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EFFECTS OF ENVIRONMENTAL FACTORS ON CARNIVORE DISTRIBUTION IN EL-JABAL EL-AKHDER, CYRENAICA, NORTH-EASTERN LIBYA

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ABSTRACT

Carnivores are vital for maintaining ecological balance by controlling prey populations and supporting biodiversity. In Libya, species such as the African golden wolf (*Canis anthus*), red fox (*Vulpes vulpes*), and striped hyena (*Hyaena hyaena*) play key roles in sustaining local ecosystems. However, habitat loss, human encroachment, and declining prey availability pose significant threats to their persistence. Understanding the spatial distribution of these species and the factors influencing their presence is essential for effective conservation planning. This study, conducted in the Cyrenaica region of north-eastern Libya, aimed to explore the relationship between carnivore distribution and environmental factors such as vegetation cover and prey availability. Three random sampling areas Jeera, Zaza, and Taknes each measuring 6 x 12 km, were designated for the study. These areas were further divided into 72 sampling units of 1 km² each. We employed statistical logistic regression with a forward conditional model to assess the influence of habitat characteristics on carnivore distribution. Results revealed that *C. anthus* was positively associated with tree and shrub cover and rabbit abundance, favoring denser vegetation with ample prey. In contrast, *V. vulpes* showed a negative correlation with vegetation height and a positive association with rodent abundance, indicating a preference for open areas with low vegetation. *H. hyaena* occurrence was primarily linked to the availability of both rabbits and rodents, highlighting the crucial role of prey resources. These findings emphasize the need for conservation strategies that address habitat preservation and prey management to ensure the long-term survival of carnivores in Libya.

Keywords: Carnivore ecology, Habitat selection, Prey availability, Conservation, Libya.

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INTRODUCTION

Carnivores play a crucial role in regulating and maintaining ecosystems (Qi *et al*., 2020) . They are identified keystone species, essentially for sustaining biodiversity and ensuring stability, resilience, and ecosystem balance (Karssene *et al*., 2019; Shukla, 2023; Carter and Di Minin, 2024). One of their most significant ecological functions is initiating trophic cascades (Estes *et al*., 2011; Ripple *et al*., 2016). Additionally, as apex predators, they regulate prey populations, promote biodiversity, control mesopredator numbers (Prugh and Sivy, 2020) , and contribute to nutrient cycling (Morris and Letnic, 2017; Monk and Schmitz, 2022) . By sustaining healthy and balanced ecosystems, carnivores act as ecological engineers and are closely linked to regions with high mammalian biodiversity (Lacher Jr *et al*., 2019; LaBarge *et al*., 2022). Their presence can also indirectly help mitigate human-wildlife conflicts (Ripple *et al*., 2014). However, the relationship between humans and carnivores has always been complex (Lozano *et al*., 2019). Carnivore habitat selection is a complex process driven by a combination of biological needs, ecological factors, and human activities. Prey availability is the primary driver, as carnivores tend to favor habitats rich in food ressources (Gaynor *et al*., 2019).

Adequate cover and shelter are critical for stalking prey, avoiding detection, resting, and denning (Prugh *et al*., 2009). Water resources were also important, particularly in arid and semi-arid regions with harsh conditions and severe climate change (Beschta and Ripple, 2019). Social structure and territorial behavior also significantly influence carnivore's habitat preferences (Ripple and Beschta, 2012), with interspecies interactions and competition directly affecting their habitat use (Karssene *et al*., 2019). Human activities increasingly affect these preferences, contributing to declines in carnivore populations through habitat loss,

prey depletion, deforestation, and ecosystem overexploitation (Di Minin *et al*., 2016; Hernández-Yáñez *et al*., 2022). Anthropogenic habitat loss and fragmentation have significantly reduced carnivore ranges worldwide, disrupting ecological dynamics (Di Minin *et al*., 2016; Bauer *et al*., 2017; Montgomery *et al*., 2019). Climate change further exacerbates challenges for carnivore populations worldwide by altering habitats, prey distribution and abundance, reproductive success, and interactions with other species (Leão *et al*., 2023; Hobbs *et al*., 2024).

