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Drivers of Scarabaeidae (Coleoptera) attraction: the roles of habitat diversity and bait type evaluated through EUNIS habitat classes

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Abstract

Scarabaeidae, particularly dung beetles, are saprophagous insects that underpin ecosystem functioning by facilitating dung removal, soil aeration, efficient nutrient turnover, seed dispersal, parasite suppression, and habitat restoration, while exploiting a broad dietary range from plant material to carrion. Understanding their feeding ecology and habitat-specific distributions is essential for habitat conservation and for developing effective strategies for soil rehabilitation. This study examined the influence of EUNIS habitat types and food sources on the richness, abundance, diversity, and composition of Scarabaeidae assemblages. Field sampling was conducted between May 2018 and October 2019 on the Kazan Hills, Ankara, Türkiye, using pitfall traps baited with banana, chicken liver, and cattle dung. To evaluate the effects of habitat and bait type on species assemblages, we compared richness using the Shannon–Wiener and evenness indices, assessed community similarities with Bray–Curtis (single-linkage) cluster analysis, and tested community variation through SHE analysis. Among the studied habitats, the steppe habitat (E1.2) supported the highest species richness and diversity, whereas forest plantation (G3.5) and ruderal areas (X18) exhibited the lowest values. Cattle dung proved to be the most effective attractant, yielding significantly higher numbers and species compared with other baits. These findings demonstrate the combined role of habitat characteristics and food resources in structuring Scarabaeidae communities. Our findings indicate that dung input can enhance dung beetle populations and indirectly provide a practical approach to support soil rehabilitation in degraded habitats. The quantitative data from this study serve as a reference for evaluating habitat conservation and monitoring changes in population trends at the species level. Standardized long-term monitoring is crucial for detecting population dynamics and assessing habitat changes.

Keywords Biodiversity, Coprophagous beetle, Phytophagous beetle, Pitfall trap, Species richness, Türkiye

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Introduction

Biodiversity patterns and the ecological processes that shape them vary widely across habitat types. Understanding these patterns requires not only species-level information but also consistent frameworks for comparing environments. However, many previous studies have focused on local disturbances or continuous environmental gradients, while relatively little attention has been given to standardized habitat classifications that enable broader ecological generalizations [1–3]. The European Nature Information System (EUNIS) offers a robust, hierarchical framework for classifying terrestrial habitats by integrating both biotic and abiotic components [4], thereby enhancing comparability among regions.

Habitat classification is essential for interpreting species–habitat relationships, particularly in biogeographically complex regions such as Türkiye, where European, Asian and Mediterranean influences intersect. The European Nature Information System (EUNIS) habitat classification provides a standardized and hierarchical framework that integrates vegetation structure, ecological characteristics and habitat functioning, enabling consistent comparisons of species richness and abundance across habitat types [5, 6]. Unlike purely land-use-based classifications, EUNIS incorporates ecological structure and characteristic species assemblages, making it especially suitable for biodiversity assessments [7]. Despite its widespread use in vegetation and landscape research, EUNIS has rarely been applied to insect ecology. In studies lacking such standardized classifications, forests and grasslands have often been compared solely through beetle-derived data, leading to conclusions that habitat structure when it does not modify dung availability has minimal influence on scarab beetles [8].

Within this broader context, dung beetles (Coleoptera: Scarabaeidae) serve as an excellent model group for evaluating habitat biodiversity relationships. They are widely recognized as key ecosystem engineers due to their crucial roles in maintaining ecosystem functioning [9]. Through diverse feeding strategies including coprophagy, necrophagy, saprophagy, and phytophagy they contribute to nutrient cycling [10, 11], secondary seed dispersal, dung decomposition, parasite suppression, and the restoration of degraded habitats [9, 12, 13]. By burying and fragmenting organic matter, dung beetles facilitate soil aeration, stimulate microbial activity, and enhance pasture productivity, thereby sustaining both soil fertility and plant growth [11, 14, 15]. Owing to these contributions, they are widely used as bioindicators of habitat quality and ecosystem multifunctionality, with their richness and community structure linked to habitat fragmentation, land-use change, and antiparasitic residues [2, 16, 17]. Understanding how Scarabaeidae communities, particularly dung beetles, respond to EUNIS-defined habitat types, in conjunction with food resource availability, can provide more precise insights into the drivers of biodiversity patterns and the ecosystem functions shaped by these assemblages in terrestrial systems.

