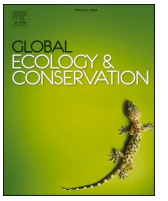
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Mesocarnivores den site selection in arid ecosystems; A case study of Rüppell's fox and sand cat in central Iran

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ABSTRACT

Understanding the relationships between species and their pattern of coexistence is essential in conservation planning. Rüppell's fox and sand cat are two poorly known species of desert areas that coexist in most parts of the desert belt of Africa and the Middle East. However, their habitat selection in many parts of their distribution are unknown. In this research, using the data collected from a three-year monitoring plan, we investigated the relationship between the den sites of Rüppell's fox and sand cat and habitat variables based on the generalized linear mixed model (GLMM) method. The results showed that for Rüppell's foxes, only the density of rodent burrows had a significant and positive effect. In the sand cat model, in addition to prey, vegetation density (P-value < 0.05) and vegetation height (P-value < 0.10) had significantly positive effects and elevation had a significantly negative effect (P-value < 0.10). We found that the sand cat is more specialized in habitat selection and depends more on the habitat cover. While the Rüppell's fox chose a more diverse range of soil and vegetation classes, the sand cat selected its den sites exclusively in sandy loam soils with the predominant cover of *Haloxylon* spp. and *Caligonum* spp. Acting as a generalist species, Rüppell's fox displayed a more pronounced response to human presence and selected dens with a broader view of their surroundings. These findings enhance our understanding of mesocarnivore coexistence in desert regions and provide valuable insights for the conservation planning of these species.

1. Introduction

Carnivorous mammals play a crucial role in ecosystem structure and functioning, yet they are highly sensitive to the quantity and quality of their habitat due to their low population density and specific biological requirements (Ripple et al., 2014; Rostro-Garcia et al., 2015; Gizachew, 2021). In general, access to prey, human presence, and interspecific competition are the three main factors that affect the distribution, habitat selection, and viability of carnivores (Hayward et al., 2007; Winterbach et al., 2014). One of the

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critical aspects of carnivores' viability is the appropriateness of the habitat structure for supporting their reproductive success (Ahmadi et al., 2014; Davies et al., 2016). The selection of den sites and associated habitat safety play a crucial role for den-dependent carnivores to maintain their reproductive success and species survival (Ripple et al., 2014; Zarzo-Arias et al., 2018). In carnivores, den site selection is affected by several biological factors, including food resources, competition with other species, and habitat cover (Hay et al., 2008; Ross et al., 2010; Ahmadi et al., 2014). It seems that carnivores have different behavior in prioritizing food resources and security in selecting their den sites. Some species tolerate the increased risk of interference and/or hunting in exchange for greater food availability (Hay et al., 2008). However, not all carnivores prioritize food resources over security. For instance, in a study on African wild dogs, researchers found that these animals selected den sites that were further away from their hunting territories to minimize disturbance and predation risks (Groom et al., 2017). Accordingly, others give up nutrition quality in the breeding season to improve offspring survival (Festa-Bianchet, 1988; Poole et al., 2007). For example, female grizzly bears have been observed to select dens in areas with low food resources during the breeding season to reduce the risk of infanticide by males (Libal et al., 2011).

However, the preference of species for habitat use, and specifically den site selection, may be altered in harsh environments with limited availability of resources. One such unique environment is the deserts of central Iran, which, despite the harsh environment, have a significant diversity of carnivores from the families Canidae (grey wolf *Canis lupus*, golden jackal *C. aureus*, common fox Vulpes vulpes, Blanford's fox *V. cana*, and Rüppell's fox *V. rueppellii*) and Felidae (Persian leopard *Panthera pardus tulliana*, Asiatic cheetah *Acinonyx jubatus venaticus*, caracal *Caracal caracal*, wild cat *Felis silvestris*, and sand cat *F. margarita*). The main reasons for this rich biodiversity are the distance from human-developed areas and proper protection of prey, especially within the network of protected areas. While the distribution and ecology of large-bodied carnivores of Iran have been well-described in numerous studies (Farhadinia et al., 2015; Ahmadi et al., 2017; Khosravi et al., 2018), small species have been less studied.

There is very limited published information about the distribution patterns, habitat selection behavior, and feeding ecology of Rüppell's fox (*Vulpes rueppellii*) and sand cat (*Felis margarita*). Furthermore, despite the widespread distribution of these two species from North Africa to the Arabian Peninsula and South Asia, global information on their trophic and spatial niche patterns is limited. Generally, the habitat of the Rüppell's fox and sand cat includes arid deserts covered by dunes and saline scrublands close to creekbeds (Sliwa et al., 2013; Ghadirian et al., 2016). Although the diet of the two species consists mainly of sand-dwelling rodents, other prey items such as birds, reptiles, and insects are also preferred (Abbadi, 1993; Lenain et al., 2004; Brighten et al., 2019). It seems that while the Rüppell's fox occupies a more diverse range of habitats, the sand cat is nocturnal and solitary and is known as a rare and specialized species in desert areas (Macdonald and Loveridge, 2010; Hemami et al., 2018). Despite their adaptation to dry habitats, these two species avoid the vast arid desert areas of Sahara, Algeria, and Rub al-Khali (Empty Quarter) in the Arabian Peninsula, and are mainly scattered in the margins of these areas (Serra et al., 2007; Murdoch et al., 2007).

