Global Ecology and Conservation 54 (2024) e03156

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: www.elsevier.com/locate/gecco

Brown bear denning habits in northeastern Türkiye

Morteza Naderi [a,*], Emrah Çoban [b], Federico Collazo Cáceres [c], J. David Blount [c], Ayşegül Çoban [d], Josip Kusak [a,c,e], Çağan H. Şekercioğlu [a,b,c]

[a] Department of Molecular Biology and Genetics, Faculty of Sciences, Koç University, Istanbul, Turkiye
[b] KuzeyDoğa Society, Kars, Turkiye
[c] School of Biological Sciences, University of Utah, Salt Lake City, USA
[d] Department of Veterinary Biology, Iğdır University, Iğdır, Turkiye
[e] Department of Veterinary Biology, University of Zagreb, Croatia

ARTICLE INFO

Keywords:
Winter den site selection
Habitat features
Denning chronology
North-eastern Türkiye
Wildlife ecology
Conservation biology
Ursus arctos
Mammals

ABSTRACT

Denning behavior is essential for species that must survive difficult seasonal conditions when food is scarce. In the first denning study conducted in Türkiye, we investigated the denning habits of brown bears in the evergreen Sarıkamış forest in the east of the country. Using the bear movement data of bears recorded by GPS between 2018 and 2023, we identified 43 winter dens and 12 day-beds (daily resting places) used by bears. This study revealed the existence of five winter dens with separate toilet chambers, a phenomenon not previously documented in the literature. These chambers were separated from the sleeping areas by rocks or in a tunnel cavity. Our results showed that most winter dens were located in rocky regions and cliffs (83 %), while 17 % were in foothills and non-rocky areas, excavated areas, or under tree roots. Males had occupied all the excavated dens, with one exception. Notably, the den entrances were narrower in the foothills. This discrepancy can be attributed to the relatively constant height of the caves, which does not differ significantly from natural caves in rocky and mountainous areas. The geographical orientation of the excavated winter dens, which mainly faced north, may also contribute to this difference. Our data on denning chronology highlighted significant differences in denning behavior between female and male bears, with females exhibiting longer denning durations. These findings contribute to our understanding of bear ecology and emphasize the importance of considering sex-specific behaviors in wildlife management and conservation efforts. Our findings highlight the potential threats that current and future human infrastructure development pose to the long-term viability of bears in an understudied region at the confluence of two global biodiversity hotspots.

1. Introduction

In the face of challenging seasons, wild animals employ diverse survival strategies to endure harsh environmental conditions, including seasonal migration (Avgar et al., 2015; Fryxell and Sinclair, 1988), torpor (Nowack et al., 2017) or hibernation in winter dens (Linnell et al., 2000a; Shiratsuru et al., 2021). Hibernation is a particularly notable strategy for enabling animals to survive harsh winter conditions. This physiological state allows animals to survive extended periods of cold temperatures and food scarcity by entering a state of reduced metabolic activity. Brown bears (*Ursus arctos*), especially in far northern latitudes (Krofel et al., 2017),

* Corresponding author.
E-mail address: mnaderi@ku.edu.tr (M. Naderi).

https://doi.org/10.1016/j.gecco.2024.e03156
Received 5 June 2024; Received in revised form 18 August 2024; Accepted 18 August 2024
Available online 6 September 2024
2351-9894/© 2024 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

invest heavily in selecting their winter quarters, where they reduce their metabolisms, and lower their heart rates and body temperatures to conserve energy (Blanchet et al., 2019). Denning is a critical adaptation for brown bears, helping them cope with adverse environmental conditions by temporarily reducing several physiological functions (González-Bernardo et al., 2020a). Bear dens provide benefits to hibernating animals by increasing their survival rate during the harsh season, thermal insulation, physical and acoustic protection (Linnell et al., 2000a), and energy conservation (Delgado et al., 2018). Since females give birth during the winter, denning can also be critical for these bears to provide safe and warmer places for the newborns (Delgado et al., 2018) and protect them from extremely low air temperatures (Sorum et al., 2019).

Studies have demonstrated that den entry and emergence times vary significantly among different bear species and populations, often influenced by environmental factors such as temperature, food availability, and photoperiod (e.g. González-Bernardo et al., 2020b; Hilderbrand et al., 2000; Manchi and Swenson, 2005). Sex-based differences play a crucial role in denning behavior. For instance, pregnant females tend to enter dens earlier and emerge later than do males and non-pregnant females, ensuring optimal conditions for cub birth and early development (Friebe et al., 2001). Additionally, bears at higher latitudes generally have more extended denning periods, attributed to harsher winter conditions and shorter growing seasons (González-Bernardo et al., 2020b). This variation highlights bears' adaptive strategies to diverse climatic conditions, emphasizing the importance of understanding these patterns for effective conservation and management of bear populations across different regions (Farahani and Asgharzadeh, 2023).

Brown bear hibernation dens come in a variety of forms, from natural rock cavities, smaller rock cavities, hollow tree dens, root or stump excavations, hollow logs, and surface beds (Linnell et al., 2000a; Schoen et al., 1987; Seryodkin et al., 2003; Ugarković et al., 2014). Brown bear dens consist of several components: a porch, an entrance, a tunnel, and a sleeping chamber(s) (Huber et al., 1996; Ugarković et al., 2014). These dens can be either natural or excavated, and in some cases, nesting chambers are furnished with vegetation (Linnell et al., 2000a).

The selection of den sites by brown bears is influenced by a complex interplay of environmental factors. Topographic features such as terrain ruggedness are crucial, as bears prefer areas with steep slopes and varied elevations, which provide natural cover and protection from predators and human disturbance (Faure et al., 2020; Nielsen et al., 2009). Forest cover is another significant factor, as dense vegetation offers thermal insulation, protection from the elements, and concealment from potential threats, thereby enhancing the safety and comfort of the den (Nielsen et al., 2009). In addition to these physical and environmental factors, the availability of food resources near the den plays a vital role in site selection. Access to high-quality food sources in the vicinity allows bears to efficiently forage and replenish their energy reserves after emerging from hibernation. This proximity to food can significantly influence the bears' overall fitness and reproductive success, making it a key factor in den site selection (Pigeon et al., 2016). Additionally, the distance from roads, human settlements, and farming areas plays a role in den site selection (Linnell et al., 2000b; Sahlén et al., 2011) and environmental physiography (Sorum et al., 2019). Overall, the combined influence of topographic, forest cover-related, and human-related factors underscores the complexity of brown bear denning ecology and highlights the importance of considering multiple variables when investigating this topic.

Along with the winter dens, day beds are critical places that affect brown bears' viability and welfare, as they spend a significant part of a day there during activity seasons (Mysterud, 1983). In our highly human-dominated study area (Blount et al., 2024), bears try to reduce the risk of encountering humans. Therefore, they are nocturnal and select their day beds in places that minimize the risks, or they use the hibernation dens also as day beds (KuzeyDoğa Society, unpublished data). During their active seasons, bears select their day beds considering the environmental factors that can protect them from anthropogenic risks. For example, Ordiz et al.(2017) concluded that day beds are more concealed to reduce the risks from people. Some investigations showed that females with cubs select their day beds in more rugged terrain and closer to the human settlements, possibly to avoid the risk of infanticide by rival males (Skuban et al., 2018). It has been reported that bears, like people, have their preferences Cristescu et al. (2013). They avoid barren land for resting regardless of land designation, and they select horizontal cover and avoid areas close to trails for bedding.