In this study, we examined how EUNIS habitat types and food resources influence the species' richness, abundance, diversity, and community composition of Scarabaeidae. We hypothesized that (i) species richness and abundance would be higher in grasslands and steppes than in other habitat types, and (ii) different food resources (dung, carrion, and fruit) would selectively attract subsets of the Scarabaeidae community, thereby shaping the overall community composition.

Materials and methods

Study area

This research was conducted in the Kazan hills, situated in the northern region of Ankara Province, Türkiye. In this region, the intersection of Anatolian steppe and forest ecosystems produces a significant edge effect. The altitude in the study area ranges from 990 meters to 1400 meters above sea level. The investigation took place at six different sites from May to October during the years 2018 and 2019 (Table 1).

Determination of habitats

Localities were randomly selected (Fig. 1), habitat characterization of the study area was performed using a multilayer GIS approach. The CORINE Land Cover 2008 dataset was first adopted as the base layer to define the general land-cover structure. Additional spatial information was incorporated sequentially, including forest stand maps, the hydrology layer, and the OpenStreetMap 2019 layer. These datasets were further complemented with high-resolution satellite imagery. The final habitat structure was verified during fieldwork by assessing the current vegetation composition and overall site conditions. Habitat classifications followed the EUNIS hierarchical system [19, 20]. Within the selected localities, the following EUNIS habitat types were identified: C2.3, C2.5, E1.2,

Table 1 Localities [18]

Localities	A	B	C	D	E	F
Latitude	40.085119°	40.130424°	40.143300°	40.132888°	40.112249°	40.125343°
Longitude	32.699098°	32.726611°	32.742748°	32.716976°	32.714409°	32.697630°
Altitude	1265 m	1040 m	1155 m	1140 m	1095 m	1295 m