In Libya, species such as the African golden wolf *Canis anthus* (Cuvier, 1820), the striped hyena *Hyaena hyaena* (Linnaeus, 1758), and the red fox *Vulpes vulpes* (Linnaeus, 1758), play a vital role in maintaining ecological balance. However, rapid development and urbanization in natural areas have severely impacted wildlife habitats, threatening many key plant and animal species (Saaed *et al*., 2022). Although certain areas, such as El-Jabal El-Akhdar (JA) and the Marmarica plateau, contain valleys and depressions with deep soil strata capable of supporting plant regeneration, ongoing anthropogenic pressures have led to significant habitat degradation (El-Barasi and Saaed, 2013).

Carnivore populations in Libya have declined due to reductions in natural prey availability and increased human-wildlife conflict. For example, the movement patterns of brown hyaenas influenced by roads, increasing their vulnerability outside protected areas (Welch *et al*., 2015). The red fox, widely distributed in north-western Libya, faces threats from habitat degradation, fragmentation, and direct persecution (Elkahwage and Jdeidi, 2018). Notably, there is a gap in available date on Libyan wildlife, we hypothesize that prey availability plays a crucial role in determining carnivore distribution and activity, with certain species being more influential due to their abundance and accessibility. In addition, we expected that carnivore Habitat preferences in Libya vary significantly, with different species selecting habitats based on prey availability, shelter, and other ecological factors. Our study aims to estimate prey importance, activity patterns, habitat use, and impacts of human activities on carnivores in the Cyrenaica region (Libya).

MATERIALS AND METHODS

Study area: The study area is situated in the Cyrenaica region, within the EL-Jabal El-Akhdar in northeastern Libya, between latitudes 32° 6’ and 32° 39’ north and longitudes 20° 32’ and 20° 59’ east. Covering a total of 1,500 km², this area exhibits elevations ranging from approximately 120 to 615 meters above sea level. A notable topographic feature is the presence of deep valleys, including the basin of Wadi Zaza. The western section is characterized by an extensive network of valleys (dry rivers) that transport water toward the Benghazi Big Plain during rainy seasons, ultimately draining into the sea to the west (Figure 1). The study area receives the highest rainfall levels in Libya, following a monsoonal pattern with an average annual precipitation of approximately 400 mm. Around 75% of this rainfall occurs during the winter months, from November to February. The average maximum temperature in July reaches about 31 °C, while in January, the average minimum temperature drops to 8 °C. During rainfall events, water is directed toward the Great Benghazi Plain before ultimately flowing into the western sea. This hydrological network plays a crucial role in wildlife dispersal. The increased moisture in lowlands and valley floors, resulting from runoff, offers protection against wind and human activities, foresting denser vegetation cover (VC) and greater biodiversity. Many of these valleys serve as refuges for wildlife species that have disappeared from other parts of the region (El-Barasi and Saaed, 2013).

Sampling data: The data for this study were collected between March 2022 to April 2023. Three random sampling area (Jeera, Zaza and Taknes) of 6 x 12 km each one, were designated within the study area. Each area was subdivided into 72 sampling units of 1 km^2 (1km X 1km). Within each unit, three transects measuring 200 m x 50 m were randomly selected, ensuring sufficient spacing between them (Karssene *et al*. 2019). A total of eight field visits were conducted during the study period. Observations were conducted by the same three-observer team for four hours. During these sessions, the observers walked parallel to each other along the transect, maintaining a steady pace within the 50 m width to ensure thorough coverage without overlap. Communication was kept to a minimum to avoid disturbing wildlife. Given the difficulty of directly observing carnivore species (*Canis anthus, Vulpes vulpes, Hyaena hyaena*), the survey focused on searching for signs of their presence, such as tracks or scats.

They also assess their impact by tracking movement paths and analyzing prey remains and burrows. A species was considered present in a given sample unit if at least one individual was observed or if signs of its presence were found in at least one survey site. For each sample unit, observers recorded the number of potential preys, specifically rabbits (RABB) and rodents (RODE), as these were presumed to influence the presence of carnivores. Additionally, vegetation cover (VC), dominant plant species, shrubs (SHRU) and trees (TREE), and vegetation height (HEIG) were documented. The average values of these variables for each sampling unit were calculated to assess their influence on species occurrence.

