Assessing Road Impacts and Mitigation Options for Wildlife in Kafue National Park and the Greater Kafue Ecosystem, Zambia

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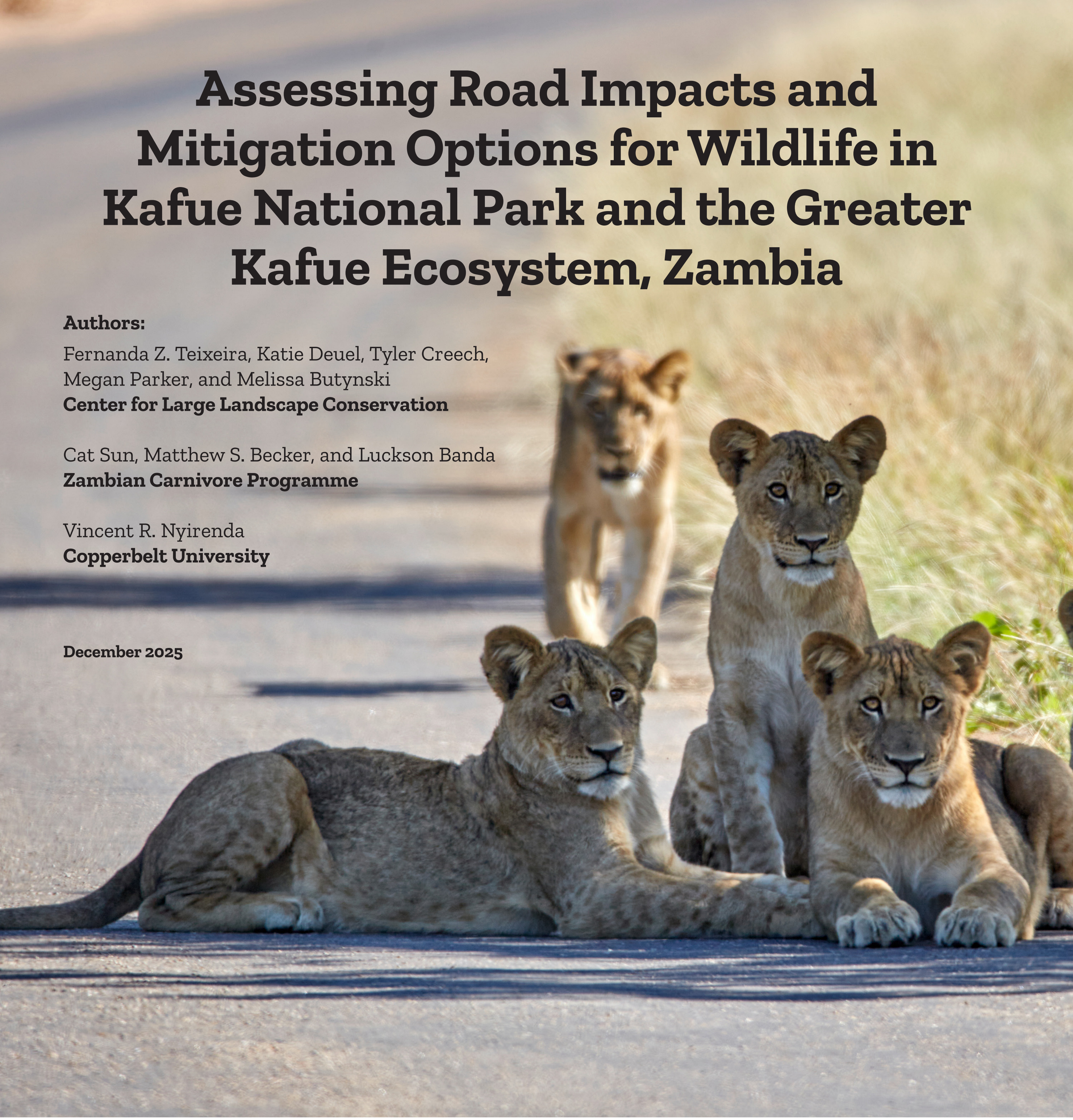

CENTER for LARGE LANDSCAPE CONSERVATION

Zambian CARNIVORE PROGRAMME

Kafue National Park Zambia

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Executive Summary

Kafue National Park, or KNP, (22, 400 km^2), IUCN Category II, Zambia's largest and oldest protected area, is a biodiversity stronghold hosting elephants, lions, cheetahs, wild dogs, and Africa's richest antelope community. Despite its importance and relatively high levels of resource protection, KNP faces a major threat from the M9 road, which cuts across 138 km of its landscape and has become notorious for wildlife-vehicle collisions. Since the road's upgrade in 2006, increased traffic speed and volume have driven higher wildlife multi-species mortality and disrupted animal movements, undermining population abundance and persistence. This project was initiated in recognition of KNP and its surrounding area's ecological value, the urgent need to mitigate road impacts on wildlife and people, and the opportunity to develop transferable protocols and recommendations for road ecology across Africa, building on previous studies and strong partnerships with the Zambian Carnivore Programme (ZCP).

In this report, we build on long-term data collected in the field and the knowledge of engaged stakeholders to identify relevant mitigation measures for the M9 road within KNP. Through spatial analysis, we pinpoint priority sites along the M9 where mitigation actions should be designed and implemented. Using a composite priority index, we combined roadkill data with data from wildlife sightings, and telemetry data to identify priority road segments for mitigation. The report presents a comprehensive assessment and spatial analysis of the impacts of the M9 road on KNP's wildlife, with particular attention to areas concentrating wildlife activity and mortality.

This study assessed wildlife-vehicle interactions along the M9 road in KNP and proposes practical mitigation measures. Immediate priorities include speed reduction and control in priority road segments, and law enforcement. Medium-term actions focus on relocating artificial water sources, restricting nighttime truck traffic, and applying average speed enforcement. These measures have the potential to substantially reduce wildlife mortality, enhance habitat connectivity, and improve road safety—securing both conservation outcomes and human benefits. Ongoing monitoring of roadkill and animal activity is essential to evaluate effectiveness and guide future interventions using an adaptive management approach. The framework developed here also offers a model for addressing road impacts in other protected areas across Africa.

Photo by Zambian Carnivore Programme

Introduction

Road Impacts on Wildlife

For wildlife populations to thrive, they must be able to move freely across the landscape, access mates and resources, and maintain high survival rates. Protected areas are established to safeguard important ecosystems, enabling species to persist and flourish while conserving biodiversity and ecosystem services. However, these areas are frequently intersected by roads and other infrastructure—not only to facilitate access for tourists and park management, but also to support the transport of goods through them—that fragment habitats and pose significant risks to wildlife (Ament et al., 2007, Ibisch et al., 2016).

Road networks are expanding rapidly across the globe, with projections indicating a particularly sharp increase in developing countries located in biodiversity-rich regions (Meijer et al., 2018). Globally, projections point to a tentative estimate of 3.0–4.7 million km of additional road length by the year 2050 when considering future population densities and GDP estimates (Meijer et al., 2018). Across Africa, road expansion is occurring at an unprecedented pace, driven by rapid economic growth, increasing trade, and the need to connect remote regions with urban centers. Major infrastructure initiatives aim to integrate markets and improve access to essential services (Laurance et al., 2017).

Much of this development is taking place in biodiversity-rich landscapes and areas of high ecological sensitivity, where new roads can fragment habitats, disrupt wildlife movement, accelerate land-use change and affect ecosystem services (Laurance et al., 2014). Without careful conservation planning and mitigation, the benefits of enhanced human and transport access can be undermined by significant and often irreversible environmental impacts. The spread of such extensive infrastructure inevitably fragments landscapes, disrupting habitat connectivity and ecological processes, and generates a range of environmental impacts that can extend thousands of meters from the road corridor. Roads can impact ecosystems directly by causing habitat loss, alterations in habitat quality, the spread of invasive species, increasing chemical, solid waste, and noise pollution, and increasing wildlife mortality from collisions, among other impacts (van der Ree et al., 2015) (Figure 1).

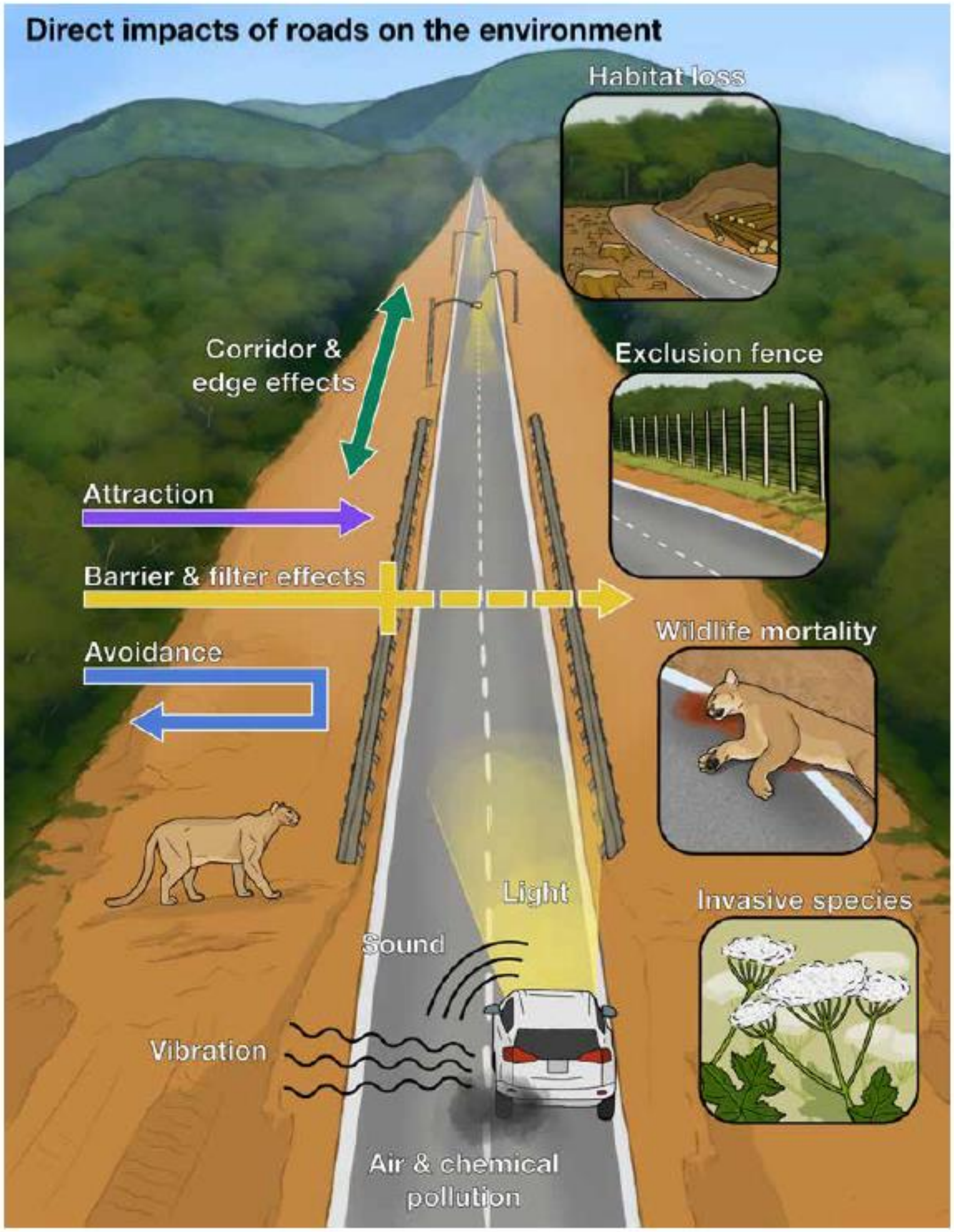

Figure 1. Direct impacts of road infrastructure on the environment. From: Ament et al. 2024.

