along the roads consist primarily of dry deciduous forests and dry thorn forests, each offering distinct habitats that attract different fauna. The reserve is home to iconic species such as the Bengal tiger, Asian elephant, and Indian leopard, as well as a wide variety of reptiles, amphibians, birds, and smaller mammals. However, these roads create barriers to animal movement and contribute to high incidences of roadkills, particularly during certain seasons when wildlife activity is heightened.

Selection of study roads

A systematic roadkill survey was conducted on three public roads in the reserve: an interstate highway segment A–B, a state highway segment C–D, and a secondary road segment E–F. The interstate highway links Karnataka's cultural center, Mysore City, to southern India's famous hill station, Udhagamandalam. Interstate highway runs across Karnataka (Bandipur Tiger Reserve) and Tamil Nadu forests, entering the Mudumalai forest in the north near Kekkanhalla and leaving the forest at Thorappalli. The inter-state highway sampling segment is the 16 km stretch from Kekkanhalla to Thorappalli through the reserve with more traffic intensity. At Teppakadu, the interstate highway becomes a state highway to Udhagamandalam and beyond via Masinagudi, a small village. The state highway sampling leg was 9 km between Teppakadu and Masinagudi. Secondary road sampling was done on the third sector of the 8 km Masinagudi-Moyar road. This road has less traffic than interstates and state highways. These three roads encompass distinct ecosystems and microhabitats.

Quantification of road kills

Road kills were recorded on interstate highways, state highways, and secondary roads passing through Mudumalai Tiger Reserve (33 km). The vegetation type of the road-passing habitats was classified as Dry Thorn Forest and Dry Deciduous Forest (Gokula & Vijayan, 1996). Ten months observations were made from January to October 2016. The study was restricted to amphibians, reptiles, birds, and mammals as major taxa. This stretch of road was traversed thrice a month (10-day intervals) on the motorbike (an observer and driver using a motorbike at a maximum speed of 10 to 15 km/hr). Once during the morning

TABLE 2. Various wild animal road kills were recorded in three different road networks in the Mudumalai Tiger Reserve.

Wild animal categories	**A-B**	**C-D**	**E-F**
Mammals	25	14	24
Birds	30	16	36
Reptiles	39	27	38
Amphibians	75	13	6
Total	163	70	110
Kills per kilometer (KPK)	10.19	10	11