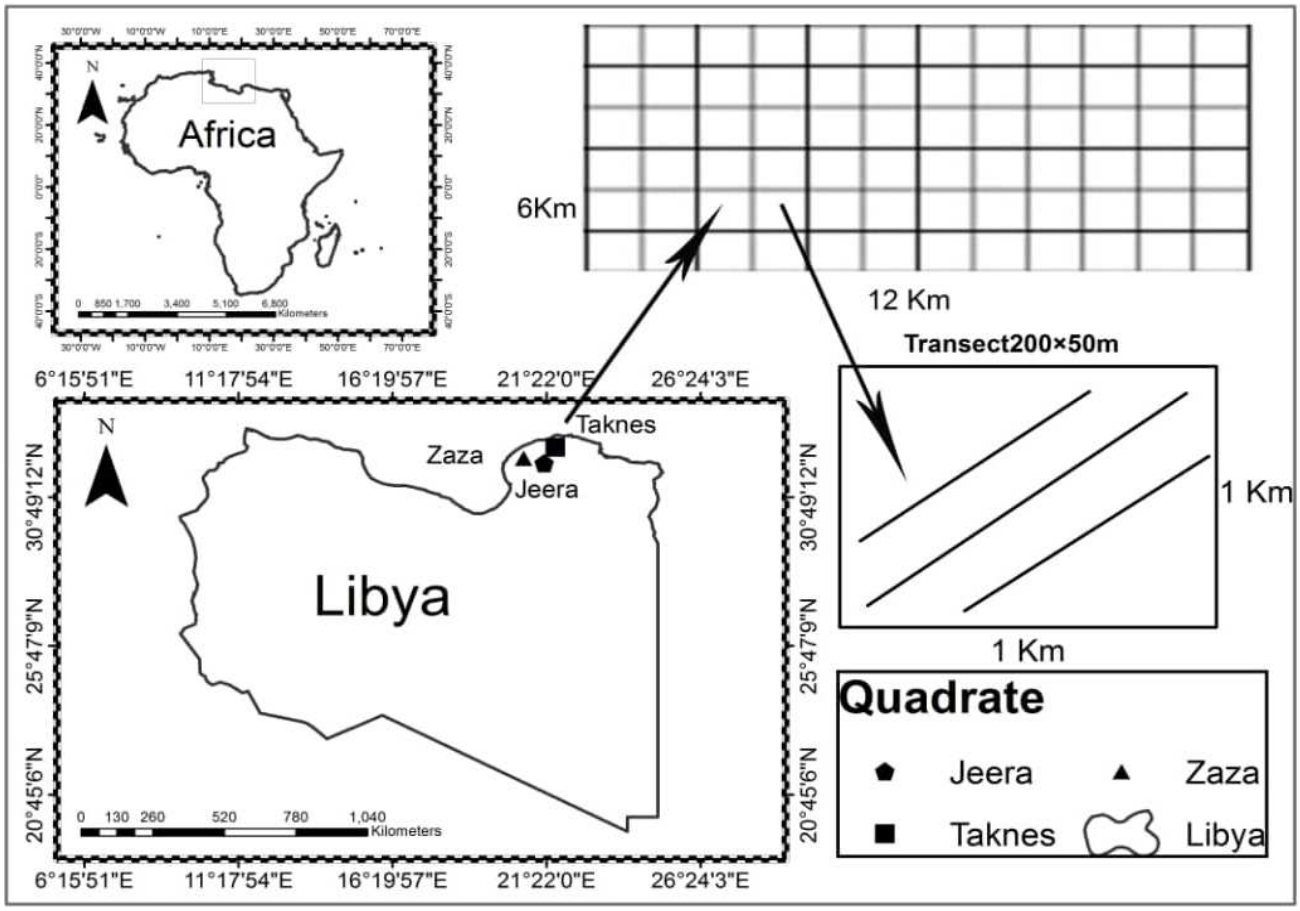


Figure 1. Location of the study area within the EL-Jabal El-Akhdar (Jeera, Zaza, Taknes), grid cells, and sampling transects.

Statistical analyses: In our study, we employed binary logistic regression using the forward conditional method to assess the influence of the following variables (SHRU, TREE ratios, prey RABB, RODE, and HEIG) on species occurrence. As the explanatory variables were interconnected, we performed separate analyses for each species to explain the variables via logistic regression. We adjusted the ratios using the inverse sine function to match better the data's natural state (Rohlf and Sokal, 1995). We then evaluated the relationships and effects of the explanatory variables on the dependent variable by conducting comprehensive tests of the independent model coefficients. Additionally, we determined the probability values of the variables and performed a classification test to understand the expected response from the observed values. For this analysis, we used MINITAB ver. 16.

