

Evaluating impacts of linear transport infrastructure on wide ranging vertebrates in the Horn of Africa region

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Abstract

Transport infrastructure supports regional connectivity but can threaten biodiversity through habitat fragmentation and wildlife mortality. We assessed threatened species exposure to the Lamu Port-South Sudan-Ethiopia-Transport Corridor (LAPSSET), identified wildlife–vehicle collision hotspots along the Modika–Modogashe section, and evaluated mitigation priorities. IUCN species distribution data, roadkill surveys and spatial modelling were integrated to assess exposure across 50–1,000 m corridor buffers in Kenya, Ethiopia, Somalia, Uganda and South Sudan. We identified 23 threatened species, comprising 48% mammals and 52% birds. Hirola and several vulture species had the highest threat-weighted exposure (0.84–0.98), which declined with distance from roads. Along the 143-km Modika–Modogashe highway, 91 wildlife–vehicle collisions were recorded from 2021–2023 (0.63 km⁻¹), mainly involving small- to medium-sized mammals (60.4%), followed by large mammals (24.7%) and birds (8.8%). Collision hotspots occurred near Modogashe, Saka and Tula, particularly around settlements and shrubland. These findings support targeted fencing, wildlife crossings, speed regulation and warning signage to reduce mortality while maintaining ecological connectivity across the Horn of Africa.

1.0 INTRODUCTION

Transportation infrastructure, including roads, railways, pipelines and ports, is fundamental to economic development but increasingly threatens biodiversity and ecosystem integrity through habitat fragmentation, disrupted ecological connectivity and wildlife mortality (Laurance & Arrea 2017). Globally, transport infrastructure contributes roughly 5–15% of national GDP, depending on industrialization level (Citaristi 2022), while roads carry more than 80% of passenger and freight movement worldwide (Noussan, Hafner & Tagliapietra 2020). In Africa, expanding road and rail networks support regional integration, market access, tourism, trade and rural connectivity (Sakanga 2024). Across the Horn of Africa, major transport corridors are being developed under regional integration initiatives (Babatunde 2020; Government of Somaliland & TradeMark Africa 2023). These include the Addis Ababa–Djibouti corridor, Ethiopia's main trade artery handling about 95% of its import and export volume, with a 752 km electrified railway and upgraded highway linking Addis Ababa to Djibouti (UNECA 2022; Keno & Szytko 2025). The approximately 937 km Berbera Corridor connects the Port of Berbera with Ethiopia's hinterland, providing an alternative maritime outlet and supporting industrial and agricultural trade (Berbera Corridor Consortium 2022; DAI Global LLC 2019; World Bank 2020). The Juba–Nadapal–Lodwar–Kitale and Malaba–Gulu–Nimule–Juba routes connect the East African Community with the Horn of Africa, while the approximately 1,100 km Uganda–South Sudan–Central African Republic Corridor is being developed to support cross-border trade, humanitarian logistics and access to isolated communities (UNOPS 2021; EAC 2022; Bulzomi et al. 2014). Collectively, these corridors seek to improve market access, food supply chains, employment and socio-economic inclusion in historically poorly connected regions. Another major initiative, the Horn of Africa Gateway Development Project (HoAGDP), covers approximately 740 km of highway between Isiolo and Mandera in northeastern Kenya, together with fibre-optic and trade facilitation infrastructure (Lesutis 2020). Co-financed by the World Bank and Government of Kenya, it aims to reduce cargo transit times and strengthen links between Kenya, Somalia and Ethiopia (World Bank 2020; Berbera Corridor Consortium 2022; Ministry of Roads and Transport, Kenya 2023). Although these corridors stimulate trade, investment, employment and regional resilience, they also create growing ecological pressures.

The LAPSSET Corridor is one of East Africa's largest infrastructure projects, linking Kenya with Ethiopia and South Sudan through more than 1,700 km of multimodal infrastructure, including highways, railways and an oil pipeline. It extends from Lamu through Garissa, Isiolo, Marsabit and Moyale, with planned connections to Juba and Addis Ababa. The Isiolo–Moyale section alone covers approximately 505 km (LAPSSET Corridor Development Authority (LCDA) 2024). The project is intended to unlock investment in Kenya's northern frontier and provide Ethiopia and South Sudan with access to the Indian Ocean. Major highways such as Nairobi–Mombasa (A109), Isiolo–Marsabit–Moyale (A2) and the Lamu–Garissa–Isiolo LAPSSET road create stronger ecological barriers than rural tracks. Wide carriageways and high traffic volumes can deter wildlife crossings, isolate populations and increase vehicle-collision mortality (Forman & Alexander 1998; Coffin 2007; Ong'anya 2024). Globally, roads and railways are major drivers of biodiversity loss. In South America, expanding transport networks through the Amazon have increased mortality of large mammals such as jaguars and tapirs (Ascensão, Barrientos & D'Amico 2024), while in Asia, leopards and elephants are frequently killed on Indian highways (Roy & Sukumar 2017). These impacts are particularly concerning in the Horn of Africa, a recognized biodiversity hotspot with more than 2,750 endemic plant species and diverse mammals, birds, reptiles and amphibians adapted to arid and semi-arid environments (CEPF 2022). Major corridors such as Addis Ababa–Djibouti, Berbera, LAPSSET and HoAGDP intersect habitats of globally threatened species, including several classified as Endangered or Critically Endangered on the IUCN Red List.

Threatened species affected across the region include Soemmerring's gazelle (*Nanger soemmerringii*), Beira antelope (*Dorcatragus megalotis*), Somali wild ass (*Equus africanus somaliensis*), Somali ostrich (*Struthio molybdophanes*) and reticulated giraffe (*Giraffa reticulata*). The Critically Endangered Somali wild ass faces habitat loss, livestock competition, hunting and human encroachment in its remaining populations in Eritrea and Ethiopia. The Beira antelope, largely restricted to coastal hills and escarpments, is vulnerable to disturbance from construction, quarrying and traffic along the Berbera Corridor. The Vulnerable Somali ostrich similarly occupies habitats exposed to infrastructure expansion. The Endangered reticulated giraffe, concentrated in northern Kenya, southern Ethiopia and southern Somalia, faces range fragmentation and increased collision risk along roads crossing savanna and acacia woodland (Ong'anya 2024; Kioko et al. 2015). In South Sudan and Ethiopia, tiang (*Damaliscus lunatus tiang*), beisa oryx (*Oryx beisa beisa*) and lesser kudu (*Tragelaphus imberbis*) occupy plains increasingly intersected by highways and pipelines, potentially restricting seasonal movements to water and dry-season refugia. In Uganda, connected transport networks extend toward the Murchison–Kidepo landscape, supporting Endangered African elephants (*Loxodonta africana*) and Rothschild's giraffes (*Giraffa camelopardalis rothschildi*) (Brown et al. 2019).

In Kenya, transport development contributes about 8% to national GDP and remains a major economic driver (Njiru 2020). Projects such as the LAPSSET corridor are expected to transform the northern frontier by improving mobility and linking Kenya with neighbouring economies (Lesutis 2020; Ong'anya 2024). However, their environmental effects remain poorly understood, particularly in arid northern Kenya. Roads and railways consume land, fragment habitats and disrupt wildlife movement, feeding and social interactions (Laurance et al. 2014; Van Der Ree et al. 2015). Northern Kenya supports several of the Horn's most threatened taxa, including Grevy's zebra (*Equus grevyi*), hirola and reticulated giraffe. Grevy's zebra ranges from Isiolo to Marsabit, overlapping the

LAPSSET alignment, while the hirola, endemic to Kenya and southern Somalia, depends on open grasslands increasingly affected by road construction and land conversion (Andanje 2002; Ali et al. 2017; Probert et al. 2015).

