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Research on the relationship between the density of Anatolian ground squirrel (*Spermophilus xanthoprymnus* Bennet, 1835) nest burrows and soil texture

ŞENGÜL AKSAN * AND HATİCE ÇOHADAR

Isparta University of Applied Sciences, Faculty of Forestry, Department of Wildlife Ecology and Management, Isparta 32260, Türkiye

* Correspondence:
Şengül Aksan
sengulaksan@isparta.edu.tr

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Abstract

This study examined the correlation between the nest density of the Anatolian ground squirrel (*Spermophilus xanthoprymnus*) and the characteristics of soil texture and stoniness. This study was conducted in Gençali plain, Isparta province, Türkiye. A mechanical analysis of the soil revealed that clay content varied from 24% to 51%, sand content ranged from 33% to 55%, and dust levels were between 13% and 28%. It was observed that *S. xanthoprymnus* exhibited a preference for loamy clay soils, with an occurrence rate of 82% in the sampled areas. The analysis indicated that the presence of stones in the soil had a statistically significant positive effect ($p < 0.01$) on the species' nest site selection, while the amount of sand had a negative impact ($p < 0.05$). Nest density increased in habitats with stoniness levels between 9% and 9.5%, whereas a decrease in nest numbers was recorded in areas with stoniness levels either below or above this range.

Keywords: Anatolian ground squirrel; *Spermophilus xanthoprymnus*; ecology; nest density; soil texture

Introduction

Three species of the genus Spermophilus are found in Türkiye (Gür 2001). These include *S. citellus* (Linnaeus 1766), known as the European ground squirrel, *S. taurensis* (Gündüz et al. 2007), referred to as the Taurus ground squirrel, and *S. xanthoprymnus* (Bennett 1835), commonly called the Anatolian ground squirrel. *S. xanthoprymnus* is distributed in Türkiye, Armenia and northwestern Iran. It occurred in the steppes of Central and Eastern Anatolia (Kryštufek and Vohralík 2005, Gür 2007), in the areas with continental climate (Toyran 2012). *S. xanthoprymnus* inhabits the flat and slightly stony parts of high mountainous areas called dolines (Sür 1994), which generally have sparse vegetation. According to the IUCN Red List of Threatened Species (Yigit and Ferguson 2020), the species is under the category of Near Threatened (NT).

This study was conducted in Onkuyular locality of Gençali village, Isparta province, which was reported as a new distribution area for *S. xanthoprymnus* by Aksan and Çohadar (2017, 2018).

The annual life cycle of the target species is divided into the active period, when they are active above ground, and the hibernation period, when animals spend the winter through the duration of their dormant period. To avoid harsh winter conditions and cold, the Anatolian ground squirrel undergoes mandatory hibernation every year (Yiğit et al. 2000, Gür 2001, Gür 2007, Aksan and Çohadar 2018).

Various studies were conducted on the ecology and population biology of the species living in different regions of Türkiye (Gür 2001, Çolak and Özkurt 2002, Matur 2009, Kalafat 2011). There are several studies on the species, including its bio-ecology (Yiğit et al. 2000, Gür 2001), hibernation biology (Gür and Kart Gür 2005, Özkurt et al. 2005), intrapopulation sex ratios (Gür and Barlas 2006), morphometric and physiological differences (Gür 2007, Gür 2010, Kalafat 2011), genetic characteristics, systematics and taxonomy (Özkurt et al. 2002, Arslan 2005, Gündüz et al. 2007, Özkurt et al. 2007, Matur, 2009, Aksan et al. 2021), animal parasites (Ayvalı 2010), place in the systematics (Gür 2004), the effects of climate change on the species (Gür 2016), new localities of the species (Toyran et al. 2012, Aksan and Çohadar 2018), vocalisation (Schneiderova and Policht 2011), genetic and karyotype studies of the species (Çolak and Özkurt 2002, Arslan 2005, Arslan and Arslan 2010, Özparlak 2011, Aksan et al. 2021). There is no sexual differentiation in fur colour in this species (Karabağ 1953).