Although den site selection is important for the survival of most canid and felid species (Punjabi et al., 2013; Ahmadi et al., 2014), it is of even greater importance for mesocarnivores such as Rüppell's fox and sand cat. These sub-ordinate carnivores use den sites year-round (authors' direct observation), and more importantly, these structures act as thermal refuges in the harsh environment of

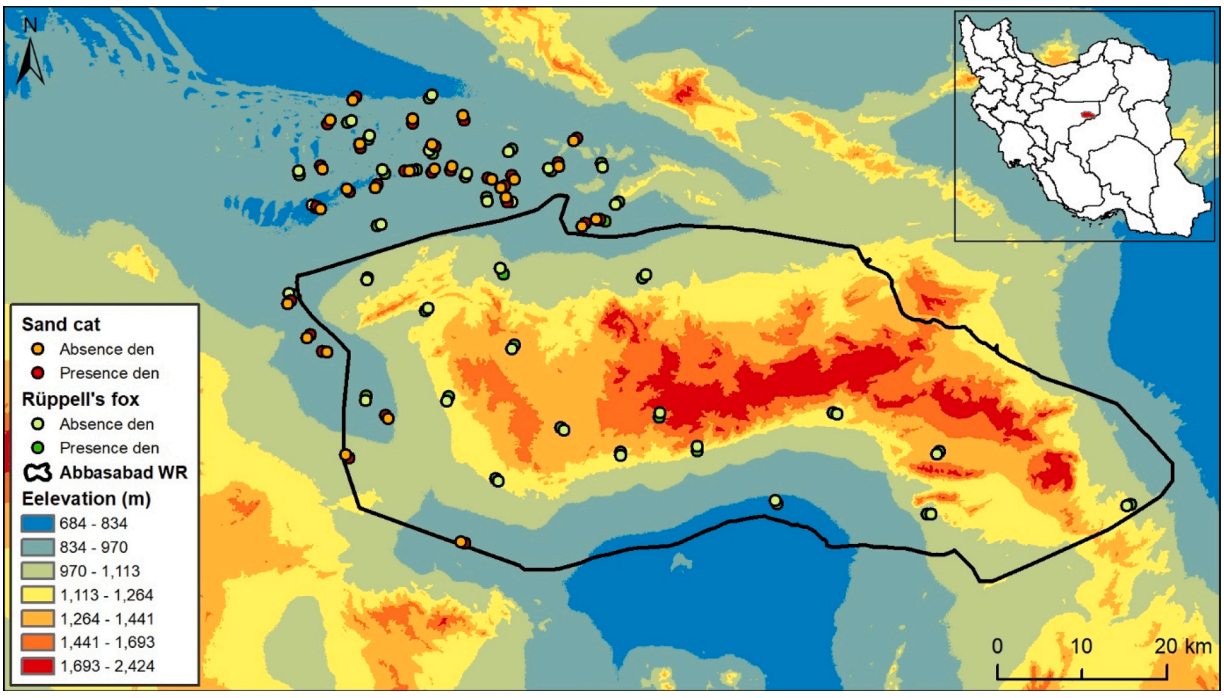


Fig. 1. Geographic distribution of the study area and presence/absence den sites of the sand cat and Rüppell's fox detected in Abbasabad W*R*, central Iran.

deserts as well as a means to avoid sub-ordinate competitors (Ross et al., 2010; Elbroch et al., 2015; Byerly et al., 2018; Reshamwala et al., 2021). Additionally, human activities such as land use change and road construction can destroy and reduce suitable den sites, leading to negative impacts on these species (Liberg et al., 2012; Sazatornil et al., 2016; Zaman et al., 2020; Farahani and Asgharzadeh, 2023). Proper den site selection can lead to increased reproductive success, optimal nutrition, and higher security against predators.

Although the general information on sightings, status, and ecology of the Rüppell's fox and sand cat in North Africa (Cuzin and Lenain, 2004; Sliwa et al., 2013), Arabian Peninsula (Cunningham, 2002; Murdoch et al., 2007; Amr, 2018), Iran (Ghadirian et al., 2016; Ghafaripour et al., 2018), and Central Asia (Brighten and Burnside, 2019), has been recorded in previous studies, detailed information on the pattern of habitat selection and their intra-and interspecies interactions is not available. In the present study, based on data collected during a 3-year survey from winter 2016 to winter 2019, the pattern of den site selection of the Rüppell's fox and sand cat in a semi-arid environment in central Iran was investigated. Specifically, our study aimed to investigate the responses of two mesocarnivores to resource limitations in the harsh desert environment and how habitat use through den site selection enables their coexistence. The findings of this study are crucial in understanding the coexistence of these poorly known species. Moreover, since assessing habitat selection and finding the environmental requirements of the species are the first step in their conservation, our study could aid in their conservation planning.

2. Materials and methods

2.1. Study area

The present study was conducted in two adjacent desert areas, namely Abbasabad Wildlife Refuge and Rig-e Jenn (AWR-RG) in Isfahan Province, central Iran (Fig. 1). While the former is legally protected, the latter is unprotected. Taken together, the two regions cover an area of about 5458 km^2 and span over 33°09 N – 33°54 N and 55°22 E - 53°26 E. The general landscape of the region includes patchily distributed mountains surrounded by dunes and vast plains with an altitude range between 2450 to 730 m.a.sl. The region's climate is hot and dry, with an average annual rainfall of 106 mm and an average annual temperature of 18 °C (Hemami et al., 2018). From a vegetative viewpoint, the area is mostly dominated by *Amygdalus – Pistacia* plant type in rocky uplands, *Artemisia – Zygophyllum* and *Salsola – Cornulaca* in vast hills and plains, and *Haloxylon – Stipagrostis* and *Haloxylon – Caligonom* in dunes. From a wildlife viewpoint, AWR-RG is among the richest areas in Iran hosting 11 mammalian carnivores including the Asiatic cheetah, Persian leopard, caracal, wild cat, sand cat, grey wolf, golden jackal, red fox, Blanford's fox, sand fox, and striped hyena (Hemami et al., 2018).