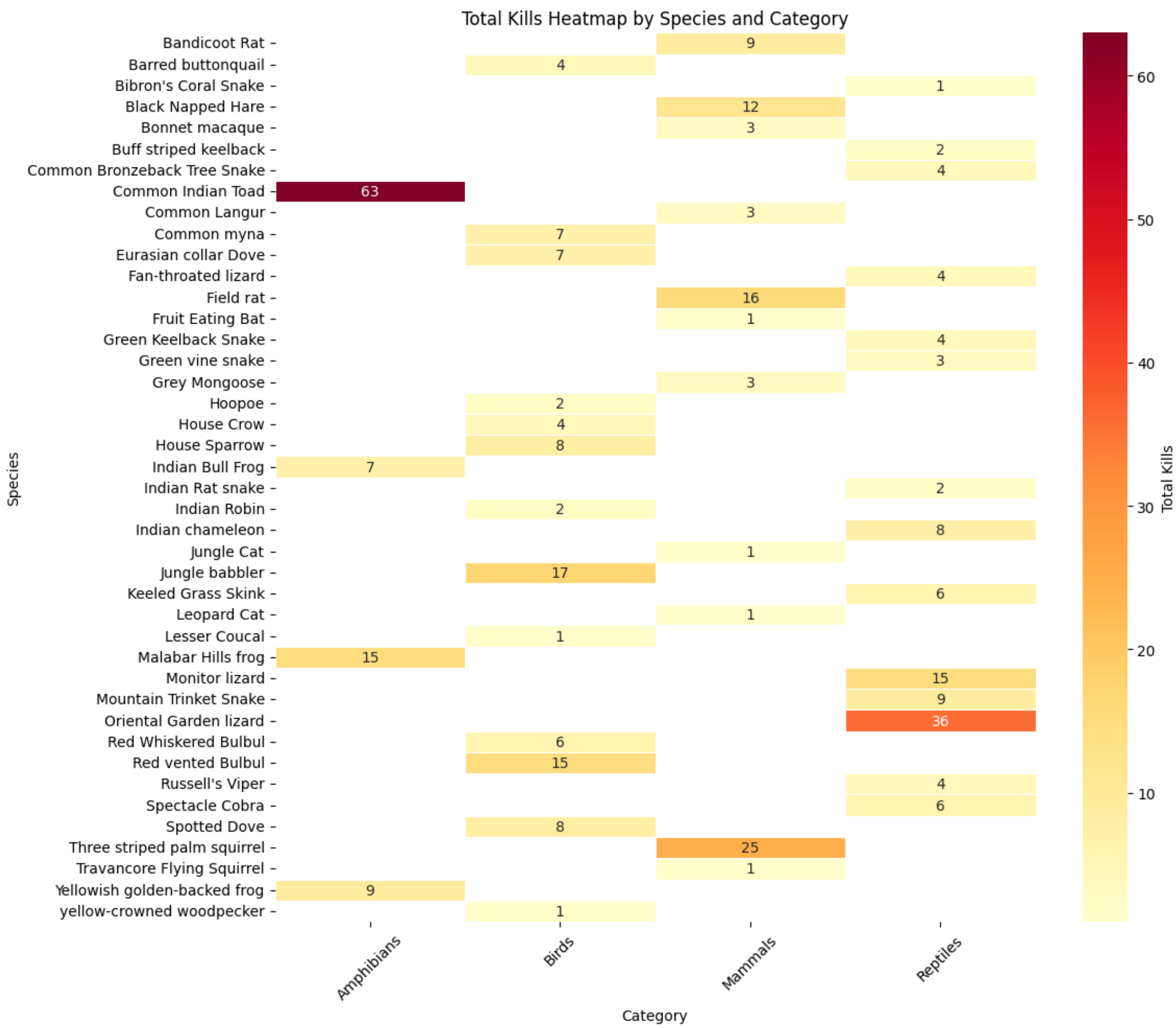

FIGURE 2. Heatmap of species-wise road kills in the MTR.

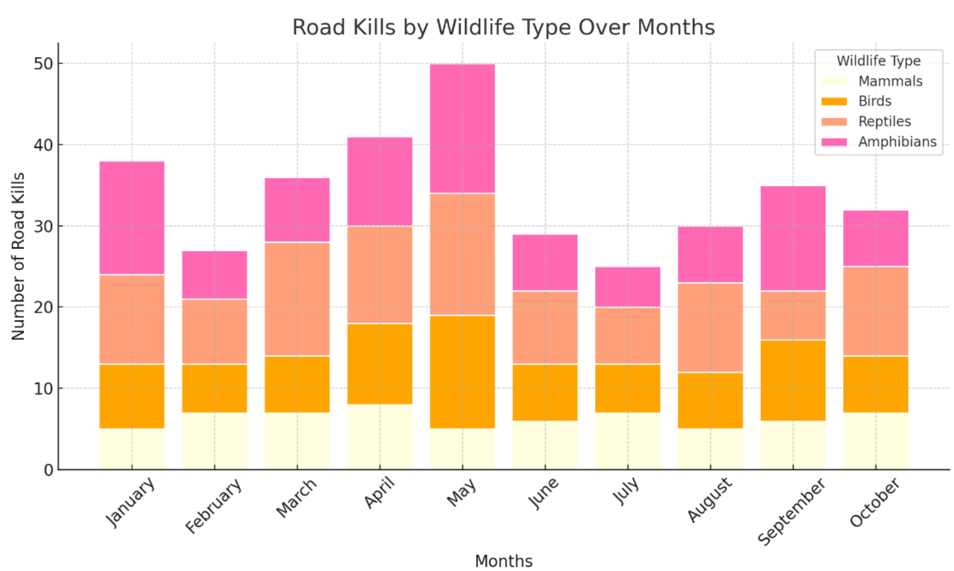

FIGURE 3. Month-wise representation of road kills in the Mudumalai Tiger Reserve.