It is estimated that wildlife-vehicle collisions cause the deaths of approximately 400 million vertebrates globally each year (Schwartz et al., 2020), making it one of the leading causes of vertebrate mortality in terrestrial environments (Hill et al., 2019). These figures likely underestimate the actual impact due to biases in monitoring, including the difficulty of detecting carcasses, the rapid removal of carcasses by scavengers or environmental factors (Teixeira et al., 2013), and the lack of systematic monitoring in many regions. Such mortality has the potential to affect the long-term persistence of wildlife populations by removing individuals, thereby reducing population abundance and eroding genetic diversity (Jackson and Fahrig, 2011).

Road Impacts in Zambia

Zambia has a road network of more than 40,000 km, with a projected 46% increase in the road network by 2050 considering population densities and GDP estimates (Meijer et al., 2018). This surge in development is at odds with Zambia's designation of nearly 40% of its land as protected areas, which are nonetheless frequently breached by infrastructure encroachment, particularly in Game Management Areas, GMAs (IUCN Category VI) (Figure 2).

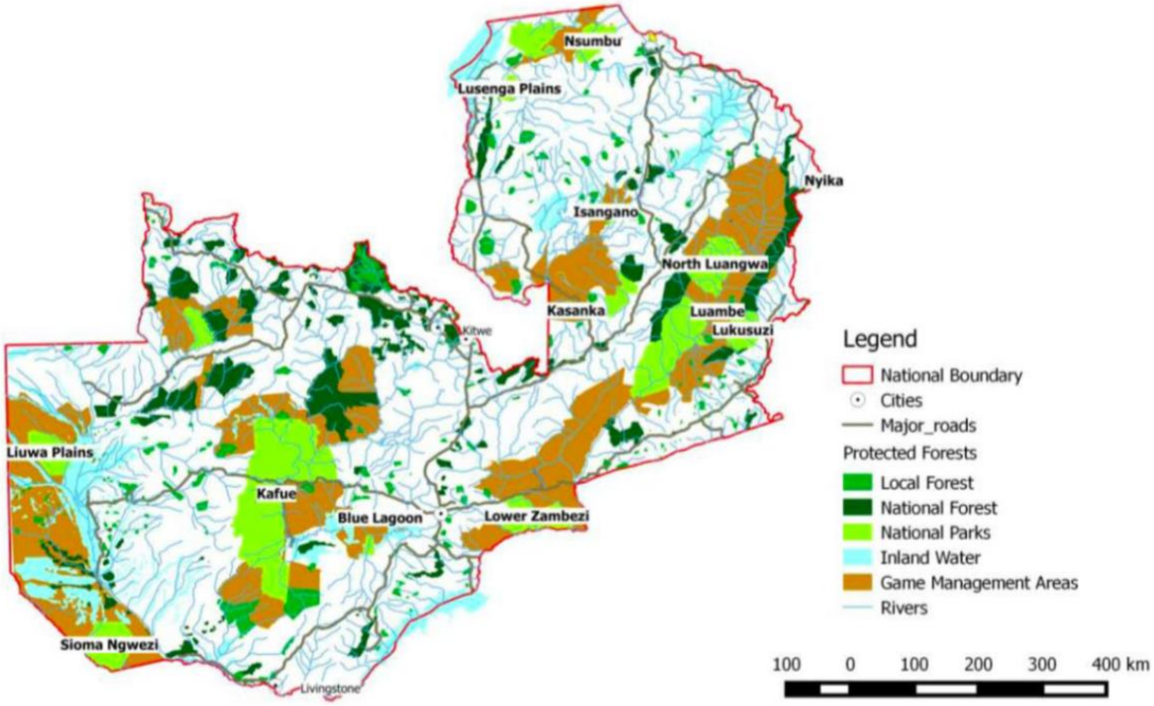

Figure 2. Statutory Protected Areas cover approximately 40% of the Zambia's landmass, according to the Zambian Ministry of Lands, Natural Resources and Environmental Protection (MLNR).

At the heart of Zambia's Greater Kafue Ecosystem is the 22,400-km^2 KNP, created as a game reserve in 1950, which attained its full status under the National Parks and Wildlife Act in 1972 (Mkanda and Chansa, 2011). The KNP is home to a diverse range of iconic wildlife, including elephants, lions, leopards, cheetahs, wild dogs, a diverse avian community, and Africa's most diverse antelope community. This protected area faces many significant threats, but most concerning is the wildlife-vehicle-collision-prone, high-speed M9 road that slices across the landscape, bisecting or bordering nearly 150 km of the Park and bordering the adjacent Mumbwa GMA (Figure 3).

In recognition of the importance of protected areas in Zambia to sustainable livelihoods, human and ecosystem health, the importance and uniqueness of KNP to the overall landscape, and the opportunity to not only assess but to potentially mitigate road impacts in Zambia were essential factors in choosing to work in this park at this time. Also contributing to the decisions were the potential for this undertaking to be a model for other parks, and the strong partnership and considerable data provided by Zambian Carnivore Programme. We intend that the protocols developed during this project will inform future projects in other African parks where road mitigation is needed to support healthy wildlife populations, and the recommendations and mitigation measures are relevant.

Figure 3. Kafue National Park and surrounding Game Management Areas. The M9 road bisects the Park for nearly 150 km, posing a risk to wildlife and drivers.

The M9 is notorious for wildlife-vehicle collisions, including the loss of 11 endangered African wild dogs to vehicle collisions in 2022 alone. The M9, improved in 2006, poses a dual threat to wildlife conservation in KNP: increased traffic speed and volume have led to elevated wildlife mortality and the road acts as a significant barrier to animal movement between core areas and proposed habitat corridors, such as the Kafue-Simalaha Wildlife Dispersal Corridor. A previous study showed a 45% increase in traffic after the rehabilitation of the M9 road, followed by a 50% increase in roadkill sightings when animal density estimates in the Park remained the same (Mkanda and Chansa, 2011). A study developed prior to the rehabilitation (Chansa, 2005) recommended the installation of speed humps, which were constructed at the mortality hotspots identified by Chansa (2005) (e.g., at Mukambi, Mwanamukinda).

In 2022, the Zambian government signed a 20-year management agreement with African Parks for KNP aimed, in part, at increasing wildlife populations and their associated economic benefits. Consequently, as KNP's wildlife populations may begin to increase, there is a pressing need to assess and mitigate the negative effects of the road to ensure driver safety, preserve biodiversity in the Park, and ensure ecological connectivity throughout the region.

Objectives

In this report, we build on long-term data collected in the field and the knowledge of engaged stakeholders to identify relevant mitigation measures for the M9 road within KNP. Through spatial analysis, we pinpoint priority sites along the M9 where mitigation actions should be designed and implemented. The report presents a comprehensive assessment and spatial analysis of the impacts of the M9 on the Park's wildlife, with particular attention to areas of concentrated wildlife activity and mortality.

Methods

Overview

In order to identify the priority sites along the M9 road where mitigation actions are needed, we considered four themes that represent different sources of data for prioritizing a road segment for mitigation: (1) wildlife-vehicle conflict, (2) wildlife observations near roads, (3) wildlife road crossings obtained from telemetry, and (4) habitat suitability. We then applied a fine-scale analysis to quantify the relative importance of each road segment for mitigation by combining the different layers of information (Creech et al., 2025). Below, we describe the data and methods used to evaluate road segments with respect to each indicator.

Field-based Collection of Wildlife Data

From May 2024 to May 2025, the Zambian Carnivore Programme (ZCP) conducted vehicle-based wildlife surveys of the 138-km segment of the double-laned M9 road that cuts through KNP in Zambia. Field teams were based out of the ZCP Kafue field camp at GPS Lat/Long: -14.959640/25.995328, close to the Mukambi M9 road junction (Table 1).

Table 1. Location of exits, entrances, and other points of traffic interest on the M9 tar road bisecting through Kafue National Park, Zambia.

Landscape Feature	Latitude	Longitude	Description
Nalusanga Gate	-14.971659	26.708019	Eastern extent of M9 study
Tateyoyo Gate	-14.895899	25.430803	Western extent of M9 study
21 km Gate	-14.947440	25.853694	Southbound access into park
Lufupa Gate	-14.943176	25.906014	Northbound access into park
Mukambi Junction	-14.959735	25.995306	Start/end per systematic survey
Itezhi turn-off	-14.971660	26.451570	Local traffic to the south (non-park)
Hook Bridge	-14.945275	25.913374	Over the permanent Kafue River
Trafx counter	-14.959235	26.004327	Under a culvert
Culvert 1	-14.959235	26.004327	Has the Trafx counter in the southern, eastbound lane
Culvert 2	-14.94056	25.893183	
Rumble strip/speed hump 1	-14.959003	25.712464	
Rumble strip/speed hump 2	-14.965211	25.782286	
Rumble strip/speed hump 3	-14.963104	25.795855	
Rumble strip/speed hump 4	-14.95245	25.834495	
Rumble strip/speed hump 5	-14.940453	25.87817	
Rumble strip/speed hump 6	-14.951703	25.944383	
Rumble strip/speed hump 7	-14.956629	25.967029	
Rumble strip/speed hump 8	-14.967394	26.11059	
Rumble strip/speed hump 9	-14.968058	26.537702	
Rumble strip/speed hump 10	-14.958899	26.011128	

Scheduled roadkill (RK) surveys occurred in the mornings approximately every 10 days with the primary purpose of detecting wildlife carcasses. A team consisted of one person driving 30-40 km/h and at least one observer. When carcasses on the road were detected, the species, age class, and sex were recorded, as well as the characteristics of the site. These characteristics included the status of the road verge (slashed, partially slashed, or overgrown), evidence of fire within 200 m, habitat, nearby attractants such as green grass or human garbage, and presence of scavengers. In addition to carcasses, data were collected for live animal observations within 50 m of the road edge (including animals actively crossing the road) during RK surveys. Data were collected with the SMART platform on a tablet, which also recorded a GPS track of the survey. Consecutive surveys alternated between direction (eastbound and westbound) and starting location (the Mukambi lodge turn-off, the eastern Nalusanga gate, and the western Tateyoyo gate). Surveys aimed to start at dawn and ended as soon as the survey was complete.

Distance sampling (DS) surveys for mammals (herbivores and primates) occurred with every third occasion of the scheduled roadkill surveys, i.e., at an average frequency of once every 31 days, in the direction that the roadkill survey was not conducted. In effect, DS surveys originated at the Mukambi junction and were driven in either the eastbound or westbound direction, with the scheduled roadkill survey conducted on the return drive back. One driver drove at approximately 30 km/h with at least one observer who recorded the species, group size, distance to group, compass bearing to group, vehicle bearing, and site characteristics similar to the RK survey site characteristics.

In addition, opportunistic data on the location and species identification of carcasses on the M9 road were collected from reports by partner organizations [including citizen science (CS) data] and by ZCP field teams driving on the M9 outside of scheduled RK and DS surveys.

The location of landmarks and road features potentially relevant to traffic and wildlife-vehicle interactions were recorded (Table 1). These include traffic-calming rumble strips and speed humps, and two Park gates that lead into the Park from the M9 road.

Telemetry Data

ZCP has worked on large carnivore conservation in the Greater Kafue Ecosystem since 2011, and the ZCP Kafue Project is now one of the longest-running and most productive ecological projects in the region. High-quality (QFP) GPS data from 23 Telonics collared cheetah (n=8), spotted hyena (n=1), lion (n=4), and wild dog (n=10) were collected between May 2024 and May 2025 and used to identify locations where large carnivores crossed the M9 road.

Traffic Volume Data

Finally, a TRAFx counter was installed on July 10, 2024, in a culvert directly underneath the southern, eastbound lane of the M9 road (Table 1). The counter aimed to help characterize traffic volume and temporal patterns on the M9 road between the Tateyoyo and Nalusanga gates. The counter recorded hourly counts of traffic using a modified electromagnetic metal detector. Data were downloaded every few months, until March 11, 2025 (date of last download). To assess the precision of the traffic counter, on average every 40 days a ZCP field team recorded the type and direction of travel of all vehicles passing the road counter for 1-2 hours.