RESULTS

The results indicated that the African golden wolf (*Canis anthus*) was found in 16 out of 58 sample units, representing 27.59% of the total. The red fox (*Vulpes vulpes*) was observed in 8 sample units (13.79%), while the striped hyena (*Hyaena hyaena*) was present in 13 units (22.41%). In the Jeera, Zaza, and Taknes areas, *C. anthus* was found in 6, 4, and 6 sample units, corresponding to 27.27%, 21.05%, and 35.29%, respectively. For *V. vulpes*, the numbers and percentages were 3 (13.64%), 4 (21.05%), and 1 (5.88%), while *H. hyaena* was found in 7, 3, and 3 sample units, constituting 31.82%, 15.79%, and 17.65%, respectively.

The logistic regression model showed a good fit for the data, however, the *P*-values for all dependent variables exceeded 0.05 (Table 1).

Table 1. Goodness-of-Fit Tests Hosmer-Lemeshow.

Species	Df	χ^2	*P* Value
C. anthus	8	5.59	0.693
V. vulpes	8	1.12	0.997
H. hyaena	8	2.01	0.981

Df: Degree of freedom, χ^2: Chi-square statistic

A total of five variables were included in the analysis. The occurrence of *C. anthus* was positively correlated with TREE (B=0.579 ± 0.231, P=0.012),

SHRU (B=1.274 ± 0.567, P=0.025) and RABB (B=2.145 ± 0.995, P=0.031) (Table 1). The presence of the red fox (*V. vulpes*) was positively correlated with RODE (B=5.20 ± 2.22, P=0.019) and negatively correlated with HEIG (B=-0.0237 ± 0.0121, P=0.050). Conversely, the occurrence of (*H. hyeana*) was positively correlated with both RODE (B=4.28 ± 1.65, P=0.009) and RABB (B=2.049 ± 0.823, P=0.013) (Table 2).

For the African golden wolf (*C. anthus*), the odds ratio (OR) for TREE, SHRU, and RABB were 1.7847, 3.5747, and 8.5397, respectively. Since their entire confidence intervals were above one, these variables were associated with a higher probability of *C. anthus* occurrence. In other words, an increase in these predictors corresponded to an increased likelihood of its presence (Table 2). For the red fox (*V. vulpes*), the odds ratios for RODE was 181.35, while that for HEIG was 0.98. A positive coefficient, along with an OR greater than one and a confidential interval excluding one, indicated a statistically significant positive relationship between RODE and the red fox (*V. vulpes*) occurrence. Conversely, HEIG had a negative coefficient, an OR below one, and a confidence interval entirely below one, suggesting a significant inverse relationship between the HEIG and the probability of *V. vulpes* occurrence. Regarding *H. hyaena*, the OR for RABB and RODE were 7.76 and 72.35, respectively. Since their confidence intervals were entirely above one, indicating these factors were positively associated with the probability of *H. hyaena* presence, meaning their increase corresponded to a higher likelihood of occurrence (Table 2).

Table 2. Results of logistic regression analysis of carnivores (*C. anthus, V. vulpes, and H. hyaena*).