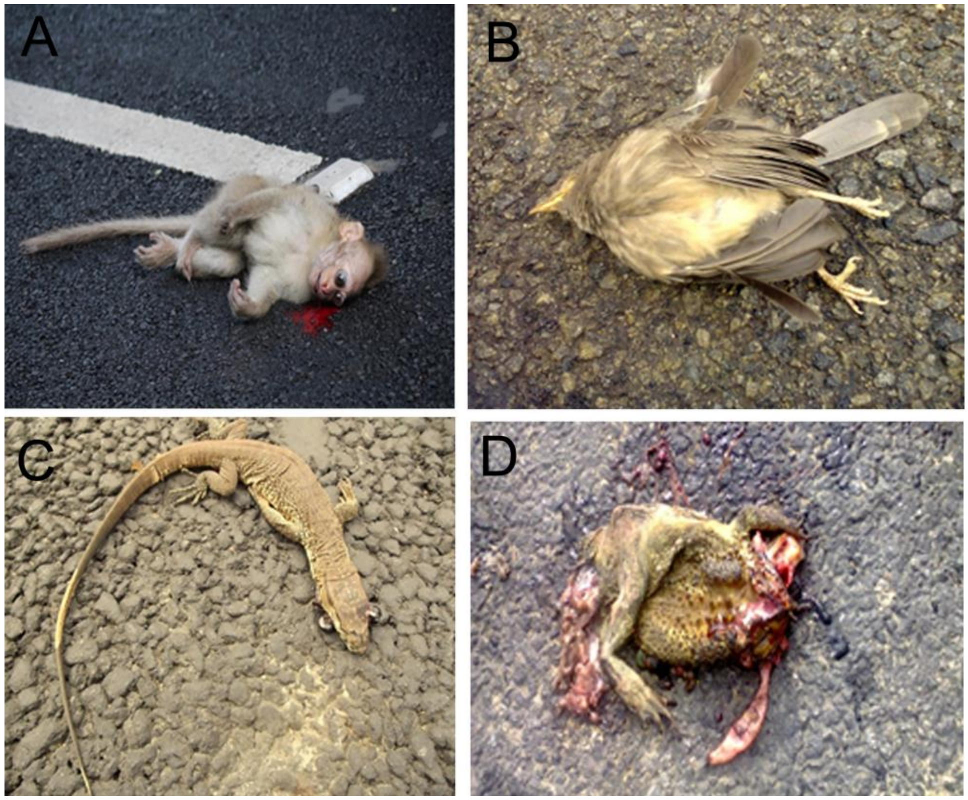

FIGURE 4. Photoplate of the wild animal road kill. A) Bonnet macaque; B) Jungle babbler; C) Monitor lizard; D) Common Indian Toad.

(0600- 0800 h) and evening (1600 - 1800 h), alternatively during the survey period. The road stretch was categorized into two types: road stretch across forested areas (27 km) and road stretch across human habitation (6 km). At each sighting, road kill, information such as the location, type of road stretch, state of the road kill, and climatic condition was recorded.

Statistical Analysis

Descriptive statistics were used to analyze roadkill patterns across taxa, habitats, and road segments. We calculated relative density (RD) and encounter rate (ER) for each major taxa group—reptiles, amphibians, birds, and mammals—to assess their frequency in roadkill incidents. Monthly counts were tabulated to identify seasonal trends. Habitat comparisons were conducted between Dry Deciduous Forests (DDF) and Dry Thorn Forest (DTF) to evaluate differences in roadkill frequency and encounter rate across habitats. Roadkill data were also categorized by road type, covering three road segments: A-B (interstate highway), C-D (state highway), and E-F (secondary road). Additionally, data were pooled by location to compare roadkill occurrences in forested versus developed areas. Findings were organized in tables 1-3, and figures to enable pattern comparisons across taxa, seasons, habitats, and road segments.

Data Verification and Validation

To ensure accuracy, each roadkill observation was recorded by two team members, who cross-checked each sighting. Species identification was verified using field guides(Vivek, 2009; Grimmett et al., 2019), and unidentified specimens were preserved in 10% formalin for subsequent expert confirmation. To prevent recounting, carcasses were removed from the road after documentation (Bager & Fontoura, 2013). Data was logged immediately after each survey, including location, species, and environmental conditions, to maintain consistency and reduce recall errors.

TABLE 3. List of wild animal road kills in the Mudumalai Tiger Reserve.