Wildlife–vehicle collision risk varies with road type, traffic intensity, geometry and surrounding environmental conditions. Winding roads, sharp corners and steep gradients can increase mortality because of reduced driver visibility, while bridges, culverts and underpasses may either facilitate or restrict wildlife movement depending on their design (Clevenger & Huijser 2011). Roadside vegetation, rivers and pasture can attract wildlife and livestock, increasing exposure to traffic (D’Amico et al. 2015; Kioko et al. 2015). In pastoral landscapes, camels, goats and donkeys commonly graze near or cross major roads and can form a substantial component of roadkill records (Akanyang 2019). Fences around conservancies and ranches may also redirect wildlife toward open road corridors, increasing vehicle encounters (Boone & Hobbs 2004). Topography, slope, water proximity, vegetation and road features such as bends, culverts and bumps interact with traffic volume to create mortality hotspots. Small mammals and ungulates may be concentrated near drainage lines and bends, while birds and reptiles are vulnerable on heat-retaining asphalt surfaces (Kibobi et al. 2025). The expansion of multi-country transport corridors across the Horn of Africa therefore presents significant risks to already small and isolated wildlife populations. Wildlife-sensitive infrastructure, including underpasses, culverts and exclusion fencing, together with continuous ecological monitoring, is essential for maintaining connectivity, gene flow and species persistence (Clevenger & Huijser 2011; CEPF 2022; Mkutu 2021). In northern Kenya, however, the ecological effects of road development remain poorly studied despite the region supporting Grevy’s zebra, hirola, beisa oryx, reticulated giraffe and Somali ostrich. Their ranges overlap emerging transport corridors, where all-weather roads may constrain movement, isolate populations and disrupt dispersal (Mkutu 2021).

The LAPSSET Corridor presents particularly important socio-ecological challenges. The Lamu–Garissa–Isiolo (A10) and Isiolo–Marsabit–Moyale (A2) roads, together with feeder routes toward North Horr, traverse important wildlife habitats and movement pathways, yet their effects on wildlife distribution, mortality and ecological connectivity remain poorly documented. Few studies have integrated species distribution, roadkill and environmental data to assess these impacts. This study therefore investigated the effects of road infrastructure on wildlife movement and survival in northern Kenya by (i) mapping threatened species and quantifying their overlap with transport corridors; (ii) identifying wildlife–vehicle collision hotspots and their environmental drivers; and (iii) proposing mitigation measures to reduce road mortality and maintain ecological connectivity. The findings provide empirical evidence to support wildlife-sensitive transport planning within the LAPSSET Corridor and contribute to regional biodiversity conservation under IFC, World Bank, Sustainable Development Goal 15 and the African Union’s Agenda 2063.

2.0 MATERIALS AND METHODS

2.1 Study Area

This study focused on the LAPSSET and the Horn of Africa corridor (Fi1). The corridor runs from Lamu Port on Kenya’s coast through Isiolo toward Juba, Addis Ababa, Kampala, Hargeisa, Berbera and Djibouti, linking East Africa’s coast to its interior. It crosses a wide range of semi-arid and arid landscapes, many of which are ecologically fragile and home to rare and threatened wildlife. The region receives between 100 and 600 mm of annual rainfall and experiences temperatures often exceeding 35°C. Vegetation is dominated by Acacia–Commiphora bushland, open grasslands and riverine forests along the Tana, Ewaso Nyiro and Juba–Shabelle rivers. The corridor supports several threatened species including the hirola, Grevy’s zebra, reticulated giraffe and Beisa oryx as well as predators such as cheetahs, lions and African wild dogs (*Lycaon pictus*).

To explore the real-world impacts of such developments, we examined a 143 km section of the Modika–Modogashe highway in Garissa County, Kenya. This segment, which forms part of the LAPSSET corridor, was selected because road construction was only complete and the road operational with reliable wildlife roadkill data available. The Hirola Conservation Program (HCP) recorded these data between 2021 and 2023, offering a rare opportunity to assess how wildlife interacts with newly developed infrastructure. The area is a typical semi-arid rangeland, marked by bushy vegetation, open grass patches and seasonal drainage lines. It lies within the Tana River basin, connecting pastoral lands that support both domestic livestock and wild herbivores. Because this section is already active and well monitored, it serves as a useful proxy for understanding how new roads may affect wildlife across similar dryland environments along the broader transport corridor.

2.2 Study Design and Data Sources

We adopted a multi-scale study design that combined a regional species–corridor exposure assessment with detailed local roadkill surveys along an operational section of the LAPSSET highway. At the regional scale, we assessed the potential exposure of threatened and endemic species to major transport corridors across Kenya, Ethiopia, Uganda, South Sudan and Somalia using species range maps and corridor networks. At the local scale, we assessed wildlife–vehicle collisions and associated environmental and infrastructure characteristics along the 143-km Modika–Modogashe section of the LAPSSET highway in Garissa County. By integrating these approaches, we examined broad-scale patterns of potential biodiversity exposure alongside fine-scale empirical evidence of wildlife mortality and road-related risk.

2.2.1 Regional Species–Corridor Exposure Assessment

We used species range data rather than point occurrence records to provide a broad-scale assessment of potential exposure to transport infrastructure. We obtained spatial range maps for threatened and endemic species from the IUCN Red List spatial database (IUCN 2023) and supplemented these with relevant published literature and selected species based on their known occurrence within or near the transport corridor network considered in the study. We used species conservation status, geographic range and spatial overlap with transport infrastructure as indicators of potential biodiversity exposure with the World Bank Environmental and Social Standard 6 (ESS6) providing a supporting framework for considering biodiversity conservation, threatened species, habitat integrity and ecological connectivity. We used ESS6 as a supporting biodiversity assessment framework rather than as a formal compliance assessment.

We compiled spatial data for the major transport corridors from the Kenya National Highways Authority (KeNHA), LAPSET Corridor Development Authority and Humanitarian OpenStreetMap Team (HOTSM) and included the LAPSET system and associated regional connections linking Lamu–Isiolo–Juba, Kampala–Juba–Addis Ababa–Djibouti, Addis Ababa–Hargeisa–Berbera and Isiolo–Addis Ababa. We conducted all spatial analyses in ArcMap 10.4 and generated buffers of 50, 100, 250, 500 and 1,000 m around the corridor alignments to represent different spatial scales of potential infrastructure influence. We considered the narrower buffers to represent areas of relatively direct disturbance and potential wildlife–vehicle collision exposure, while we considered the broader buffers to represent potential habitat modification, edge effects and reduced ecological connectivity in line with the biodiversity considerations emphasized under ESS6. We clipped each species range to the regional study boundary and calculated the area overlapping each corridor buffer. We expressed exposure as the percentage of each species' total range occurring within each buffer, allowing us to compare exposure among species with different geographic ranges.

We incorporated conservation status into the exposure assessment by assigning threat weights to IUCN categories as follows: Critically Endangered (CR) = 4, Endangered (EN) = 3, Vulnerable (VU) = 2 and Near Threatened (NT) = 1 and calculated a threat-weighted exposure score by combining the proportion of each species' range overlapping the corridor with its corresponding IUCN threat weight. This study-specific threat-weighted approach allowed us to give greater analytical weight to species of higher conservation concern, consistent with the emphasis of ESS6 on avoiding and minimizing impacts on biodiversity of high conservation importance. We standardized the resulting scores to a 0–1 scale to facilitate comparison among species and identify taxa with the greatest relative exposure to transport infrastructure.