Despite extensive research on brown bear denning in Europe and the northern latitudes, there is a notable gap in studies focusing on the denning behavior of brown bears in the Middle East and Türkiye, with only a few studies available (Zarei et al., 2018; Zarei and Mahmoudi, 2019), and no denning publications from Türkiye. Considering that Türkiye hosts a significant population of brown bears (Ambarli et al., 2016) and serves as a crucial land bridge connecting the eastern and western Palaearctic, understanding den selection in this region is vital for effective bear conservation strategies. Addressing this research gap is essential to ensure the protection and viability of brown bear populations in Türkiye.

This study aimed to fill this gap by conducting a detailed survey of brown bear dens in eastern Türkiye and examining the factors influencing den site selection, including structural features and environmental factors. Specifically, we address two questions: 1) What are the physical characteristics of bear dens in eastern Türkiye, and 2) what environmental covariates can predict where the bears are? We predict that bears in this region will choose den sites based on proximity to the roads, human settlements, and the den's inaccessibility or seclusion from people. We hypothesize that bear dens in our region will be in rocky areas, cliffs, and hillsides, with naturally existing or excavated features. Brown bears generally avoid dens that are too close to people and that have sources of potential disturbance (e.g., Sahlén et al., 2011). In our study area, the rocky landscape provides ample opportunities for den sites inaccessible to people, which we expect to be a critical factor in den site selection. Addressing these gaps in the literature, this is the first study to describe and analyze the den characteristics of brown bears in Türkiye.

2. Materials and methods

2.1. Study area

The research was conducted in the Kars province of northeastern Türkiye, near the town of Sarıkamış (40° 11' to 40° 27'N and 42° 24' to 42° 49' E). The study area comprised four forest patches totaling 338.5 km^2 (Fig. 1). Among these, three southern patches are subject to commercial logging activities, while the northern patch is protected within the Sarıkamış Forest-Allahuekber Mountains National Park. The Caucasian climatic regime influences the region that experiences a semi-continental climate (Blount et al., 2024). August is the warmest month with a mean temperature of 15.6°C, while January is the coldest with a mean temperature of −8.1°C. Snowfall typically commences in October, and the average snow cover depth exceeds 53 cm from January to March. The study area remains snow-covered for over 200 days annually (Sarıkamış Weather & Snow Trends, 2020). Altitudes range from around 1500–3120 m above sea level.

The landscape of the study area has undergone a notable transformation due to extensive agrarian activities, including livestock grazing, commercial logging, and other types of habitat destruction and degradation. These changes include tree cover reduction, forest fragmentation, logging, and, to some extent, changes in the overall composition of the regional flora (Chynoweth et al., 2015). This area's growing vegetation season is around 150 days (Naderi et al., 2020). All forest patches show considerable fragmentation, with Scots pine (*Pinus sylvestris var. hamata*) being the predominant tree species and some other accompanying species such as trembling aspen (*Populus tremula*), ash (*Fraxinus* spp.) and occasional oak (*Quercus petraea*) (Atalay, 1983). Forest understory vegetation varies from minimal to dense undergrowth of different *Rubus* genera. The study area is home to a diverse community of large carnivores, including brown bears (*Ursus arctos arctos*), gray wolves (*Canis lupus*) and Caucasian lynx (Lynx lynx dinniki) (Chynoweth et al., 2015; Capitani et al., 2016; Kusak and Şekercioğlu, 2021; Naderi et al., 2021; Blount et al., 2024). High levels of human activity, particularly logging, impact the forest (Blount et al., 2024; Capitani et al., 2016; Chynoweth et al., 2015, 2016), as is increasingly the case across Türkiye (Şekercioğlu et al., 2011a). Approximately 85 % of the study area, especially the three southern forest patches, experiences regular seasonal logging activities, primarily in late spring and summer, which have substantially increased since 2019 (Blount et al., 2024). Illegal tree-cutting is prevalent throughout the area, including within the national park (Şekercioğlu, 2012). Apart from the winter season, human activities involve livestock herding, recreation (picnicking), and wild herb and mushroom collecting (Cozzi et al., 2016; Kusak and Şekercioğlu, 2021).

2.2. Bear capture and locating dens

This study is part of a long-term conservation ecology and population biology research program on northeastern Türkiye's large carnivores (brown bears, wolves, and lynx) conducted by the KuzeyDoğa Society since 2006 (Akkucuk and Sekercioglu, 2016). Bears were captured using Aldrich foot snares in a "European cubby" (Huber et al., 1996). GSM-equipped camera traps were also installed at cubbies to send instant photos when captures happened. We also used GSM-equipped alarms to send signals when any snares were triggered. After tranquilization using a combination of ketamine and medetomidine (Kreeger and Arnemo, 2012), target animals were equipped with Vectronic Aerospace GPS-GSM/Iridium collars (Vectronic Aerospace GmbH, Berlin, Germany). Using GPS data with a fixation rate of one hour and a cluster identification code (R Version 3.3.1; Kindschuh et al., 2016), we identified locations that formed a cluster, indicating the location of potential bear bed/den sites. Den locations have been identified using clusters of GPS points belonging to 30 collared bears (18 males and 12 females) during late fall and early spring that started or ended within the same area. These areas were then searched, and only used as "den locations" if dens were found there. After dens were found, GPS locations were updated to include the exact locations of the den sites. We used movement data from collared bears from 2018 to 2023.



Fig. 1. The study area, Sarikamiş, has fragmented forests in the country's northeastern part. The colored dots indicate the den and day bed locations (see Fig. 2).

2.3. Den measurement

Den and day bed sites were searched and examined during the summer of 2023. We visited the recorded locations and searched for dens near the coordinates proven to have been used by the bears, e.g., through scats and footprints. The locations were classified as winter (hibernation) dens or day beds. Winter dens were then subclassified into natural cavities or excavated ones. Only the dens/day beds with signs of activity were measured. Once the den was located, a protocol form (Huber et al., 1996) was filled out to record factors, such as the exact geographic coordinates, elevation, whether it was a natural or excavated den, vegetation density, density of tree canopy, slope, orientation, height, and width of the entrance (immediately at the entrance's outer edge (height, length, and width of the tunnel, dimensions of the chamber(s) and distance to entrance, the height of the chamber and any evidence of a toilet chamber. Canopy density estimation (canopy openness) was conducted through visual estimation (Pisani et al., 2023), which was confirmed by image analysis using APS Assess 2.0 image analyzer (Lamari, 2002). To do this, a camera aimed upward at the canopy and foliage was analyzed to obtain the percentage of foliage area occupied by the canopy. Vegetation density was also visually estimated (Naderi et al., 2014). The layout of the den was visually documented using sketches or photos to provide a comprehensive representation of the den's structure and features. The same number of pseudo-absence points equal to the total number of dens and daily beds were randomply positioned within an average radius of 500 m (ranging from 400 to 2000 m). These pseudo-absence points with a specific geographic distance from the presence points were selected based on expert knowledge and forest patch size (Senay et al., 2013) to avoid the selection of points outside the forest patches or very close to the anthropogenic activity points. Elevation, slope, aspect, canopy cover, density of shrubs/herbaceous cover, and distal factors such as distance to the roads, farms, and human settlements were recorded. The distance variables, including distance to farmland, roads, and distance to human settlements, were measured using ArcGIS (version 10.8, ESRI, Redlands, CA, USA) and Google Earth software (version 7.3, Google LLC, Mountain View, CA, USA). An experienced researcher measured all the variables to ensure the measurements' consistency.