Analysis

Wildlife Datasets

Data from surveys, carcass reports, telemetry data from large carnivores collared by ZCP, and habitat data were used to identify priority regions of the M9 road for considering wildlife-vehicle conflict mitigation strategies. Broadly, this was done by scoring segments of the road according to each of the datasets on 0-1 scales and then combining scores across datasets using a weighted average approach. Datasets were grouped into themes (Table 2), which were given equal weighting, but datasets and species within themes could be weighted differently. The 138-km section of the M9 road between Tateyoyo gate to the west and Nalusanga gate to the east was divided into 1-km segments. This approach closely followed Creech et al. (2025).

Table 2. Breakdown of themes, constituent datasets, and their weights and sample sizes used in a weighted-sums approach to prioritize areas of the M9 tar road through Kafue National Park, Zambia. Data were collected between May 2024 and May 2025.

Theme	Theme Weight	Dataset	Dataset Weight within Theme	Sample size	Comments
Wildlife-Vehicle Conflict	0.25	Roadkill survey	0.6	67 surveys	Systematic surveys approximately every 10 days
		ZCP sightings	0.2	35	Opportunistic with no effort information
		Citizen Science sightings	0.2	30	Opportunistic sightings, with no effort information, by partner organizations
Wildlife Observations	0.25	Live sightings during Roadkill survey	0.4	67 surveys	Systematic surveys approximately every 10 days
		Distance Sampling	0.6	23 surveys	Systematic surveys approximately every 31 days
Wildlife Crossings	0.25	GPS collared cheetah	0.35	725 points	From 8 individuals
		GPS collared spotted hyena	0.04	1708 points	From 1 individual
		GPS collared lion	0.17	5296 points	From 4 individuals
		GPS collared wild dog	0.43	8835 points	From 10 individuals
Habitat Suitability	0.25	Distance to permanent water	0.5	NA	
		Distance to seasonal water	0.5	NA	

Wildlife species detected in the scheduled roadkill (RK) surveys, DS surveys, and CS and ZCP carcass reports were grouped into 11 taxonomic groups. The spatially referenced wildlife observations were aggregated into taxonomic-specific counts and assigned to the 1-km segments. The segment-specific counts from RK and DS surveys were further standardized to 31 days based on the average survey frequencies. Finally, within each dataset, the segment-specific counts per taxonomic group were scored from 0 to 1 relative to the other road segments, following ($value_i$ – min)/(max-min) for each road segment *i*, from *i =1, …, 138*. In this way, segments with a 1 had the maximum counts and segments with a 0 had the smallest (0) counts.

For the telemetry data, GPS fix intervals varied by species, individual, and time due to field monitoring needs and battery considerations, ranging from every 2 hours to intermittently every few days. GPS points were removed as outliers if they resulted in inferred hourly speeds for an individual greater than the third quartile + 1.5*inner quartile range of speeds of that individual. Locations of road crossings for each individual were associated with the 1-km road segments. As only the location of road crossings and not the number of road crossings was calculated, each road segment took on only a 0 or 1 value per individual. Therefore, scoring road segments from 0 to 1 occurred only after aggregating across all collared individuals.

Permanent rivers and seasonal streams within 100 m of the M9 road were identified using multiple spatial GIS layers. The distances of each road segment to the closest permanent and seasonal water source were calculated. Distances per road segment were then converted to a score from 0-1 but required an addition step of taking the complement of the score, i.e., $1-score_{water}$, so that areas closer to water (smaller distances) would score higher (closer to 1).

Wildlife Dataset Weighting and Road Prioritization

The taxonomic groups for species, in datasets under the Wildlife-Vehicle Conflict and Wildlife Observation themes, were ranked according to an *a priori* determined priority (Table 3), so that their ranks influenced scores for road segments. This was necessary to capture the priority of a roadkilled cheetah, for example, over a roadkilled squirrel. Ranks within datasets were relative to what other taxonomic groups were present within the datasets. For example, while large ungulates were always ranked after large carnivores, their relative rank value would be the greatest in a dataset if large carnivores were not present in that dataset.

Table 3. Animals that the Zambian Carnivore Programme field teams detected during roadkill and distance sampling surveys of the M9 road through Kafue National Park, Zambia, from May 2024 to 2025 were grouped into 11 taxonomic groups, ranked in importance. A total of at least 58 different species were detected.

	Large Carnivore	**Large Ungulates**	**Medium-sized Ungulates**	**Vultures and Birds of Prey**	**Small, Medium-sized Carnivores**	**Small Ungulates**	**Birds**	**Reptiles**	**Small Mammals**	**Primates**	**Livestock/ Domestic**
Rank	**Most important**						**Least Important**				
Species	Lion	Buffalo	Bushbuck	Vulture spp.	Civet	Common duiker	Dove spp.	Snake spp.	Bush baby	Baboon	Cattle
	Hyena	Roan	Impala	Owl spp.	Genet	Sharpes grysbok	Nightjar spp.	Monitor lizard spp.	Scrub hare	Vervet Monkey	Goat/Sheep
	Wild dog	Eland	Puku	Yellow-billed kite	Serval	Oribi	Helmeted guineafowl	Tortoise spp.	Porcupine		Dog
	Cheetah	Elephant	Waterbuck		Honey badger		Francolin spp.	Crocodile	Squirrel spp.		
	Leopard	Hartebeest	Reedbuck		Side-striped jackal		Western cattle egret		Shrew spp.		
		Sable			Mongoose spp.		Water thick-knee		Warthog		
		Hippo					Crane spp.		Bushpig		
		Kudu					Duck spp.				
		Zebra					Goose spp.				
							Stork spp.				
							Heron spp.				
Total											
58	5	9	5	3	6	3	11	4	7	2	3

The relative ranks of taxonomic groups determined their weights for scoring within each dataset in the following way. The least important groups (birds, reptiles, small mammals, primates, and livestock/domestic) were collectively assigned rank 1, and increasingly more important groups were assigned consecutively higher ranks (2, 3, 4, etc.). For all categories ranked greater than 1, their weights were their ranks divided by the nth triangular number (sum of the unique rank values). For example, for a group ranked 2nd (second to least important) in a dataset with a maximum taxonomic rank of 4, the weight would be 2/(1+2+3+4) = 2/10 = 0.2. For the groups collectively ranked 1, i.e., least important, their weights were equal portions of 1/(sum of the unique rank values). In this way, the contribution of taxonomic groups to scoring was dependent on its priority and the number of other detected taxonomic groups.

The final prioritization score *PrioritizationScore* for each road segment *i* was therefore the sum of 8 weighted datasets across each of 4 weighted themes:

PrioritizationScore$_i$ =

> WildlifeVehicleConflict_weight*[(RKScore$_i$ *SpeciesRK_weights) + (ZCPScore$_i$ *SpeciesZCP_weights) + (CSScore$_i$ *SpeciesCS_weights)] +
>
> WildlifeObs_weight*[(LiveScore$_i$ *SpeciesLive_weights) + (PreyScore $_i$ *SpeciesPrey_weights)] +
>
> Xing_weight*(xingScore$_i$) +
>
> Habitat_weight*(PermH2OScore$_i$ + SeasonalH2OScore$_i$)

where scores and species weights in the first two summands are vectors composed of values for each taxonomic group present in the respective datasets.

Traffic Counter

Patterns in traffic volume were characterized over 24-hour, weekly, and monthly time scales. Outlier hourly count values, based on Q3+1.5*IQR for each hour in the day, were removed due to potential bias in counts (see below).

To evaluate potential bias in counts, a Wilcoxon signed-rank test was conducted, and a simple set of 4 linear regressions was evaluated using AICc <delta 2. For the linear regressions to explore potential associations with or causes of the overcounting, vehicles during manual counts were categorized as: sedan (n=22); commercial truck (n=62); coach bus (n=21); passenger truck (n=82); unknown truck (n=14); or motorized/unmotorized bicycle (n=3). Linear regressions modeled the difference between counter and manual counts as a function of direction of travel (due to the counter being under the east-bound lane and potentially less sensitive to the traffic in the farther west-bound lane), and proportions of sedans, commercial trucks, and coach buses.

Results

Wildlife and Road Prioritization

The results used in the prioritization analysis were from a total of 6,129 km driven for 67 RK and 23 DS surveys, a total distance equivalent to driving the M9 from gate to gate 44.4 times (Table 4). The species data used in the analysis is described in Table 5.

Table 4. Breakdown of type and direction of surveys conducted of the M9 road bisecting Kafue National Park, Zambia, that the Zambian Carnivore Programme conducted between May 2024 and May 2025. Surveys were divided by whether they were east of the Mukambi junction (i.e., eastern segment) or west of the junction (i.e., western segment) and differentiated between whether the Mukambi junction served as the survey start location or end location (i.e., eastbound or westbound).

Survey Type	Eastern Segment (E-bound+ W-bound)	Western Segment (W-bound + E-bound)	Total
Roadkill	17 (8+9)	50 (25+25)	67
Distance Sampling	11 (11+0)	12 (1+11)	23
Total	28	62	90

Table 5. Wildlife detected along the M9 road segment on Kafue National Park, Zambia, recorded as roadkill or observed alive on or near the road.

Species/Group	Detected Dead	Detected Alive
Antelope	X	
Baboon	X	X
Bird	X	X
Buffalo	X	X
Bushpig		X
Bushbaby	X	
Bushbuck		X
Cattle		X
Cattle egret	X	
Cheetah	X	
African civet	X	
Common duiker	X	X
Crane		X
Crocodile		X
Domestic animals		X
Domestic dog	X	
Dove	X	X
Duck		X
Eland		X
Elephant		X
Francolin	X	X
Genet	X	
Goat/Sheep		X
Goose		X
Grysbok	X	X

Guinea fowl	X	X
Hartebeest		X
Heron		X
Hippo		X
Honey Badger	X	
Human	X	
Hyena	X	X
Impala	X	X
Jackal	X	X
Kudu		X
Lion	X	
Mongoose	X	X
Monitor lizard	X	X
Nightjar	X	
Oribi		X
Owl	X	
Porcupine	X	
Puku	X	X
Rat	X	
Reedbuck		X
Roan Antelope		X
Rodent	X	
Sable		X
Scrub hare	X	X
Serval	X	
Shrew	X	
Snake	X	X
Squirrel	X	X
Stork		X
Tortoise	X	
Vervet Monkey		X
Vulture	X	X
Warthog	X	X
Water thick knee	X	
Waterbuck	X	X
White tailed mongoose	X	
Wild Dog	X	X
Yellow billed kite	X	
Zebra		X

Wildlife, both roadkill carcasses and live animals from scheduled RK and DS surveys, were detected across the M9 road, but distributed unevenly (Figure 4). A total of 58 different species in 11 taxonomic categories, excluding Human and Other/Unknown, were detected. From RK surveys, 126 roadkill of at least 32 different species and 2,335 live animals of at least 39 species were detected. From DS surveys, 2,599 mammals from at least 21 species were detected.