2.2.2 Local Roadkill Surveys and Environmental Data

We conducted the local-scale assessment along a 143-km section of the Modika–Modogashe highway in Garissa County. We selected this section because it forms an operational component of the LAPSET corridor allowing us to assess wildlife–vehicle collisions under active traffic conditions. The road traverses semi-arid rangelands supporting threatened species, including the hirola and Grevy's zebra and intersects areas used by community conservancies and seasonal livestock movements. We used verified roadkill records collected by the HCP between January 2021 and December 2023 as the empirical basis for assessing collision patterns and associated environmental conditions. We conducted systematic roadkill surveys twice weekly in both directions along the section travelling at approximately 20–40 km h⁻¹ to maximize carcass detection. We georeferenced each carcass using a Garmin GPSMAP 64s and photographed it using a GPS-enabled digital camera recording the date, time, geographic coordinates and species identity where identification was possible. We subsequently removed documented carcasses from the road to prevent repeated counting and to protect scavengers. We categorized carcasses according to decomposition stage as fresh (< 12 h), recent (1–3 days) or old (> 3 days) and identified species based on morphological characteristics and verified identifications using field guides (Estes 2012). Where remains were insufficient for species-level identification, we assigned records to the genus or family level. We also recorded road and environmental characteristics at each roadkill location including road width, curvature, surface type and adjacent vegetation, land cover, nearby settlements, water sources and relevant infrastructure. We obtained spatial data on roads, bridges, culverts and fences from KeNHA, LCDA and HOTSM. We obtained additional spatial layers, including settlements, croplands, conservancies, ranches and drainage networks, from Google Earth, HydroSHEDS and county administrative datasets. We derived elevation and slope from a 30-m SRTM digital elevation model. We projected and spatially aligned all datasets to a common coordinate system before analysis. We checked infrastructure features against Google Earth Pro imagery from 2020–2024 and field GPS observations to improve positional accuracy.

We generated land-cover information using Sentinel-2 imagery and ESA WorldCover 2022 in Google Earth Engine. We processed cloud-free imagery and classified the study area using a supervised Random Forest algorithm into seven land-cover classes: woodland, shrubland, grassland, cropland, settlement, wetland and bare ground and assessed classification accuracy using 250 field-based validation points and achieved more than 85% overall accuracy. We characterized vegetation condition using the Normalized Difference Vegetation Index (NDVI) which we calculated from monthly Sentinel-2 composites for 2016–2024 and summarized by wet and dry seasons. We used NDVI as a proxy for vegetation productivity and forage availability (Pettorelli et al. 2011). We calculated distances from roadkill locations to settlements, rivers, fences and croplands and derived road curvature and width from the road network. Where reliable records were available, we also incorporated traffic intensity into the analysis.

2.2.3 Roadkill Density, Hotspot and Risk Analysis

We calculated roadkill density as the number of recorded carcasses per kilometre per year and restricted all records and associated environmental layers to a 500-m buffer on either side of the LAPSET road to maintain a consistent spatial extent across analyses. We examined spatial concentrations of roadkill using Kernel Density Estimation (KDE) and the Getis–Ord Gi* statistic in ArcGIS 10.4. We used KDE to identify areas of concentrated mortality and the Getis–Ord Gi* statistic to identify statistically significant clusters of high and low roadkill occurrence. We used these analyses to delineate roadkill hotspots and identify sections requiring further investigation or mitigation. We fitted generalized linear models (GLMs) and generalized additive models (GAMs) to examine environmental and infrastructure predictors of roadkill occurrence. We used Poisson or negative binomial distributions depending on the degree of dispersion in the response variable. Predictor variables included land-cover type, elevation, slope, NDVI, distance to settlements, rivers, fences and croplands, road curvature, road width and traffic intensity where available. We used Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) to guide model selection. We additionally applied a Random Forest model to evaluate the relative importance of predictors and generate spatially explicit estimates of roadkill risk. We evaluated model performance using 10-fold cross-validation and predictive metrics including AUC, Cohen's Kappa and overall classification accuracy (Cutler et al. 2007).

3.0 RESULTS

3.1 Regional-scale spatial assessment, examining how threatened species ranges overlap with Transport Corridor

3.1.1 Species of Conservation Concern within the Transport Corridor

We identified 23 species of conservation concern whose distributions overlapped the transport corridor (Table 1; Supplementary Fig. S1–S4). Mammals comprised 48% of the species and birds 52%. Among mammals, the hirola (*Beatragus hunteri*) was Critically Endangered; Grevy’s zebra, Beisa oryx, African elephant and African wild dog were Endangered, while cheetah (*Acinonyx jubatus*), lion (*Panthera leo*), leopard (*Panthera pardus*) and giraffe were Vulnerable. Among birds, White-backed vulture (*Gyps africanus*), Rüppell’s vulture (*Gyps rueppelli*), Hooded vulture (*Necrosyrtes monachus*) and White-headed vulture (*Trigonoceps occipitalis*) were Critically Endangered, while Lappet-faced vulture (*Torgos tracheliotos*) was Endangered. Other species of conservation concern included Steppe eagle (*Aquila nipalensis*), Saker falcon (*Falco cherrug*) and Bateleur (*Terathopius ecaudatus*).

Table1: Species of Conservation Concern within the Transport Corridor

Species (scientific)	Common name	Taxa	IUCN status	Assessm
<i>Acrocephalus griseldis</i>	Basra Reed-warbler	Bird	EN	2012–2
<i>Aquila nipalensis</i>	Steppe Eagle	Bird	EN	BirdLife
<i>Ardeola idae</i>	Malagasy / Madagascar Pond-heron	Bird	EN	(assess
<i>Balearica regulorum</i>	Grey Crowned-crane	Bird	EN	2016 / r
<i>Falco cherrug</i>	Saker Falcon	Bird	EN	BirdLife
<i>Gyps africanus</i>	White-backed Vulture	Bird	CR	(recent
<i>Gyps rueppelli</i>	Rüppell’s Vulture	Bird	CR	2015–2
<i>Necrosyrtes monachus</i>	Hooded Vulture	Bird	CR	2015 (u
<i>Neophron percnopterus</i>	Egyptian Vulture	Bird	EN	2021 (B
<i>Sagittarius serpentarius</i>	Secretarybird	Bird	EN / VU depending on region (global: EN / VU assessments exist)	2020 (g
<i>Terathopius ecaudatus</i>	Bateleur	Bird	EN	2020–2
<i>Torgos tracheliotos</i>	Lappet-faced Vulture	Bird	EN	2015–2
<i>Trigonoceps occipitalis</i>	White-headed Vulture	Bird	CR	2015–2
<i>Acinonyx jubatus</i>	Cheetah	Mammal	VU	2022 / ε
<i>Beatragus hunteri</i>	Hirola (Hunter’s hartebeest)	Mammal	CR	(various
<i>Equus grevyi</i>	Grevy’s zebra	Mammal	EN	2016 / :
<i>Giraffa camelopardalis</i>	Giraffe (genus/complex)	Mammal	VU/ EN (species complex some subspecies higher threat)	2016 (g
<i>Loxodonta africana</i>	African savanna elephant	Mammal	EN	2021–2
<i>Lycaon pictus</i>	African Wild Dog (Painted dog)	Mammal	EN	2012 / :
<i>Oryx beisa</i>	Beisa Oryx (Eastern Oryx)	Mammal	EN	2018 / :
<i>Panthera leo</i>	Lion	Mammal	VU	2018 / t
<i>Panthera pardus</i>	Leopard	Mammal	VU	2015–2
<i>Redunca fulvorufula</i>	Mountain (Southern) reedbeek	Mammal	EN (regional assessments; some subspecies vary)	Regiona

Species conservation status (source: IUCN Red List 2012–2024). Note: CR = Critically Endangered; EN = Endangered; VU = Vulnerable

3.1.2 Species Range Overlap with Transport Corridor Buffers

We identified 23 species of conservation concern whose regional ranges overlapped the assessed transport corridors, including mammals and birds classified as Vulnerable, Endangered or Critically Endangered on the IUCN Red List. Regional range sizes varied from approximately 11,329 km² for the hirola to over 3.2 million km² for wide-ranging species such as the African wild dog and leopard. The proportion of range overlapping the corridors decreased with buffer distance, from 0.17–2.43% at 1,000 m to 0.09–1.22% at 500 m, 0.04–0.61% at 250 m, 0.02–0.24% at 100 m and 0.009–0.12% at 50 m. At 1,000 m, mammalian overlap ranged from 0.35–2.43% and avian overlap from 0.17–1.17%. The lowest values were recorded for the Malagasy pond heron (0.17%) and cheetah (0.35%). Mean overlap across species was 0.56% at 1,000 m, 0.28% at 500 m, 0.14% at 250 m, 0.056% at 100 m and 0.028% at 50 m (Table 2).

