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Spatiotemporal Patterns of Wildlife Road Mortality in Lakki Marwat, Khyber Pakhtunkhwa, Pakistan

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ABSTRACT

Road expansion is a major cause of wildlife mortality, yet data from semi-arid regions of South Asia, particularly Pakistan, remain limited. This study provides the first systematic spatiotemporal assessment of wildlife road mortality in Lakki Marwat, southern Khyber Pakhtunkhwa, Pakistan. Standardized roadkill surveys were conducted along 90 km of two major roads over six months from October 2024 to March 2025. Species identity, spatial location, temporal variables, road characteristics, and surrounding habitat types were recorded for each incident. A total of 58 carcasses representing 14 vertebrate species were recorded. Mammals accounted for 44.8% of incidents, followed by reptiles (29.3%) and birds (25.9%). The Asiatic jackal (*Canis aureus*), Bengal monitor lizard (*Varanus bengalensis*), and house sparrow (*Passer domesticus*) were the most frequently recorded species. Roadkill records were unevenly distributed across routes, road width classes, habitat context, and time categories, with significantly higher incidence on the primary highway (N-55), on wider road sections, and in settlement–agriculture mosaics. Temporal patterns showed higher mortality during daytime and weekdays, with monthly variation peaking in October–November, declining in December–January, and rising again in March. Spatial hotspot analysis identified concentrated mortality zones along specific segments of the N-55. These findings suggest that wildlife road mortality in Lakki Marwat is associated with road type, road width, surrounding land use, and temporal traffic-related patterns, and provide a baseline for future monitoring and targeted mitigation in semi-arid landscapes of Pakistan.

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Key words
Roadkill, Road ecology, Hotspot habitat, Temporal pattern, Carcass, Pakistan

INTRODUCTION

Roads are fundamental for socio-economic development, enhancing regional connectivity and transportation efficiency (Kuncoro *et al*., 2024; Zuhori *et al*., 2024). However, their rapid global proliferation has made them a dominant driver of ecological change, with wildlife-vehicle collisions (WVCs) among the most pervasive and direct threats to biodiversity (Bíl *et al*., 2019). Beyond causing significant animal mortality and contributing to population declines, WVCs pose substantial risks to human safety and impose considerable economic

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costs due to vehicle damage and accidents (Laube *et al*., 2023; Llagostera *et al*., 2022; Perez-Guerra *et al*., 2024). Globally, road traffic causes hundreds of millions of vertebrate deaths annually, highlighting WVCs as a major conservation and management challenge (Schwartz *et al*., 2020).

Ecologically, roads function as linear barriers that fragment habitats, disrupt movement corridors, and alter animal behaviour (Forman and Alexander, 1998; Shepard *et al*., 2008). Traffic-related disturbances, such as noise, artificial lighting, and vibration, can further degrade habitat quality and influence wildlife activity patterns (Forman and Alexander, 1998). Certain taxa are particularly vulnerable to road mortality, including slow-moving species, nocturnal animals, scavengers attracted to carcasses or anthropogenic food sources, and species that regularly move between natural habitats and human-dominated landscapes (Collinson *et al*., 2019). Even relatively low levels of road mortality may have substantial population-level consequences, particularly for species with low reproductive rates or small local populations (Rytwinski and Fahrig, 2011; Moore *et al*., 2023).

The socio-economic impacts of WVCs are also substantial. In the United States alone, collisions involving large mammals cause nearly 2 million accidents annually, costing over USD 8 billion (Huijser *et al*., 2008). Europe reports up to 500,000 wildlife-related road accidents each year (Langbein *et al*., 2011). Collisions can result in injuries and fatalities, impose repair and insurance costs, and increase burdens on road maintenance and emergency services (Bíl *et al*., 2019). Consequently, understanding when and where collisions occur is important for both wildlife conservation and road safety.