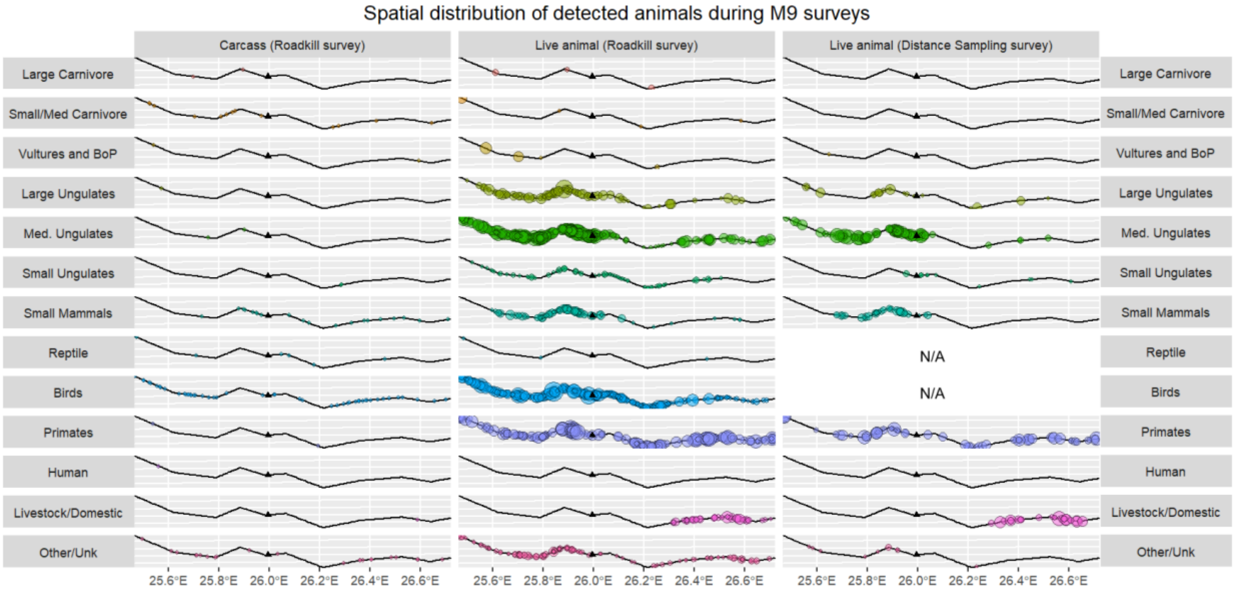

Figure 1. Location of carcasses and live animals detected during scheduled roadkill and distance sampling surveys, collected by ZCP field teams between May 2024 and May 2025 on the M9 road through Kafue National Park, Zambia. Circle size indicates the number of detected animals. The triangle indicates the Mukambi junction from which surveys either started (and travelled either eastbound – right – to Nalusanga Gate or westbound – left – to Tateyoyo Gate) or ended.

Outside of scheduled surveys, partner organizations and ZCP also reported carcasses of at least 15 species over the M9 stretch (Figure 5). A total of 30 roadkill carcasses were reported by partners, and 35 roadkill carcasses reported by ZCP.

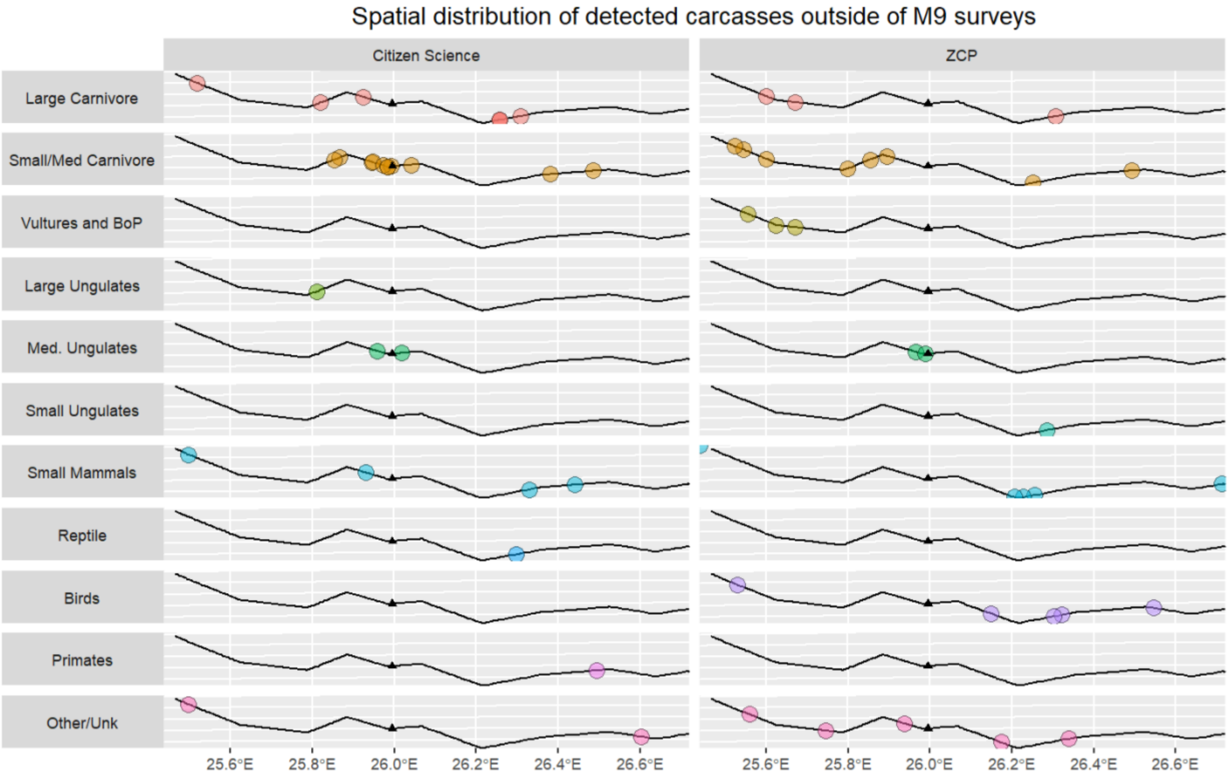

Figure 2. Location of carcasses on the M9 road bisecting Kafue National Park, Zambia, reported as citizen science by partner organizations and ZCP field teams outside of scheduled surveys between May 2024 and May 2025. The triangle indicates the Mukambi junction, which served as the start or end point of various scheduled surveys of the M9 road.

From the 23 collared large carnivores, a total of 230 road crossing locations were identified. Individuals had an average of 10 crossing locations (SD=7; range: 1-23) (Figure 6).

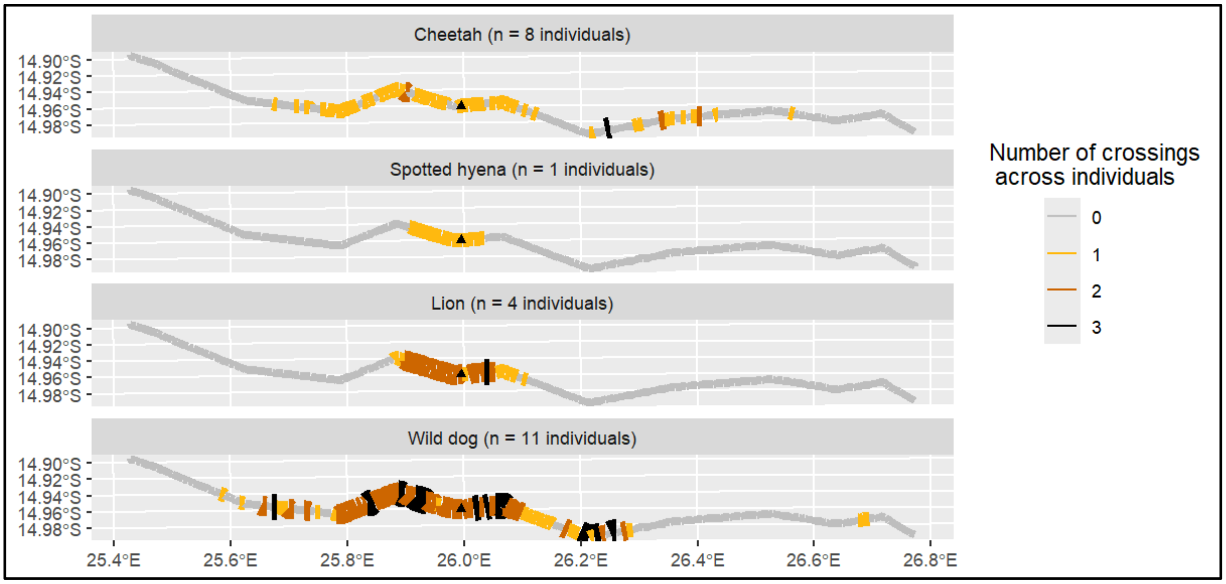

Figure 3. Crossing locations on the M9 road between Nalusanga Gate to the east (right) and Tateyoyo Gate to the west (left) for 23 collared large carnivores, between May 2024 and May 2025. The triangle indicates the Mukambi junction, which served as the start or end point of various scheduled surveys of the M9 road. Large carnivores experience increased mortality and injury risk from vehicles when crossing the M9, so identifying locations where crossings occur help to develop effective mitigation locations and strategies for reducing wildlife mortalities.

The M9 road intersected with known water bodies at 25 locations, including two with the permanent Kafue River (Figure 7).

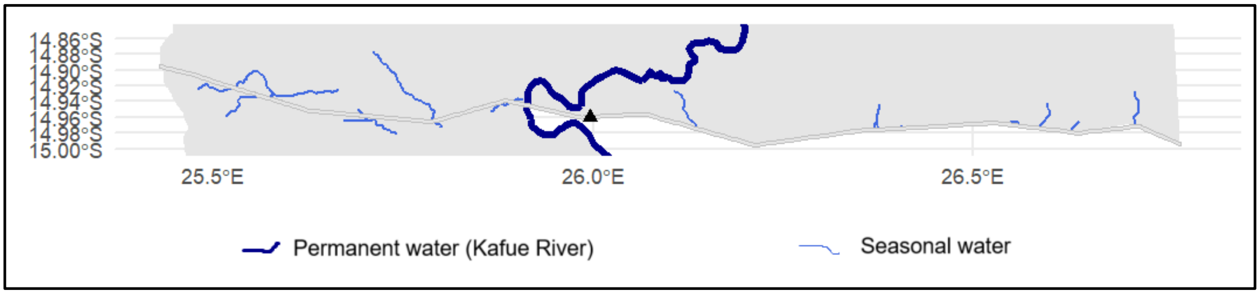

Figure 4. Water bodies cross the M9 road cutting through Kafue National Park, Zambia, in a total of 25 locations, of which two are from the permanent Kafue River. The triangle indicates the Mukambi junction, which served as the start or end point of various scheduled surveys of the M9 road. Locations of water sources are important landscape features that influence wildlife distribution and therefore important areas near roads for heightened attention when developing appropriate mitigation strategies for reducing wildlife mortalities.

Overall prioritization scores for the surveyed portion of the M9, within KNP, ranged 0 – 0.58, with a mean of 0.24 (SD = 0.10) (Figure 8).