Table 2: Regional range and overlap of species of conservation concern with transport corridor buffers

Species	Regional range (km ²)	1000 m buffer (km ² (%))	500 m buffer (km ² (%))	250 m buffer (km ² (%))	100 m buffer (km ² (%))	50 m buffer (km ² (%))
<i>Acinonyx jubatus</i>	2,699,737.82	9,405.32 (0.35)	4,703.22 (0.17)	2,351.89 (0.09)	940.81 (0.03)	470.46 (0.02)
<i>Acrocephalus griseldis</i>	370,915.41	4,329.17 (1.17)	2,164.87 (0.58)	1,082.57 (0.29)	433.13 (0.12)	216.59 (0.06)
<i>Aquila nipalensis</i>	2,305,640.60	11,061.04 (0.48)	5,528.70 (0.24)	2,763.44 (0.12)	1,105.45 (0.05)	552.54 (0.02)
<i>Ardeola idae</i>	400,959.34	687.18 (0.17)	343.14 (0.09)	171.35 (0.04)	68.69 (0.02)	34.30 (0.01)
<i>Balearica regulorum</i>	498,260.67	2,631.75 (0.53)	1,315.16 (0.26)	657.22 (0.13)	262.92 (0.05)	131.39 (0.03)
<i>Beatragus hunteri</i>	11,329.32	275.40 (2.43)	137.81 (1.22)	68.96 (0.61)	27.58 (0.24)	13.80 (0.12)
<i>Equus grevyi</i>	90,839.27	900.73 (0.99)	450.08 (0.50)	224.90 (0.25)	89.97 (0.10)	44.95 (0.05)
<i>Falco cherrug</i>	1,088,073.84	5,485.62 (0.50)	2,742.14 (0.25)	1,370.74 (0.13)	548.32 (0.05)	274.09 (0.03)
<i>Giraffa camelopardalis</i>	530,034.27	3,433.51 (0.65)	1,716.52 (0.32)	858.15 (0.16)	343.26 (0.06)	171.61 (0.03)
<i>Gyps africanus</i>	2,901,311.06	11,538.50 (0.40)	5,767.61 (0.20)	2,882.98 (0.10)	1,154.19 (0.04)	576.93 (0.02)
<i>Gyps rueppelli</i>	2,602,576.52	11,539.42 (0.44)	5,769.71 (0.22)	2,884.85 (0.11)	1,154.52 (0.04)	577.26 (0.02)
<i>Loxodonta africana</i>	637,960.19	2,930.73 (0.46)	1,465.36 (0.23)	732.68 (0.11)	292.90 (0.05)	146.45 (0.02)
<i>Lycaon pictus</i>	3,188,843.10	11,544.48 (0.36)	5,771.23 (0.18)	2,885.11 (0.09)	1,154.03 (0.04)	576.91 (0.02)
<i>Necrosyrtes monachus</i>	3,201,043.59	11,542.84 (0.36)	5,769.70 (0.18)	2,883.99 (0.09)	1,153.17 (0.04)	576.42 (0.02)
<i>Neophron percnopterus</i>	2,717,340.33	10,353.54 (0.38)	5,177.38 (0.19)	2,588.99 (0.10)	1,036.79 (0.04)	518.46 (0.02)
<i>Oryx beisa</i>	896,636.02	4,460.70 (0.50)	2,230.64 (0.25)	1,115.47 (0.12)	445.54 (0.05)	222.80 (0.02)
<i>Panthera leo</i>	3,154,651.89	10,955.50 (0.35)	5,475.95 (0.17)	2,737.08 (0.09)	1,095.07 (0.03)	547.36 (0.02)
<i>Panthera pardus</i>	3,249,208.39	11,548.45 (0.36)	5,766.73 (0.18)	2,879.62 (0.09)	1,154.53 (0.04)	576.52 (0.02)
<i>Redunca fulvorufula</i>	370,526.17	2,771.55 (0.75)	1,385.02 (0.37)	692.14 (0.19)	277.24 (0.07)	138.54 (0.04)
<i>Sagittarius serpentarius</i>	2,356,084.81	11,345.15 (0.48)	5,669.02 (0.24)	2,832.74 (0.12)	1,133.84 (0.05)	566.57 (0.02)
<i>Terathopius ecaudatus</i>	2,816,466.24	11,540.75 (0.41)	5,768.97 (0.20)	2,883.78 (0.10)	1,153.65 (0.04)	576.69 (0.02)
<i>Torgos tracheliotos</i>	2,927,020.78	11,539.76 (0.39)	5,768.15 (0.20)	2,883.21 (0.10)	1,152.87 (0.04)	576.26 (0.02)
<i>Trigonoceps occipitalis</i>	2,812,182.04	11,537.25 (0.41)	5,766.99 (0.21)	2,882.67 (0.10)	1,155.33 (0.04)	577.50 (0.02)

Regional ranges were derived from the IUCN Red List (2023) and clipped to the five LAPSET countries. Transport corridor buffers (50–1000 m) were created from official shapefiles sourced from KeNHA, LCDA and HOTOSM. Overlap values indicate the area and percentage of each species' range intersecting the corridor footprint.

3.1.3 Threat-weighted exposure risk of species to transport corridors

Threat-weighted exposure varied among species (Fig. 2; Supplementary Table S1). Critically Endangered vultures had the highest normalized risk indices, with White-backed Vulture (*Gyps africanus*) scoring 0.98, followed by Rüppell's Vulture (*Gyps rueppelli*, 0.93), White-headed Vulture (*Trigonoceps occipitalis*, 0.90) and Hooded Vulture (*Necrosyrtes monachus*, 0.87). Among mammals, the highest indices were recorded for Hirola (0.84), African Wild Dog (0.81) and African Savanna Elephant (0.78). Giraffe (0.66) and Lion (*Panthera leo*, 0.62) had moderate indices, while Beisa Oryx and Mountain (Southern) Reedbuck (*Redunca fulvorufula*) had lower values (<0.40).

3.2 Relationship between Road Infrastructure and Wildlife Mortality

3.2.1 Composition and Frequency of Roadkill

Between 2021 and 2023, we recorded 91 wildlife roadkills along the 143-km Modika–Modogashe highway (0.63 roadkills/km). Individuals were identified to species and grouped as large mammals (>15 kg), small to medium-sized mammals (<15 kg), birds and reptiles. Large mammals comprised 24.7% of records. Somali giraffe (**Plate 1**), striped hyena (*Hyaena hyaena*) and gerenuk (*Litocranius walleri*) were the most frequent, each accounting for 16.7% of large-mammal collisions. Other records included aardvark (*Orycteropus afer*), Grevy's zebra, spotted hyena (*Crocuta crocuta*), Beisa oryx (*Oryx beisa*) and common warthog (*Phacochoerus africanus*). Collision frequencies did not differ significantly among species ($\chi^2 = 12.32$, $df = 7$, $p = 0.09$). Small to medium-sized

mammals accounted for most roadkills (n = 55; 60.4%). African civet (*Civettictis civetta*) accounted for 41.8%, followed by dik-dik (*Madoqua kirkii*, 23.6%) and Cape hare (*Lepus capensis*, 14.5%). Collision frequencies differed significantly among species ($\chi^2 = 85.89$, df = 6, $p < 0.001$). Birds accounted for 8.8% (n = 8), including vulturine guineafowl (*Acryllium vulturinum*), ring-necked dove (*Streptopelia capicola*) and marabou stork (*Leptoptilos crumenifer*), with no significant difference among species ($\chi^2 = 1.75$, df = 2, $p = 0.42$). Only one reptile, the red-spitting cobra (*Naja pallida*), was recorded. Species-specific records are presented in Table 3.