Özkurt et al. (2002, 2005) reported that they found differences in the elevation, habitat factors, surface stoniness, soil texture and vegetation cover characteristics of the areas, where the species was distributed. However, the information provided in recent publications is not based on a data set correlating the number of nests and soil stoniness but only on visual evaluations. To our knowledge, no study was found investigating the relationship between nest density and soil texture.

The population of Anatolian ground squirrels has a wide tolerance range and prefer steppe areas in Central Anatolia. However, they live also in mountainous regions of southern Türkiye and build burrows in stony areas. According to Karabağ (1953), there are two types of nests: the first one is temporary (summer nest) and the second one is permanent (winter nest). The summer and winter burrow locations are also different (Özkurt et al. 2005, Aksan and Çohadar 2018). They generally burrow in flat or gently sloping areas in steppe regions. The winter burrows were generally constructed in areas located far from flooding (Özkurt et al. 2005).

Species of Spermophilus are diurnal and live in colonies, where their burrows are close to each other. Contrary to Özkurt et al. (2005), it was observed that they used nests of other species when escape or hide in semi-arid habitats with poor vegetation cover; they sometimes colonize areas close to water sources or basins. Squirrels do not nest in grain fields, sometimes preferring to live close to them and consume tolerable amounts of grains. However, they do not cause damage to agriculture. According to the Bern Convention, these species are listed for protection in Appendix II; however, Türkiye has not officially recognized these species as protected (Özkurt et al. 2005).

Our research examined how soil structure influences the distribution, construction, and placement of nests of *S. xanthoprymnus*. Burrowing rodents aerate the soil, move the substrate to the surface, carry plants to the nest or remove feces from the nest, contributing to the distribution of organic material. Thus, they are considered ecosystem engineers because they extensively modify, maintain and create habitats, changing the resource availability for other organisms (Lindtner et al. 2019). It is critical to protect this species, which contributes to the soil, meadow ecosystem and biodiversity. The destruction of pasture and meadow ecosystems is recognized to result in habitat fragmentation, thereby affecting the habitat choices of different species (Aksan and Çohadar 2018). The research conducted by Kryštufek et al. (2008) revealed that the population of *S. xanthoprymnus* has been diminishing over the previous decade, attributed to widespread agricultural operations that resulted in the destruction and fragmentation of its habitat. However, an analysis of the latest distribution maps of *S. xanthoprymnus* suggests that climatic conditions are a primary determinant of these habitat preferences (Gür 2007). Understanding the nesting site requirements of this endangered species and exploring the external influences that threaten its survival in the environment are essential.

Materials and methods

This study was conducted in 2016–2019 in Onkuyular locality, situated in Gençali village of the Senirkent district of Isparta province, populated by the target species. This area occupies 59.5 hectares and is positioned between the following coordinates: 38°16’51.89” N to 38°16’45.19” N latitude and 30°44’23.19” E to 30°44’22.39” E longitude (Figure 1).

Figure 1. Location of Onkuyular situated not far from the city Isparta, Gençali plain, Türkiye

An analysis of meteorological records for the Gençali-Onkuyular area, which experiences a continental climate, reveals that from 1981 to 2018, the average annual temperature was 12.2°C (TSMS 2018). During this period, the average annual maximum temperature reached 18.3°C, and the average annual minimum temperature was 6.1°C. The yearly average for total rainfall was recorded at 564.3 mm (TSMS 2018).

The geomorphological characteristics. The study area is situated on the Onkuyular Plateau within doline terrain with elevations ranging from 1,590 to 1,630 m. The geological map of the region indicates that the underlying bedrock consists of limestone (Karatepe 2004).

This area is classified within the category of calcareous brown forest soils, exhibiting stony and moderately stony features (Karatepe 2004, MTA 2015).