S. No	Name of the species	Scientific Name	Total Kills	IUCN Status
Mammals				
1	Three-striped palm squirrel	*Funambulus palmarum*	25	Least Concern
2	Field rat	*Rattus rattus*	16	Least Concern
3	Black Napped Hare	*Lepus nigricollis*	12	Least Concern
4	Bandicoot Rat	*Bandicota indica*	9	Least Concern
5	Common Langur	*Semnopithecus entellus*	3	Least Concern
6	Grey Mongoose	*Herpestes edwardsii*	3	Least Concern
7	Bonnet macaque	*Macaca radiata*	3	Vulnerable
8	Fruit Eating Bat	*Pteropus giganteus*	1	Least Concern
9	Leopard Cat	*Prionailurus bengalensis*	1	Least Concern
10	Travancore Flying Squirrel	*Petinomys fuscocapillus*	1	Least Concern
11	Jungle Cat	*Felis chaus*	1	Least Concern
Birds				
1	Jungle babbler	*Turdoides striata*	17	Least Concern
2	Red vented Bulbul	*Pycnonotus cafer*	15	Least Concern
3	Spotted Dove	*Spilopelia chinensis*	8	Least Concern
4	House Sparrow	*Passer domesticus*	8	Least Concern
5	Common myna	*Acridotheres tristis*	7	Least Concern
6	Eurasian collar Dove	*Streptopelia decaocto*	7	Least Concern
7	Red Whiskered Bulbul	*Pycnonotus jocosus*	6	Least Concern
8	House Crow	*Corvus splendens*	4	Least Concern
9	Barred buttonquail	*Turnix suscitator*	4	Least Concern
10	Indian Robin	*Saxicoloides fulicatus*	2	Least Concern
11	Hoopoe	*Upupa epops*	2	Least Concern
12	yellow-crowned woodpecker	*Leiopicus mahrattensis*	1	Least Concern
13	Lesser Coucal	*Centropus bengalensis*	1	Least Concern
Reptiles				
1	Oriental Garden lizard	*Calotes versicolor*	36	Least Concern
2	Monitor lizard	*Varanus bengalensis*	15	Near Threatened
3	Mountain Trinket Snake	*Coelognathus helena*	9	Least Concern
4	Indian chameleon	*Chamaeleo zeylanicus*	8	Least Concern
5	Spectacle Cobra	*Naja naja*	6	Least Concern
6	Keeled Grass Skink	*Eutropis carinata*	6	Least Concern
7	Common Bronzeback Tree Snake	*Dendrelaphis tristis*	4	Least Concern
8	Russell's Viper	*Daboia russelii*	4	Least Concern
9	Fan-throated lizard	*Sitana ponticeriana*	4	Least Concern
10	Green Keelback Snake	*Macropisthodon plumbicolor*	4	Least Concern
11	Green vine snake	*Oxybelis fulgidus*	3	Least Concern
12	Indian Rat snake	*Ptyas mucosa*	2	Least Concern
13	Buff striped keelback	*Amphiesma stolatum*	2	Least Concern
14	Bibron's Coral Snake	*Calliophis bibroni*	1	Least Concern
Amphibians				
1	Common Indian Toad	*Duttaphrynus melanostictus*	63	Least Concern
2	Malabar Hills frog	*Hylarana malabarica*	15	Least Concern
3	Yellowish golden-backed frog	*Hylarana flavescens*	9	Vulnerable
4	Indian Bull Frog	*Hoplobatrachus tigerinus*	7	Least Concern
	Total		343	

RESULTS

A total of 343 roadkills belonging to 42 species (Fig. 3, Table 3) were recorded. Of which 30% were reptiles, 28% were amphibians, 24% were birds, and 18% were mammals.

Reptiles (Table 1.) had the highest relative density (30.32) and encounter rate (0.105), followed by Amphibians (RD -27.41 & ER—0.094), Birds (RD -23.91 & ER—0.082) and Mammals (RD -18.37 & ER—0.063), which were the least encountered.

The roadkill of 11 mammalian species was observed during the survey (Fig 2.). Of which, the Three-striped Palm Squirrel was found to be the most susceptible mammal (n=25; RD=39.68; ER=0.025), followed by the Field Rat (n=16; RD=25.40; ER=0.016) and Black-naped Hare (n=12; RD=19.05; ER=0.012) Fruit-eating Bat, Leopard Cat, Travancore Flying Squirrel, and Jungle Cat had the fewest road kills (n=1; RD=1.59; ER=0.001). For birds, 13 species were killed by roads. The Jungle Babbler was the most susceptible bird (n=17; ER=0.017; RD=20.73), followed by the Red-vented Bulbul (n=15; ER=0.015; RD=18.29), House Sparrow, and Spotted Dove. The Yellow-crowned Woodpecker had the fewest road kills (n=1; ER=0.001; RD=1.22). 14 reptile species were found. The most common species was the Garden Lizard (n=36; ER=0.0036; RD=34.62), followed by the Monitor Lizard (n=15; ER=0.015; RD=14.42) and the Mountain Trinket Snake (n=9). The Skink had the fewest road kills (n=1; ER=0.001; RD=0.96). The Common Indian Toad was the most affected amphibian, which was observed 10 over 18 visits (ER=0.1633; Mean=1.5; SD=0.5; SE=0.35).