Table 3: Roadkill species in each vertebrate category recorded along the Modika-Modogashe highway in Garissa and Tana River County, Kenya between 2021 and 2023

Vertebrate category	Species	Scientific name	Conservation status	Roadkill per km	Frequency	%
Large mammals (>15kg)	Aardvark	<i>Orycteropus afer</i>	LC	0.02	3	12
	Beisa Oryx	<i>Oryx beisa</i>	EN	0.01	2	8.3
	Common warthog	<i>Phacochoerus africanus</i>	LC	0.01	1	4.2
	Gerenuk	<i>Litocranius walleri</i>	NT	0.03	4	16
	Grevy Zebra	<i>Equus grevyi</i>	EN	0.02	3	12
	Somali Giraffe	<i>Giraffa reticulata</i>	EN	0.03	4	16
	Spotted Hyena	<i>Crocuta crocuta</i>	LC	0.02	3	12
	Striped Hyena	<i>Hyaena hyaena</i>	NT	0.03	4	16
Small to medium size mammals (<15kg)	African Golden Wolf	<i>Canis lupaster</i>	LC	0.03	4	7.3
	African Civet	<i>Civettictis civetta</i>	LC	0.16	23	41
	Cape Hare	<i>epus capensis</i>	LC	0.06	8	14
	Porcupine	<i>Hystrix cristata</i>	LC	0.01	1	1.8
	Silver backed Jackal	<i>Lupulella mesomelas</i>	LC	0.01	2	3.6
	Dik Dik	<i>Madoqua kirkii</i>	LC	0.09	13	23
	Bat-Eared Fox	<i>Otocyon megalotis</i>	LC	0.03	4	7.3
Birds	Marabou Stork	<i>Leptoptilos crumenifer</i>	LC	0.01	1	12
	Ring-necked Dove	<i>Streptopelia capicola</i>	LC	0.02	3	37
	Vulturine Guinea Fowl	<i>Acryllium vulturinum</i>	LC	0.03	4	50
Reptiles	Red-Spitting Cobra	<i>Naja pallida</i>	LC	0.03	4	10

Conservation status (LC- least concern, NT- Near Threatened, EN- Endangered)

3.2.2 Seasonal Variation in Roadkill

We recorded wildlife roadkill during both wet and dry seasons with a slightly higher proportion occurring during the wet season (52.7%) than the dry season (47.3%). We found no significant difference in roadkill frequency between seasons when we considered all vertebrate classes combined ($\chi^2 = 0.0001$, df = 1, $p = 0.98$), or among large mammals ($p = 0.42$) and small to medium-sized mammals ($p = 0.11$). We recorded birds and reptiles only during the wet season (Fig 3).

3.2.3 Spatial Distribution and Hotspots

We identified distinct roadkill hotspots along the Modika–Modogashe corridor with the highest concentrations occurring between Modogashe and Madogo. We recorded large-mammal collisions mainly around Saka and Tula, particularly during the dry season, while small to medium-sized mammal roadkills clustered around Modogashe, Saka and Madogo with denser concentrations during the dry months. We recorded avian and reptile roadkills only during the wet season with bird fatalities concentrated around Saka and reptile incidents occurring mainly between Modogashe and Saka (Fig 4).

We recorded bird and reptile roadkills only during the wet season. Bird roadkills showed high clustering near Saka, while reptile roadkills were concentrated along the highway section between Modogashe and Saka (Fig 5).

3.2.4 Determinants of Road Kills along the Modika–Modogashe Highway

We found that roadkill occurrence varied with surrounding environmental and infrastructural characteristics. Roadkill locations were, on average, 41.8 m from road junctions and 48.5 km from conservation areas. Our logistic regression identified seven significant predictors of roadkill occurrence ($p < 0.05$): distance to road junctions, settlements, conservation areas, rivers, road bumps, road corners and land-cover type (Table 4). Across all vertebrate groups, we recorded the highest roadkill occurrence in shrubland and open grassland, while increasing distances from road junctions, road corners and conservation areas were associated with lower roadkill occurrence. For large mammals (>15 kg), roadkill occurrence was associated with proximity to settlements, rivers and open

habitats, whereas we recorded fewer collisions near road junctions and corners. Shrubland had the strongest positive association with large-mammal roadkill occurrence ($\beta = 0.835$, $p < 0.001$). For small mammals (<15 kg), we recorded fewer collisions near settlements but higher occurrence in shrubland and open grassland. For birds, roadkill occurrence was significantly associated with distance from settlements and conservation areas and with land-cover type with shrubland ($\beta = 0.231$, $p < 0.001$) and grassland ($\beta = 0.101$, $p < 0.001$) showing positive associations with fatalities (Table 4).

Table 4: Logistic regression results showing the effects of environmental and infrastructural predictors on wildlife roadkill occurrence along the Modika–Modogashe section of the LAPSET highway.

Taxa	Parameter	Coefficient (β)	Std. Error	p-value
All animal species	Distance to road junction	−0.00008	0.00015	0.0106
	Distance to settlement	0.0028	0.00003	0.0001
	Distance to conservation area	−0.00018	0.0001	0.0043
	Distance to river	0.0022	0.0003	0.0108
	Distance to road bump	−0.00016	0.00003	0.0001
	Shrubland	0.70359	0.31237	0.0003
	Open grassland	0.68372	0.024	0.0024
Large mammals (>15 kg)	Distance to road junction	−0.00015	0.0001	0.0111
	Distance to settlement	0.0072	0.0004	0.0001
	Distance to conservation area	0.00018	0.0002	0.0001
	Distance to river	0.00013	0.00008	0.0004
	Distance to corner	−0.0021	0.0003	0.0003
	Shrubland	0.8351	0.0242	0.0001
	Open grassland	0.5623	0.057	0.0021
Small mammals (<15 kg)	Distance to settlement	−0.0162	0.0021	<0.0001
	Distance to conservation area	0.0298	0.0452	<0.0001
	Distance to river	0.0001	0.0023	0.0004
	Shrubland	0.7451	0.0041	0.0021
	Open grassland	0.7112	0.0253	0.0011
Bird	Distance to settlement	0.0122	0.0043	<0.0001
	Distance to conservation area	0.013	0.021	<0.0001
	Shrubland	0.2311	0.0001	0.0001
	Open grassland	0.1012	0.0322	0.0001

Positive coefficients indicate a higher probability of roadkill occurrence with increasing variable values, while negative coefficients suggest reduced likelihood.

DISCUSSION

The overlap analysis showed that threatened mammals and birds occur within the influence zones of the proposed transport corridors. Northern and eastern Kenya and adjoining areas of Ethiopia and Somalia support diverse large mammals and raptors. The high representation of vultures and large carnivores is consistent with their severe declines from poisoning, habitat loss, electrocution and prey depletion (Botha et al. 2017; Durant et al. 2017). The presence of the hirola is particularly important because it has a small, restricted range in eastern Kenya and southern Somalia (Ali et al. 2017). Further habitat fragmentation could therefore place additional pressure on its population. These overlaps support the inclusion of biodiversity safeguards in infrastructure planning and environmental assessments (Laurance et al. 2015; Van Der Ree et al. 2015). Range overlap declined as buffer distance narrowed, showing that road effects may extend beyond the physical road footprint. Noise, edge effects, altered movement and increased human access can affect habitats beyond the alignment (Forman & Alexander, 1998; Trombulak & Frissell 2000). Restricted-range species such as the hirola and Beisa oryx showed higher overlap than wide-ranging species such as leopard, consistent with the greater vulnerability of species with limited distributions to concentrated human activity and landscape change (Newbold et al. 2015). Large vultures and other raptors may also face increased exposure because of their extensive movements and use of open habitats near transport corridors (McClure et al. 2021).