During the season of activity, animals of the species have used two types of burrows. The first type of burrows is the nest burrows, which animals excavates anew after every hibernation period and uses during its daily routine. Due to constant use and cleaning, the mound of soil material and nest waste is high at the nest entrances. A second and well-known type of the burrow is the escape one; they are vertical and have no mound of soil nearby (Figure 2).

To investigate the relationship between the distribution of nests and soil properties, only nest burrow (no escape burrow) soil samples were collected from 50 randomly distributed locations within Onkuyular area and were subjected to analysis. The soil samples were taken in June 2018. The soil samples from each sample area were taken from depth levels of 0–30 cm and 30–60 cm without damaging the nest. At the laboratory stage, the soil samples were air-dried, ground in a porcelain mortar and sieved through a 2 mm sieve to prepare them for analysis. The

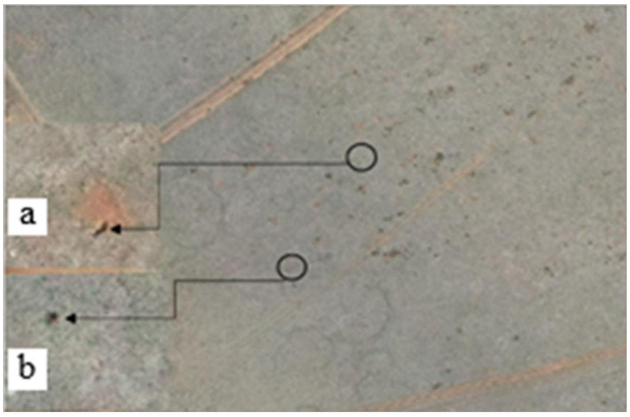

Figure 2. Unmanned aerial vehicle (UAV) photo of the a) nest burrow and b) escape burrow

analysis of texture for these samples was performed using the Bouyoucos hydrometer method (Bouyoucos 1962). The stone ratio was determined by measuring the volume of water displaced when pebbles and stones exceeding 2 mm in diameter, extracted from the soil in the volume samples, were put into a water-filled measuring device.

The data obtained were statistically evaluated using the IBM SPSS Statistics 25 software package (IBM 2017). To reveal the relationship between soil properties (stone, sand, dust and clay content) and nest density, a correlation analysis was performed for 50 sample areas. Obtained statistical data were interpreted ecologically.

To map the nest densities, 24-bit coordinated images were taken with the aid of a Phantom 4 Pro unmanned air vehicle (UAV; SZ DJI Technology Co., Ltd., PR China) from a height of 20 m using the Map Pilot Pro software package (Apple 2024) with 4864 × 3648 dimensions and combined using the Agisoft Metashape software package that allows to perform photogrammetric processing of digital images and generate 3D spatial data. The pixel size of the captured images is 1.5 × 1.5 cm. To compare the image quality, Map Made Easy Online Mapping web application and Pix4Dmatic software (Kuker-Ranken 2023) were used for digitization and conversion. However, the highest efficiency was obtained using Agisoft Metashape. The created orthophoto was divided into 100 × 100 m grids, and the number of residential nests in each grid was determined. For spatial nest density determination, the coordinates of the nest entrances were taken, and a point density map was created using the ArcGIS 10.2 software package (ESRI 2013).

Results

The relationship between *S. xanthoprymnus* nest density and soil texture was examined and the results of the analysis are given below.

As a result of the soil analysis, since the results of texture analysis were very close to each other (± 1), calculations were made by taking the average depth of 0–30 cm and 0–60 cm of both soil levels. It was determined that loamy clay soil type is common in the study area. Since the stoniness volume was between 1–10%, it was determined that the nest soil had a low stony soil skeleton. The grain size was measured between 6.00–20.00 mm and was classified as medium gravel. Texture analysis revealed that the amount of clay varied between 24% and 51%. The sand was documented at levels between 33% and 55%, whereas