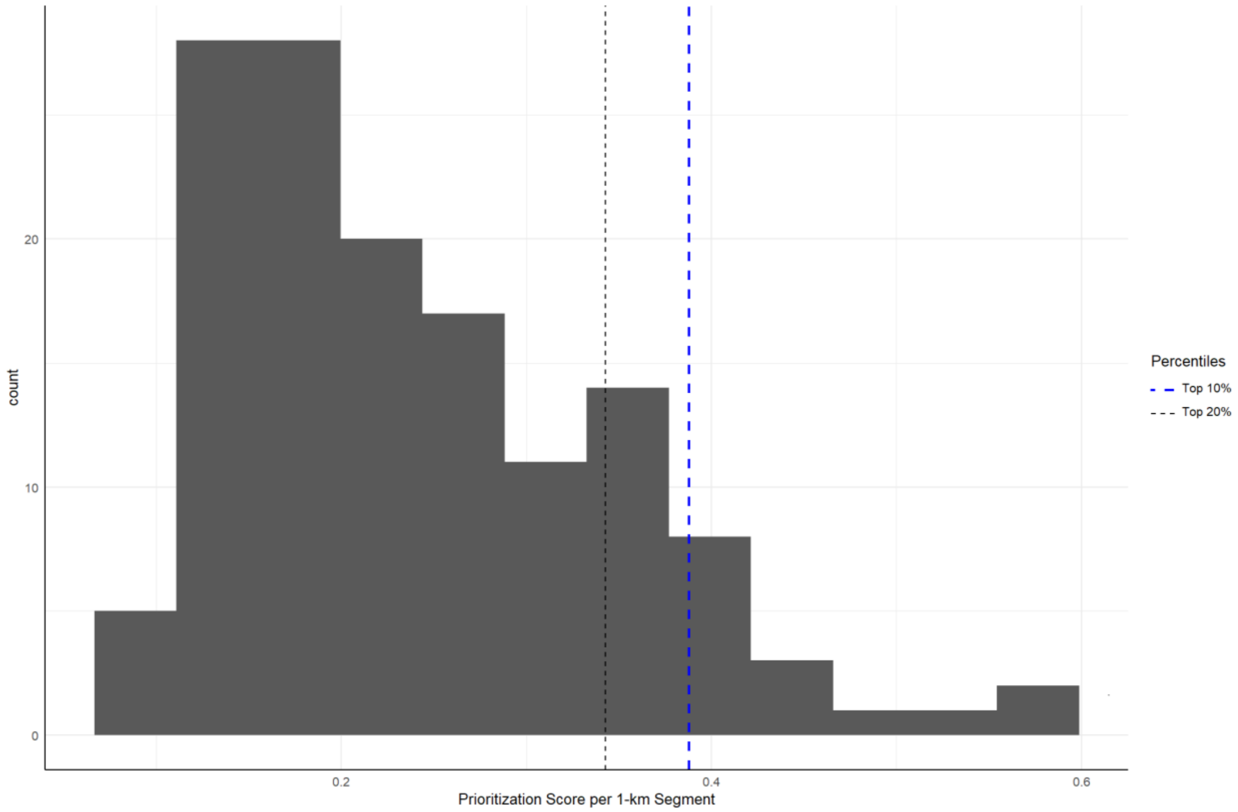

Figure 5. Distribution of prioritization scores for the n=138 1-km segments of the M9 road between Nalusanga and Tateyoyo Gates in Kafue National Park, Zambia. Scores were based on a weighted sums approach incorporating eight wildlife and habitat datasets.

Of the 138 road segments, n=14 were in the top 90th percentile (i.e., prioritization score > 0.39), and n=28 segments in the top 80th percentile (prioritization score > 0.34) (Figures 9, 10 and 11).

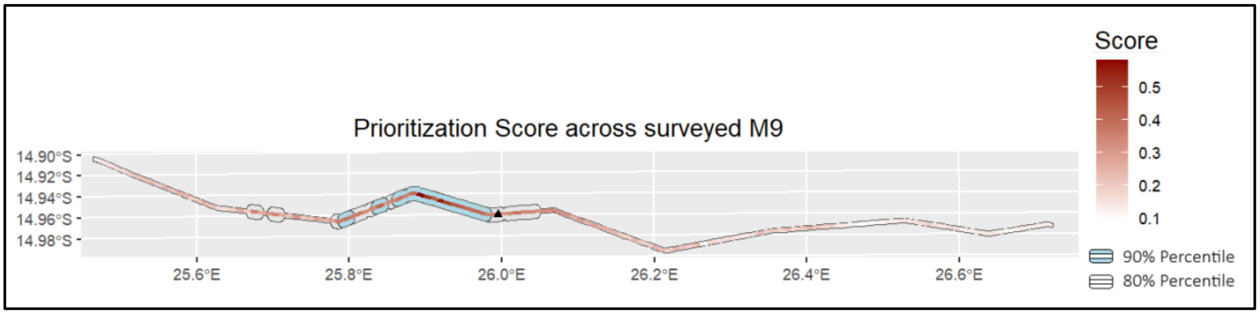

Figure 9. Prioritization scores for each 1-km segment of the M9 road between Nalusanga Gate to the east (right) and Tateyoyo Gate to the west (left), based on eight wildlife and habitat datasets collected during May 2024 to 2025 by ZCP field teams. The triangle indicates the Mukambi junction, which served as the start or end point of various scheduled surveys of the M9 road. Areas of highest priority scores should be investigated for potential mitigation strategies to reduce risk of wildlife mortality and injury.

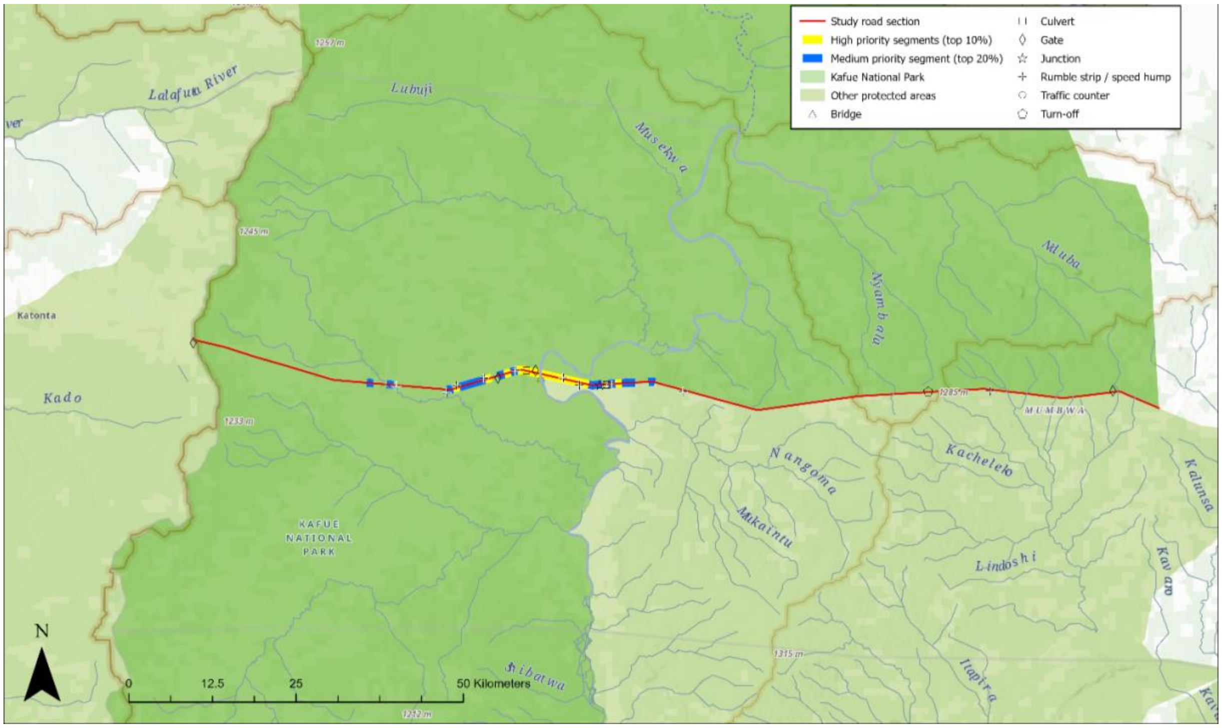

Figure 10. Priority sections of the M9 road identified for mitigation in Kafue National Park, Zambia, highlighting segments above the 90th percentile (prioritization score > 0.39) and above the 80th percentile (prioritization score > 0.34). Existing mitigation features (speed humps, rumble strips), Park gates and nearby water sources are also shown.

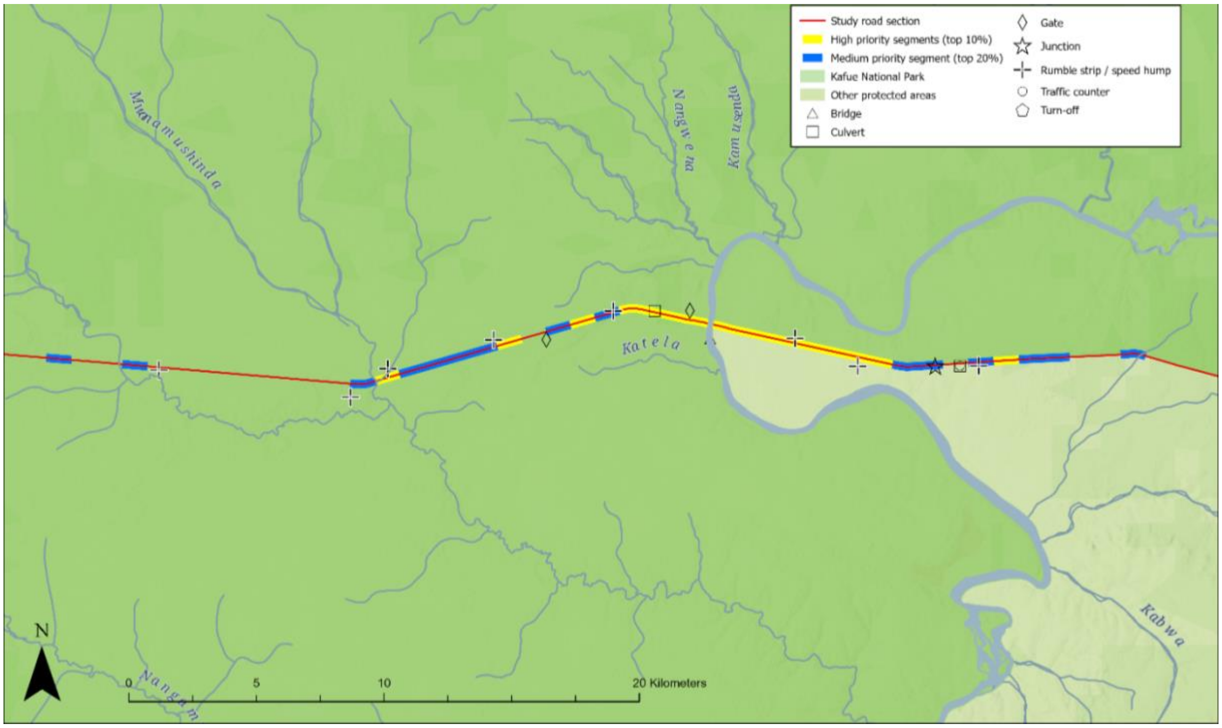

Figure 10. Detail of the M9 road section with the identified priority locations for mitigation in Kafue National Park, Zambia, highlighting segments above the 90th percentile (prioritization score > 0.39) and above the 80th percentile (prioritization score > 0.34). Existing mitigation features (speed humps, rumble strips), Park gates and nearby water sources are also shown.

Figure 11. Luckson Banda of the Zambian Carnivore Programme collecting roadkill data on the M9 highway.

Traffic Volume

Traffic patterns varied across multiple temporal scales (Figure 12). As expected within each day, traffic was least in volume and in volume variability during the late evening and early morning hours. The greatest variation in traffic volume was during hour 12:00 – 13:00. Average daily traffic volume was estimated to be 415 vehicles. Over the course of the week, traffic slowly increased and reached its highest level over the weekend. Traffic volume also varied greatly over the course of the year, although no data were collected for March–June. The greatest daily traffic occurred most consistently in November.