The highest number of roadkills (Fig 3.) were recorded in May (n=50), April (n=41), and January (n=38). The lowest were in July (n=25), February (n=27), and June (n=29). Mammal roadkills peaked in April (n=15), with the lowest in January, May, and August (n=5). Bird roadkills were highest in May (n=14) and lowest in February and July (n=6). Reptile roadkills were most frequent in May (n=15) and least in September (n=6). Amphibian roadkills peaked in May (n=16) and were lowest in July (n=5).

Road kills were higher in the Dry Deciduous Forest (DDF) (n=203) than in the Dry Thorn Forest (DTF; n=140). However, the DTF had a higher Encounter Rate (ER=0.42) than the DDF (ER=0.31). The DDF affected amphibians (n=84), reptiles (n=46), birds (n=40), and mammals (n=33). Reptiles were most affected (n=58), followed by birds (n=42), mammals (n=30), and amphibians (n=10) in the DTF. DDF habitats affected amphibians more, while DTF habitats affected reptiles (n=58) and birds (n=42). Roadkill data were collected and pooled based on the legal status of the roads. The results showed that 298 road kills occurred where roads bisected forest areas on both sides, compared to 45 incidents on roads adjacent to development areas.

Of the three roads (Table 2), the A-B road network (Thorapalli to Kakkanalla) had the highest number of road kills (n=163; KPK=10.19). Mammal road kills were highest here (n=25), along with the highest kills for reptiles (n=39) and amphibians (n=75). E-F road network (Masinagudi to Moyar) had the second highest number of road kills recorded on this road (n=110; KPK=10). It had the highest bird road kills (n=36). C-D road network (Theppakadu to Masinagudi) had the lowest number of road kills (n=70; KPK=11). It recorded the lowest road kills for mammals (n=14), birds (n=16), and reptiles (n=27). ER values showed that the E-F road network had a slightly higher rate (0.37) compared to the A-B (0.34) and C-D (0.33) road networks.

DISCUSSION

This study highlights significant patterns in roadkill across taxa within the Mudumalai Tiger Reserve (MTR), revealing the profound impacts of road networks on local wildlife. With a total of 343 roadkills recorded across 42 species, this data provides crucial information on species-specific vulnerabilities, habitat-related risks, and broader conservation implications in this globally recognized biodiversity hotspot. The observed distribution of roadkills across various taxa is (30.32%) reptiles, (27.41%) amphibians, (23.91%) birds, and (18.37%) mammals indicating that reptiles and amphibians are particularly vulnerable to road mortality within MTR. Amongst the results, reptiles and amphibians showed the highest mortality rates (30.32% and 27.41%, respectively), this research aligns with global observations that herpetofauna is particularly vulnerable to roadkill as previously observed by Machado et al., 2015 and Lala et al., 2021). This phenomenon is majorly accounted to the reptile’s preference for warmth on road surfaces (Andrews et al., 2015), exposing them to increased risk as they linger and thereby becoming susceptible to vehicular movements and moralities during breeding seasons and rainy periods (Balčiauskas et al., 2020). Previous studies in similar ecosystems, such as the Western Ghats of southern India, have also documented disproportionately high road mortality rates among reptiles and amphibians, emphasising the widespread risk to these groups in regions intersected by road networks (Vijayakumar et al., 2001; Santhoshkumar et al., 2017).

The high mortality of these species in MTR suggests potential ecological impacts, as declines in herpetofauna could disrupt food webs and essential processes like pest control and nutrient cycling (Ray et al., 2023). Many reptile species are attracted to the warmth of sunlit road surfaces, which helps them regulate body temperature but also increases their exposure to vehicular traffic, making them highly susceptible to road mortality (Shine et al., 2004; Andrews & Gibbons, 2005). These reptiles serve critical ecological roles within their habitats, primarily through pest control as predators of insects and small mammals, and as prey for larger species, contributing to ecosystem stability (Gibbons et al., 2000; Selvan et al., 2012). Their role as mesopredators (Prugh et al., 2009) supports balanced food webs, and their decline due to roadkill could disrupt these dynamics (Dean et al., 2019).