Table 1. Grain size and stoniness values of the soils studied

Sample number	Coordinates	Stoniness (%)	Sand (%)	Dust (%)	Clay (%)	Soil type
1	36+301689-4237806	7.75	54.9	21.2	23.9	CL
2	36+301515-423767	9.00	44.2	15.7	40.0	CL
3	36+301502-423772	9.50	34.1	14.6	51.3	C
4	36+301536-4237789	7.50	49.3	13.9	36.8	LC
5	36+3022960-4239424	7.50	41.4	20.6	38.1	LC
6	36+302947-4239424	8.50	43.3	21.9	34.8	LC
7	36+302935-4239423	9.50	46.6	18.5	35.0	LC
8	36+302925-4239427	9.50	41.0	22.4	36.6	LC
9	36+302909-4239407	7.00	40.1	19.7	40.2	LC
10	36+304687-4239535	9.50	37.0	21.9	41.1	LC
11	36+304684-4239530	9.50	38.3	21.9	39.8	LC
12	36+304727-4239533	8.50	36.8	24.2	39.0	LC
13	36+304187-4239129	6.50	34.8	19.8	45.4	LC
14	36+303019-4239579	7.50	48.8	13.3	37.9	LC
15	36+302726-4239542	9.50	45.8	15.9	38.3	LC
16	36+302705-4239536	9.50	42.7	21.1	36.3	LC
17	36+302687-4239518	9.00	47.9	19.4	32.7	LC
18	36+302623-4239475	7.00	46.8	28.3	24.9	LC
19	36+302640-4239423	7.50	38.7	17.1	44.2	LC
20	36+301657-4239003	7.50	33.0	23.5	43.5	LC
21	36+301844-4238532	7.50	35.2	19.3	45.5	LC
22	36+301823-4238542	7.50	36.9	24.6	38.5	LC
23	36+301871-4238506	7.50	46.6	19.5	33.9	LC
24	36+302792-4239559	9.00	35.4	24.4	40.2	LC
25	36+301996-4239170	6.50	39.5	20.4	40.1	LC
26	36+301466-4237796	7.50	45.3	19.4	35.3	LC
27	36+301492-4237782	9.00	40.0	16.7	43.4	LC
28	36+301842-4235808	9.50	45.3	19.5	35.3	LC
29	36+301682-4237795	7.50	48.8	23.8	27.4	LC
30	36+302882-4239426	9.50	41.0	22.4	36.6	LC
31	36+302833-4239401	9.50	41.0	22.4	36.6	LC
32	36+302754-4239431	9.00	47.9	19.4	32.7	LC
33	36+302734-4239369	7.00	40.1	19.7	40.2	LC
34	36+302499-4239451	7.00	46.8	28.3	24.9	CL
35	36+302472-4239410	9.00	47.9	19.4	32.7	LC
36	36+302593-4239508	7.00	46.8	28.3	24.9	CL
37	36+302863-4239559	9.00	35.4	24.4	40.2	LC
38	36+303147-4239519	7.50	48.8	13.3	37.9	LC
39	36+303055-4239521	7.50	48.8	13.3	37.9	LC
40	36+302447-4239369	7.00	46.8	28.3	24.9	CL
41	36+302362-4239322	7.00	46.8	28.3	24.9	CL
42	36+303183-4239477	7.50	48.8	13.3	37.9	LC
43	36+303252-4239545	7.50	48.8	13.3	37.9	LC
44	36+303193-4239511	7.50	48.8	13.3	37.9	LC
45	36+302968-4239556	7.50	48.8	13.3	37.9	LC
46	36+302899-4239665	9.00	35.4	24.4	40.2	LC
47	36+302658-4239360	9.00	47.9	19.4	32.7	LC
48	36+302578-4239331	9.00	47.9	19.4	32.7	CL
49	36+302463-4239286	7.00	46.8	28.3	24.9	CL
50	36+303252-4239621	7.50	48.8	13.3	37.9	LC

Notes: CL – Clay loam, LC – loamy clay, C – Clay.