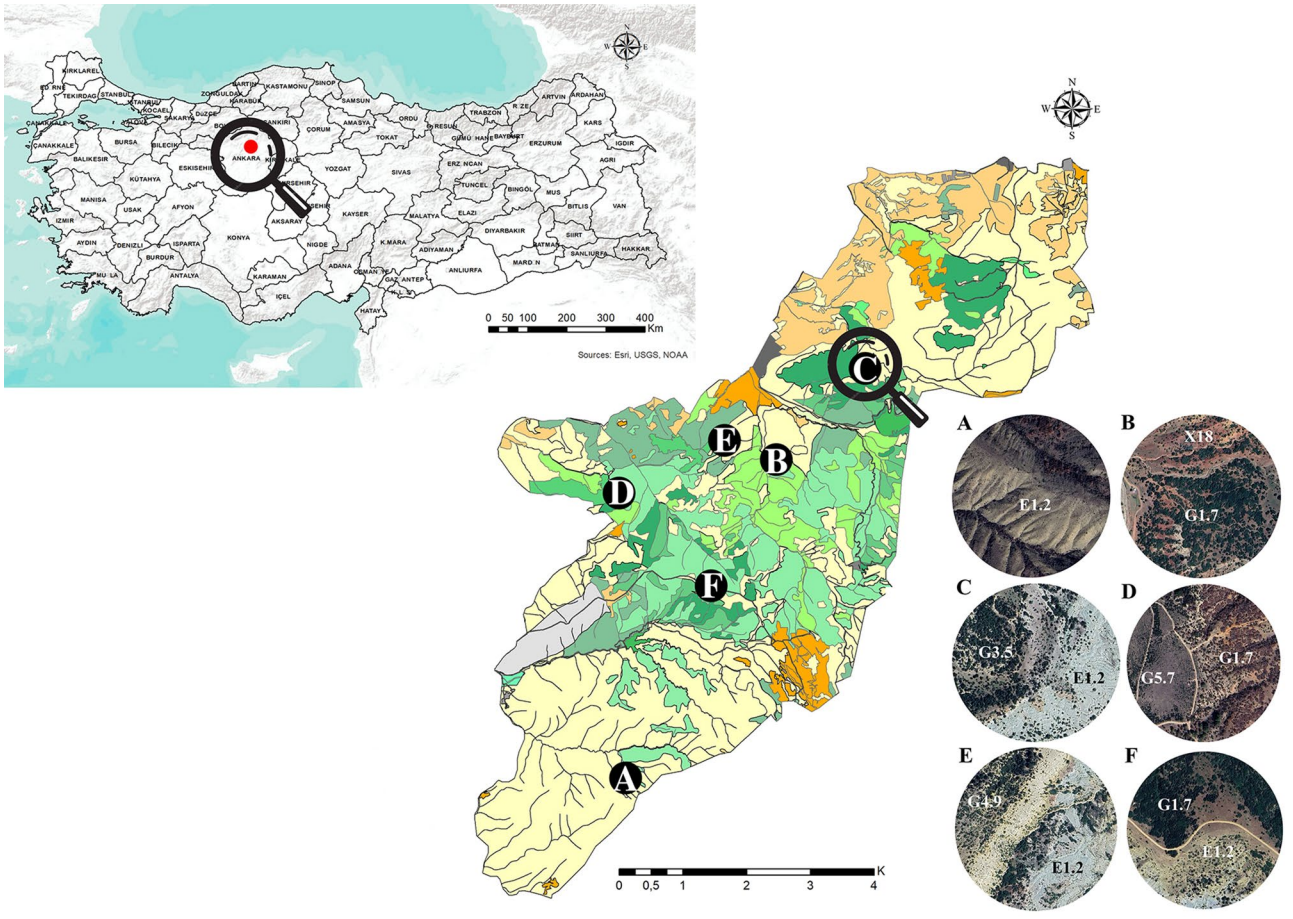


Fig. 1 Maps of the study area. **A**, **B**, **C**, **D**, **E**, and **F** show localities

E2.6, G1.1, and G1.7. All maps were generated in ArcGIS 10.8.

Sampling method

There are two main methods for capturing Coleoptera: active and passive. The active method involves direct collection by hand or specialized equipment, whereas the passive method relies on traps. Standardizing the active method is challenging, whereas the passive method is easily repeatable and can be standardized [11, 21]. Among passive sampling techniques, pitfall traps are the most widely employed for capturing Scarabaeidae. They offer a rapid, cost-efficient, and relatively unbiased approach for assessing species diversity and abundance patterns [22]. When baited, pitfall traps become particularly effective [23, 24]. To ensure the study's repeatability and standardization, the dimensions of transects and the number of deployed traps must be kept constant. For this purpose, hexagonal grids are used [25] (Fig. 1).

Each hexagon was selected to be at least 500 meters apart, with a minimum distance of 50 meters maintained between each bait array and at least 2 meters between individual traps. The 2-m trap spacing used in the study is consistent with established sampling practices. Louzada & Carvalho e Silva [26] employed paired pitfall traps separated by 3 m, and Mora-Aguilar et al. [11] emphasized that cluster arrangements 1–5 m are widely used and accepted in standardized Scarabaeinae sampling. Although Larsen & Forsyth [27] proposed a 50-m spacing, their estimate was based on *Canthon acutus* in a closed forest and was not intended as a general standard. Furthermore, three different bait types were used in our study, which reduces the likelihood of strong cross-attraction toward any single trap. Considering the broader literature, typical dung beetle sampling protocols, and the mixed-bait design of our study, a 2-m spacing provides appropriate independence for the aims of this research. Hexagonal plots were selected while avoiding settlements, agricultural areas, artificial structures, roads, water bodies, and dry streambeds.

The quantities of baits used in the traps were determined on the basis of references from previous studies [23, 28, 29]. Each bait array included four pitfall traps: one baited with 500 g of fresh cow dung collected from a cattle barn to attract coprophagous insects; one baited with 50 g of fresh banana for phytophagous insects; and one

baited with 50 g of fresh chicken liver for necrophagous insects. A fourth trap without any attractant was used as the control group (Fig. 2). The container was made by cutting off the threaded neck of a 5-liter water canister. It was then buried in the ground 2 cm above the surface. A total of 250 ml storage solution was placed inside the trap. The storage solution was prepared by mixing antifreeze solution and water at a 3:1 ratio. The baits were placed in a freezer bag, and sticks were attached to the top of the container. A freezer bag slows the drying of the bait and helps it remain attractive for a longer period. A total of 192 traps were deployed during the expedition, with four traps placed within each of the eight hexagons at six different localities.