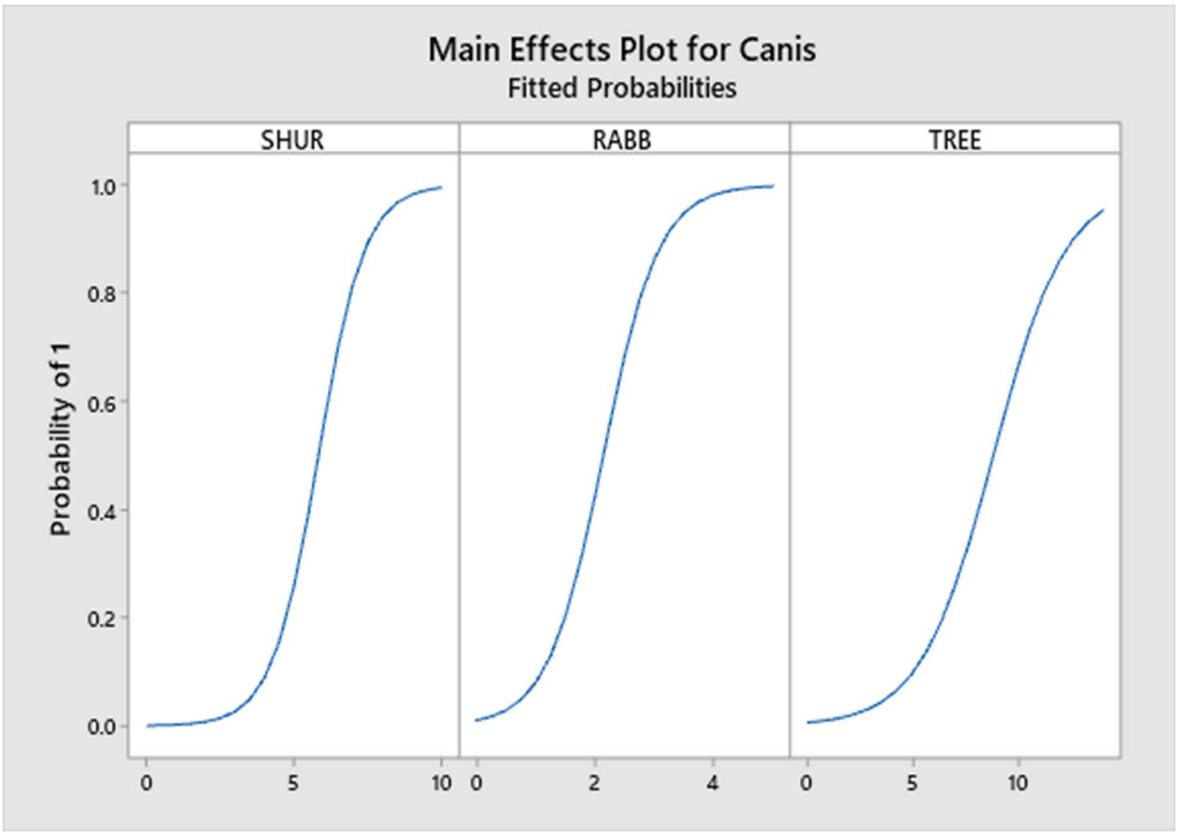
Species	Variable	B	S.E	χ^2	*p*	Df	R^2	OR	95% CI	
									Upper	Lower
C. anthus	SHRU	1.274	0.567	5.05	0.025	1	77.49%	3.57	1.176	10.864
	RABB	2.145	0.995	4.65	0.031	1		8.54	1.214	60.045
	TREE	0.579	0.231	6.31	0.012	1		1.78	1.136	2.805
	Constant	-4.66	4.46							
V. vulpes	RODE	5.20	2.22	5.48	0.019	1	71.80%	181.35	2.327	14133.764
	HEIG	-0.024	0.012	3.86	0.050	1		0.98	0.954	0.999
	Constant	2.92	2.84							
H. hyaena	RABB	2.049	0.823	6.20	0.013	1	74.93%	7.7636	1.546	38.982
	RODE	4.28	1.65	6.76	0.009	1		72.3488	2.872	1822.478
	Constant	-5.47	3.48							

B: coefficient, SE: standard error, χ^2: Chi-Square statistic, *P*: p-value, Df: degree of freedom, R^2: R squared, OR: Odds Ratio, CI: Confidence Interval