Table 2. Results of correlation analysis

		Nest Density and Number of Sample Sites	Amount of Stoniness	Sand (%)	Dust (%)	Clay (%)
Nest Density and Number of Sample Sites	Pearson Correlation	1				
	Sig. (2-tailed)					
	N	50				
Amount of Stoniness	Pearson Correlation	,909**	1			
	Sig. (2-tailed)	,000				
	N	50	50			
Sand (%)	Pearson Correlation	-,305*	-,199	1		
	Sig. (2-tailed)	,031	,166			
	N	50	50	50		
Dust (%)	Pearson Correlation	,068	-,079	-,263	1	
	Sig. (2-tailed)	,640	,586	,066		
	N	50	50	50	50	
Clay (%)	Pearson Correlation	,217	,235	-,679**	-,530**	1
	Sig. (2-tailed)	,131	,101	,000	,000	
	N	50	50	50	50	50

Notes: ** – Correlation is significant at the 0.01 level (2-tailed); * – Correlation is significant at the 0.05 level (2-tailed).

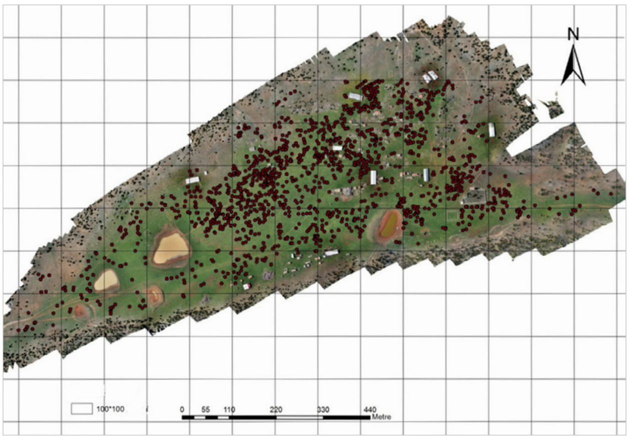

Figure 3. Orthophoto showing species' nest burrows

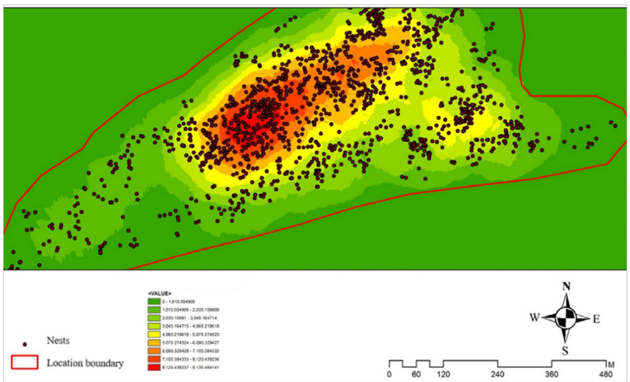

Figure 4. Nests density map

dust was observed in the range of 13% to 28%. Table 1 presents the coordinates of the soil sample locations and the respective soil stoniness and texture values.

The correlation analysis revealed a positive relationship between the level of stoniness and the species preference for nesting sites, with a confidence interval of 0.01. The analysis revealed that the quantity of sand adversely influenced the selection of nest burrow sites, with a confidence interval of 0.05 (Table 2).

It was observed that the density of nest burrows increased in habitats, where stoniness ranged from 9% to 9.5%. In contrast, a decline in nest burrow numbers was noted in the areas featured by stoniness levels that were either lower or higher than this range. From the point of view of the soil skeleton, it was determined that animals preferred areas with less stony structure than other places.

Point data corresponding to the nest burrows were collected through unmanned aerial vehicle (UAV) imagery captured in the field. The locations of the species' nests are depicted in the orthophoto presented in Figure 3.

Orthophotos derived from UAV images were spatially analyzed using the ArcGIS 10.2 software package and it was determined that there was no homogeneously distributed nesting in the area. It was recorded that the species nests densely close to the animal shelters used by the local people for transhumance in the area. The orthophotos revealed a concentration of burrows located on the southern slope of the doline bowl. Figure 3 also illustrates that the quantity of nests is minimal in the vicinity of the doline floor, where water tends to accumulate.