2.2. Data sampling

We collected data on the species presence areas based on published literature sources, local community information, direct field surveys and using the camera traps from winter 2016 to winter 2019. Data sampling included identifying the active dens of Rüppell's fox and sand cat, and measuring environmental information. We discovered den burrows based on field surveys along hypothetical tracks. To improve sampling efficiency, we visually checked the target areas in the Google Earth and then placed survey tracks in areas with higher probability of presence based on our knowledge of the region and the species. We surveyed tracks by foot (385 km) and a motorcycle (2800 km) and the location of identified dens was recorded by GPS. We set up a total of 10 camera traps in locations where we expected to observe the species according to our previous experience. Based on remote monitoring with binoculars, searching for footprints and feces, and setting camera traps, the identified dens were checked to ensure that they belong to the two target species. To evaluate the pattern of den site selection of the species, five 20 × 20 m plots were located around den sites, one with the center of den opening and the other four plots 50 m from the den in the cardinal directions (Trapp et al., 2008; Punjabi et al., 2013). The measured variables in these 5 plots were then averaged for each den.For each identified den burrows, we conservatively placed absence sites 1 km far from den sites based on previous studies (Person and Russell, 2009; Ahmadi et al., 2014) in a random direction where we assured of the absence of the species. Punjabi et al. (2013) in a use – available approach considered 800 m radius around Indian red fox to investigate its den site selection pattern. Based on prior knowledge of den sites and our three-years extensive surveys in the study area, we are confident that, to perform the GLMM analyses, we detected appropriate absence sites for identified den sites. Again for each absence site, we placed five 20 × 20 m plots and measured the same environmental variables.

Generally, prey availability, cover, and avoidance from anthropogenic effects are three basic component of mesocarnivores habitat selection (Ross et al., 2012; Barocas et al., 2022). Hence to evaluate den site selection of the species, within each plot we measured environmental variables related to the vegetation, prey availability, soil, topography, and human presence (proximity to roads and settlements); the first three were measured in situ and the last two (topography and human presence) were measured in ArcGIS and Google Earth (Table 1). Sparse vegetation in desert ecosystems plays a key role in habitat selection of the Rüppell's fox and sand cat by

Table 1
Selected candidate models explaining Rüppell's fox den site selection patterns in arid ecosystems of central Iran.

#Model	Variables	df	logLik	AICc	ΔAICc	AICc wi
1	Prey	3	-35.59	77.5	0	0.11
2	Prey + Road	4	-35.25	79.04	1.54	0.06
3	Prey + Slope	4	-35.26	79.06	1.56	0.05
4	Prey + Settlement	4	-35.46	79.46	1.96	0.04

providing them with cover, thermal comfort, and prey resources (Ghadirian et al., 2016; Barocas et al., 2022). For vegetation, we measured the proportion of vegetation cover (based on an approximate visual estimate) and the height of vegetation (by using a graded stick with a height of 3 m). Specifically, to determine vegetation height, we randomly positioned the graded stick within the plot and measured the maximum height of the nearest vegetation element within a 0.1 m radius surrounding the stick. Both Rüppell's fox and sand cat have an omnivorous diet, based mostly on rodents, lizards and insects (Ghafaripour et al., 2018; Brighten et al., 2019; Barocas et al., 2022). The majority of sand cat diet in Iran consists of sand-dwelling rodents with a high habitat overlap with *Allactaga*, *Meriones*, and *Gerbillus* genera (Ghadirian et al., 2016). To include prey availability in our habitat selection analysis, we counted the number of rodent burrows in den and absence plots, as the number of burrows is correlated with the true abundance of rodents (Ramesh et al., 2013).

Topography can influence desert-dwelling mesocarnivores by providing them with creekbeds where prey items such as invertebrates and rodents are readily available (Geffen et al., 1992; Barocas et al., 2022). Furthermore, rugged landscapes away from flatter areas act as habitat cover when carnivores select for den sites (Ahmadi et al., 2014). In our research, we calculated elevation above sea level and slope by using the raster map of the digital elevation model (DEM) in the ArcGIS v. 10.3 software. To do this, we downloaded a 30 m DEM layer from USGS Earthexplorer data set (https://earthexplorer.usgs.gov/). To account for anthropogenic effects, we measured the distance from roads, distance from human settlements, and distance from croplands in the Google Earth software. At each den opening, the soil type was measured as an index of digging ease and soil stability in six categories including sand, sand-loam, clay, clay-sand, pebble and gravel. Vegetation type was also determined in six categories recommended by the Iranian Forests, Range and Watershed Management Organization (IFRWO) including *Artemisia-Cornulaca*, *Haloxylon-Stipagrostis*, *Salsola--Cornulaca*, *Seidlitzia-Salsola*, *Artemisia-Salsola*, *Caligonum-Haloxylon* within a 1×1 m plot at the opening of each den. We didn't sample soil and vegetation types in absence sites so we didn't use them in the following stastitical analysis.