2.4. Data analysis

Since the data were not normally distributed based on Shapiro–Wilk tests and graphical examinations, we used a nonparametric Mann-Whitney U test to assess the differences in den structural metrics between different dens (natural or excavated) and all dens and random points. Data manipulation and visualization were performed using R core functions and the dplyr and ggpubr packages in RStudio (v 1.1.447—R Development Core Team, 2019), and we thoroughly explored the impact of potential outliers on our results by running the analysis with and without outliers to observe how they affected the results (Wilcox, 2016). Outliers were identified through visual inspection using boxplots and Q-Q plots and calculating descriptive statistics, considering deviations from the central tendency and predetermined ranges. Additionally, we conducted sensitivity analyses by running the analysis with and without these outliers to assess their impact on the results and inform decisions regarding their treatment. Outliers were identified and excluded from the analysis through visual inspection using boxplots and Q-Q plots, and descriptive statistics were calculated considering the deviations from the central tendency and predetermined ranges. Specifically, values deviating more than 1.5 times the interquartile range (IQR) from the first and third quartiles were considered potential outliers. This approach ensures that our findings are robust and not unduly influenced by extreme values. We assessed the relationship between environmental variables and the probability of den selection with generalized linear mixed models (GLMM). GLMMs provide suitable estimates, especially for unbalanced designs with nested samples and repeated measures and for modeling spatiotemporal autocorrelated structures by considering the random effect term (Bolker et al., 2009; Dormann et al., 2012). Accordingly, in our case, we used environmental variables at the den sites and their paired absence points as predictors in the GLMM analysis. In our case, we used individual dens as a random effect in the GLMM analysis to account for repeated measurements of the same individuals. Multiple observations from the same bear are not independent, and this random effect controls for this dependency. We used presence points (actual den sites) and pseudoabsence points (locations not used as den sites but otherwise similar) to compare environmental variables. This helps us understand what factors are associated with den site selection. The GLMM analyses were conducted using the lme4 package in R (Bates, 2011; Bates et al., 2015), which is widely used for fitting linear mixed-effects models.

We then created all possible combinations of the explanatory variables as model candidates. We used the Akaike information criterion for small sample sizes (AICc) to rank them and identify the best models explaining the species' pattern of den site selection. Models were selected based on $\Delta AICc < 2$, and Akaike weights (AICc wi) were used to determine the best model. The criterion $\Delta AICc < 2$ was used for model selection (Ahmadi et al., 2024). This threshold is commonly used in AIC-based model selection. It indicates that models with a difference in AICc values of less than 2 are similar in their ability to explain the observed data (Snipes and Taylor, 2014). The choice of this threshold is based on the principle that models with similar AICc values provide comparable support and the decision between them is considered less critical (Feizabadi et al., 2024). Models meeting this criterion were considered to have similar explanatory power, and the best model was selected based on the Akaike weights (AICc wi) (Otis et al., 1978) Prior to the GLMM analysis, multicollinearity between the explanatory variables was calculated based on a pairwise Pearson correlation coefficient. Variables with correlation coefficients exceeding a predetermined threshold, typically set at 0.7 or higher, were considered correlated. This threshold was chosen based on established guidelines in statistical literature to identify significant correlations that may impact the stability and interpretability of regression models. Response curves were constructed to illustrate the importance of the environmental variables, focusing on vegetation density as measured by tree cover in the immediate den perimeter.

2.5. Denning chronology

We also investigated denning chronology and its difference between males and females. For this analysis, we used more data from an extended period (2012–2023). This dataset comprised 64 collared bears (27 females, 37 males). A Welch Two-Sample t-test was conducted to compare the number of days female and male bears stayed in their dens. We compared mean start dates, end dates, and denning duration between male and female individuals. Descriptive statistics, including mean and standard deviation, were calculated for each variable.

3. Results

A total of 43 winter dens (78 %) and 12 (22 %) day beds were identified during our study. Of these, 41 dens were recorded using the coordinates from tracked bears, and 14 dens were detected opportunistically (Fig. 2). Among the 43 dens, 17 % (n=7) were excavated, while 83 % (n=36) were natural cavities under rocks. Most dens (79 %, n=34) had one entrance, while others had two (17 %, n=7) or three (4 %, n=2) entrances. Of the excavated dens, six dens had been used by males, and only a single den was used by a female bear.

The excavated dens were located in the foothills, with six under pine roots and one under bedrock. Twelve hibernation dens were found in rocky forest areas, with the remainder in forest patches. The dens in the rocky areas were also close to the forest patches (average distance < 300 m). Tunnels were present in most hibernation dens (92 %, n = 39). Both day beds and dens had identifiable "beds" constructed from vegetation and pine needles. Fourteen dens were lined with pine needle bedding material. We found five dens with evident toilet chambers, and we report this for the first time in the literature. The toilet chambers were located on the side of the entrance tunnel, usually one meter away from the den entrance. Some dens were used during the summer, which we inferred from fresh footprints and scats. Scat accumulations were observed at single points near the day beds (Figs. 3 and 4 and the illustrations in the appendices).

The mean elevation (above sea level) of the excavated winter dens was 2256 m (Min = 2076 m, Max = 2464 m, SD=116.75, n = 7), while natural hibernation dens had a mean elevation of 2180 m (Min = 1730 m, Max = 2585, SD= 240.15, n = 36). Natural cavities mainly faced south, southeast, or southwest (n=22), whereas excavated dens predominantly faced north (n=5), west (n=1), and southwest (n=1).