A density map illustrating the nests identified within the study area was generated through point density analysis utilizing the ArcGIS 10.2 software (Figure 4).

The data indicated that the number of nests per 100 × 100 m grid varied, with a minimum of 1 nest/100 m and a maximum of 131 nests/100 m observed.

Discussion

The analysis concluded that the predominant soil types presented at the site are loamy clay, clay, and clay loam. The research conducted by Karatepe (2004) in Gençali revealed that the dominant soil types in the field are loamy clay, clay, clayey loam which agrees with the results of our investigation. A soil analysis performed by Karatepe (2004) in the Gençali field revealed that the sand content of the soil ranged from 20.7% to 62.4%, the clay content varied from 20.6% to 53.1%, and the dust content was between 18.4% and 28.9%. These percentage values are consistent with our study results (clay varied between 24% and 51%, sand was documented at levels between 33% and 55%, whereas dust was observed to be in the range of 13% to 28%). Laundré and Reynolds (1993) noted in their research that *S. townsendii* built larger burrows in firmer loamy soils. Laundré and Reynolds (1993) conducted multiple regression analyses to compare various characteristics of the burrows of *S. elegans*, including maximum depth, total volume, total length, volume-to-length ratio, and complexity, with factors, such as bulk density and soil texture. Their findings revealed that as the percentage of dust and clay increased, the burrows of *Spermophilus elegans* exhibited greater depth, length, and complexity, and at the same time a decrease in the percentage of sand and bulk density was also noted.

Our results showed a positive relationship between the level of stoniness and the species' preference for nesting sites, with a confidence interval of 0.01. Lindner et al. (2019) reported that *S. citellus* mounds are poorer in soil organic matter and often rich in rock clasts as the material comes from deeper layers. The data obtained by us revealed that the presence of sand adversely affected the selection of nest sites, with a confidence interval of 0.05. In line with our results, Laundré and Reynolds (1993) reported that the soil components of *S. townsendii* burrows were negatively influenced by the proportion of sand.

Özkurt et al. (2005) studied nest types in Niğde and Ankara, revealing that nests in stony regions were less complex and shallower than those found in steppe areas. In comparing UAV images and ground data, no geometric shape or meaningful systematic relationship was observed in the distance and position between the nests. It has been observed that the animals of this species strategically place their nests in a way to maximise visibility of the surrounding area, indicating that safety is a crucial consideration in their nesting locations.

As a result of the statistical analysis, a positive relationship between the 9% to 9.5% stone ratio and the number of nests was found. It is thought that the increased stone ratio up to a certain level in heavy clay soil provides both aeration and facilitates nest digging, stoniness weaker water holding capacity (Saxton and Rawls 2006) and gain drainage for burrow. The results of the soil texture analysis show a marked scarcity of nests in places with high sand content. Wyoming ground squirrel burrows had the most significant regression coefficients between burrow characteristics and soil components. The burrow characteristics decreased with increasing sand content (Laundré and Reynolds 1993). This observation can be explained by the tendency of species to select nesting sites that provide greater resilience, given that sandy soils are less resilient than clay soils. In addition, the fact that sandy soils can be easily excavated and dug by the predators of the species compared to clay soils can be shown as the reason why they are less preferred as nest sites compared to clay soils. Our findings are reinforced by Aksan et al. (2014), who asserted that soil excavability plays a crucial role for burrowing animal species.

The orthophoto derived from the UAV images clearly illustrates that the nests are predominantly located on the southern slope of the doline bowl. This can be explained by the fact that the southern slopes are relatively warmer than the northern ones in the area where winter is cold and snowy. It was determined that the number of nests was low around the doline floor where there was a puddle. This can be explained by the rising groundwater table in winter and spring, which poses a threat to the nests of the animals. Another constraint in the nest distribution of the species is the decrease in soil depth and increase in limestone exposure at the edges of the doline. Hence, the nests of the species are located where there is sufficient soil depth in the doline basin. Despite having adequate soil depth, no nesting was detected near the puddles due to the high subsurface water level.