The overlap gradient broadly corresponds with established road-effect zones. Areas within about 100 m are more associated with direct mortality and habitat loss, while 250–500 m may include behavioural effects such as habitat avoidance and reduced reproductive success (Coffin 2007; Benítez-López et

al. 2010). Beyond 1,000 m, roads may contribute to land-use change, grazing and increased human access (Laurance et al. 2014). Although mean overlap at 1,000 m was only 0.56%, even small habitat losses may affect species with restricted ranges or small populations through reduced dispersal and connectivity (Haddad et al. 2015). The threat-weighted index combined range overlap with IUCN conservation status, providing a clearer measure of conservation risk than spatial overlap alone. Similar approaches have been used to assess biodiversity risks from infrastructure development (Ascensão et al. 2018; Clements et al. 2014). The index identified species for which relatively small areas of overlap may still represent substantial conservation risks and therefore require greater mitigation attention. The highest values among vultures and large carnivores reflect the interaction between infrastructure exposure and species ecology. African vultures have declined by more than 80% over three decades, mainly because of poisoning, power infrastructure and habitat loss and fragmentation (Botha et al. 2017). The high values for White-backed, Rüppell's and White-headed vultures therefore indicate additional pressure on an already threatened group. The hirola and African wild dog also showed high exposure despite their restricted ranges. Both depend on open savanna habitats and may be affected by disturbance, altered prey distribution, disease transmission and persecution (Durant et al. 2017; IUCN 2023). The African elephant also showed high exposure despite its broad distribution, consistent with evidence that roads can increase mortality and disrupt movement and gene flow (Laurance et al. 2014; van Aarde et al. 2021). Lower values for Beisa oryx and mountain reedbuck do not necessarily indicate low risk because limited overlap may still involve important habitat or movement routes (Newmark et al. 2023). The normalized exposure gradient further shows the value of incorporating conservation status into infrastructure risk assessment. Species with similar spatial exposure may face different consequences because of differences in population size and extinction risk. Combining exposure and vulnerability can therefore improve prioritisation of mitigation measures (Ascensão et al. 2018; Clements et al. 2014).

The 0.63 roadkills/km recorded along the Modika–Modogashe highway falls within the 0.5–0.8 roadkills/km reported for medium and large mammals on other Kenyan roads, including Tsavo East and West (Ngoprasert, Lynam, & Gale 2007; Gunson, Mountrakis, & Quackenbush 2011). Road impacts, however, extend beyond direct mortality. Wildlife use of railway underpasses varies with species, environmental conditions and structure dimensions (Lala et al. 2022). Similar mortality patterns have been reported in Kruger National Park and the Serengeti–Mara ecosystem (Gunson et al. 2011; D'Amico et al. 2015). Habitat type and proximity to settlements have also been identified as important predictors of roadkill along the Nairobi–Mombasa Highway (Kibobi et al. 2025), while high mortality of large and medium-sized mammals has been reported along northern Tanzanian highways (Kioko et al. 2015).

Large mammals accounted for 24.7% of roadkills, with Somali giraffe, striped hyena and gerenuk contributing substantially. Their mobility and use of open habitats may increase vehicle encounters, as reported for giraffes and zebras in Tsavo and Amboseli (Ngoprasert et al. 2007). Small- to medium-sized mammals accounted for 60.4%, with African civet and Kirk's dik-dik among the most frequent. Road-edge and open-habitat use may increase their exposure to traffic (Benítez-López et al. 2010; Clevenger et al. 2003). Birds and reptiles accounted for fewer records, although all were recorded during the wet season. Seasonal changes in movement, foraging and prey availability may contribute to these patterns (Clevenger et al. 2003). Roadkill hotspots were concentrated near settlements, junctions and open habitats. Shrubland and open grassland were the strongest predictors of mortality, consistent with studies linking roadkill to habitat and human activity (Gunson et al. 2011; Ngoprasert et al. 2007). Risk declined with increasing distance from settlements, junctions and protected areas, indicating that both habitat and human activity influence wildlife exposure. The mean distance of roadkills from conservation areas was approximately 48.5 km, showing that wildlife outside protected areas also remains vulnerable to roads. This is important for species with small populations or restricted ranges, including the hirola and Beisa oryx, for which even limited mortality may affect population viability and connectivity (Haddad et al. 2015).

Taken together, the results show that infrastructure risk is determined by more than the amount of species range crossed by a road. Spatial overlap identifies exposure, the threat-weighted index identifies species of greater conservation concern, and roadkill analysis identifies locations of direct mortality. Their combined use therefore provides a stronger basis for prioritising mitigation than any single measure. Wildlife crossings, fencing and speed regulation should be targeted at identified hotspots and important movement routes, with continued monitoring to assess changes in mortality and wildlife movement as the transport network develops (Ascensão et al. 2018).

In conclusion, the LAPSET corridor overlaps the ranges of several threatened species and is associated with wildlife mortality. The hirola, African wild dog, African elephant and several vulture species showed high exposure, while small- and medium-sized mammals accounted for most roadkills. Mortality was concentrated in shrubland, open grassland, near settlements and around road junctions. The threat-weighted index showed that conservation risk depends on both infrastructure exposure and species vulnerability. Mitigation should focus on identified roadkill hotspots and important wildlife movement routes. Wildlife crossings, guiding fences and speed control should be prioritised, with designs suited to target species (Clevenger et al. 2001; Ascensão et al. 2018; Lala et al. 2022). Roadside habitat should be managed carefully, while additional risks to vultures and other scavengers, including hazardous powerline structures, should also be addressed (Murn & Botha 2018). Regular roadkill surveys, camera trapping and wildlife movement monitoring should be used to assess mitigation effectiveness and guide adjustments (Gunson et al. 2011; D'Amico et al. 2015). Biodiversity considerations should also be incorporated into future LAPSET development and wider regional transport planning to maintain wildlife connectivity across northern Kenya and the Horn of Africa (Ascensão et al. 2018; Clements et al. 2014).

Declarations

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

Abdullahi H. Ali conceived and designed the study, contributed to data processing and led the preparation of the manuscript. Haruki B. Mwangi contributed to data processing, analysis and interpretation of the results, and preparation of the manuscript. Adam G. Mureithi contributed to data collection and preparation of the manuscript. Edwin L. Sangale and Mohamed H. Ali contributed to data collection. All authors contributed to the revision of the manuscript and approved the final version.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Figures

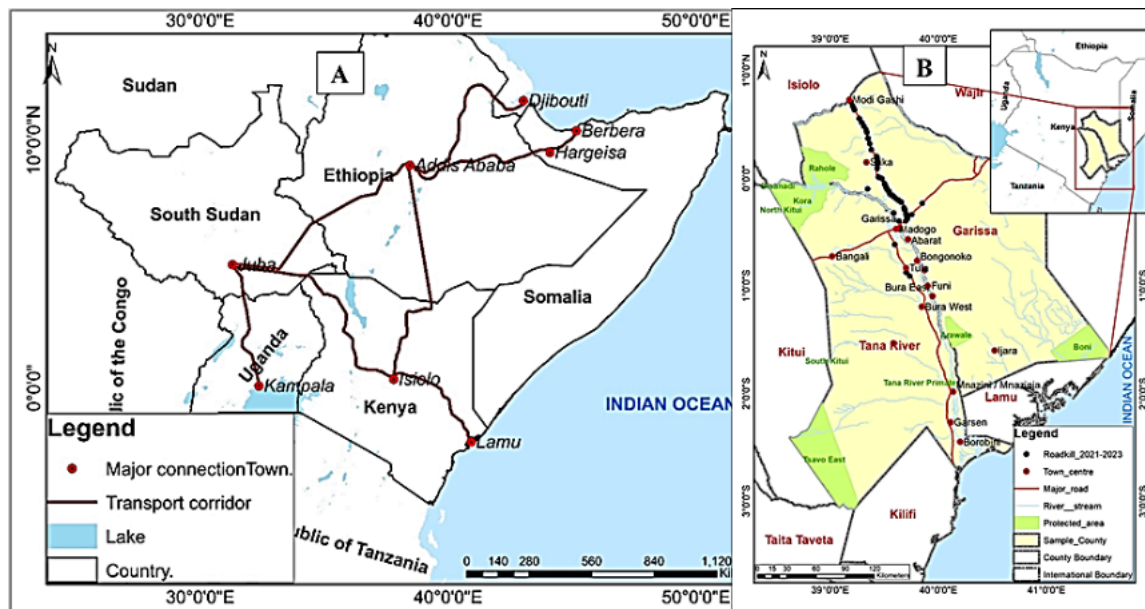


Figure 1

A: Map showing the location of Transport corridors.