And in the case of the amphibians, specific to this study, the Common Indian Toad, showed high vulnerability in the Dry Deciduous Forest (DDF) habitat, a trend that has been observed in other studies where amphibians are disproportionately affected by road mortality due to their reliance on specific microhabitats like wetlands and moist areas (Baskaran & Boominathan, 2010). This is particularly evident during breeding seasons or after rainfall when amphibians are more likely to cross roads. Studies from other parts of India, such as the Nilgiris and Kaziranga, have also reported similar patterns, underscoring the widespread risk faced by amphibians in road-adjacent habitats (Sur et al., 2022; Samson, 2023).

This elevated roadkill risk for amphibians during breeding seasons or after rainfall is linked to their natural behaviours (Zhang et al., 2018). Amphibians rely on water bodies for breeding, and many species undertake seasonal migrations to reach suitable habitats. Rainfall, especially during monsoon periods, triggers increased movement as amphibians seek out moist environments essential for survival and reproduction. This movement often brings them across roads, heightening their vulnerability to vehicular collisions (Hels & Buchwald, 2001; Fahrig et al., 1995). Studies in other regions, such as Europe and North America, consistently show that amphibians suffer high mortality rates in road-adjacent habitats, underscoring that this is a widespread conservation issue in biodiversity-rich areas (Beebee, 2013; Gibbs & Shriver, 2005).

As these species play a key role in controlling insect and small mammal populations, while amphibians contribute to nutrient cycling and act as bioindicators, their loss impacts broader ecological health (Selvan et al., 2012; Lala et al., 2021). Declines in amphibian populations due to roadkill can disrupt these functions, leading to imbalances in local food webs and altered ecological processes (Hamer & McDonnell, 2008; Collins & Crump, 2009). Conservation strategies to mitigate amphibian road mortality have seen success in similar contexts. These strategies include the use of seasonal road closures during peak amphibian activity, the installation of culverts that serve as safe underpasses, and roadside fencing to direct movement away from high-risk areas (Jochimsen et al., 2004). These structures, especially when positioned in known roadkill hotspots, provide reptiles with alternative routes across roads, preventing direct encounters with traffic (Aresco, 2005). Thermally reflective materials or shaded crossings in high-risk areas can also be used to deter reptiles from using road surfaces thus preventing road-related fatalities (Dodd et al., 2004).These interventions, tested in various parts of North America and Europe, have significantly reduced mortality and can serve as effective models for biodiversity-rich areas. Adopting such measures in places like MTR could help protect amphibian populations and preserve the ecological integrity of the ecosystems they support (Lesbarrères & Fahrig, 2012; Andrews et al., 2005).

Among mammals, smaller species like the Three-striped Palm Squirrel (*Funambulus palmarum*) and the Field Rat (*Rattus rattus*) are the most frequently recorded victims of roadkill. This trend aligns with global research that has observed a higher susceptibility among smaller mammals to road mortality, often attributed to their foraging behaviours and frequent road crossings in search of food (Forman & Alexander, 1998; Seiler, 2001; Selvan et al., 2012). Small mammals are particularly at risk due to their limited home range sizes and lower detection of oncoming vehicles, leading to increased collision rates (Taylor & Goldingay, 2010). Studies in other biodiversity hotspots, such as the Brazilian Atlantic Forest and Costa Rican rainforests, have also noted elevated roadkill rates for small mammals, highlighting the potential impacts on local population structures and ecosystem functions (Coelho et al., 2008; González-Suárez et al., 2018). The ecological implications of high road mortality among these small mammals can be substantial, as they play critical roles in seed dispersal and soil aeration, and serve as prey for higher trophic levels, supporting the overall trophic dynamics of forest ecosystems (Ascensão et al., 2019). Research from the Western Ghats and other mountainous regions in India supports these findings, emphasizing the vulnerability of small mammals to roadkill and the cascading impacts on food webs and ecosystem stability when these populations decline (Pragatheesh & Rajvanshi, 2013; Kichloo et al., 2022).

Birds, though generally less affected than reptiles and amphibians, still experience notable roadkill rates in areas intersected by roads. Species such as the Jungle Babbler (*Turdoides striata*) and the Red-vented Bulbul (*Pycnonotus cafer*) are among the most frequently impacted (Benítez-López et al., 2010; Ray et al., 2023). The tendency of these birds to forage close to roads, where open areas or roadside vegetation may offer feeding opportunities, increases their risk of vehicle collisions (Grilo et al., 2021). Additionally, the presence of attractive road-adjacent habitats, like fruit-bearing trees or insect-rich ditches, further contributes to their vulnerability, as they are drawn into high-risk zones with increased vehicle traffic (Morelli et al., 2015; Miranda et al., 2024). These patterns mirror findings from other regions, such as Northern Spain and parts of Australia, where proximity to roads has been linked to increased mortality rates in bird species due to the concentration of feeding resources or habitat structures near roads (Santos et al., 2013; Kociolek et al., 2011). In India, roads that cut through forested areas or run parallel to wetlands have similarly been documented to disproportionately affect avian populations, particularly species that forage or nest near ground level (Seshadri et al., 2009; Ray et al., 2023).