Mounds are poorer in soil organic matter and often rich in rock clasts as the material comes from deeper layers (Lindner et al. 2019). Low organic matter and stoniness weaken water holding capacity of the soil (Saxton and Rawls 2006). For the hibernating target species animals, drainage in the nest is important (Shaw 1926). Therefore, the reason why they prefer to nest in the areas where the stony level is 9–9.5% can be explained as they tends towards these areas in terms of water permeability and nest drainage.

Lindner et al. (2019) indicated that the ground squirrel *S. citellus* plays a significant role in soil ventilation and processing by utilizing the mound soil, which possesses various physico-chemical and biological properties, it excavates from its nest in the underlying soil layers to the surface. This activity enhances the biological diversity of grasslands by fostering heterogeneity. Consequently, the decline of this species, recognized as an ecosystem engineer for its contributions, could have detrimental effects on grassland systems and ecosystems, underscoring the need for its protection (Lindner et al. 2019). In the Gençali region, the habitat of the species is intensively used by people for transhumance and livestock grazing activities. One of the results of this research was the study of the species adaptation to human activity in the field which remained undisturbed by the presence of livestock. After grazing, feed, hay and straw are given to livestock in the corrals. In addition to the meadow vegetation found in the field, the species was observed to be found predominantly near corrals to have access to nutritious and high-quality food sources. It is considered that the presence of humans and shepherd dogs forms a deterrent against predators, leading to a more concentrated distribution of these species near the corrals. Gür (2001, 2007) has reported that the species is distributed on the area, where animal husbandry activities are performed. In this respect, these results support our findings. In 2004–2005, a recent habitat protection project in Poland suggested that the reintroduction of cattle breeding practices in the steppe may be positive for the population viability of the spotted souslik (*S. suslicus*) (UNDP 2024). Reflecting on our study results and the relevant publications, we underline a positive relationship between human impact and the species in areas characterised by livestock farming activities. It is important to acknowledge that, when assessing species sensitivity, a particular factor does not influence all areas uniformly. The results will vary based on the location, timing, nature, and duration of the effect of the factor under consideration.

According to the findings of Çolak and Özkurt (2002) and Gündüz et al. (2007), *S. xanthoprymnus* inhabits small-area mountain steppe strips that are encircled by stony landscapes. However, at lower elevations, the availability of suitable habitats and distribution areas for this species is considerably restricted because of active human influence. The protection of this species, which aerates the soil by digging burrows and contributes to the meadow ecosystem and plant diversity by providing a mixture of organic material, is important in terms of biodiversity. As a result, measures for *in situ* conservation designed to protect species diversity ought to be specifically aligned with the individual needs of the considered species. Aksan and Çohadar (2018) conducted a field study in Yassıbel village (Isparta province) to examine the population, where it was reported to be distributed. However, because of both their observations and interviews with local people, they reported that the species could not survive in the area due to increased agricultural activities. The species existence can be sustained by implementing *in situ* protection practices in the areas, where they are distributed, against the risk of extinction.

Conclusions

This study was conducted to reveal the effect of soil texture on the nest site preferences in *S. xanthoprymnus*. In addition, this study examined nest distribution and stoniness rate according to soil structure, based on nest density. No similar research has been found in the recent literature that examined the spatial distribution of nest burrow densities of the *S. xanthoprymnus* and studied the soil texture characteristics in the areas, where the species is distributed. Thus, the findings of this study have the quality to contribute to the literature on this topic.

This species, considered an ecosystem engineer, is crucial for meadow ecosystems because of its direct presence and function in the habitat. The continued existence of this species can be ensured by knowing its habitat and nesting requirements and taking appropriate measures. Therefore, the above-ground habitat characteristics of this soil-nesting species, as well as subsoil characteristics (soil texture, physicochemical and biological soil properties) and nesting requirements should be known and this study provides valuable insights.

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