The science of road ecology is well established in Europe and North America, where extensive datasets have enabled the identification of collision hotspots and seasonal patterns, and the evaluation of mitigation measures such as fencing and wildlife crossings (Grilo *et al*., 2014; Rytwinski *et al*., 2016). In stark contrast, South Asia, and Pakistan in particular, represents a significant research gap (Akrim *et al*., 2019). In Pakistan, the rapid expansion of road infrastructure associated with economic growth, agricultural intensification, and tourism has increased the potential for wildlife road mortality (Anjum *et al*., 2019). Yet empirical evidence remains sparse and geographically limited. While a handful of studies have documented WVCs in Punjab (Azam *et al*., 2023; Chattha *et al*., 2017; Munir *et al*., 2023), the Pothwar Plateau (Akrim *et al*., 2019), and Khyber Pakhtunkhwa (Anjum *et al*., 2019), large parts of Pakistan, particularly its semi-arid regions, remain ecologically unassessed in the context of road impacts. This paucity of localized data severely constrains evidence-based decision-making for road planning and wildlife conservation.

Lakki Marwat district in southern Khyber Pakhtunkhwa is a key landscape for addressing this knowledge gap. The district is intersected by the major Indus Highway (N-55), and it features a mosaic of agricultural land, scrub forest, and rural settlements, creating zones of intense interface between wildlife movement and vehicular traffic. This study provides the first baseline assessment of wildlife road mortality in this region. Specifically, this study aims to: (1) document the species composition and frequency of roadkill; (2) describe preliminary spatial and temporal patterns of mortality; and (3) identify high-risk road sections and associated habitat contexts. We explicitly frame this work not as a test of broad hypotheses, but as an essential baseline survey to guide future research and immediate conservation attention, acknowledging the constraints of our six-month study period.

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MATERIALS AND METHODS

Study area

The study was conducted in Lakki Marwat, a semi-arid district in southern Khyber Pakhtunkhwa, Pakistan (Fig. 1). The district is centered at 32.609046° N and 70.903722° E, with elevations ranging from 210–1328 m above sea level. The study area covers approximately 3,296 km² and comprises central plains surrounded by the Marwat, Baittani, and Karak Niazi hill ranges, with the Kurram and Gambila rivers supporting local biodiversity (Khan *et al*., 2025). The climate is characterized by hot summers (30–45°C) and mild winters (4–27°C), with average annual rainfall of 300–326 mm (Khan *et al*., 2020, 2025; Ullah *et al*., 2022). The region supports diverse mammals, birds, and reptiles, including wide-ranging scavengers and opportunistic foragers that frequently move between natural habitats and human-dominated areas (Khan *et al*., 2025). The district road network spans approximately 660.6 km, including 547.9 km of paved roads and 112.7 km of unpaved roads (Pakistan Almanac, 2025).

Roadkill survey design

A total of 90 km of road was systematically surveyed, comprising two 45 km segments representing contrasting routes: the major, high-traffic Indus Highway (N-55) (Fig. 1A–B) and the secondary Lakki-Mianwali Road (C–D and E–B). Surveys were conducted twice daily (07:00–09:00 and 16:00–18:00 h) for six consecutive months from October 2024 to March 2025, comprising 135 days. Approximately 45 days were not surveyed due to logistical constraints. During each survey session, both

road segments were surveyed equally, yielding 270 survey occasions across the 90 km study network and a total survey effort of 24,300 km, with 12,150 km surveyed per route. Surveys were conducted using a motorbike traveling at 20–45 km/h to optimize carcass detection (Collinson *et al*., 2014; Oliveira *et al*., 2021). The same trained observer conducted all surveys to maintain consistency. Only carcasses on the road surface were recorded, photographed, and then removed to prevent double-counting (Collinson *et al*., 2014).

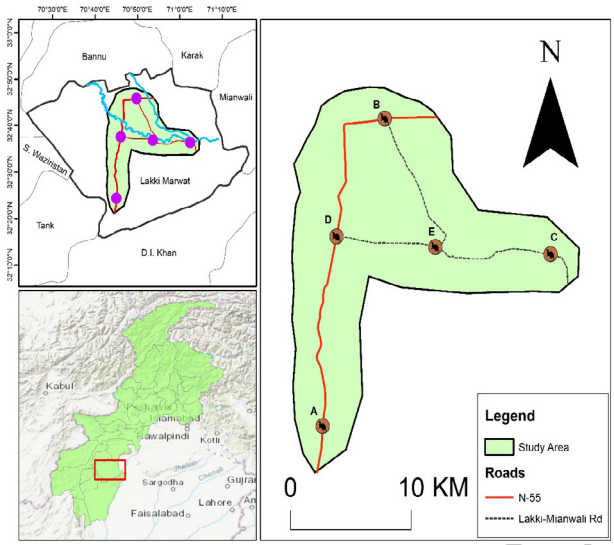

Fig. 1. Map of Lakki Marwat district showing surveyed road segments along N-55 (A–B) and the Lakki-Mianwali Road (C–D and E–B) for wildlife road mortality.