B: Study area map showing roadkill and on the section of the highway in Garissa and Tana River county

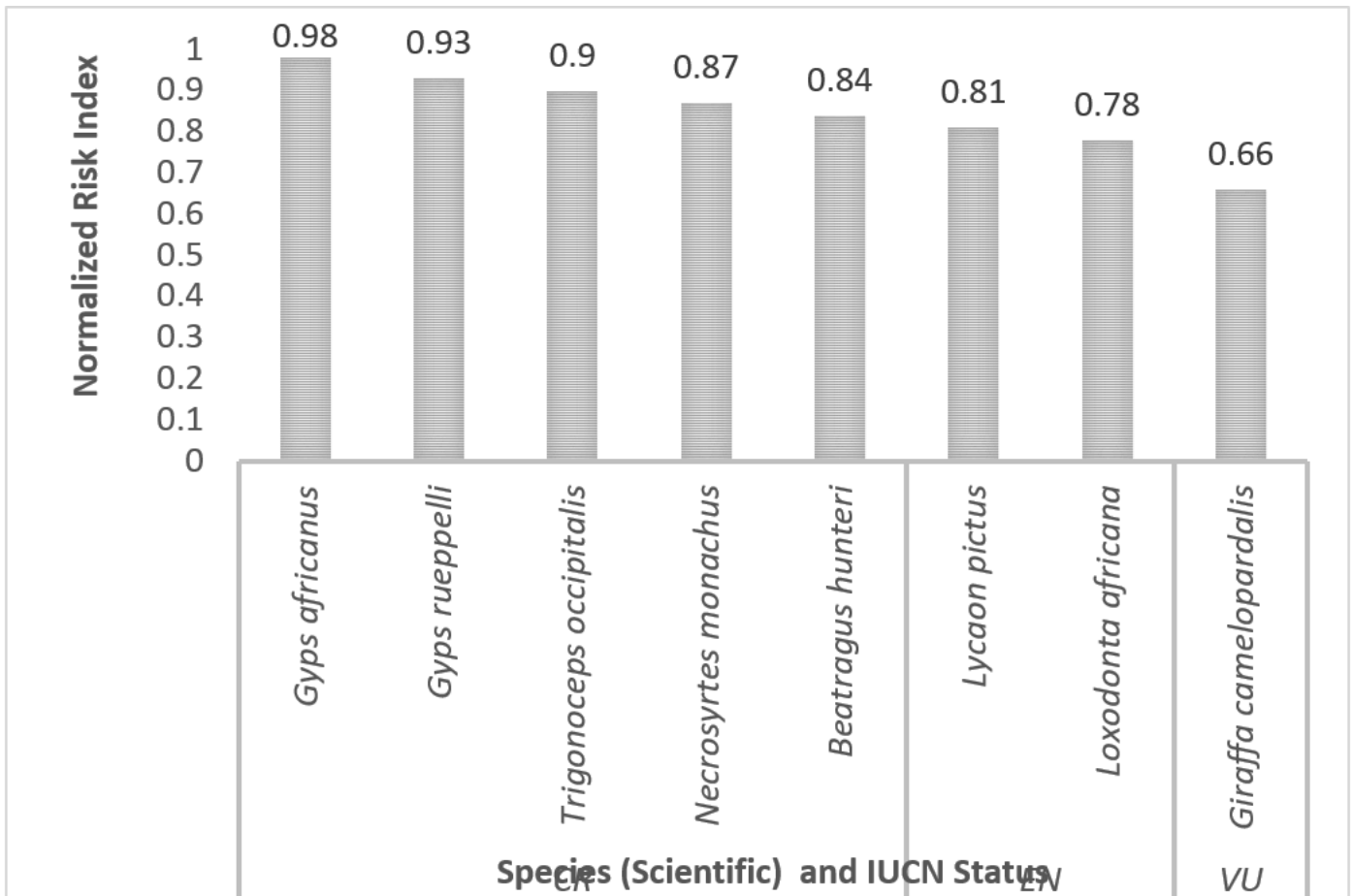


Figure 2

Threat-weighted composite exposure risk indices for the top eight species.

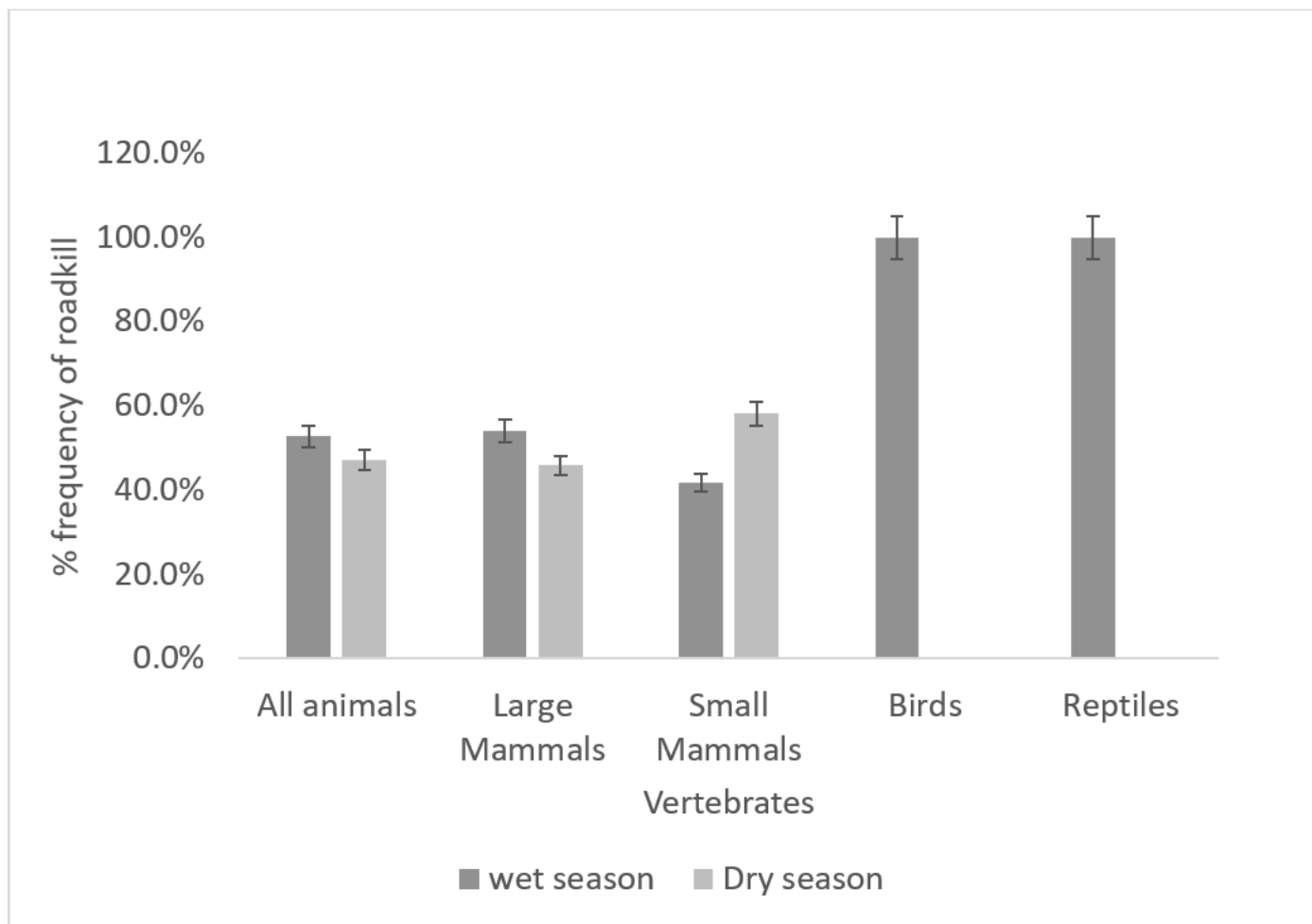


Figure 3
Seasonal distribution of wildlife roadkill incidents recorded along the Modika–Modogashe section of the LAPSET highway 2021–2023.