All variables had correlation coefficients below |0.5|, so they were included in the GLMM analysis. The results revealed that terrain slope and distance to agricultural land were the most influential factors in den site selection (P-value < 0.05) (see Table 1). The six best

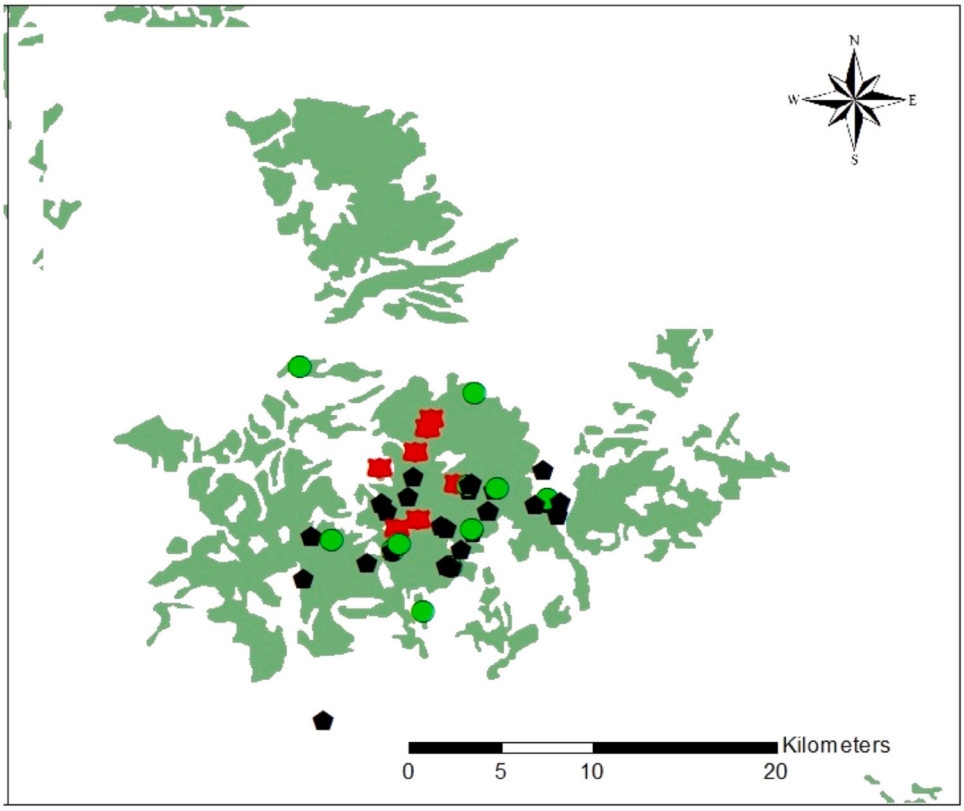


Fig. 2. Distribution of the identified dens in the study area. The green circles show daily resting places, and the black and red icons indicate winter dens. The red circles show the excavated winter dens.



Fig 3. Day beds with scat clusters (Photo by Morteza Naderi, (see appendices and illustration by Reihaneh Naderi).



Fig. 4. A cross-section of the excavated winter den (upper photos) in the hillside and the view from the inside of a natural den (lower photo). Excavated dens had only one chamber and a shorter tunnel compared to the natural cavities (see appendices and the illustration by Reihaneh Naderi).

Table 1
Results from the global model derived from Generalized Linear Mixed Model (GLMM) analysis showing the influence of environmental and anthropogenic factors on brown bear den site selection in northeastern Türkiye. ** indicates significance level at $P < 0.01$.

Variables	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	−5.974e+00	2.623e+00	−2.277	0.0228 *
Elevation	−1.650e−04	1.353e−03	−0.122	0.9029
Slope	1.208e−01	3.055e−02	3.953	7.72e−05 ***
Vegetation density	2.114e−02	1.492e−02	1.417	0.1565
Distance to patch edge	−7.646e−05	2.170e−04	−0.352	0.7246
Distance to road	−1.189e−03	1.134e−03	−1.048	0.2944
Distance to human settlements	2.034e−04	1.880e−04	1.082	0.2793
Distance to farmlands	1.062e−03	4.475e−04	2.374	0.0176 *

models, based on ΔAICc < 2, included combinations of slope, distance to farmland, and tree cover (see Table 2).

Response curves (Fig. 5) from the regression models highlight the importance of each predictor in den site selection. Roads had a significant impact, while elevation and distance to forest did not.

The entrances of the excavated dens in the foothills were significantly narrower than those in mountainous or rocky terrains (Mann-Whitney U = 115, $n_1 = 7$, $n_2 = 36$, P < 0.005). Additionally, significant differences were found in the tunnel lengths and chamber heights between natural and excavated dens. Tunnel length was significantly longer in natural caves in rocky areas (Mann-Whitney U = 102, $n_1 = 36$, $n_2 = 7$, P < 0.01). Remarkably, all excavated dens featured a single bed. In contrast, we observed multiple beds (between two and three) in 16 natural winter dens, a pattern related to the bedding area preferences of females and cubs. There was no significant difference in elevation above sea level between natural caves and excavated dens. Table 3

Table 2
Details of the best-fitting models for brown bear den site selection based on Akaike Information Criterion corrected for small sample sizes (AICc). This table includes models with a ΔAICc of less than 2, indicating robust support relative to other models. The table highlights models that best explain variation in den site selection considering environmental factors.

		df	logLik	AICc	delta	weight
1	Tree cover+Distance to farmlands+Slope	5	−32.462	75.5	0.00	0.258
2	Distance to farmlands+Slope	4	−33.620	75.6	0.12	0.243
3	Tree cover+Distance to farmlands+Distance to human settlements+Slope	6	−31.927	76.7	1.17	0.144
4	Distance to farmlands+Distance to human settlements+Slope	5	−33.144	76.9	1.37	0.130
5	Tree cover+Distance to farmlands+Distance to roads+Slope	6	−32.109	77.0	1.53	0.120
6	Distance to farmlands+Distance to roads+Slope	5	−33.369	77.3	1.81	0.104