Data collection

For each confirmed roadkill incident, the species identity (common and scientific names), geographic coordinates, date and time of observation, road width, surrounding habitat type, and carcass condition were recorded. Road width was classified into two categories: wide roads (6–8 m) and narrow roads (approximately 2 m), following the classification used by Zhou *et al*., (2020). These categories were used to examine potential differences in roadkill incidence, as road characteristics, including road width, can influence wildlife–vehicle collision risk (Su *et al*., 2023). Nighttime roadkill incidents were inferred when fresh carcasses were detected during morning surveys and were absent during the previous evening survey, consistent with standard roadkill monitoring protocols that assume carcass persistence is short and that detections across closely spaced survey intervals reflect new collision events (Santos *et al*., 2011). Carcass freshness was assessed using visible indicators (e.g., tissue moisture, blood presence, bloating, and scavenger activity) and categorized as fresh (< 24 h) or not fresh (> 24 h) (Baskaran and Boominathan, 2010). Each record was photographed to support species identification and prevent duplication.

Habitats were classified into five categories—agricultural field, settlement, scrub forest, plantation, and barren land—based on field observations, land-use maps, and GPS-referenced satellite imagery. Coordinates were recorded using a Garmin 62S handheld GPS (±3 m accuracy). Species identification was confirmed using regional field guides (Grimmett *et al*., 2008; Khan, 2006; Roberts, 1997) and expert consultation. Unidentified specimens were preserved in 10% formalin for later confirmation. Conservation status was assigned according to the IUCN Red List (https://www.iucnredlist.org). Data were compiled and cleaned in Microsoft Excel before statistical analysis in R.

Statistical analysis

All statistical analyses were performed in R (version 4.3) using two complementary datasets. The first consisted of event-level roadkill records, with each row representing a single incident and including temporal, spatial, and ecological variables: weekday, time of occurrence, month, road type, road width, habitat type, and taxonomic class. This dataset was used for descriptive summaries and categorical analyses. The second dataset consisted of aggregated survey-level count data, in which the response variable was the number of roadkill incidents per survey unit. Because survey effort varied across units, total kilometers surveyed were included as an offset in the count model. Descriptive summaries were used to characterize the distribution of roadkill frequencies across temporal and environmental categories. Pearson's chi-square tests of independence or goodness-of-fit tests, as appropriate, were used to examine associations among categorical variables. To assess the combined relationship between roadkill frequency and multiple explanatory variables, a Poisson Generalized Linear Model (GLM) was fitted with an offset for surveyed distance. Given the limited sample size, GLM results are presented as exploratory and descriptive rather than confirmatory. Spatial clustering was visualized using Kernel Density Estimation (KDE) in ArcGIS 10.8 with a 1 km bandwidth, selected to smooth the point data appropriately at the landscape scale (Kim *et al*., 2023). Statistical significance was set at $p = 0.05$.

RESULTS

Species composition

A total of 58 roadkill incidents were recorded, involving 14 vertebrate species over the six-month study period (Table I). Mammals were the most frequently affected class (26 incidents, 44.8%), followed by reptiles

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(17 incidents, 29.3%) and birds (15 incidents, 25.9%); however, the difference among classes was not statistically significant ($\chi^2 = 3.55$, df = 2, $p = 0.169$). No amphibian roadkill incidents were recorded during the study. Species-level analysis revealed that three species accounted for 50% of all mortality: the Asiatic jackal (*Canis aureus*, n = 11), the Bengal monitor lizard (*Varanus bengalensis*, n = 10), and the house sparrow (*Passer domesticus*, n = 8) (Table I).

Table I. Species composition of wildlife road mortality recorded in Lakki Marwat (October 2024-March 2025).