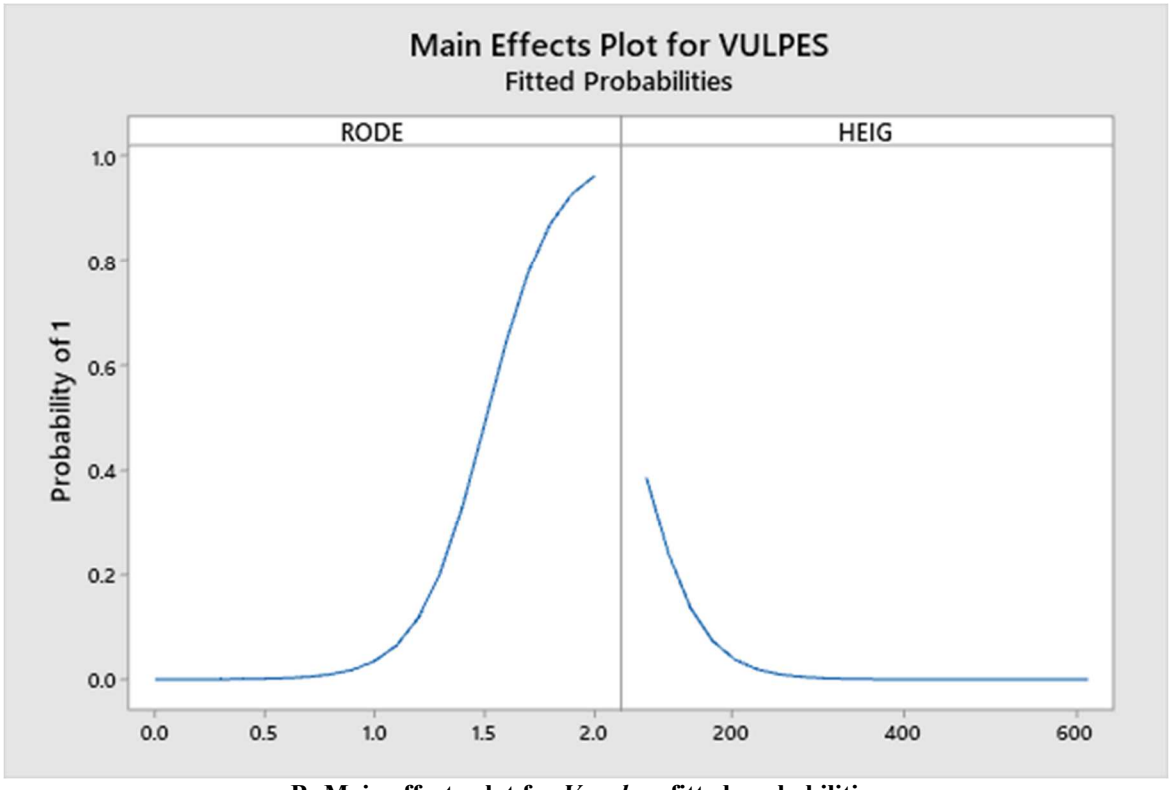
Overall, the probability diagrams of the normal distribution for dependent variables *C. anthus*, *V. vulpes*, and *H. hyaena* (Figure 2 A, B, C), along with the independent variables (TREE, SHRU, RABB, RODE, HEIG) are consistent with the logistic regression analysis, indicating a positive direct relationship. Specifically, the presence of *C. anthus* increases with the abundance of TREE (0 to 10), SHRU (0 to 5), and RABB (0 to 4), based on their significance levels. The probability curve follows an upward trend, eventually reaching a probability rate of one. Similarly, *V. vulpes* is influenced by RODE and HEIG, with RODE contributing to an increase in probability from zero to two. As the growth rate rises, its presence and the relationship curve increase, reaching a probability rate of one.

However, the presence of *H. hyaena* is primarily associated with RABB and RODE, indicating the importance of prey availability, specifically RABB. The statistical curve shows a positive relationship, with *H. hyaena* presence increasing as the number of RABB rises from zero to five. Additionally, the rodent variable (RODE) exhibits a strong positive relationship, as indicated by statistical significance, with *H. hyaena* presence increasing as RODE values rise from 0 to 0.2 (Figure 2 A, B, and C).