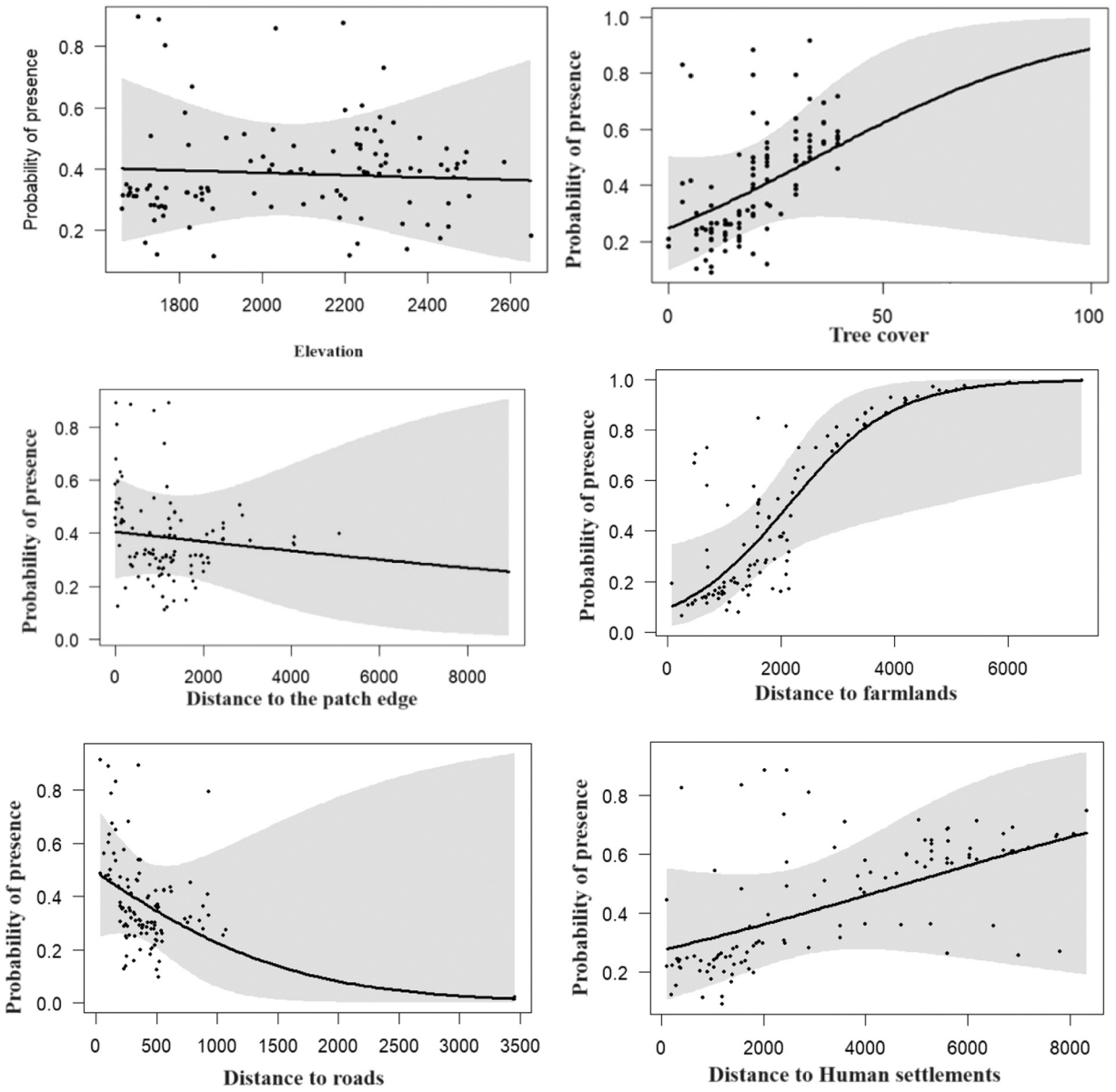


Fig. 5. Response curves of variables influencing brown bear den site selection. Elevation from sea level did not affect den site selection, while the distance to farmlands and roads was more critical.

Table 3
Descriptive statistics for dimensions of winter dens (cm): Comparison between natural cavities and excavated structures. The values represent mean measurements with standard deviations in parentheses.

	Entrance height	Entrance width	Tunnel length	Tunnel Height	Tunnel width	Chamber height (floor to den roof)	Chamber length	Chamber width	Porch Length	Porch width
Natural cavities	90.90 (47.66)	93.09 (65.23)	324.03 (185.21)	82.09 (43.99)	97.41 (47.72)	87.13 (35.26)	119.93 (76.94)	97.36 (37.74)	164.08 (94.69)	182.6 (103.12)
Excavated	69.02 (13.67)	76 (26.07)	213.75 (30.92)	72.5 (14.43)	96.25 (46.25)	103 (24.64)	122.14 (48.29)	118.57 (35.79)	157 (62)	142 (31.14)

3.1. Denning chronology

The number of days spent in dens differed significantly between females (mean = 138.25 days) and males (mean = 91.16 days) ($t(37.5) = 3.30$, $p = 0.002$). Females began denning around early to mid-November, staying about 4.6 months on average, while males started later, around late November to early December, staying about three months.

4. Discussion

Our study provides novel insights into the denning ecology of brown bears in the Sarıkamış region of northeastern Türkiye. By examining the physical characteristics of bear dens and the environmental factors influencing den site selection, we aimed to fill the significant research gap on brown bear denning behavior in the Middle East and Türkiye. We identified five winter dens with toilet chambers, a discovery not previously described in the literature. This finding prompts comparisons with other studies on den architecture and brown bear physiology, which have focused on structural components such as sleeping chambers, tunnels, and porches (Faure et al., 2020; Huber et al., 1996; Schoen et al., 1987; Ugarković et al., 2014). The presence of toilet chambers raises intriguing questions about their function and potential effects on behavior, warranting further investigation. Our observations of summer activity inside the dens suggest that some bears use these winter dens for temporary stays during the active season. The preference for rocky regions and cliffs as denning sites aligns with broader literature indicating bears' preference for hilly terrain (Faure et al., 2020; Nielsen et al., 2009). This consistency in habitat choice suggests that terrain nature is a universal factor influencing site preferences across different populations.

4.1. Den characteristics and environmental influences

Contrary to Faure et al. (2020), who found that bear den entrances in mountainous regions are narrower than those in foothill regions, we observed the opposite. We found that den entrances in the foothills were narrower. This difference may be due to the constant height of the caves, which did not significantly differ from natural caves in rocky and mountainous areas, and their predominantly north-facing geographical orientation. While narrower den entrances on north-facing slopes were posited to minimize heat loss and maintain stable microclimates within dens, empirical support for this explanation from specific data on the denning behaviors of brown bears or other animals is lacking. Adapting to natural caves is more accessible than digging a hole, even if it means a colder winter den. Differences in the dimensions of the two types of dens can be related to the suitability of natural holes. More research is needed to determine if bears digging holes for dens do so because they cannot find suitable natural caves or learn this behavior from their mothers.

Our findings underscore the pivotal roles of anthropogenic variables, indicating an increased likelihood of den site selection in remote areas with fewer anthropogenic disturbances. The influence of terrain slope and distance to farmlands in den site selection was consistent with the findings from other studies (Faure et al., 2020; Nielsen et al., 2009). However, variations in the importance of specific environmental variables have been documented across different bear populations. For instance, studies in North America have emphasized the significance of vegetation cover, large rocks, and natural cavities (Ciarniello et al., 2007; Libal et al., 2011). Our study highlights the prominence of slope and proximity to farmland, underscoring the need for region-specific considerations in understanding bear habitat preferences.

The presence of open day -beds alongside winter dens parallels the findings from other regions (Linnell et al., 2000b; Schoen et al., 1987). The bears' ability to utilize different types of shelters depending on their immediate needs demonstrates behavioral flexibility, crucial for survival in human-dominated landscapes where disturbances may necessitate frequent relocation of day beds. Our results significantly contribute to the limited body of knowledge on brown bear denning in the Middle East, emphasizing the importance of regional studies for a comprehensive understanding of species-specific behaviors.

Our study indicates a significant difference in the duration of denning between female and male bears, with females spending notably longer times at dens than males. This finding aligns with previous research showing that females exhibit more prolonged denning periods due to their reproductive strategies, as they typically enter dens for extended periods during gestation and cub rearing (Hilderbrand et al., 2000). Environmental factors such as food availability and climate conditions influence bear denning behaviour. Females may enter dens earlier and remain longer to conserve energy during periods of food scarcity or harsh weather, particularly when pregnant or caring for young cubs (Garshelis and Pelton, 1981).