No.	Group/Species/ Scientific name	IUCN	n	%
	Mammalia			
1	Asiatic jackal (*Canis aureus*)	LC	11	19.0
2	Indian Long-eared hedgehog (*Hemiechinus collaris*)	LC	3	5.2
3	Five-striped palm squirrel (*Funambulus pennantii*)	LC	7	12.1
4	Indian gerbil (*Tatera indica*)	LC	3	5.2
5	Small Indian mongoose (*Urva auropunctata*)	LC	1	1.7
6	House mouse (*Mus musculus*)	LC	1	1.7
	Reptilia			
7	Bengal monitor lizard (*Varanus bengalensis*)	NT	10	17.2
8	Red sand boa (*Eryx johnii*)	NT	3	5.2
9	Common krait (*Bungarus caeruleus*)	LC	3	5.2
10	Diadem snake (*Spalerosophis diadema*)	LC	1	1.7
	Aves			
11	House sparrow (*Passer domesticus*)	LC	8	13.8
12	House crow (*Corvus splendens*)	LC	4	6.9
13	Rock pigeon (*Columba livia*)	LC	2	3.4
14	Common myna (*Acridotheres tristis*)	LC	1	1.7
Total			58	100

LC, Least Concern; NT, Near Threatened; IUCN Red List.

Temporal patterns

Roadkill incidence showed significant temporal variation. Overall, 70.8% of fresh carcasses were inferred to have resulted from daytime collisions ($\chi^2 = 8.33$, p = 0.0039). A strong weekday bias was also evident, with 82.8% of incidents occurring from Monday to Friday ($\chi^2 = 24.90$, $p < 0.001$). Monthly variation was significant in the Poisson GLM ($p < 0.001$), with roadkill peaking in October-November, declining in December-January, and increasing again in March (Fig. 2).

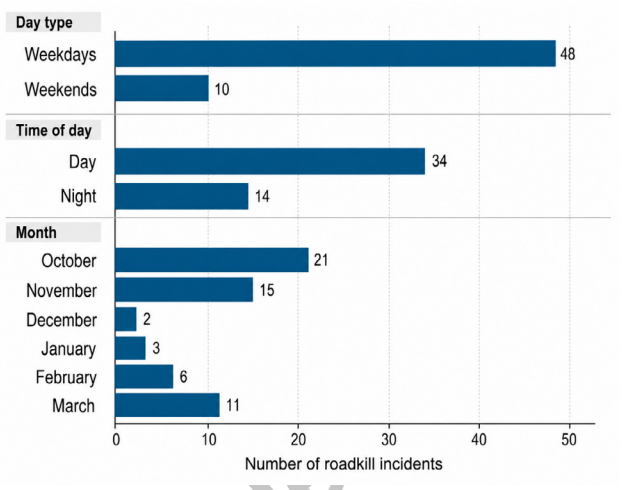

Fig. 2. Temporal distribution of wildlife road mortality incidents across months and by time and type of day.

Spatial and habitat-related patterns

Spatial analysis revealed pronounced clustering of incidents. KDE identified clear hotspots along specific segments of the N-55 (Fig. 3). The KDE output classified roadkill density into eight classes ranging from very low

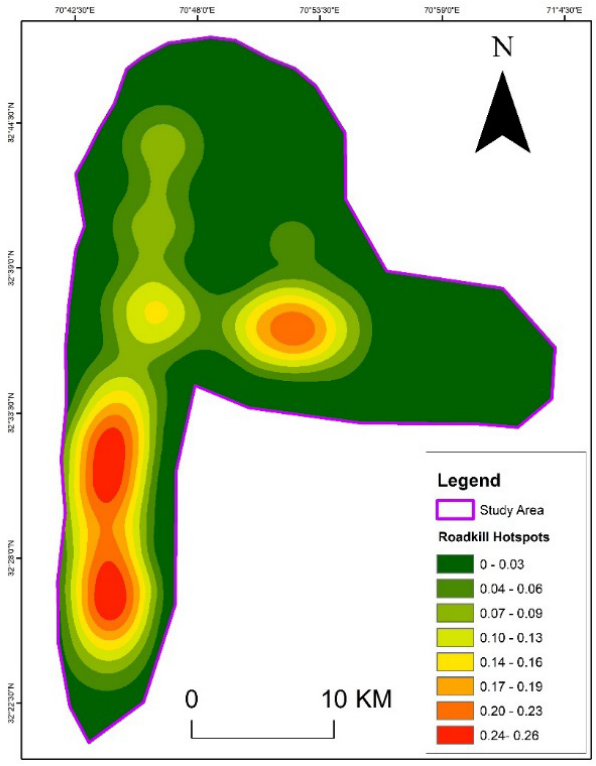

Fig. 3. Kernel density estimation (KDE) hotspot map of wildlife road mortality in Lakki Marwat.