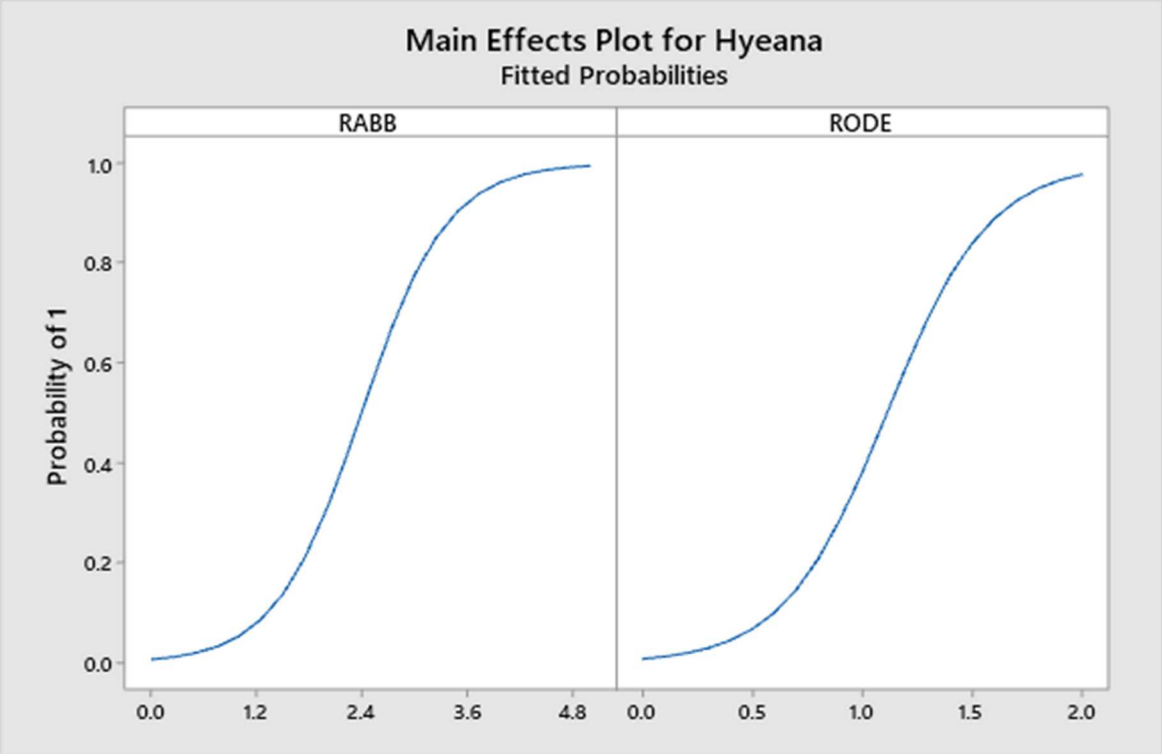
The results presented in Table 3 present the classification test outcomes, which used a cut-off value of 0.5 to predict species presence while accounting for the effects of the variables (TREE, SHRU, RABB, RODE, HEIG). The predicted values closely aligned with the actual observations, achieving an accuracy of 93.1% for *C. anthus*, 89.7% for *V. vulpes*, and 91.4% for *H. hyaena* within the study area.



A: Main effects plot for *C. anthus* fitted probabilities



B: Main effects plot for *V. vulpes* fitted probabilities



C: Main effects plot for *H. hyaena* fitted probabilities

Figure 2. Probability diagrams of the normal distribution for the dependent variables *C. anthus, V. vulpes,* and *H. hyaena* (A, B, C), and for the independent variables (TREE, SHRU, RABB, RODE, HEIG).

Table 3. Displays the results of the logistic regression model for predicting the presence of carnivores.

Species	Observed	Predicted		Total
		Occurrence (1)	No Occurrence (0)	
C. anthus	Occurrence (1)	13	3	16
	No Occurrence (0)	1	41	42
	Total	14	44	58
	Overall percentage			93.1
V. vulpes	Occurrence (1)	3	5	8
	No Occurrence (1)	1	49	50
	Total	4	54	58
	Overall percentage			89.7
H. hyaena	Occurrence (1)	10	3	13
	No Occurrence (0)	2	43	45
	Total	12	43	58
	Overall percentage			91.4

DISCUSSION

In this study, we investigated the impact of environmental factors on the distribution and density of three carnivores in Cyrenaica, specifically in the EL-Jabal El-Akhdar: the African golden wolf (*Canis anthus*), the ref fox (*Vulpes vulpes*), and the striped hyena (*Hyaena. hyaena*). This area hosts a rich diversity of plant and animal species (El-Barasi and Saaed, 2013; Saaed *et al*., 2022), making it a key location for studying species-habitat interactions.

Our results confirmed the presence of all three carnivores in north-eastern Libya, each with distinct occupancy rates. These species are known for their ability to adapt to a range of habitats (Karssene *et al*., 2019). The African golden wolf's was positively associated with forest cover, indicating a preference for densely forested areas, while also exhibiting adaptability to varying

environmental conditions. In contrast, the red fox showed an aversion to densely forested areas, favoring open, low-lying terrain and appearing sensitive to habitats with taller vegetation. The striped hyaena, which prefer rocky landscapes and large caves, highlighted the role of spatial relationships among species in maintaining ecosystem resilience and structure (Boron *et al*., 2023).