2.3. Data analysis

To evaluate the relationship between environmental variables and the probability of den selection and identify the most important variables, for each species we used a multivariate logistic regression method based on generalized linear mixed models (GLMM). GLMM, by taking into account the random effect term, provides appropriate estimations especially for unbalanced designs of nested sampling, repeated measurements, as well as for modeling spatio-temporal auto-correlated structures (Dormann et al., 2007; Bolker et al., 2009). Accordingly, in our case, for each species we used paired presence/absence den sites as the random effect in the GLMM analysis (Bolker et al., 2009). We then generated all possible combinations of the explanatory variables, i.e., fixed factors, as the candidate models and used Akaike's Information Criterion for small sample sizes (AICc) to rank them. Generally, AIC is a penalty for model overfitting and allows one to identify the most informative models explaining the relationship between dependent and independent variables. Among all candidate models we selected those with ΔAICc < 2, and based on the Akaike weights (AICc *wi*) the best model was identified. To evaluate variables relative importance we calculated model-averaged standardized parameter estimates across top candidate models as recommended by Galipaud et al. (2017). The 'lme4' package (Bates et al., 2015) was used to fit the general GLMM and 'MuMIn' package (Barton, 2022) was used to generate and rank candidate models both in R environment. To assess the response of the species to the gradients of the explanatory variables, we depicted response curve of each variable based on the fitted general GLMM using 'visreg' package (Breheny and Burchett, 2017). Before the GLMM analysis, the multicollinearity between the explanatory variables was calculated based on a variance inflation factor (VIF). Moreover, due to the dummy nature of the categorical variables, i.e., soil types (with seven categories) and vegetation types (with six categories), their use in the regression model complicates the model (Venkataramana et al., 2016). Hence, we didn't use these two sets of variables in the GLMM analysis, and the response of each species to them was depicted in descriptive plots.

3. Results

We recorded a total of 79 den burrows during our field surveys (43 dens for Rüppell's fox and 36 dens for sand cat). For five dens that were identified based on local people's information no sign of activity was found during direct field check, hence we removed them. After removing the suspicious dens, 40 dens of the Rüppell's fox and 34 dens of the sand cat were identified (Fig. 1). For each species, an equal number of absence sites were selected pair-wise for each den site. For both species, VIF of no variable was > 6, hence, all variables were used in the GLMM analysis. For the Rüppell's fox, the top four candidate models with ΔAICc < 2 consisted of prey availability, distance to roads, slope, and distance to human settlements (Table 1). The coefficients of the variables showed a

Table 2
Parameter estimates (beta) and relative importance (Rel.imp) of the environmental variables from the top models of the Rüppell's fox den site selection.

	β	SE	Z-value	*p*-value	Rel.imp
(Intercept)	-1.83	0.58	3.09	0.01	
Prey	0.38	0.09	3.91	0.001	1.0
Road	-3.34E-05	3.87E-05	0.84	0.39	0.20
Slope	0.05	0.06	0.80	0.42	0.20
Settlement	-1.76E-05	2.86E-05	0.60	0.54	0.16

significant impact only for prey availability (P-value < 0.05; Table 2). For the sand cat, the top model consisted of prey availability, vegetation cover, and vegetation height (Table 3). For this species, beta estimates of variables showed a significant impact of prey availability and vegetation cover (p-value < 0.05), and the vegetation height and elevation (p-value < 0.1) on den-site selection (Table 4). Based on the model-averaged parameter estimates of the variables, these variables were identified as the most important variables influencing sand cat den site selection, respectively (Table 4).

Response curves of the regression models indicated that Rüppell's fox and sand cat to some levels similarly react to the gradient of environmental variables (Fig. 2 and 3). For example, as we expected, the probability of den site selection increased with the increasing number of rodent burrows. The species' most apparent difference in response curves of explanatory variables was seen in the vegetative cover of den sites. Our results showed that while sand cat tightly reacts to the height and availability of vegetation cover, Rüppell's fox prefers areas with lower vegetation cover compared to sand cat (Fig. 2 and 3).

The comparison of dominant vegetation types at the opening of den sites showed that 64% of sand cat den sites were covered by *Haloxylon – Stipagrostis* followed by *Caligonum – Haloxylon* (23% of den sites, Fig. 4). For Rüppell's fox, *Haloxylon – Stipagrostis* and *Artemisia – Cornulaca* were the dominant vegetation types at den openings (in 40% and 27% of dens, respectively; Fig. 4). Given the soil texture, sand-loam and clay-sand soil types were seen in 59% and 24% of sand cat den openings, respectively (Fig. 5). For Rüppell's fox, although pebble was the dominant soil texture of the den openings (30% of den sites), the species' preference for other soil types was apparent (Fig. 5).

4. Discussion

Planning for biodiversity conservation requires obtaining sufficient information about the geographical distribution of species and natural and human parameters affecting it. Adopting the best strategy for habitat use, den site selection and reproductive success, accessing optimal nutrition and cover, and avoiding the risk of predators lead to increased fitness and, thus, species survival (Hayward et al., 2007; Ripple et al., 2014).

The results of GLMM revealed that while for the Rüppell's fox only the density of rodent burrows was reliably associated with the den site selection of the species, for the sand cat, in addition to the prey, vegetation cover and vegetation height also significantly explain the den site selection of the species. These two variables can be considered as an indicator of habitat shelter for the species. Various studies have also highlighted the importance of vegetation in providing food and shelter for sand cats (Ghafaripour et al., 2018) and other species such as lynx in central Europe (Filla et al., 2017), wild dog in Africa (Davies et al., 2016) and kit fox in the United States (Eckrich et al., 2018).