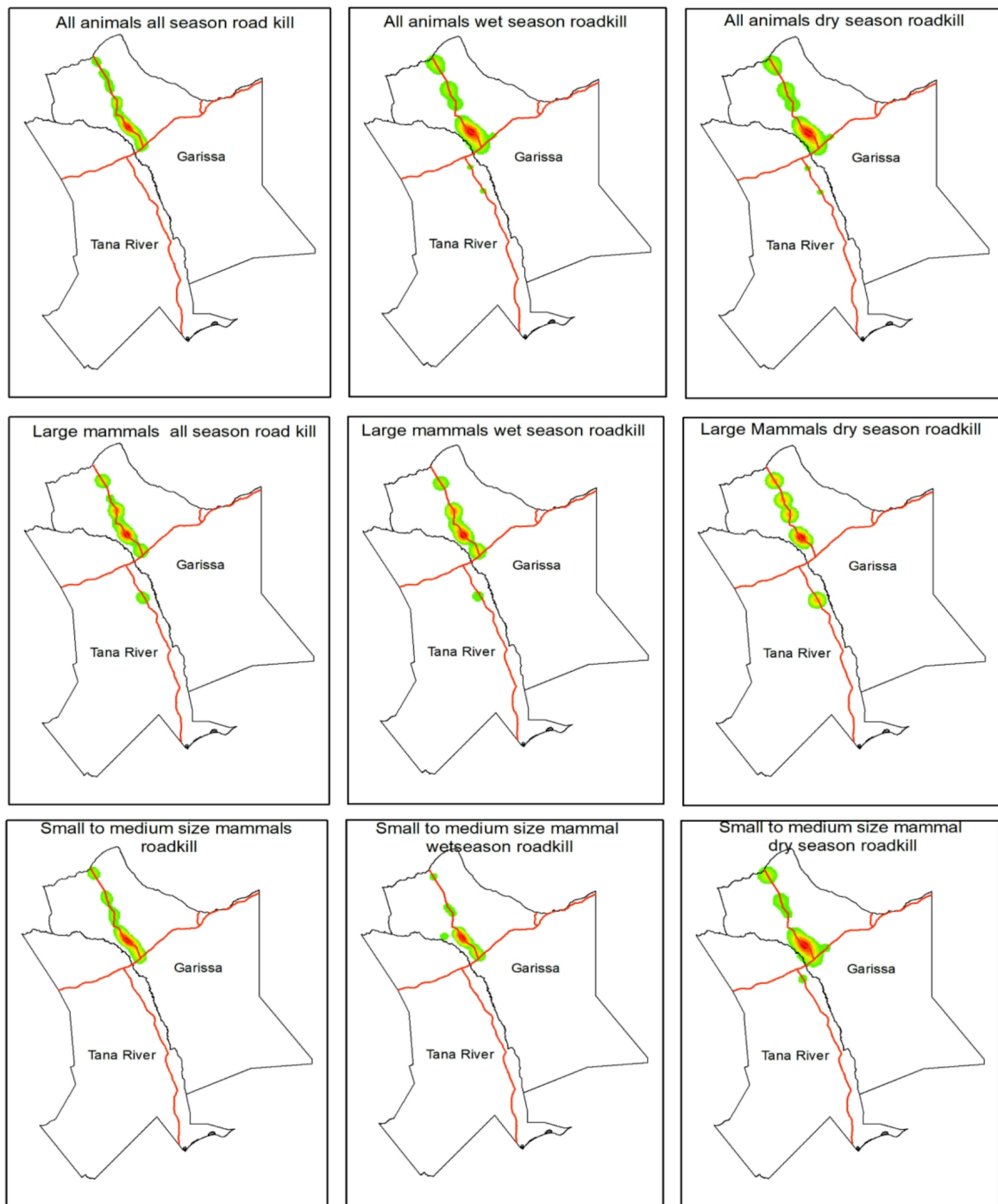


Figure 4

Roadkill hotspots for all vertebrates, large wildlife (>15kg) and small to medium-sized wildlife mammals (<15kg) along Modika-Modogashe highway in Garissa and Tana River County, Kenya between 2021 and 2023

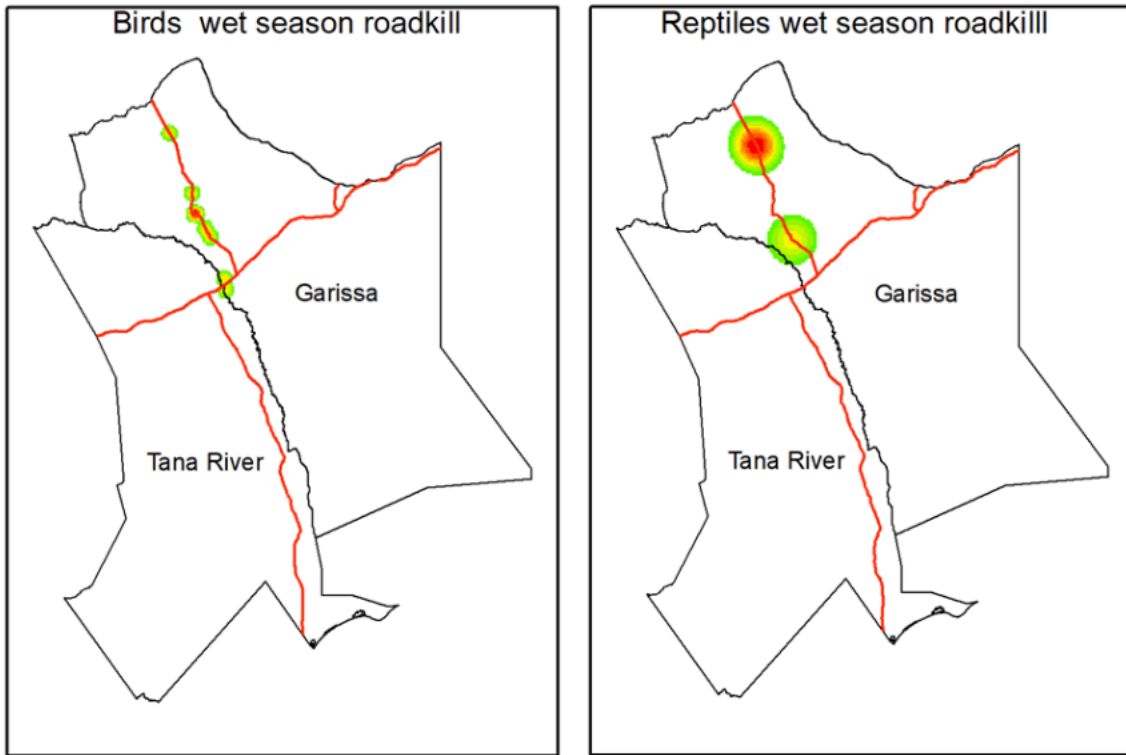


Figure 5

Roadkill hotspots (2021–2023) for birds and reptiles along Modika-Modogashe highway in Garissa and Tana River County, Kenya

Supplementary Files

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