Conserving carnivores requires an understanding of the factors influencing species distribution and habitat selection (McClure *et al*., 2017). Our results indicate that vegetation variables, specifically shrub cover and tree cover, significantly affect *C. anthus*. This species prefers areas with dense vegetation, which provide hiding, cover, and a high abundance of prey. Karssene *et al*. (2019) observed that African golden wolves were more active in valleys, where dense and tall vegetation offers better cover for prey. In contrast, the red fox exhibited a negative response to vegetation height, indicating a preference for regions with lower vegetation cover (Zhong *et al*., 2022; Feizabadi *et al*., 2024). Generally, this species is found in open areas with low vegetation height and density. However, the red fox's response to vegetation varies by location. (Lesmeister *et al*., 2015; Murdoch, 2016) found that its occupancy is positively influenced by shrubland habitats and tall grasslands in certain areas.

Our results showed that vegetation cover features had no significant influence on the presence of Stripped Hyena. These findings align with previous studies suggesting notable variations in hyena frequency across different habitat types. Specifically, (Alam *et al*., 2015; Bhandari *et al*., 2020) reported that the species tends to frequent hilly areas with sparse forest cover and more open, semi-arid, and rocky environments with available water sources. Such habitats have also been identified as favorable for various ungulates and small mammals, which constitute the primary prey for hyenas (Bhandari *et al*., 2021).

In addition to vegetation effects, the results showed that these carnivores responded differently to prey availability. Unlike *V. vulpes*, *C. anthus* was more closely associated with rabbit abundance than with rodent' abundance, while *H. hyaena* was affected by the availability of both prey types. These prey species constitute major components of all three carnivores' diets (Bhandari *et al*., 2020; Eddine *et al*., 2017; Karssene *et al*., 2019). Given that carnivores rely heavily on prey availability, diet partitioning may be a crucial mechanism facilitating their coexistence (Shao *et al*., 2021). In Libya, these three carnivores are sympatric across much of their range and form the majority of the region's mammalian carnivore guild, leading to interspecific interactions. Resource availability, the presence of refuges, and interactions with potential competitors and predators play fundamental roles in shaping their distribution. Predators often select energy-efficient areas based on prey abundance (Martín-Díaz *et al*., 2018) and seek refuges for resting, raising offspring, or avoiding competition (Mitchell *et al*., 2012). Variations in predator body size can influence resource sharing and community structure (Cuthbert *et al*., 2020). According to Hirt *et al*. (2020), the maximum prey size a carnivore can hunt is generally constrained by its own body size. However, cooperative hunting allows some predators to target much larger prey (Hansen *et al*., 2023). The trophic niche of smaller carnivores often overlaps with that of larger species. Differences in body size and morphometrics among African golden wolves, striped hyenas, and foxes likely contribute to variations in prey selection (Cuthbert *et al*., 2020).

The results indicated that the three carnivore species studied in north-eastern Libya were influenced by different habitat factors. However, we believe that other factors, particularly human activities and climate change, also significantly affect their distribution. Given the crucial role of carnivores in maintaining ecosystem functions, it is essential to explore how these factors affect their presence (Basak *et al*., 2023; Leão *et al*., 2023). Furthermore, interactions between canid species may affect their habitat selection, as many species pairs experience strong interference competition (Gompper *et al*., 2016; Karssene *et al*., 2019). To the best of our knowledge, this is the first study investigating carnivore habitat selection in Libya. Future research on their distribution, trophic niches, daily activities, and the effects of human activity and climate change could offer valuable insights into the carnivore community.

Conclusion: This study highlights the significant role of environmental factors in shaping the distribution and habitat preferences of key carnivore species in EL-Jabal El-Akhdar, northeastern Libya. The African golden wolf, red fox, and Hyaena exhibit distinct habitat preferences driven by vegetation cover and prey availability, underscoring the complexity of carnivore ecology in the region. The African golden wolf trends to favor areas with dense vegetation and abundant rabbits, indicating a preference for habitats rich in tree and shrub cover. In contrast, the red fox is more adaptable to open spaces with sparse vegetation and an abundance of rodents. The hyena's reliance on both rabbits and rodents emphasizes the crucial role of prey availability in its habitat selection. These findings underscore the necessity of implementing conservation plans and programs that protect the natural environment, particularly (VC) and prey populations.

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