The traps were collected at approximately 20-day intervals, with 14 sampling events conducted. The traps remained at the study sites throughout the study period, and the baits were periodically renewed at intervals of approximately three weeks. Deviations in the renewal dates occurred as a result of climatic conditions.

Data analysis and software

The analyses of the studies were performed via the software programs BİÇEB [30], Biodiversity Pro [31], and Past 4.0 [32]. The normality of the data for food types and habitats was assessed using the Kolmogorov–Smirnov test with SPSS, which indicated a significant deviation from normality ($p < 0.05$, observed $p < 0.001$). Because the data exhibited skewness and outliers, it did not follow a normal distribution; therefore, a non-parametric approach was adopted. Habitats and food sources were analysed using a Poisson Generalized Estimating Equations (GEE) model based on insect counts. This approach allowed the assessment of insect abundance and the identification of the habitat and food source exhibiting the highest abundance. Diversity was quantified using the Shannon diversity index.

The similarity, dissimilarity, and hierarchical clustering of food types and habitats were assessed using the Bray–Curtis dissimilarity index. To demonstrate the relationship between habitats and feeding species, the NMDS test was conducted using the "R" software [33]. Non-metric Multidimensional Scaling (NMDS) was used to visualize similarities in dung beetle species composition among samples. The analysis was based on Bray–Curtis dissimilarity, which is appropriate for ecological abundance data. Each Habitat × Food combination (e.g., E1.2 – Dung) was treated as a single sampling unit, and species abundance data were used as input. The ordination was performed in two dimensions to facilitate visualization of community patterns.

The Shannon index was used to assess the homogeneity and heterogeneity of the habitats. H' represents the number of observations, Hmax indicates homogeneity, and J' reflects heterogeneity or dominance. The metric H' evaluates the frequency of species within a given habitat in relation to their occurrence in other habitats. Hmax measures the extent to which species in a given habitat are shared with other habitats. When Hmax was analyzed, the values across different habitats were relatively similar. In contrast, J' evaluates the presence of species that are exclusive to a single habitat and absent from others.



Fig. 2 At each locality, eight different bait arrays of pitfall traps were arranged in a hexagonal pattern. Each bait array consisted of four attractant: (**a**) dung, (**b**) banana, (**c**) liver, and (**d**) an unbaited control

Identification of specimens

Specimen identification was based on taxonomic keys and descriptions [34–51].

Results

This study provides a comprehensive overview of scarab beetle diversity and habitat associations in the Kazan Hills. A total of 50 taxa at the species and subspecies level were recorded across six main EUNIS habitat types, with distributions of species richness (S) and abundance (N) reflecting both habitat characteristics and feeding preferences (Table 2). Across the study area, 21 third-level EUNIS habitat types were identified (C2.3, C2.5, E1.2, E2.6, G1.1, G1.7, G1.D, G3.5, G3.9, G4.9, G5.7, H2.5, H5.3, I1.1, I1.3, J1.2, J2.1, J4.2, J5.3, X07, and X18), highlighting the ecological heterogeneity of the region. Observations from six randomly selected localities confirmed the presence of habitats E1.2, G1.7, G3.5, G4.9, G5.7, and X18 (Table 3), emphasizing that both habitat type and resource availability influence scarab community composition (Fig. 3). Many habitat and attractant variables showed significant differences ($p < 0.001$).

Habitat data

An evaluation of the total sample and species counts across the habitats revealed that the E1.2 habitat presented the highest species richness and individual abundance. In contrast, the G3.5 habitat presented the lowest values for both metrics. A consistent correlation was observed between sample size and species richness across all habitats (Fig. 4).

Feeding data

In this study, species–nutrient relationships were quantified using a parsimonious, yet ecologically informative framework based on species richness and abundance.

Considering the attractiveness of foods, the highest number of individuals and species is seen in dung, the lowest number of species is in the liver, and the lowest number of individuals is in bananas (Fig. 5). Species diversity and species abundance are closely related to each other.

The two-dimensional NMDS ordination yielded a stress value of 0.273, indicating a moderate but acceptable level of distortion for the ecological community data. The relatively high variability in species abundances among traps (ranging from zero to several hundred individuals) likely contributed to this stress value.