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(dark green: 0.00–0.03) to very high (red: 0.24–0.26), with pronounced hotspots in the southwestern and central segments of the surveyed area. Statistically, 70.7% of incidents occurred on the N-55 compared to the Lakki-Mianwali Road ($\chi^2 = 9.93$, $p = 0.0016$), while 63.8% occurred on wider road sections ($\chi^2 = 4.41$, $p = 0.036$). Habitat associations were significant ($\chi^2 = 11.31$, $p = 0.02$), with over 60% of incidents occurring in human-modified landscapes, i.e., near settlements (32.8%) and agricultural fields (27.6%), followed by scrub forest (20.7%), plantations (12.1%), and barren areas (6.9%).

DISCUSSION

The present study demonstrates that wildlife road mortality in Lakki Marwat is non-random and appears to be associated with interactions among species ecology, road characteristics, traffic patterns, and surrounding land use. As the first systematic survey from this semi-arid district, it provides an important baseline for understanding wildlife-vehicle collisions in an understudied region of Pakistan. The relatively high mortality of the Asiatic jackal aligns with findings from other parts of South Asia, where scavenging behaviour and use of roadside habitats increase collision risk along major highways of Pakistan (Akrim *et al*., 2019; Chattha *et al*., 2017; Munir *et al*., 2023), India (Haq *et al*., 2022; Kichloo *et al*., 2022; Mandal, 2024), and Nepal (Koju *et al*., 2025). Similarly, reptile mortality, especially dominated by the Bengal monitor lizard, may reflect the use of roads for thermoregulatory basking and opportunistic foraging on warm road surfaces (Ray *et al*., 2023). The presence of two Near Threatened reptiles–Bengal monitor lizard and Red sand boa (*Eryx johnii*)–highlights the conservation importance of road mortality in the study area, even at low absolute numbers.

Bird mortality, particularly that of house sparrows, was concentrated near agricultural fields and settlements, suggesting that human-modified landscapes may increase exposure to roads by providing food resources and encouraging frequent local movement between roosting and foraging sites (Chattha *et al*., 2017; Haq *et al*., 2022). More broadly, the surrounding land-use mosaic on both sides of the road likely contributes to crossing behaviour by shaping access to cover, food, nesting areas, and other resources. For small mammals such as the Indian gerbil (*Tatera indica*), five-striped palm squirrel (*Funambulus pennantii*), and Indian long-eared hedgehog (*Hemiechinus collaris*), such crossings may reflect short-distance daily movements within fragmented habitat rather than wide-ranging dispersal. However, because broader land-cover composition beyond the immediate roadside was not quantified, these interpretations remain preliminary.

The higher incidence of daytime roadkill likely reflects the combined influence of increased daytime traffic and the greater contribution of reptiles and birds to daytime mortality, as reported in other studies from comparable systems (Baskaran and Boominathan, 2010; Chattha *et al*., 2017; Haq *et al*., 2022). In contrast, mammal roadkill often peaks at night or during crepuscular periods (Anjum *et al*., 2019; Seiler, 2005), which is consistent with the nocturnal or crepuscular behaviour of the Asiatic jackal. This suggests that temporal mortality risk may differ among taxa. The strong weekday bias probably reflects heavier commuter and freight traffic on transport corridors such as the N-55, a pattern also documented elsewhere (Chattha *et al*., 2017; Grilo *et al*., 2014). The observed monthly fluctuations, with peaks in October–November and March, may be linked to seasonal shifts in wildlife activity, agricultural cycles, and climatic conditions (D'Amico *et al*., 2015; Garriga *et al*., 2017; Snow *et al*., 2018). Similar trends reported in other landscapes suggest that temporal variation in road mortality often results from interacting biological and anthropogenic factors (Akrim *et al*., 2019; Olson *et al*., 2014; Orłowski and Nowak, 2006; Seo *et al*., 2015). Nevertheless, the six-month study period does not permit full annual inference.