Collectively, the research indicates that roads not only impact small mammals and birds but also create ecological traps that disrupt local food webs and can lead to altered species dynamics over time (Laurance et al., 2009; Trombulak & Frissell, 2000). The consequences are far-reaching, as these high road mortality rates may diminish the resilience of ecosystems by reducing populations of species that fulfill essential ecological roles, ultimately impacting ecosystem health and stability (Coffin, 2007; Fahrig & Rytwinski, 2009).

Our findings highlight the role of habitat type in influencing roadkill risk. Specifically, Dry Deciduous Forests (DDF) exhibited a higher absolute count of road kills than Dry Thorn Forests (DTF), underscoring the impact of habitat density and biodiversity on wildlife-vehicle interactions (Baskaran & Boominathan, 2010). The increased number of roadkill incidents in DDF habitats may stem from higher animal density, greater biodiversity, and increased habitat attractiveness, which elevate the likelihood of wildlife encountering roads (Selvan et al., 2012; Grilo et al., 2021). Interestingly, while DDF habitats had a higher number of total incidents, the encounter rate was highest in DTF habitats, which suggests that roads in more open environments, despite supporting fewer animals, may expose those present to greater per-kilometre risks due to lower visibility, fewer natural barriers, and increased vehicular speeds in open areas (Santhoshkumar et al., 2017).

Habitat Influence on Roadkill Rates

The study's findings that roadkill rates were higher in DDF habitats compared to Dry Thorn Forest (DTF) areas underscore the importance of habitat type in influencing roadkill risk. The denser vegetation and higher biodiversity of DDF likely contribute to the higher absolute number of roadkills, as more animals are present and may be forced to cross roads more frequently (Baskaran & Boominathan, 2010). These findings are supported by similar studies in other Indian reserves, where denser habitats have been associated with higher roadkill rates (Magar et al., 2022).

Interestingly, while DDF habitats recorded a higher total number of roadkills, the higher encounter rate in DTF suggests that roads in this habitat type, despite supporting fewer animals overall, may pose a greater per-kilometre risk to wildlife. The more open nature of DTF habitats might increase the visibility of animals to drivers, but it also increases the likelihood of animals being hit if drivers notice them too late (Selvan et al., 2012). This is consistent with findings from the Kashmir Himalayas, where open habitats along mountainous highways were associated with higher rates of roadkill (ul Haq et al., 2022). The habitat-specific patterns of roadkill also reflect the spatial distribution of different species within MTR. Amphibians were most affected in DDF habitats, likely due to the presence of seasonal water bodies and moist microhabitats that attract these species (Baskaran & Boominathan, 2010). In contrast, reptiles and birds were more frequently killed in DTF habitats, possibly due to the higher exposure and lower cover in these areas, making them more vulnerable to road mortality (Santhoshkumar & Kannan, 2017). Similar patterns have been observed in other studies across the Western Ghats, suggesting that habitat structure and quality play a critical role in determining roadkill risk (Vijayakumar et al., 2001).

Road Type and Wildlife Mortality

The study revealed that roadkills were most frequent on roads bisecting forest areas, accounting for 86.88% of all roadkills, with the A-B road network (Thorapalli to Kakkanalla) recording the highest number of roadkills. This finding aligns with global patterns where roads that cut through or border protected areas pose significant threats to wildlife (Grilo et al., 2021; Lala et al., 2021). The A-B road's high roadkill rates can be attributed to its location in areas of high biodiversity, combined with factors such as high traffic volume and speed, lack of mitigation measures, and possibly higher wildlife density near these roads (Baskaran & Boominathan, 2010). In contrast, the E-F road network (Masinagudi to Moyar), while recording the second-highest total roadkills, had the highest number of bird roadkills. This may be due to the road's alignment with bird movement corridors or proximity to key habitats like nesting or feeding sites (Samson et al., 2016). The patterns observed here echo findings from other regions where roads intersecting key habitats, such as wetlands or forest edges, have been shown to disproportionately affect bird species (Saxena et al., 2019).