Although the beta coefficient of elevation was only significant (at 90% CI) for the sand cat, the two species showed different patterns of den site selection in response to topographic variables. While sand cat prefers areas with lower slope and height (800 – 1100 m.a.s.l.), Rüppell's fox selects for more rugged and higher regions (800 – 1600 m.a.s.l.). This is due to the greater dependency of the sand cat on sand dunes adjacent to a low-elevated plains. Nonetheless, the species' response to an elevation increase is negative.

In general, researches show that prey, human presence, and interaction with other species (competition and prey-predator relationships) are the most important factors affecting the distribution pattern of carnivores, especially on a large scale (Ripple et al., 2014; Rostro-Garcia et al., 2015). In the present study, since the rate of human activities and development in the study area is not very high, the effect of other variables became more highlighted, e.g. habitat safety against dominant competitors and predators and prey availability. However, comparing the best models of the two species showed that for the Rüppell's fox, two variables of road and human settlements are among the highly ranked models. This means that since Rüppell's fox, as a generalist species, has more mobility, shows a more significant response to human presence and considers the existence of humans in the den selection process. Altogether, the stronger influence of human presence and tendency to open habitats indicates that the Rüppell's fox selects den sites with a broader view of their surroundings during habitat use which might be due to the higher activity of this generalist species compared to the sand cat. The high tendency to open habitat has also been reported in other fox species that distribute in arid and semi-arid ecosystems. For example, Blanford's fox, *Vulpes cana*, selects for open dry creekbeds and avoids surrounding dense vegetation cover (Geffen et al., 1992). Similarly, in arid ecosystems of central India Indian fox, *V. bengalensis* (Punjabi et al., 2013), and white-footed fox *V. v. pusilla* (Misher and Vanak, 2021), have been shown to occupy open grasslands, even in human-dominated landscapes (Vanak and Gompper 2010). In the Arabian Peninsula and the Sahara, Rüppell's foxes inhabit a diverse range of desert environments, including rocky, gravelly, and sandy terrains, characterized by minimal vegetation and low rainfall (Lenain, 2000). Barocas et al. (2022) also highlight that the tendency of Rüppell's fox for valley-like landscapes of Negev desert. Thus, our results align with previous studies on the species' habitat preferences, though prior research has largely focused on general habitat selection rather than den site selection of the

Table 3
Selected candidate models explaining sand cat den site selection patterns in arid ecosystems of central Iran.

#Model	Variables	df	logLik	AICc	delta	weight
1	Prey + Veg_cover + Veg_height	5	-16.85	47.08	0	0.11
2	Prey + Veg_cover + Veg_height + Elevation	6	-16.22	48.31	1.23	0.06
3	Prey + Veg_cover + Elevation	5	-18.69	48.35	1.27	0.06
4	Prey + Veg_cover + Veg_height + Road	6	-16.35	48.56	1.48	0.05
5	Prey + Veg_cover + Veg_height + Crop	6	-17.6	48.59	1.51	0.05
6	Prey + Veg_cover + Veg_height + Slope	5	-18.92	48.81	1.74	0.04

Table 4
Parameter estimates (beta) and relative importance (Rel.imp) of the environmental variables from the top models of the sand cat den site selection.

	β	SE	Z-value	*p*-value	Rel.imp
(Intercept)	-19.58	14.44	1.34	0.18	-
Elevation	-0.02	0.01	1.73	0.08	0.63
Veg_cover	0.29	0.12	2.39	0.02	0.93
Veg_height	0.01	0.01	1.87	0.06	0.68
Prey	0.38	0.15	2.54	0.01	0.96
Crop	6.41E-05	5.07E-05	1.24	0.21	0.29
Road	7.40E-05	7.73E-05	0.94	0.35	0.14
Slope	0.01	0.01	1.84	0.25	0.11

species. Moreover, the tendency of Rüppell's foxes to use human landfills as an easy-access source of food, especially in the absence of larger competitors, explains the effect of human presence on the habitat selection of this species.

The highest number of sand cat dens was seen in two soil categories sandy loamy (a mixture of aeolian sand, clay, and humus compacted under the canopy of shrubs) and mixed and compacted sandy-clay sediments (in the walls of dry rivers and stream beds). In addition to ease of digging, these soil types have good stability due to the amount of clay, humus, root network, and higher humidity (Hassanzadeh Eskafi et al., 2020). These soil types provide the best habitat for small rodent species as the sand cat's main prey, as reported in similar studies (Naderi et al., 2011; Akbari Feizabadi et al., 2018). In contrast, Rüppell's fox den sites were found in all soil classes, although the use of gravel was more than other classes. Rüppell's foxes seem to have more power to dig in different types of soil than sand cats, which don't necessarily dig their dens and use rodent burrows (Ghadirian et al., 2016).

As expected, in parallel with the soil texture types, our results revealed that the vegetation cover of the den sites of the two species was different. A higher diversity of vegetation types were seen around the Rüppell's fox dens, although this species is more inclined to the two types of *Haloxylon* – *Stipagrostis* and *Artemisia* – *Cornulaca*. However, the highest number of den sites for the sand cat was covered by the *Haloxylon* – *Stipagrostis* followed by the *Caligonum* – *Haloxylon*. Dependence on sandy habitats with specific plants, especially *Haloxylon* and *Caligonum* shrubs, in similar studies on Rüppell's foxes (Sillero-Zubiri et al., 2004; Akbari Feizabadi et al., 2010) and sand cats (Ghadirian et al., 2016; Sliwa et al., 2013; Hemami et al., 2018) have been reported. It is important to note that the species of *Haloxylon* and *Caligonum* genera have the highest canopy height among the plant types of the region. In the present study, we considered height and percentage of vegetation as habitat cover (i.e. habitat refuge). These variables were among the most important variables affecting sand cat den site selection. The selection of such areas allows for better camouflage and cover against their predators, such as caracals, wolves and herding dogs (Ghadirian et al., 2016).