The ordination plot shows that samples tend to group according to bait type, with particularly noticeable separation for Dung and Liver baits, suggesting that food type plays a vital role in structuring dung beetle assemblages. In contrast, samples from control traps, which generally contained very few individuals, were located near the center of the ordination or displayed a more scattered distribution. Overall, the NMDS results support the conclusion that bait type influences species composition across habitats (Fig. 6).

Discussion

Understanding Scarabs feeding and habitat preferences is crucial for analyzing ecosystem dynamics. The variation in the number of species and individuals attracted to pitfall traps set in the same habitats but along different transects may be attributed to factors such as habitat size, the presence of surrounding habitats, edge effects between habitats, the availability of food resources around the trap (e.g., grazing areas), anthropogenic impacts, and the orientation of the trap [3, 27, 52].

After controlling for interspecific variation, insect abundance differed significantly among habitats ($p < 0.001$). The reference habitat E1.2 showed the highest abundance, while all other habitats exhibited significantly lower values. Among them, G1.7 was the closest to E1.2 but still harbored approximately 29% fewer insects ($e^{-0.339} \approx 0.71$) (Table 4). The remaining habitats (G3.5, G4.9, G5.7, and X18) displayed similarly low abundance levels; for example, X18 supported about 77% fewer insects than E1.2 ($e^{-1.48} \approx 0.23$). These findings suggest that habitat characteristics such as vegetation structure and microclimatic conditions in E1.2 are more favorable for sustaining high abundances of coprophagous insects.

According to the GEE Poisson Model results, bait type had a statistically significant effect on insect attractiveness ($p < 0.001$). Compared to banana, dung was the most attractive bait, increasing insect abundance by approximately 4.1 times [exp (Coef) ≈ 4.1]. Liver also showed a positive effect relative to banana, attracting about 1.5 times more insects. As expected, the control traps without bait attracted substantially fewer insects than banana (Table 5).

The study analyzed species diversity across various habitat types and evaluated species similarity and richness among these habitats. Most species exhibited no significant habitat specificity, except for a few taxa infrequently captured in traps (Table 4). Species richness and abundance within the habitats of the study area constitute fundamental metrics for determining their ecological significance. The distribution and dynamics of species richness and abundance predominantly structure the associations between species and habitats. According to the species diversity analysis conducted via the Shannon index, the highest value was recorded in the E1.2 habitat, whereas the lowest was observed in the X18 habitat. The dissimilarities and similarities among habitats were evaluated via single-linkage Bray–Curtis cluster analysis, which quantifies the distances and similarities between habitats (Table 6).

Table 2 Number of taxa and individuals caught by each attractant type according to habitats