The concentration of roadkill along the N-55 and on wider road sections supports the general road ecology theory that road width, vehicle speed, and traffic volume increase wildlife collision risk (Akrim *et al*., 2019; Hallisey *et al*., 2022; Kazemi *et al*., 2016; Özcan *et al*., 2022; Ray *et al*., 2023; Wang *et al*., 2022). Therefore, the KDE hotspots identified in the southwestern and central parts of the study area should be considered practical priority zones for targeted mitigation. The significant concentration of roadkill in settlements and agricultural fields suggests that human-modified landscapes may elevate risk by attracting wildlife through food subsidies, refuse, roadside carrion, and routine movement near roads (Cereghetti *et al*., 2019; Hui *et al*., 2021; Schwartz *et al*., 2018). This pattern is consistent with studies showing that surrounding land-use composition is an important determinant of roadkill probability (Wu *et al*., 2024). Overall, these findings indicate that mitigation should be spatially targeted and ecologically contextualized, especially along high-risk sections of the N-55 crossing settlement-agriculture mosaics.

Limitations

The six-month survey period did not cover a full annual cycle; therefore, monthly patterns should be viewed as preliminary rather than representative of year-round roadkill dynamics. The relatively small number of carcasses also limited statistical power, especially

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for multivariable modelling, so the results should be interpreted as descriptive patterns and preliminary associations rather than causal evidence. Roadkill numbers may have been underestimated because only carcasses on the road surface were recorded, while animals displaced off the carriageway, small-bodied taxa, or carcasses removed by scavengers, vehicles, or roadside cleaning may have been missed. Although repeated surveys by the same observer improved consistency, detectability bias remains possible. Daytime and nighttime collision timing was inferred from survey intervals and carcass freshness rather than direct observation, so these temporal classifications are approximate. Habitat classification was limited to the immediate roadside environment and did not quantify broader land-cover composition. Finally, the absence of independent data on traffic volume, vehicle speed, species abundance, and carcass persistence further limits interpretation of the factors influencing roadkill occurrence.

CONCLUSION AND RECOMMENDATIONS

This study provides the first systematic baseline assessment of wildlife road mortality in the southern part of Khyber Pakhtunkhwa, Pakistan. Roadkill records were mainly concentrated on the N-55 highway, wider road sections, and roadside areas dominated by settlements and agricultural land. Higher incidence was also observed during daytime and weekdays. The record of Near Threatened reptiles among the roadkill species highlights the conservation relevance of these findings. Although the results represent a preliminary baseline rather than a definitive ecological assessment, they provide useful guidance for mitigation and future monitoring.

Mitigation should be prioritized along roadkill hotspot sections, particularly on the N-55 and other wide, high-risk road segments passing through settlement–agriculture mosaics. Immediate low-cost actions may include wildlife warning signs, targeted speed reduction and enforcement, and improved management of roadside attractants such as waste, animal carcasses, and spilled agricultural materials. Community awareness programs involving local residents, drivers, and other road users may also help reduce collision risk. Future studies should extend monitoring to a full annual cycle and include broader land-cover analysis, traffic volume, vehicle speed, carcass persistence, and independent wildlife occurrence data. These data would improve understanding of species-specific road exposure, hotspot formation, and the ecological drivers of road mortality. Continued monitoring should also inform long-term infrastructure planning, including wildlife passage structures such as culverts and underpasses, especially where roads intersect natural drainage lines or suspected wildlife movement corridors.

DECLARATIONS

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IRB approval

The study was approved by the Animal Welfare Committee of Quaid-i-Azam University (Approval No. BEC-FBS-QAU2024-112) and conducted in accordance with applicable local legislation and institutional animal welfare guidelines.

Ethical statement

Permits for fieldwork were granted by the office of the Divisional Forest Officer, Wildlife Division Bannu, under permit number 664/WL (B).

Data availability

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

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Statement of conflict of interest

The authors have declared no conflict of interest.

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