Thus, it can be concluded that for sand cats, areas with sufficient prey and habitat cover are the main priority for den site selection which is consistent with a similar study conducted in southeastern Iran (Ghafaripour et al., 2018). But for the Rüppell's foxes, better visibility around the den is more important in selecting den sites which is also reported for Indian foxes (Punjabi et al., 2013; Misher and Vanak, 2021). The broader selection of Rüppell's foxes compared to sand cats in terms of soil texture and vegetation types reveals that sand cat is a specialist species and Rüppell's foxes act as a generalist species in arid ecosystems of central Iran.

5. Conclusion

Desert and semi-desert ecosystems of the Central Plateau of Iran are among the last natural refuges for many imperiled wildlife species. Understanding distribution patterns, habitat selection behavior, and factors affecting the dynamics of biological communities in these remote areas are essential for conservation planning. In general, the results of the present research show that the sand cat represents a highly specialized habitat selection behavior. It is worth mentioning that most of the suitable habitats for this species are located outside the Abbasabad Wildlife Refuge (Hemami et al., 2018). In contrast, Rüppell's foxes distribute in most of the natural landscapes of the study area due to the general habitat selection behavior. Our findings show that sand habitats dominated by soil-stabilizing shrubs such as *Haloxylon* and *Caligonum* are critical to provide habitat needs (food and cover), especially for sand cats.

Moreover, both species are believed to be experiencing a decline in arid regions of central Iran (Ghadirian et al., 2016; Akbari Feizabadi et al., 2018). The factors contributing to this decline remain ambiguous. The encroachment of rural development into desert habitats is likely diminishing the available habitat for these species. Additionally, climate change and droughts have been influencing the distribution of the species and their prey (Ghadirian et al., 2016). Over the past few years, the red fox population has expanded into rural areas due to the spread of cities and towns, leading to the displacement of Rüppell's foxes in multiple locations within their range (Akbari Feizabadi et al., 2018). To comprehensively assess the conservation status of both the sand cat and Rüppell's fox, it is imperative to acquire additional information regarding their distribution. Obtaining such information will enable researchers to effectively monitor population trends, evaluate the effects of threats like human development and competition from red foxes, and potentially implement measures to mitigate declines. Therefore, it is strongly recommended to conduct standardized and repeated surveys to determine the abundance of these species across different arid environments.

In the first step, it is necessary to assess the population status and feeding ecology of the Rüppell's fox and sand cat, and improve understanding of their behavioral ecology to quantify the impacts of human activity on their population. Moreover, most sand cat burrows were observed in saline scrub land outside the boundary of the Abassabad Wildlife Refuge. As this habitat patch, in addition to the sand cat, supports a significant diversity of desert-dwelling rodents, reptiles, and invertebrates (Ghafaripour et al., 2018), expanding the AWR boundaries to cover this area can more effectively assist sand cat conservation as well as improve the conservation