Species	Bait	E1.2	X18	G1.7	G3.5	G5.7	G4.9	Species	Bait	E1.2	X18	G1.7	G3.5	G5.7	G4.9
Ateuchetus armeniacus (Ménétriés, 1832)	D.	365	2	3	13	0	40	*Oxythyrea funesta* (Poda von Neuhaus, 1761)	D.	4	0	1	0	0	0
	B.	74	0	0	0	3	8		B.	11	0	7	0	0	0
	L.	369	0	10	5	2	0		L.	0	0	0	0	0	0
	C.	22	0	0	0	0	0		C.	0	0	0	0	0	0
Aphodius fimetarius (Linnaeus, 1758)	D.	0	0	1	0	0	0	*Onthophagus furcatus* (Fabricius, 1781)	D.	19980	5185	13844	6312	8663	6093
	B.	0	0	0	0	0	0		B.	3379	1559	4874	647	1092	762
	L.	0	0	0	0	0	0		L.	7837	1720	5084	1890	1804	2395
	C.	0	0	0	0	0	0		C.	116	88	112	1	0	0
Bodiloides ictericus ictericus (Laicharting, 1781)	D.	0	0	0	0	1	0	*Onthophagus furciceps* (Marseul, 1869)	D.	0	0	0	0	0	0
	B.	0	0	0	0	0	0		B.	0	0	0	0	0	0
	L.	0	0	0	0	0	0		L.	0	0	0	0	1	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Blitopertha nigripennis (Reitter, 1888)	D.	0	0	0	2	0	0	*Onthophagus lemur* (Fabricius, 1781)	D.	2	0	1	14	0	0
	B.	0	0	0	0	0	0		B.	0	0	0	0	0	0
	L.	0	0	0	0	0	0		L.	1	0	0	9	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Copris armeniacus (Faldermann, 1835)	D.	2	0	4	0	0	0	*Onthophagus marginalis marginalis* (Gebler, 1817)	D.	22	0	0	0	0	0
	B.	0	0	2	0	0	0		B.	0	0	0	0	0	0
	L.	0	0	0	0	0	0		L.	14	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Cetonia aurata pallida (Drury, 1773)	D.	0	0	0	0	0	0	*Onthophagus nuchicornis* (Linnaeus, 1758)	D.	38	0	3	0	0	0
	B.	13	0	0	0	0	2		B.	9	0	0	0	0	0
	L.	1	0	0	0	0	0		L.	0	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Colobopterus erraticus (Linnaeus, 1758)	D.	2	0	0	0	0	0	*Onthophagus ruficapillus* A. Brullé, 1832	D.	51	0	6	0	0	0
	B.	1	0	0	0	0	0		B.	79	0	1	0	0	0
	L.	0	0	0	0	0	0		L.	2	0	7	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Copris hispanus cavolinii (Petagna, 1792)	D.	1	0	0	0	0	0	*Onthophagus sacharovskii* (Olsoufieff, 1918)	D.	0	0	0	0	1	0
	B.	0	0	0	0	0	0		B.	0	0	0	0	0	0
	L.	0	0	0	0	0	0		L.	0	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Caccobius histeroides (Ménétriés, 1832)	D.	98	11	241	6	24	32	*Onthophagus taurus* (Schreber, 1759)	D.	0	0	3	1	0	0
	B.	60	3	44	0	4	2		B.	0	4	0	0	0	0
	L.	87	4	43	2	9	2		L.	0	0	3	0	0	0
	C.	0	0	1	0	0	0		C.	0	0	0	0	0	0

Table 2 (continued)

Species	Bait	E1.2	X18	G1.7	G3.5	G5.7	G4.9	Species	Bait	E1.2	X18	G1.7	G3.5	G5.7	G4.9
Copris lunaris (Linnaeus, 1758)	D.	2	0	2	0	1	0	*Onthophagus vacca* (Linnaeus, 1767)	D.	19	3	0	0	0	0
	B.	0	0	0	1	0	0		B.	0	0	0	0	0	0
	L.	0	0	0	0	0	0		L.	0	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Caccobius schreberi (Linnaeus, 1767)	D.	2	0	2	0	1	0	*Onthophagus verticicornis* (Laicharting, 1781)	D.	125	4	61	0	0	12
	B.	0	0	1	0	0	0		B.	0	0	8	0	0	0
	L.	8	0	30	0	0	2		L.	24	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	1	0	0	0	0	0
Copris umbilicatus (Abeille de Perrin, 1901)	D.	0	0	0	0	0	0	*Protaetia afflicta afflicta* (Gory & Percheron, 1833)	D.	0	0	0	0	0	0
	B.	0	0	0	0	0	0		B.	0	0	0	0	0	0
	L.	0	0	0	2	0	0		L.	0	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	1	0	0	0	0	0
Euonthophagus amyntas alces (Fabricius, 1792)	D.	0	0	59	0	0	0	*Protaetia cuprina* (Motschulsky, 1849)	D.	0	0	1	0	0	0
	B.	0	0	0	0	0	0		B.	2	1	2	0	2	3
	L.	0	0	0	0	0	0		L.	1	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Euonthophagus atramentarius (Ménétriés, 1832)	D.	0	0	0	0	0	0	*Planolinus fasciatus* (A. G. Olivier, 1789)	D.	0	0	0	0	0	1
	B.	1	0	0	0	0	0		B.	0	0	0	0	0	0
	L.	0	0	0	0	0	0		L.	0	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Euoniticellus fulvus (Goeze, 1777)	D.	16	11	21	1	19	5	*Protaetia splendidula splendidula* (Faldermann, 1838)	D.	0	0	0	0	0	0
	B.	4	1	3	0	0	7		B.	3	0	0	0	0	0
	L.	6	1	23	0	1	13		L.	0	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Euonthophagus gibbosus (Scriba, 1790)	D.	158	11	79	36	18	0	*Protaetia subpilosa subpilosa* (Desbrochers des Loges, 1869)	D.	0	0	0	0	0	0
	B.	26	0	5	1	1	0		B.	2	0	0	0	0	0
	L.	52	0	33	0	0	0		L.	0	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Eudolus quadriguttatus (Herbst, 1783)	D.	1	2	20	0	2	18	*Protaetia trojana godeti* (Gory & Percheron, 1833)	D.	14	0	0	0	0	0
	B.	0	0	0	1	0	0		B.	117	0	6	0	8	2
	L.	1	0	0	0	0	0		L.	32	0	0	0	1	4
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Gymnopleurus flagellatus asperatus Motschulsky, 1849	D.	1	0	0	0	0	0	*Protaetia ungarica auliensis* (Reitter, 1901)	D.	13	0	0	0	1	0
	B.	0	0	0	0	0	0		B.	29	0	0	0	8	3
	L.	0	0	0	0	0	0		L.	10	0	0	0	3	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0