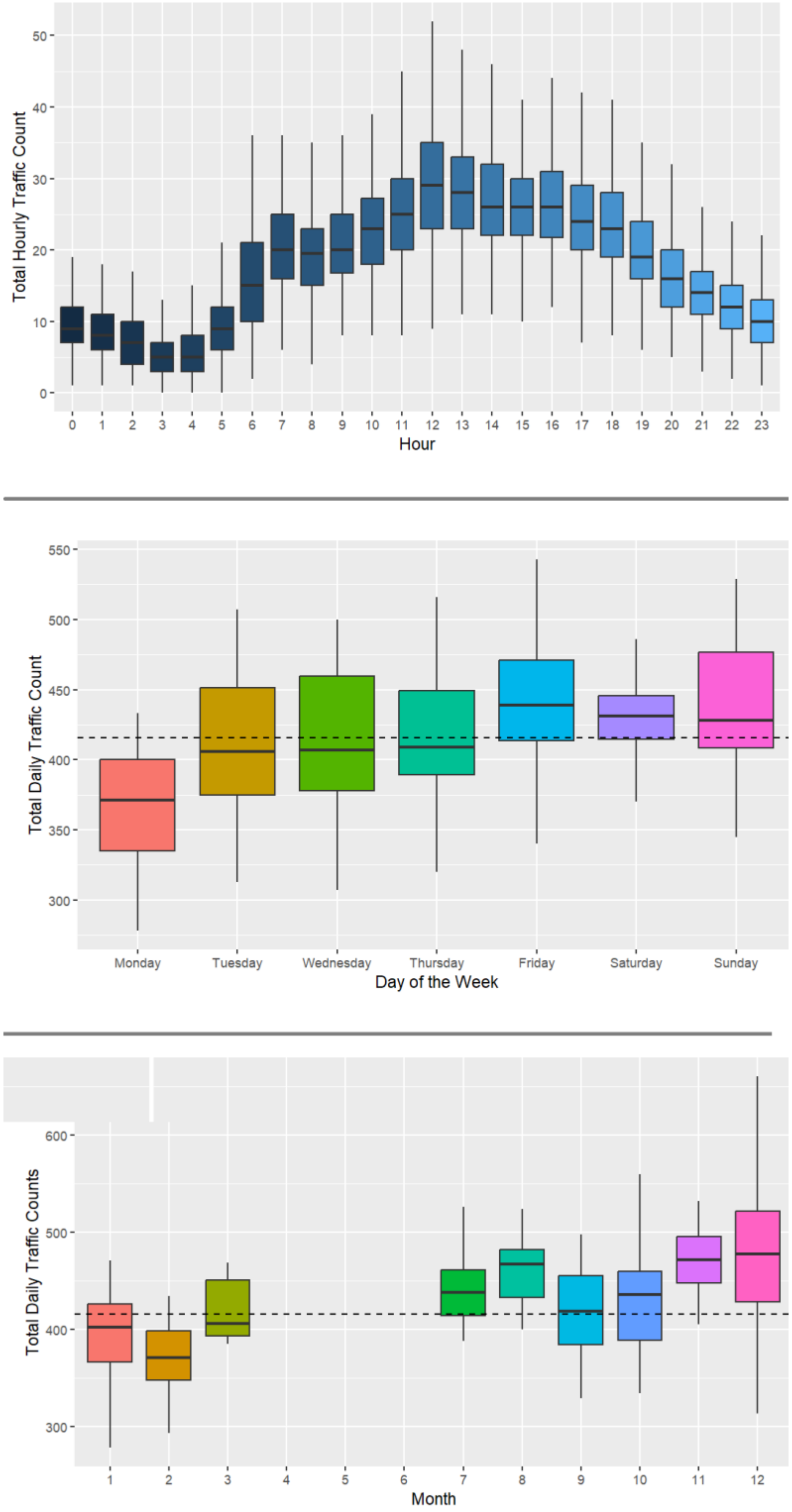

Figure 12. Traffic volume at hourly, over the week, and across months, collected by an electromagnetic Trafx counter deployed in a culvert east of the Mukambi junction on the M9 road cutting through Kafue National Park, Zambia. Data were collected from July 10, 2024, through March 11, 2025. Hourly traffic (top) was greatest during midday and least during the early hours of the morning. Traffic increased slowly over the course of the week (middle). Daily traffic volumes also varied over the year (bottom), with the least detected traffic on average in February and the greatest amount of traffic on average in November and December.

The ZCP field team conducted a total of 8 manual calibrations of the Trafx counter. One calibration had a duration of 2 hours, while all others were for 1 hour. Times of day ranged from 10:00 to 16:00. A Wilcoxon signed-rank test rejected the null hypothesis that the Trafx and manual counts were equal (approximate p value = 0.036). Indeed, out of 8 calibration events, 88% (n=7) indicated that the Trafx counter had detected and recorded more vehicles than had actually passed (Figure 13). Based on AICc comparing 3 linear regressions, with data from the first calibration removed, coach buses contributed to traffic overcounting by the Trafx counter (Table 5). There was no support for the placement of the counter under one lane contributing any bias in counting between the two lanes.

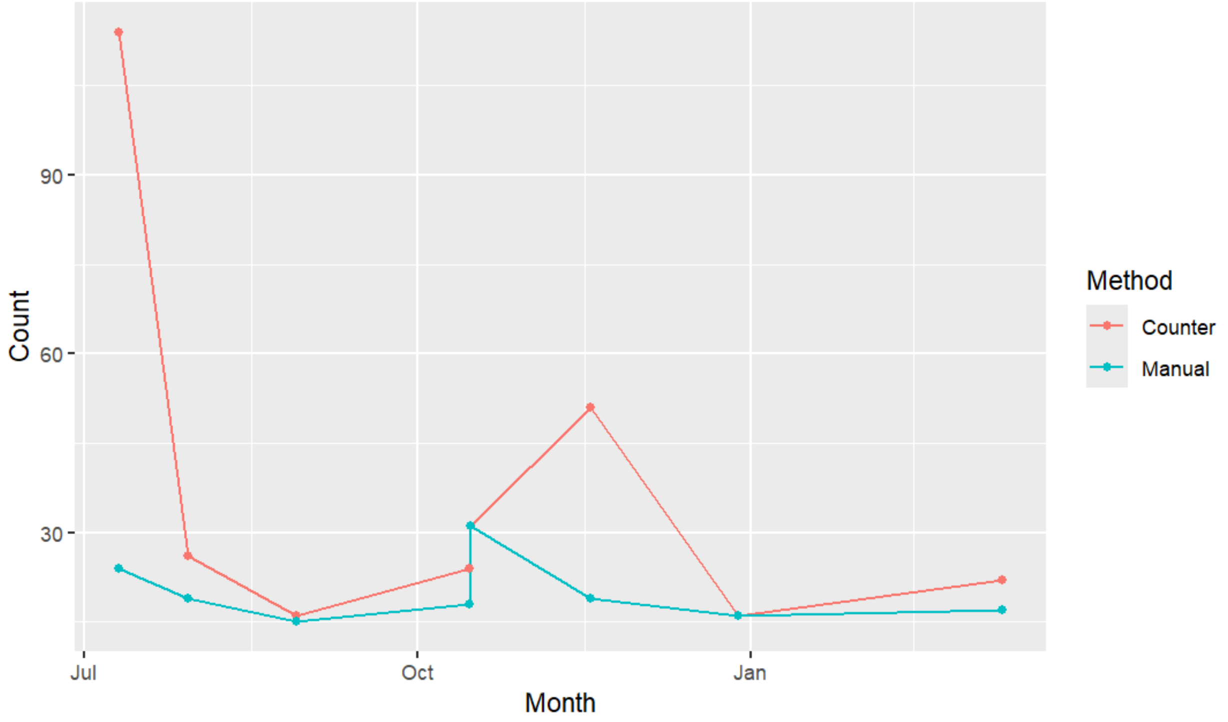

Figure 6. Eight instances of manual counting of vehicles for 1-2 hours indicated that the Trafx counter typically overcounts traffic volume.

Table 6. A set of 4 linear regressions evaluating the difference between manual and Trafx counter volume data as a function of direction of travel, and proportions of sedans, coach buses, and commercial trucks. The top model by ΔAIC=5 provided strong support for the Trafx counter inflating counts when more coach buses drove by.

Model	Intercept	PropEastbound	PropCoachBus	PropSedan	PropCommTruck	AICc
Diffcounter-manual ~ Intercept+ PropEastbound + PropCoachBus	1.8 ± 9.0 (p0.05=0.85)	-11.3 ± 16.7 (p0.05=0.54)	88.0 ± 25.2 (p0.05=0.03)	NA	NA	70.1
Diffcounter-manual ~ Intercept+ PropEastbound +PropSedan	38.0 ± 14.9 (p0.05=0.06)	-49.0 ± 26.5 (p0.05=0.14)	NA	-75.6 ± 37.8 (p0.05=0.12)	NA	75.0
Diffcounter-manual ~ Intercept+ PropEastbound +PropcommTruck	20.3 ± 21.2 (p0.05=0.39)	-23.4 ± 32.6 (p0.05=0.52)	NA	NA	-4.5 ± 25.3 (p0.05=0.87)	79.8
Diffcounter-manual ~ Intercept	7.3 ± 4.3 (p0.05=0.14)	NA	NA	NA	NA	79.8

Photo by Zambian Carnivore Programme

Discussion

The findings of this study underscore the significant risks that roads pose to both wildlife and human safety. The M9 road crosses crucial habitat for wildlife, and animals are being killed by vehicles when attempting to cross, potentially reducing population abundance and genetic diversity and affecting population persistence (Jackson and Fahrig, 2011). Moreover, wildlife-vehicle collisions can result in substantial damage to vehicles and even human fatalities, emphasizing the broader safety implications of roadways intersecting natural habitats (Huijser, 2008).

The true mortality magnitude occurring within the Park is likely higher than recorded in this study, as the roadkill surveys were carried out every 10 days. Although some carcasses of large-bodied animals can persist for periods longer than this on a road, we did not account for the effects of carcass persistence and detection probability in this study (Korner-Nievergelt et al., 2015; Teixeira et al., 2013). Carcasses of some species, particularly herbivores, may be removed from the road by scavengers or people, contributing to the underestimate of total mortality (Barrientos et al., 2018).

The priority sections of the M9 road identified in our study seem to be associated with water availability, as areas of high animal activity and mortality both overlap with the Kafue River and other intermittent water sources. This confirms that wildlife mortality from vehicle collisions is closely linked to landscape features, as shown by previous studies (Gunson et al., 2011). For instance, Drews (1995) reported that hotspots of roadkills in Mikumi National Park in Tanzania occurred close to waterholes and traditionally used animal tracks. Water sources can be an important and restrictive resource, especially in places with a strong wet-dry seasonal cycle like KNP. Therefore, road segments that cross or run near water sources should be prioritized for measures to mitigate potential wildlife mortality.

Previous research along the M9 road section adjacent to the Park before the rehabilitation of the road identified mortality hotspots and recommended a few traffic-calming measures, such as speed humps, which were constructed in a few sections following the recommendations of Chansa (2005) (e.g., at Mukambi, Mwanamukinda; also, see Figures 10 and 11). However, Mkanda and Chansa (2011) showed an increase in traffic and a consequent increase in wildlife mortality on the M9 road after the rehabilitation, indicating that improvements in the mitigation system are needed. Our study provides a prioritization of segments along the M9 road to be considered for mitigation, and our results indicate that several of our identified priority sections overlap with or are situated near existing speed humps at known mortality hotspots such as Mukambi and Mwanamukinda. This overlap implies that, despite past interventions, these areas remain high-risk zones, highlighting the need for additional or complementary measures to further reduce wildlife-vehicle collisions (see Figures 10 and 11).

While telemetered crossing locations provided spatial data on where animals cross, this metric does not equate to the frequency of crossings per site. We prioritized spatial independence by avoiding counting repeated crossings by the same individual at a single location over short time frames, reducing autocorrelation bias. Nonetheless, understanding the temporal scale of repeated site use could be valuable for identifying sustained high-risk areas. Although we did not explore temporal patterns in wildlife road use and collisions in this study, Mkanda and Chansa (2011) identified a peak in road mortality of mammals (half of which were impala) in the late wet season (January–March). Their study highlighted how reduced visibility from dense vegetation and heightened animal activity (rutting season for impala) during the wet season increase collision risks. The authors recommended mitigation measures such as timely verge slashing, speed cameras, and public awareness campaigns (Mkanda and Chansa, 2011).

The priority areas for mitigation that we identified in this study coincide with portions of the M9 road flanked by KNP on both sides. This is similar to what was found by Nyirenda et al. (2017). The authors of that study attributed this spatial pattern to animal activity concentrating in the high-quality habitats available and animal movement being funneled from human settlements that exist in the Mumbwa GMA, which was experiencing a considerable growth rate and spread of human settlements.