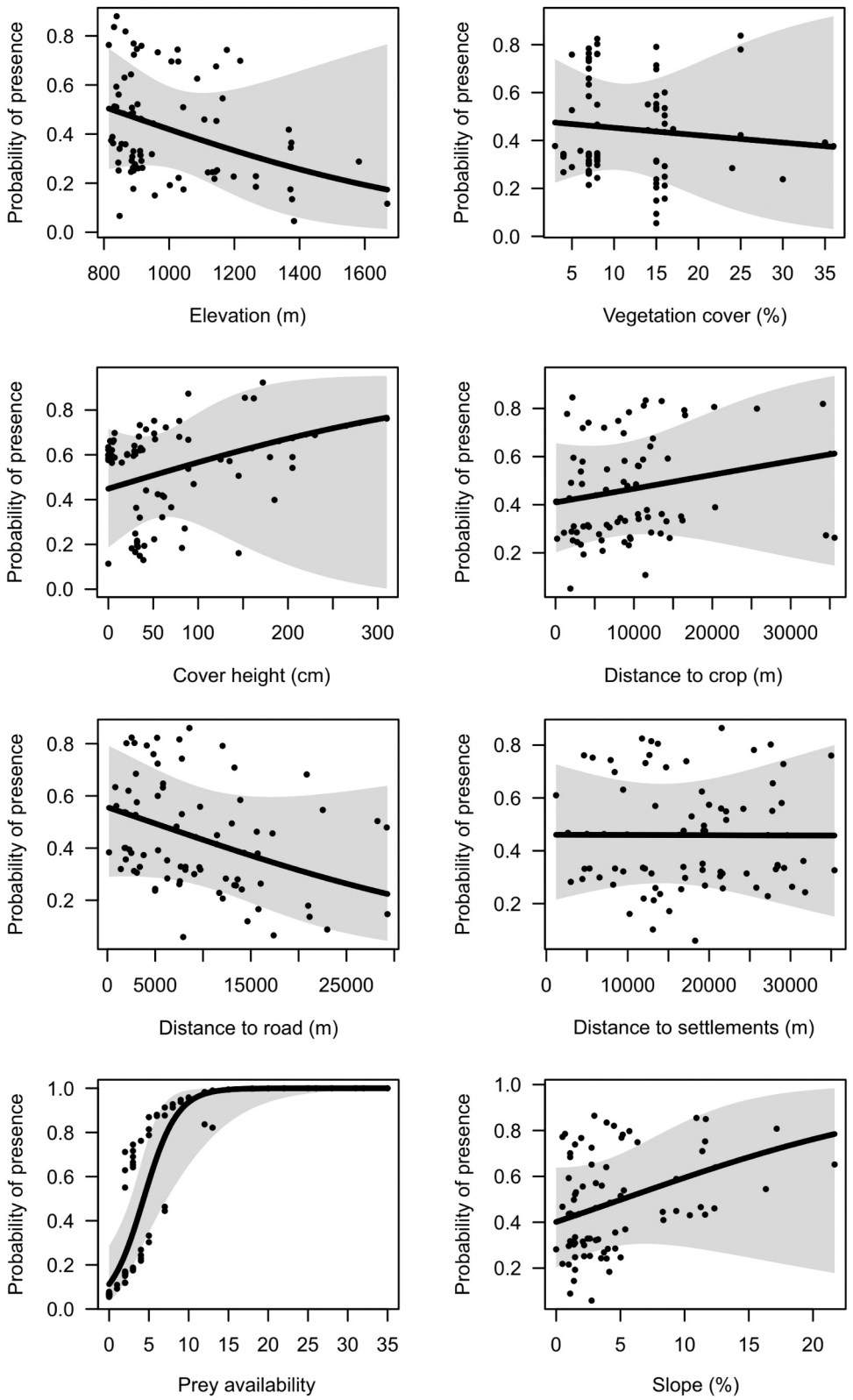


Fig. 2. Response curves of the variables influencing Rüppell's fox den site selection pattern. For prey availability we used the total number of rodent burrows.

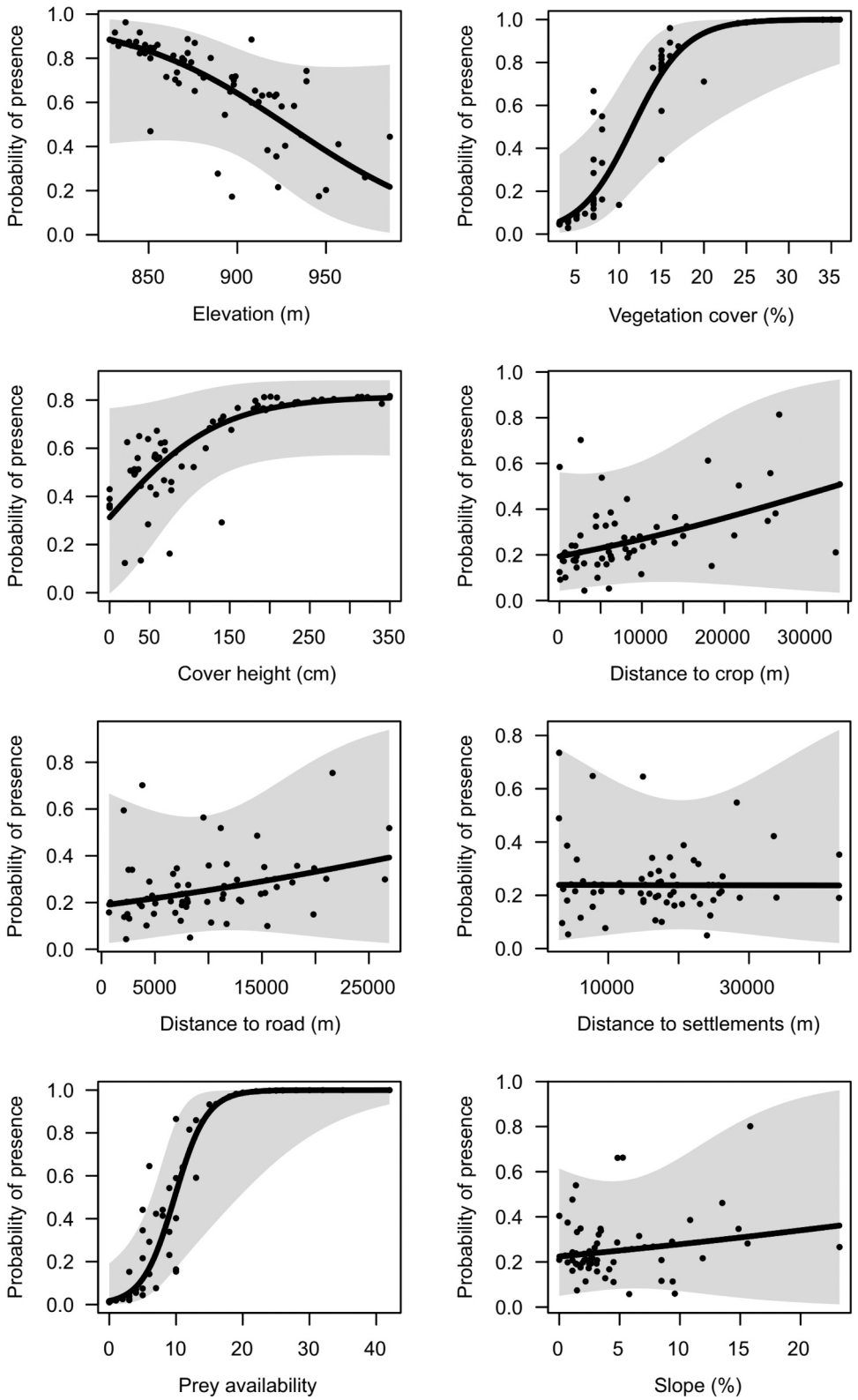


Fig. 3. Response curves of the variables influencing sand cat den site selection pattern. For prey availability we used the total number of rodent burrows.