Similarly, the C-D road network (Theppakadu to Masinagudi), which had the lowest overall roadkills, still posed a significant threat to reptiles and mammals. This suggests that even roads with lower traffic volumes or less direct alignment with key habitats can still have substantial impacts on wildlife, particularly if they act as barriers or bisect critical habitats (Grilo et al., 2021). These findings are consistent with studies from other Indian reserves where even low-traffic roads have been shown to significantly impact wildlife, particularly in regions with high biodiversity and complex terrain (Patel et al., 2023). The roadkill rates per kilometer (KPK) further highlight the variation in wildlife mortality risk across different road sections. The slight differences in encounter rates among the road networks suggest that while some roads may pose a higher overall risk due to factors like traffic volume or road alignment, others may still be significant due to specific local factors, such as habitat quality, species presence, or road design features (Selvan et al., 2012). This finding is supported by research from the Kaziranga-Karbi Anglong landscape, where roadkill rates varied significantly across different road sections depending on habitat and species distribution (Sur et al., 2022).

Implications for Conservation

The findings from this study underscore the urgent need for targeted conservation measures to mitigate roadkill in MTR. The high mortality rates, particularly among reptiles and amphibians, suggest that these groups should be a primary focus of conservation efforts. Potential strategies include the construction of wildlife corridors or underpasses specifically designed for these taxa, as well as seasonal road closures or speed reductions during peak activity periods (Grilo et al., 2021; Machado et al., 2015). These measures have been successfully implemented in other regions, such as the Anamalai Hills and Nagarjunasagar-Srisailam Tiger Reserve, where they have significantly reduced roadkill rates (Behera & Borah, 2010; Vijayakumar et al., 2001). Additionally, enhancing driver awareness through signage and public education campaigns could help reduce wildlife-vehicle collisions, particularly on roads that pass through high-risk areas like the A-B and E-F networks (Samson, 2023). Studies from the Sigur Plateau and Nilgiris have shown that public awareness campaigns, combined with clear signage, can lead to a significant reduction in roadkill incidents (Santhoshkumar et al., 2017). Given the significant impact of roads that bisect forest areas, it is crucial to incorporate roadkill mitigation into broader conservation planning. This might include reevaluating existing road alignments, implementing wildlife crossings at key points, and restoring habitats adjacent to roads to reduce the likelihood of animals needing to cross (Baskaran & Boominathan, 2010). For example, the creation of dedicated wildlife corridors in the Periyar Tiger Reserve has been successful in reducing the fragmentation of wildlife habitats and minimizing roadkill incidents (Rajvanshi et al., 2001).

Moreover, ongoing monitoring of roadkill incidents is essential to assess the effectiveness of these measures and to identify emerging hotspots or species at risk (Selvan et al., 2012). Regular monitoring and adaptive management strategies have been successfully implemented in other reserves, such as the Bandipur Tiger Reserve, where they have helped refine conservation strategies and reduce roadkill over time (Patel et al., 2023). The study also highlights the need for a landscape-level approach to conservation in MTR, recognizing that roadkill is not just a local issue but one that can have broader implications for ecosystem health and biodiversity. By integrating roadkill data with other ecological data, such as population dynamics, habitat use, and movement patterns, conservationists can better understand the cumulative impacts of roads on wildlife and develop more effective strategies to protect the biodiversity of the MTR and similar ecosystems (Grilo et al., 2021). This approach has been successfully applied in other regions, such as the Western Ghats, where landscape-level conservation planning has helped mitigate the impacts of infrastructure development on wildlife (Rajvanshi et al., 2001).

CONCLUSION

This study highlights the severe impact of road networks on wildlife within the Mudumalai Tiger Reserve (MTR), with reptiles and amphibians particularly vulnerable to road mortality. The patterns of roadkill, which vary by species and habitat, highlight the urgent need for targeted conservation strategies. High roadkill rates among reptiles, amphibians, small mammals, and certain bird species reveal complex interactions between wildlife behaviour, habitat preferences, and road infrastructure. These interactions contribute to disruptions at the ecosystem level. Conservation efforts like wildlife corridors, underpasses, and public awareness campaigns are essential to protect MTR's biodiversity. By incorporating these strategies into a landscape-level conservation framework and supporting them with continuous monitoring, we can help preserve the ecological integrity of MTR. Such efforts are vital to mitigate the broader impacts of road-induced wildlife mortality in biodiversity-rich areas.

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