4.2. Conservation implications and future research

Our study expands the existing literature on brown bear denning by uncovering unique features, emphasizing regional-specific habitat preferences, and contributing valuable insights for broader conservation strategies. Understanding the intricacies of brown bear denning behavior is crucial for effective conservation strategies. Recent studies have highlighted significant advancements in this area (Zarzo-Arias et al., 2018). As climate change continues to reshape habitats globally, its impact on den selection and timing has become a critical research focus (Ashrafzadeh et al., 2022). Although not the primary focus of this study, the presence of ski resorts and increasing logging in the region pose potential risks to brown bear denning sites due to increased human activity and habitat alteration, which may need particular attention or further studies in the future (Goldstein et al., 2010). Increasing logging and infrastructure introduce complex challenges for habitat and species management (Joshi et al., 2024). For instance, Goldstein et al., (2010) underscore the threats posed by such developments, necessitating adaptive conservation measures tailored to these impacts. The results offer

useful insights to mitigate potential threats linked to current and future infrastructure development within bear denning habitats. Implementing educational programs for local communities could aid in addressing disturbances from forestry activities, villages, or domestic dogs in crucial bear denning zones. Brown bears enjoy legal protection in the EU, making it paramount to identify areas highly suitable for denning to protect them for bear conservation. Future studies comparing different populations will reveal variations in denning behavior and help tailor conservation efforts to each population's needs. Understanding the complex interplay of environmental factors influencing brown bear denning behavior in Türkiye can ensure this iconic species' long-term survival and conservation.

Ethical considerations

This study was conducted in accordance with ethical standards and guidelines for research involving wildlife. All procedures involving the capture, handling, and monitoring of brown bears were approved by the relevant institutional and governmental authorities. Specifically, the research protocol was reviewed and approved by the ethic committee of Kafkas University in Kars province, ensuring compliance with the national and international regulations for wildlife research.

Animal welfare was a priority throughout the study, and efforts were made to minimize stress and disturbance to the bears during capture and collaring. The use of GPS collars was in line with ethical guidelines to ensure the safety and well-being of the animals. Data collection and handling procedures adhered to the international guidelines

Permits for conducting this research were obtained from Türkiye's General Directorate of Nature Conservation and National Parks (DKMPGM). We are grateful for the cooperation and support of all local stakeholders and authorities involved in this research.

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

The authors express their gratitude to all those who contributed to the fieldwork, including KuzeyDoğa staff and volunteers. We thank Reihaneh Naderi from İstanbul Bahçelievler İhlas Koleji for her artwork. This study was supported by the Scientific and Technological Research Council of Turkey (TÜBITAK) under Grant Number 219Z066. We are grateful to Fondation Segré and the Sigrid Rausing Trust for providing critical funding for this project and to H. Batubay Özkan and Barbara Watkins for their support of the Biodiversity and Conservation Ecology Lab at the University of Utah School of Biological Sciences. Other generous donors, including Bilge Bahar, Seha İşmen, Ömer Koç, Ömer Külahçıoğlu, Burak Över, Emin Özgür, and Suna Reyent, also supported this research. We thank Türkiye's Department of Nature Conservation and National Parks and the Ministry of Agriculture and Forestry for granting the permit for this research (No. 72784983-488.04-114100). We also thank the residents of Erzurum, Kars, and Sarıkamış for their hospitality. We would like to thank the anonymous reviewers for their invaluable feedback and insights, which greatly improved the quality and clarity of this manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2024.e03156.

References

Ahmadi, M., Nawaz, M.A., Asadi, H., Hemami, M., Naderi, M., Shafapourtehrany, M., Shabani, F., 2024. Protecting alpine biodiversity in the Middle East from climate change: implications for high-elevation birds. Divers. Distrib 30, e13826. https://doi.org/10.1111/ddi.13826.

Akkucuk, U., Sekercioglu, C., 2016. NGOs for environmental sustainability: the case of KuzeyDoga Society. Fresenius Environ. Bull. *25*, 6038–6044.

Ambarli, H., Ertürk, A., Soyumert, A., 2016. Current status, distribution, and conservation of brown bear (Ursidae) and wild canids (gray wolf, golden jackal, and red fox; Canidae) in Turkey. Turk. J. Zool. (6), 944–956. https://doi.org/10.3906/zoo-1507-51.

Ashrafzadeh, M.R., Khosravi, R., Mohammadi, A., Naghipour, A.A., Khoshnamvand, H., Haidarian, M., Penteriani, V., 2022. Modeling climate change impacts on the distribution of an endangered brown bear population in its critical habitat in Iran. Sci. Total Environ. *837*, 155753 https://doi.org/10.1016/j.scitotenv.2022.155753.

Atalay, İ., 1983. A General Survey of The Vegetation of North - Eastern Anatolia. Ege Coğrafya Dergisi 1, 14–39.

Avgar, T., Baker, J.A., Brown, G.S., Hagens, J.S., Kittle, A.M., Mallon, E.E., McGreer, M.T., Mosser, A., Newmaster, S.G., Patterson, B.R., Reid, D.E.B., Rodgers, A.R., Shuter, J., Street, G.M., Thompson, I., Turetsky, M.J., Wiebe, P.A., Fryxell, J.M., 2015. Space-use behaviour of woodland caribou based on a cognitive movement model. J. Anim. Ecol. *84* (4), 1059–1070. https://doi.org/10.1111/1365-2656.12357.

Bates, D., 2011. Penalized least squares versus generalized least squares of linear mixed models. Lme4 Vignette 1–7 papers2://publication/uuid/5A314^{64}F–^{9}D9C-475C-9561-78833A1C0225%5Cnpapers2://publication/uuid/08AD48C2-3DFC-4971-922A-203CA28F09EF%5Cnpapers2://publication/uuid/7D508310-F19A-4865-B359-A547FED66AD9.

Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. *67* (1) https://doi.org/10.18637/jss.v067.i01.

Blanchet, L., Fuchs, B., Støen, O.-G., Bergouignan, A., Ordiz, A., Laske, T.G., Arnemo, J.M., Evans, A.L., 2019. Movement and heart rate in the Scandinavian brown bear (Ursus arctos). Anim. Biotelemet. *7* (1), 18. https://doi.org/10.1186/s40317-019-0181-7.

Blount, J.D., Green, A.M., Chynoweth, M., Kittelberger, K.D., Hipólito, D., Bojarska, K., Çoban, E., Kusak, J., Şekercioğlu, Ç.H., 2024. Seasonal activity patterns and home range sizes of wolves in the human-dominated landscape of northeast Türkiye. Wildl. Biol. e01257. https://doi.org/10.1002/wlb3.01257.

Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H., White, J.-S.S., 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol. Evol. *24* (3), 127–135. https://doi.org/10.1016/j.tree.2008.10.008.

Capitani, C., Chynoweth, M.W., Kusak, J., 2016. Wolf diet in an agricultural landscape of north-eastern Turkey. Mammalia *80* (3), 329–334. https://doi.org/10.1515/mammalia-2014-0151.