Traffic volume on the M9 road can be considered low. At such volumes, many animals may not hesitate to enter the roadway; some may collide with vehicles while attempting to cross, whereas others will cross successfully (Seiler, 2003). Because the M9 road is elevated above the surrounding landscape, it is regularly used by many animals, including carnivores that search for prey along it or move through it as a corridor. The continuous removal of individuals from wildlife populations through this additional source of mortality has the potential to affect population genetics and, consequently, long-term persistence (Jackson and Fahrig, 2011), and therefore requires mitigation. Furthermore, many vehicles on the M9 exceed the posted speed limits of 80 km/h during the day and 50 km/h at night, particularly during nighttime, which increases the risk of wildlife-vehicle collisions. Comparative analyses of traffic volume and speed variations in relation to road mortality on the M9 could provide valuable insights to guide and improve future mitigation strategies.

Mitigation Hierarchy and Mitigation Options

Both in the context of any road network expansion and any regularization of the existing network, it is essential to assess environmental impacts and plan mitigation measures within the framework of the mitigation hierarchy (CEQ, 2000). According to this approach (Figure 12), avoiding impacts is the first measure that should be considered in the planning of any development project (e.g., careful spatial and/or temporal delimitation of infrastructure elements, prioritizing infrastructure locations farther from areas important for biodiversity conservation or at risk of ecosystem service degradation). This is followed by minimization (actions taken to reduce the duration, intensity, and/or extent of impacts that cannot be completely avoided), restoration (rehabilitation of degraded areas or restoration of ecosystems during construction and throughout infrastructure operation when impacts cannot be fully avoided and/or minimized), and offsetting of environmental damage (compensating for adverse residual impacts that cannot be avoided, minimized, and/or restored) (Villarroya et al., 2014).

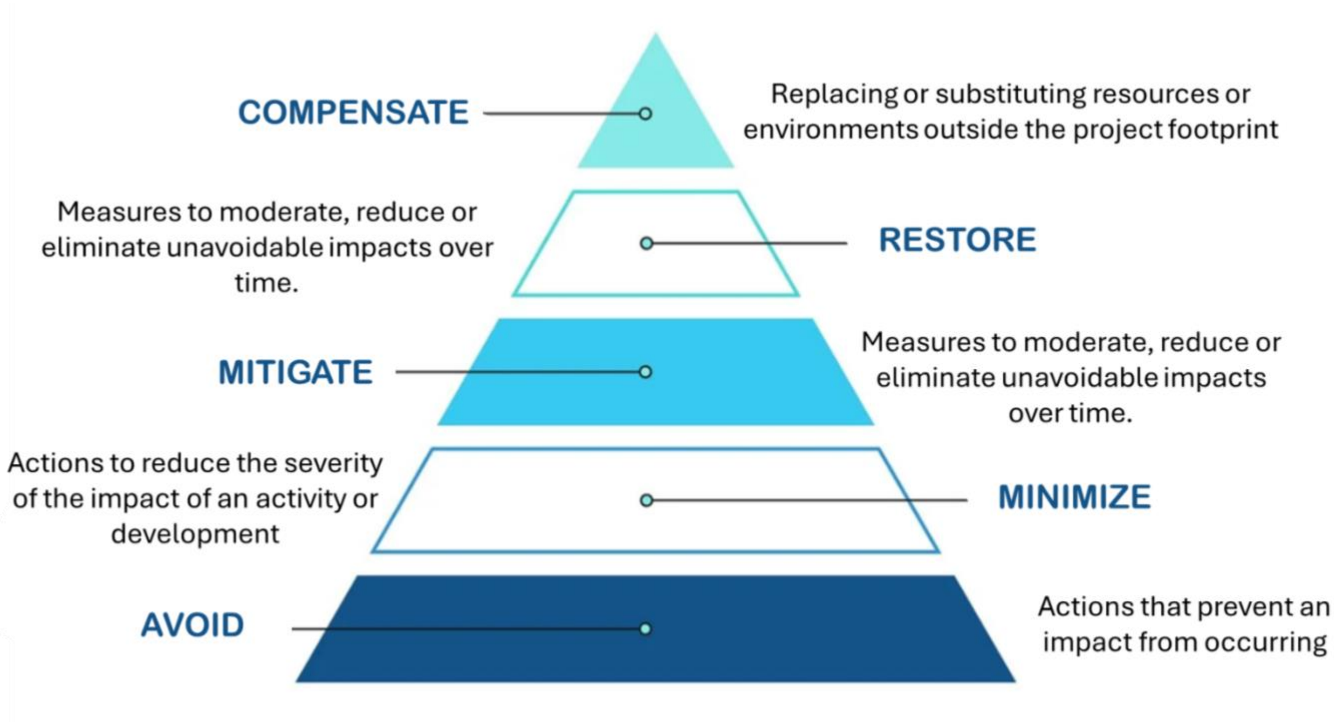

Figure 12. The steps of the mitigation hierarchy.

Measures to Separate Wildlife from Traffic

There is a wide variety of mitigation measures available, some aimed at modifying animal behavior, such as fencing and wildlife crossings either under or over the road, and others aimed at modifying driver behavior, such as warning signs and speed humps (Seiler and Helldin, 2006).

Wildlife Crossing Structures

Wildlife crossing structures are the main measures used to separate wildlife from traffic. They connect habitats across roads, supporting safe movement (Dodd et al., 2007; Gagnon et al., 2010; Huijser et al., 2015, 2016). The most implemented structures worldwide are underpasses or culverts, but overpasses are also being increasingly implemented. Effectiveness increases when paired with fencing and can be dependent on species and designs of wildlife crossing structures (Naidenko et al., 2021).

Wildlife Underpasses

Wildlife underpasses allow animals to cross under the road. They accommodate large and small species and designs may include vegetation, woody debris, or water flow. Existing bridges or culverts can be adapted for wildlife passage, often in riparian areas, with the construction of a dry ledge (Soanes et al., 2025). Open-span or bottomless structures allow natural substrate and aquatic connectivity.

Wildlife Overpasses

Wildlife overpasses, also called ecoducts, allow animals to cross over the road. They maintain habitat connectivity and are effective for many species, especially large mammals, but design can also attract small species (Clevenger and Barrueto, 2014; Ford et al., 2017; Sawyer et al., 2016).

Wildlife Fencing (with Crossings)

Fencing can cut collisions by 87% (Huijser, 2008), and it is important that it is paired with crossings to also allow animal passage (Rytwinski et al., 2016). Fencing guides animals to crossings but must include escape ramps to let animals out of the road corridor—if they are able to get in—and barriers for climbers and diggers so they cannot overcome the fence barrier. Longer, continuous sections of fences outperform shorter ones, and fence ends should include treatments like cattle guards or detection systems (Clevenger and Barrueto, 2014; Gagnon et al., 2010; Huijser et al., 2016; Huijser and Begley, 2022).

Measures to Influence Driver Behavior

Permanent or Temporary Warning Signs

Permanent warning signs rarely reduce wildlife-vehicle collisions in the long-term, though they may temporarily slow drivers or raise awareness (Pojar et al., 1975; Coulson, 1982; Al-Ghamdi, 2004; Sullivan et al., 2004; Meyer, 2006; Bullock et al., 2011). Temporary or seasonal signs can be more effective (9–50%), especially when placed precisely during high-risk periods, though effectiveness drops when used over long stretches year-round (Sullivan et al., 2004; Colorado DOT, 2014; Huijser et al., 2015). Unique signage or outreach campaigns may enhance results.

Animal Detection Systems

Animal detection systems reduce collisions by 33–97% when sensors reliably detect target species (Mosler-Berger and Romer, 2003; Dai et al., 2009; Gagnon et al., 2010; Strein 2010; Minnesota DOT, 2011; Sharafsaleh et al., 2012; Huijser et al., 2006). This type of measure works for large species and it works best for low-volume roads, as animal detection systems require significant speed reduction (55–65 km/h) to work effectively (Huijser et al., 2015). They are often most effective when combined with fencing or crossing structures.

Reduced Speed Limit

Lowering posted speeds without changing road design speed often fails to reduce wildlife-vehicle collisions due to speed dispersion and driver noncompliance (Elvik, 2014; Huang et al., 2013; Fitzpatrick, 2003; Ouyang et al., 2016; Donnell et al., 2018). Enforcement yields limited results (Colorado DOT, 2014; Riginos et al., 2019). Even 65 km/h may be too fast to avoid large animals at night; around 40 km/h is often required (Huijser et al., 2017; Huijser et al., 2015). For this measure to be effective, there is a need to adapt the road so that the design matches speed changes, for example, by altering lane widths, curves, surface texture, and roadside environments.

Road Lighting

Lighting can cut collisions by 57–68% (McDonald, 1991; Riley and Marcoux, 2006; Wanvik, 2009) but may deter or attract species, creating ecological impacts (Blackwell et al., 2015), so it should not be a preferred mitigation measure in protected areas. Selective or motion-activated lighting can reduce negative effects.

Recommendations

Based on the results of the assessment of roadkill and wildlife-vehicle interactions along the M9 road across KNP and on previous studies on the same road (Chansa, 2005; Mkanda and Chansa, 2011), the following recommendations are proposed:

Short-term measures (immediate implementation)

Speed Management and Law Enforcement

- Install **movable speed humps** or other temporary measures to reduce vehicle speed in high-risk segments. These measures are low-cost and relocatable to other locations with potential wildlife-vehicle conflicts as needed.
- Deploy **speed enforcement teams** to monitor traffic and enforce limits, including the use of **speed traps** at high-risk areas.
- Monitor **truck and bus travel times** at Park gates to track speed and enforce limits, helping reduce collisions with wildlife.
- **Place signage (posters or billboards) at all park gates** to remind motorists about the following:
  - Speed limits and associated penalties
  - The importance of giving way to animals
  - Proper disposal of litter at designated points, not inside the park.

Carcass and Wildlife Management

- Maintain **carcass removal** by patrols and enforcement teams to reduce attraction of scavengers.
- Explore the use of **detection dogs** at Park gates to monitor and investigate incidents where wildlife is deliberately killed so carcasses are collected by drivers.

Vegetation and Visibility Management

- Prioritize **roadside vegetation slashing** during the wet season along the priority sections to improve visibility and reduce wildlife presence close to the road.

Medium-term measures (1-3 years)

Water Source Management

- Fill **artificial water sources** near the road, including gravel pits from previous road upgrades, to reduce wildlife attraction. Construct new water points further from the road before closing the nearby ones to maintain wildlife access to water.

Speed Management and Law Enforcement

- Implement **nighttime restrictions** for heavy commercial trucks to reduce collision risk. Although overall traffic volume on the M9 road is low at night, trucks traveling at high speeds during these hours might be responsible for a disproportionate number of collisions.
- **Reduce the design speed** on high-risk segments to lower collision probability using a combination of **physical modifications** to the road that naturally encourage slower driving. Recommended strategies include narrowing lane widths, introducing horizontal curves or chicanes, installing additional vertical deflections such as speed humps, and applying textured surfaces, such as rumble strips.
- **Average speed enforcement along high-risk sections:** Record vehicle entry and exit times at designated points to calculate average speed. Vehicles exceeding the speed limit can be penalized, encouraging drivers to maintain safe speeds throughout the critical road segments.

Long-term considerations

Wildlife crossings

- **Dedicated crossing structures:** Although not currently part of the management strategy, the need for dedicated wildlife crossing structures should be revisited in the future, particularly if animal mortality continues occurring at similar rates.

To ensure efficient and impactful investment of mitigation efforts—especially those that might be permanent or costly—we want to acknowledge potential overemphasis in the current analysis towards the Hook Bridge area due to the weightings of correlated data in the vicinity of Hook Bridge and the Kafue River. We explicitly recommend that mitigation efforts also be considered for the area west of Hook Bridge, not just those segments with the highest "prioritization scores," and recognize that further data collection and analysis in this area may be helpful.