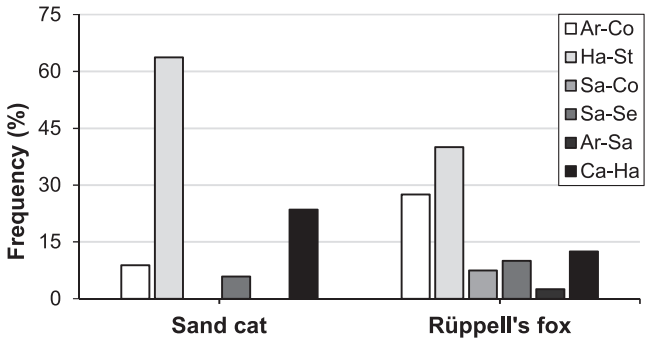


Fig. 4. Vegetation types at the den opening of Rüppell's fox and sand cat. Ar-Co:*Artemisia-Cornulaca*, Ha-St: *Haloxylon-Stipagrostis*, Sa-Co: *Salsola-cornulaca*, Sa-Se: *Seidlitzia-Salsola*, Ar-Sa: *Artemisia-Salsola*, Ca-Ha: *Caligonum-Haloxylon*.

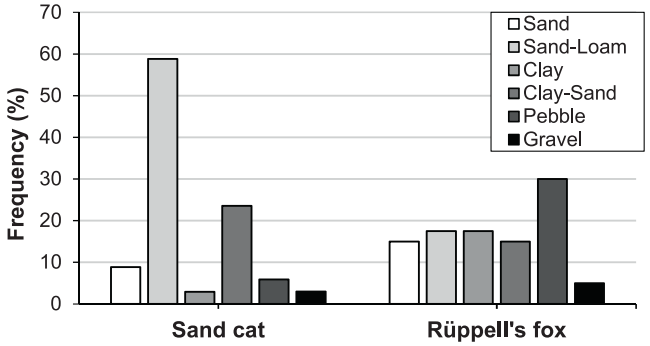


Fig. 5. Soil types at the den opening of Rüppell's fox and sand cat. We measured soil types as an index of digging ease only for presence sites.

status of other coexisting prey species. As understanding the species' ecology is the first step to better quantifying the conservation status of Rüppell's fox and sand cat and mitigating anthropogenic impacts, the results of this study represent important information for understanding their ecology, specifically the resistance of two unknown mesocarnivores in the harsh environments.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

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Appendix



Sand cat's den under the shelter of *Haloxylon* shrubs in the sand dune habitat (Photo: Hossein Akbari Feizabadi)



Sand cat's den under the shelter of *Caligonum* shrubs in the sand dune habitat (Photo: Hossein Akbari Feizabadi)



Sand cat's den under the shelter of *Haloxylon* shrubs in the sand dune habitat (Photo: Hossein Akbari Feizabadi)

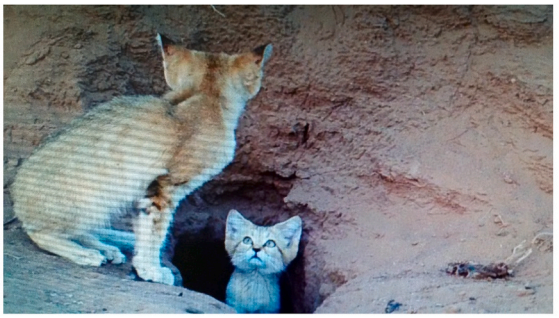


Sand cat's den on dried stream wall (Photo: Hossein Akbari Feizabadi)



Sand cat's den under the shelter of *Caligonum* shrubs in the sand dune habitat (Photo: Hossein Akbari Feizabadi)

Sand cat's den under the shelter of *Caligonum* shrubs in the sand dune habitat (Photo: Hossein Akbari Feizabadi). Sand cat's den under the shelter of *Haloxylon* shrubs in the sand dune habitat (Photo: Hossein Akbari Feizabadi). Sand cat's den on dried stream wall (Photo: Hossein Akbari Feizabadi). Sand cat's den under the shelter of *Caligonum* shrubs in the sand dune habitat (Photo: Hossein Akbari Feizabadi)



Two juveniles at a sand cat's den in a sand dune habitat (Photo: Hossein Akbari Feizabadi)



Sand cats camouflaging under *Haloxylon* bushes (Photo: Hossein Akbari Feizabadi)



Rüppell's fox's den on a gravel bed (Photo: Hossein Akbari Feizabadi)



Rüppell's fox's digging a den in a gravel bed (Photo: Hossein Akbari Feizabadi)

Two juveniles at a sand cat's den in a sand dune habitat (Photo: Hossein Akbari Feizabadi). Sand cats camouflaging under *Haloxylon* bushes (Photo: Hossein Akbari Feizabadi). Rüppell's fox's den on a gravel bed (Photo: Hossein Akbari Feizabadi). Rüppell's fox's digging a den in a gravel bed (Photo: Hossein Akbari Feizabadi)



Rüppell's fox in a den site in the sand dune habitat (Photo: Hossein Akbari Feizabadi)



Rüppell's fox digging a den in a sand dune habitat (Photo: Hossein Akbari Feizabadi)



Setting camera traps to identify activity of dens (Photo: Mohammad Reza Halvani)

Rüppell's fox in a den site in the sand dune habitat (Photo: Hossein Akbari Feizabadi). Rüppell's fox digging a den in a sand dune habitat (Photo: Hossein Akbari Feizabadi). Setting camera traps to identify activity of dens (Photo: Mohammad Reza Halvani).

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