Chynoweth, M.W., Çoban, E., Şekercioğlu, Ç.H., 2015. Conservation of a new breeding population of Caucasian lynx (Lynx lynx dinniki) in eastern Turkey. Turk. J. Zool. 39 (3), 541–543. https://doi.org/10.3906/zoo-1405-10.

Chynoweth, M.W., Çoban, E., Altin, Ç., Şekercioğlu, Ç.H., 2016. Human-wildlife conflict as a barrier to large carnivore management and conservation in Turkey. Turk. J. Zool. 40 (6), 972–983. https://doi.org/10.3906/zoo-1509-6.

Ciarniello, L.M., Boyce, M.S., Seip, D.R., Heard, D.C., 2007. Grizzly bear habitat selection is scale dependent. Ecol. Appl. *17* (5), 1424–1440. https://doi.org/10.1890/06-1100.1.

Cozzi, G., Chynoweth, M., Kusak, J., Çoban, E., Çoban, A., Ozgul, A., Şekercioğlu, H., 2016. Anthropogenic food resources foster the coexistence of distinct life history strategies: year-round sedentary and migratory brown bears. J. Zool. *300* (2), 142–150. https://doi.org/10.1111/jzo.12365.

Cristescu, B., Stenhouse, G.B., Boyce, M.S., 2013. Perception of human-derived risk influences choice at top of the food chain. PLoS ONE *8* (12), e82738. https://doi.org/10.1371/journal.pone.0082738.

Delgado, M.M., Tikhonov, G., Meyke, E., Babushkin, M., Bespalova, T., Bondarchuk, S., Esengeldenova, A., Fedchenko, I., Kalinkin, Y., Knorre, A., Kosenkov, G., Kozsheechkin, V., Kuznetsov, A., Larin, E., Mirsaitov, D., Prokosheva, I., Rozhkov, Y., Rykov, A., Seryodkin, I.V., Penteriani, V., 2018. The seasonal sensitivity of brown bear denning phenology in response to climatic variability. Front. Zool. 15 (1), 41. https://doi.org/10.1186/s12983-018-0286-5.

Dormann, C.F., Schymanski, S.J., Cabral, J., Chuine, I., Graham, C., Hartig, F., Kearney, M., Morin, X., Römermann, C., Schröder, B., Singer, A., 2012. Correlation and process in species distribution models: bridging a dichotomy. J. Biogeogr. *39* (12), 2119–2131. https://doi.org/10.1111/j.1365-2699.2011.02659.x.

Farahani, R., Asgharzadeh, A., 2023. Golestan National Park's ecosystem services, a case with brown bears habitat suitability. Sci. Rep. Life Sci. *4* (1), 1–7.

Faure, U., Domokos, C., Leriche, A., Cristescu, B., 2020. Brown bear den characteristics and selection in eastern Transylvania, Romania. J. Mammal. *101* (4), 1177–1188. https://doi.org/10.1093/jmammal/gyaa047.

Feizabadi, H.A., Ashrafi, S., Hemami, M.R., Ahmadi, M., Naderi, M., 2024. Mesocarnivores den site selection in arid ecosystems; A case study of Rüppell's fox and sand cat in central Iran. Glob. Ecol. Conserv. *49*, e02793 https://doi.org/10.1016/j.gecco.2023.e02793.

Friebe, A., Swenson, J.E., Sandegren, F., 2001. Denning chronology of female brown bears in central Sweden. Ursus *12*, 37–45 http://www.jstor.org/stable/3873227.

Fryxell, J.M., Sinclair, A.R.E., 1988. Causes and consequences of migration by large herbivores. Trends Ecol. Evol. *3* (9), 237–241. https://doi.org/10.1016/0169-5347(88)90166-8.

Garshelis, D., Pelton, M.R., 1981. Movements of black bears in the Great-Smoky mountains-National-Park. Journal of Wildlife Management 45, 912–925. https://doi.org/10.2307/3808099. Research, 1(2), 158–162.

Goldstein, M.I., Poe, A.J., Suring, L.H., Nielson, R.M., Mcdonald, T.L., 2010. Brown bear den habitat and winter recreation in south-central Alaska. J. Wildl. Manag. 74 (1), 35–42. https://doi.org/10.2193/2008-490.

González-Bernardo, E., Russo, L.F., Valderrábano, E., Fernández, Á., Penteriani, V., 2020. Denning in brown bears. Ecol. Evol. *10* (13), 6844–6862. https://doi.org/10.1002/ece3.6372.

González-Bernardo, E., Russo, L.F., Valderrábano, E., Fernández, Á., Penteriani, V., 2020. Denning in brown bears. Ecol. Evol. *10* (13), 6844–6862. https://doi.org/10.1002/ece3.6372.

Hilderbrand, G., Schwartz, C., Robbins, C., Hanley, T., 2000. Effect of hibernation and reproductive status on body mass and condition of coastal brown bears. J. Wildl. Manag. *64*, 178. https://doi.org/10.2307/3802988.

Huber, D., Josip, K., Berislav, R., 1996. Analysis of efficiency in live-capture of European Brown Bears. J. Wildl. Res. 1 (2), 158–162.

Joshi, A., Areendran, G., Naithani, S., Cs, A., Joshi, S., Ranjan, K., 2024. Mapping of the Asian Elephant (Elephas maximus) corridors of Rajaji National Park using GIS and remote sensing techniques. Sustain. Biodivers. Conserv. 3 (1), 18–28.

Kindschuh, S.R., Cain, J.W., Daniel, D., Peyton, M.A., 2016. Efficacy of GPS cluster analysis for predicting carnivory sites of a wide-ranging omnivore: the American black bear. Ecosphere *7* (10). https://doi.org/10.1002/ecs2.1513.

Kreeger, T., & Arnemo, J. (2012). *Handbook of Wildlife Chemical Immobilization*.

Krofel, M., Špacapan, M., Jerina, K., 2017. Winter sleep with room service: denning behaviour of brown bears with access to anthropogenic food. J. Zool. *302* (1), 8–14. https://doi.org/10.1111/jzo.12421.

Kusak, J., Şekercioğlu, Ç.H., 2021. Large carnivores and livestock in northeast Turkey: a pragmatic coexistence. Carnivores Damage Prevention News 21, 1–9.

Lamari, L. (2002). Assess: Image Analysis Software for Plant Disease Quantification. APS Press.

Libal, N.S., Belant, J.L., Leopold, B.D., Wang, G., Owen, P.A., 2011. Despotism and risk of infanticide influence grizzly bear den-site selection. PLoS ONE *6* (9), e24133. https://doi.org/10.1371/journal.pone.0024133.

Linnell, J., Swenson, J., Andersen, R., Barnes, B., 2000. How vulnerable are denning bears to disturbance? Wildl. Soc. Bull. *28*, 400–413. https://doi.org/10.2307/3783698.

Linnell, J., Swenson, J., Andersen, R., Barnes, B., 2000. How vulnerable are denning bears to disturbance? Wildl. Soc. Bull. *28*, 400–413. https://doi.org/10.2307/3783698.

Manchi, S., Swenson, J., 2005. Denning behaviour of Scandinavian brown bears Ursus arctos. Wildl. Biol. 11 (2), 123–132.