Beyond the measures recommended above aiming to reduce wildlife-vehicle collisions, we recommend long-term monitoring of road mortality and animal activity along the M9 road, as it is essential to understand how impacts vary over time and to assess potential effects on wildlife populations. Such monitoring will also enable evaluation of mitigation effectiveness, when measures are implemented, by comparing spatial patterns before and after intervention. Monitoring may be implemented through periodic sampling campaigns within defined temporal windows, complemented by the continuous curation of a centralized georeferenced database of roadkill and wildlife activity records derived from dedicated surveys but also from rangers' patrols along the M9 road.

The approach used in this study—combining existing telemetry datasets with targeted road mortality and animal activity surveys—provides a transferable framework for identifying priority mitigation locations on other roads across Africa. Applying standardized monitoring protocols for data collection and analysis can maximize the value of existing data, facilitate comparisons across sites, and help address a critical conservation challenge that extends beyond a single road or protected area.

References

Al-Ghamdi, A. 2004. “Warning Signs as Countermeasures to Camel–Vehicle Collisions in Saudi Arabia.” Elsevier 36: 749–60. https://doi.org/10.1016/j.aap.2003.05.006.

Ament, R.J., Clevenger, A.T., Yu, O. and A. R. Hardy. 2007. An Assessment of Road Impacts on Wildlife Populations in U.S. National Parks. WTI-MSU Technical Report REP-0701, Western Transportation Institute at Montana State University. 37 pp.

Barrientos R, Martins RC, Ascensão F, et al (2018) A review of searcher efficiency and carcass 283 persistence in infrastructure-driven mortality assessment studies. Biol Conserv 222:146–284 153. doi: 10.1016/j.biocon.2018.04.014

Bullock, K, G Malan, and M Pretorius. 2011. “Mammal and Bird Road Mortalities on the Upington to Twee Rivieren Main Road in the Southern Kalahari, South Africa.” African Zoology 46 (1): 60–71. Clevenger and Barrueto, 2014;

CEQ, Council on Environmental Quality. Protection of the enviroment (under the National Envoronmental Policy Act).Washington, D.C., USA, 2000.

Chansa, W. 2005. Report on road kills along the Lusaka–Mongu Highway in Kafue National Park – North, for the period November 1995 to January 2004. Typescript, Zambia Wildlife Authority, Lusaka.

Colorado Department of Transportation. 2014. “Final Report – HB 1238 Wildlife Crossing Zones.”

Coulson, G. 1982. “Road-Kills of Macropods on a Section of Highway in Central Victoria.” Wildlife Research 9 (1): 21–26.

Creech, T., M. Huijser, M. Bell, E. Fairbank, and A. Breuer (2025). Gallatin County Wildlife and Transportation Assessment: Spatial Analysis. Center for Large Landscape Conservation and Western Transportation Institute, Montana State University (Bozeman, MT). Report prepared for Gallatin County and City of Bozeman. 94 pp.

Dai, Q, R Young, and S Vander Giessen. 2009. “Evaluation of an Active Wildlife-Sensing and Driver Warning System at Trapper’s Point.” Wyoming Department of Transportation. Cheyenne, WY.

Donnell, E, K Kersavage, and L Tierney. 2018. “Self-Enforcing Roadways: A Guidance Report.” US Department of Transportation, Federal Highway Administration. McLean, VA.

Drews, C. 1995.Road kills of animals by public traffic in Mikumi National Park, Tanzania, with notes on baboon mortality. Afr. J. Ecol. 33: 89–100.

Elvik, R. 2014. “Speed and Road Safety-New Models.” TØI Report, no. 1296/2014.

Fitzpatrick, K. 2003. “Design Speed, Operating Speed, and Posted Speed Practices.” Vol. 38. Transportation Research Board. Washington, DC.

Ford, A, M Barrueto, and A Clevenger. 2017. “Road Mitigation Is a Demographic Filter for Grizzly Bears.” Wildlife Society Bulletin 41 (4): 712–19.

Gagnon, J, N Dodd, S Sprague, K Ogren, and R Schweinsburg. 2010. “Preacher Canyon Wildlife Fence and Crosswalk Enhancement Project Evaluation: State Route 260.” Arizona Game and Fish Department. Phoenix, AZ.

Gunson, K.E., Mountrakis, G., Quackenbush, L.J., 2011. Spatial wildlife-vehicle collision models: a review of current work and its application to transportation mitigation projects. J. Environ. Manag. 92:1074–1082. https://doi.org/10.1016/j.jenvman.2010.11.027.

Hill, J. E.; Devault, T. L.; Belant, J. L. Cause-specific mortality of the world's terrestrial vertebrates. Global Ecology and Biogeography. v. 00, p.1–10, 2019.Laurance, William F. et al. A global strategy for road building. Nature, V. 513, p. 229 - 232, 2014.

Huang, B, Y Zhang, J Lu, and L Lu. 2013. "A Simulation Study for Minimizing Operating Speed Variation of Multilane Highways by Controlling Access." Procedia-Social and Behavioral Sciences 96: 2767–81.

Huijser, M, C Mosler-Berger, M Olsson, and M Strein. 2015. "Wildlife Warning Signs and Animal Detection Systems Aimed at Reducing Wildlife-vehicle Collisions." Van der Ree, R, D Smith, and C Grilo (eds). Handbook of Road Ecology, 198–212.

Huijser, M, E Fairbank, and F Abra. 2017. "The Reliability and Effectiveness of a Radar-Based Animal Detection System." US Department of Transportation. Washington, DC.

Huijser, M, E Fairbank, W Camel-Means, J Graham, V Watson, P Basting, and D Becker. 2016. "Effectiveness of Short Sections of Wildlife Fencing and Crossing Structures along Highways in Reducing Wildlife–Vehicle Collisions and Providing Safe Crossing Opportunities for Large Mammals." Biological Conservation 197: 61–68.

Huijser, M, K Gunson, and C Abrams. 2006. "Animal-Vehicle Collisions and Habitat Connectivity along Montana Highway 83 in the Seeley-Swan Valley, Montana: A Reconnaissance." Montana Department of Transportation. Helena, MT.

Huijser, M. 2008. "Wildlife Vehicle Collision Reduction Study: Report to Congress." US Department of Transportation, Federal Highway Administration. McLean, VA.

Huijser, M.P. & J.S. Begley. 2022. Implementing wildlife fences along highways at the appropriate spatial scale: A case study of reducing road mortality of Florida Key deer. In: Santos S., C. Grilo, F. Shilling, M. Bhardwaj & C.R. Papp (Eds.). Linear Infrastructure Networks with Ecological Solutions. Nature Conservation 47: 283–302. https://doi.org/10.3897/natureconservation.47.72321

Ibisch, P. L., Hoffmann, M. T., Kreft, S., Pe'er, G., Kati, V., Biber-Freudenberger, L., DellaSala, D. A., Vale, M. M., Hobson, P. R., Selva, N. (2016). A global map of roadless areas and their conservation status. Science 354, 1423–1427.

Jackson, N. D.; Fahrig, L. Relative effects of road mortality and decreased connectivity on population genetic diversity. Biological Conservation, V. 144, P, 3143–3148, 2011.

Korner-Nievergelt F, Behr O, Brinkmann R, et al (2015) Mortality estimation from carcass 317 searches using the R-package carcass — a tutorial. Wildlife Biol 21:30–43. doi: 318 10.2981/wlb.00094

Meijer JR, Huijbregts MAJ, Schotten KCGJ, Schipper AM (2018) Global patterns of current and future road infrastructure. Environ Res Lett 13:. https://doi.org/10.1088/1748-9326/aabd42

Meyer, E. 2006. “Assessing the Effectiveness of Deer Warning Signs.” Kansas Department of Transportation. Topeka, KS.

Minnesota Department of Transportation. 2011. “Deer Detection and Warning System.” St. Paul, MN.

Mkanda, F.X., Chansa, W. 2011. Changes in Temporal and Spatial Pattern of Road Kills Along the Lusaka-Mongu (M9) Highway, Kafue National Park, Zambia. South African J. of Wildlife Research, 41(1):68-78. https://doi.org/10.3957/056.041.0114

Mosler-Berger, C, and J Romer. 2003. “Wildwarnsystem CALSTROM.” Wildbiologie 3: 1–12.

Nyirenda, V.R., Namukonde, N., Fushike, P. Road kills of wild vertebrates in Kafue National Park, Zambia, between January 2008 and December 2012. African Journal of Ecology, 55(4), 738–741. https://doi.org/10.1111/aje.12388

Ouyang, Y, Z Jiang, and K Jadaan. 2016. “Speed Harmonization-Design Speed vs. Operating Speed.” Illinois Department of Transportation. Springfield, IL.

Pojar, T, R Prosence, D Reed, and T Woodard. 1975. “Effectiveness of a Lighted, Animated Deer Crossing Sign.” The Journal of Wildlife Management, 87–91.

Riginos, C, E Fairbank, E Hansen, J Kolek, and M Ham. 2019. “Effectiveness of Night-Time Speed Limit Reduction in Reducing Wildlife-Vehicle Collisions.” Wyoming Department of Transportation. Cheyenne, WY.

Rytwinski, T., Soanes, K., Jaeger, J. A. G., Fahrig, L., Findlay, C. S., Houlahan, J., … Van Der Grift, E. A. (2016). How effective is road mitigation at reducing road-kill? A meta-analysis. PLoS ONE, 11(11), 1–25. https://doi.org/10.1371/journal.pone.0166941

Sawyer, H, P Rodgers, and T Hart. 2016. “Pronghorn and Mule Deer Use of Underpasses and Overpasses along US Highway 191.” Wildlife Society Bulletin 40 (2): 211–16.

Schwartz, A. L.; Shilling, F. M.; Perkins, S. R. The value of monitoring wildlife roadkill. European Journal of Wildlife Research, V. 66, N. 18, P. 1 - 12, 2020Villarroya, A.; Barros, A.C.; Kiesecker, J. Policy Development for Environmental Licensing and Biodiversity Offsets in Latin America. PloS one, [s. l.], v. 9, n. 9, p. e107144, 2014.

Seiler, A. 2003. “The Toll of the Automobile - Wildlife and Roads in Sweden.” Doctoral Thesis. Swedish University of Agricultural Sciences. Uppsala.

Seiler, A.; Helldin, J. Chapter 8 : Mortality in wildlife due to transportation. The Ecology of Transportation: Managing Mobility for the Environment, p. 165–189, 2006.

Sharafsaleh, M, M Huijser, C Nowakowski, M Greenwood, L Hayden, J Felder, and M Wang. 2012. “Evaluation of an Animal Warning System Effectiveness Phase Two- Final Report.” California Department of Transportation. Sacramento, CA.

Soanes, K., Rytwinski, T., Fahrig, L., Huijser, M. P., Jaeger, J. A. G. G., Teixeira, F. Z., … van der Grift, E. A. (2024). Do wildlife crossing structures mitigate the barrier effect of roads on animal movement? A global assessment. Journal of Applied Ecology, 61(3), 417–430. https://doi.org/10.1111/1365-2664.14582

Strein, M. 2010. “Restoring Permeability of Roads for Wildlife: Wildlife Warning Systems in Practice.” Programme and Book of Abstracts. IENE International Conference on Ecology and Transportation: Improving Connections in a Changing Environment, 27:77.

Sullivan, T, A Williams, T Messmer, L Hellinga, and S Kyrychenko. 2004. “Effectiveness of Temporary Warning Signs in Reducing Deer-vehicle Collisions during Mule Deer Migrations.” Wildlife Society Bulletin 32 (3): 907–15.

Teixeira FZ, Coelho AVP, Esperandio IB, Kindel A (2013) Vertebrate road mortality estimates: 344 Effects of sampling methods and carcass removal. Biol Conserv 157:317–323. doi: 345 10.1016/j.biocon.2012.09.006