Mysterud, I., 1983. Characteristics of summer beds of European brown bears in Norway. Bears: Their Biology and Management 5, 208–222. https://doi.org/10.2307/3872540.

Naderi, M., Çoban, E., Kusak, J., Kemahli Aytekin, M.Ç., Chynoweth, M., Ağirkaya, İ.K., Güven, N., Çoban, A., Şekercioğlu, Ç.H., 2020. The first record of raccoon dog (*Nyctereutes procyonoides*). J. Zool. 44 (2), 209–213. https://doi.org/10.3906/zoo-1910-29.

Naderi, M., Kusak, J., Bojarska, K., Chynoweth, M., Green, A., Şekercioğlu, Ç.H., 2021. Hares, humans, and lynx activity rhythms: who avoids whom? *Hystrix*. Ital. J. Mammal. 32 (2), 147–152. https://doi.org/10.4404/hystrix-00462-2021.

Naderi, G., Mohammadi, S., Imani, A., Karami, M., 2014. Habitat selection of Williams' Jerboa (*Allactaga williamsi* Thomas, 1897) in Ardabil Province, Iran. Turkish J. Zool. *38*, 432–436. https://doi.org/10.3906/zoo-1304-8.

Nielsen, S., Cranston, J., Stenhouse, G., 2009. Identification of priority areas for grizzly bear conservation and recovery in Alberta, Canada. J. Conserv. Plan. *5*, 38–60.

Nowack, J., Stawski, C., Geiser, F., 2017. More functions of torpor and their roles in a changing world. J. Comp. Physiol. B *187* (5–6), 889–897. https://doi.org/10.1007/s00360-017-1100-y.

Ordiz, A., Støen, O.G., Delibes, M., Swenson, J.E., 2017. Staying cool or staying safe in a human-dominated landscape: which is more relevant for brown bears? Oecologia *185* (2), 191–194. https://doi.org/10.1007/s00442-017-3948-7.

Otis, D.L., Burnham, K.P., White, G.C., Anderson, D.R., 1978. Statistical inference from capture data on closed animal populations. Wildl. Monogr. *62*, 3–135 http://pubs.er.usgs.gov/publication/70119899.

Pigeon, K.E., Côté, S.D., Stenhouse, G.B., 2016. Assessing den selection and den characteristics of grizzly bears. J. Wildl. Manag. *80* (5), 884–893. https://doi.org/10.1002/jwmg.1069.

Pisani, C., Bock, C.H., Randall, J., 2023. Visual rating and the use of image analysis for assessing canopy density in a pecan provenance collection during leaf fall. J. For. Res. *34* (6), 1843–1854. https://doi.org/10.1007/s11676-023-01635-0.

R Core Team. (2019). R: A Language and Environment for Statistical Computing. https://www.r-project.org/.

Sahlén, E., Støen, O.-G., Swenson, J., 2011. Brown bear den site concealment in relation to human activity in Sweden. Ursus *22*, 152–158. https://doi.org/10.2307/41304067.

Sarıkamış Weather and Snow Trends. (2024). https://www.snow-forecast.com/resorts/.

Schoen, J.M., Beier, L.R., Lentfer, J.W., Johnson, L.J., 1987. Denning ecology of brown bears on Admiralty and Chichagof Islands, Southeast Alaska, and implications for management. Int. Conf. Bear. Res. Manag. *7*, 293–304.

Şekercioğlu, Ç.H., Anderson, S., Akçay, E., Bilgin, R., 2011. Turkey's rich natural heritage under assault. Science 334, 1637–1639.

Şekercioğlu, Ç.H., 2012. Turkey's first wildlife corridor links bear, wolf and lynx populations to the Caucasus forests. National Geographic News Watch. URL: http://blog.nationalgeographic.org2012/02/13/turkeys-first-wildlife-corridor-links-bear-wolf-and-lynx-populations-to-the-caucasus-forests/.

Senay, S.D., Worner, S.P., Ikeda, T., 2013. Novel Three-Step Pseudo-Absence selection technique for improved species distribution modelling. PLoS ONE *8* (8), e71218. https://doi.org/10.1371/journal.pone.0071218.

Seryodkin, I., Kostyria, A., Goodrich, J., Miquelle, D., Smirnov, E., Kerley, L., Quigley, H., Hornocker, M., 2003. Denning ecology of brown bears and Asiatic black bears in the Russian Far East. Ursus 14 (2), 153–161.

Shiratsuru, S., Majchrzak, Y.N., Peers, M.J.L., Studd, E.K., Menzies, A.K., Derbyshire, R., Humphries, M.M., Krebs, C.J., Murray, D.L., Boutin, S., 2021. Food availability and long-term predation risk interactively affect antipredator response. Ecology 102 (9), e03456. https://doi.org/10.1002/ecy.3456.

Skuban, M., Find'o, S., Kajba, M., 2018. Bears napping nearby: daybed selection by brown bears (*Ursus arctos*) in a human-dominated landscape. Can. J. Zool. 96 (1), 1–11. https://doi.org/10.1139/cjz-2016-0217.

Snipes, M., Taylor, D.C., 2014. Model selection and Akaike Information Criteria: an example from wine ratings and prices. Wine Econ. Policy *3* (1), 3–9. https://doi.org/10.1016/j.wep.2014.03.001.

Sorum, M.S., Joly, K., Wells, A.G., Cameron, M.D., Hilderbrand, G.V., Gustine, D.D., 2019. Den-site characteristics and selection by brown bears (Ursus arctos) in the central Brooks Range of Alaska. Ecosphere 10 (8), e02822. https://doi.org/10.1002/ecs2.2822.

Ugarković, D., Mikac, S., & Kelava Ugarković, N. (2014). Denning ecology of brown bear (Ursus arctos L.) in the Nature Park Velebit, Croatia.*Proceedings of the 49th Croatian and 9th International Symposium on Agriculture,* 514-518.

Wilcox, R.R. (2016). Introduction to Robust Estimation and Hypothesis Testing (4th ed.). Academic Press.

Zarei, A., Kaboli, M., Nourani, E., 2018. The ecology of winter den sites of brown bears (Ursus arctos) in Kouhkhom region, Fars province. J. Anim. Res. 31 (4), 1–11.

Zarei, A., Mahmoudi, M., 2019. Determination of dispersion pattern and estimating relative abundance of Brown Bear (*Ursus arctos syriocus*) in Fars province. Exp. Anim. Biol. 8 (2), 35–44. https://doi.org/10.30473/eab.2019.6203.

Zarzo-Arias, A., Delgado, M. del M., Ordiz, A., García Díaz, J., Cañedo, D., González, M.A., Romo, C., Vázquez García, P., Bombieri, G., Bettega, C., Russo, L.F., Cabral, P., García González, R., Martínez-Padilla, J., Penteriani, V., 2018. Brown bear behaviour in human-modified landscapes: the case of the endangered Cantabrian population, NW Spain. Glob. Ecol. Conserv. *16*, e00499 https://doi.org/10.1016/j.gecco.2018.e00499.