Table 2 (continued)

Species	Bait	E1.2	X18	G1.7	G3.5	G5.7	G4.9	Species	Bait	E1.2	X18	G1.7	G3.5	G5.7	G4.9
Gymnopleurus geoffroyi (Fuesslins, 1775)	D.	1167	233	691	15	63	79	*Protaetia vidua* (Gory & Percheron, 1833)	D.	5	0	0	0	0	1
	B.	65	41	77	7	29	30		B.	209	0	0	0	1	65
	L.	314	68	1047	14	45	28		L.	18	0	0	0	0	1
	C.	5	4	16	0	0	0		C.	1	0	0	0	0	1
Loraphodius suarius (Faldermann, 1835)	D.	4	0	0	0	0	0	*Scarabaeus pius* (Illiger, 1803)	D.	212	0	2	0	0	2
	B.	1	0	0	0	0	0		B.	2	0	17	0	1	0
	L.	0	0	0	0	0	0		L.	199	0	1	0	0	0
	C.	0	0	0	0	0	0		C.	1	0	1	0	0	0
Oxythyrea albopicta (Motschulsky, 1845)	D.	1	0	0	0	0	0	*Scarabaeus sacer* Linnaeus, 1758	D.	209	2	27	0	3	3
	B.	148	0	0	0	4	0		B.	1	0	1	0	0	0
	L.	1	0	0	0	0	0		L.	77	0	6	0	0	0
	C.	0	0	0	0	0	0		C.	1	0	0	0	0	0
Oxythyrea cinctella (Schaum, 1841)	D.	111	5	3	0	1	26	*Sisyphus schaefferi schaefferi* (Linnaeus, 1758)	D.	1773	136	1213	105	528	509
	B.	1033	29	100	6	134	561		B.	530	144	555	6	59	17
	L.	102	3	15	1	1	27		L.	879	40	693	85	58	161
	C.	2	0	0	0	0	1		C.	38	5	5	0	0	1
Onthophagus coenobita (Herbst, 1783)	D.	3	2	0	0	0	12	*Subrinus sturmi* (Harold, 1870)	D.	1	0	0	0	0	0
	B.	0	0	0	0	0	0		B.	0	0	0	0	0	0
	L.	0	0	0	0	0	0		L.	0	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Onthophagus fissicornis (Steven, 1809)	D.	69	0	15	0	2	23	*Scarabaeus typhon* (Fischer von Waldheim, 1823)	D.	355	21	57	7	34	8
	B.	3	0	1	0	9	8		B.	2	2	16	0	1	0
	L.	18	0	0	0	4	13		L.	114	2	46	1	6	23
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0
Onthophagus fracticornis (Preyssler, 1790)	D.	55	0	0	0	0	0	*Tropinota hirta suturalis* (Reitter, 1913)	D.	1	0	0	0	0	0
	B.	0	0	0	0	0	0		B.	0	0	0	0	0	0
	L.	32	0	0	0	0	0		L.	1	0	0	0	0	0
	C.	0	0	0	0	0	0		C.	0	0	0	0	0	0

Abbreviations: D. Dung; B. Banana; L. Chicken Liver; C. Control group

Table 3 EUNIS habitat classes of the areas where traps are located

EUNIS Code	EUNIS Name
E1.2	Perennial calcareous grassland and basic steppes
G1.7	Closed non-Mediterranean dry acid and neutral grassland
G3.5	Moist or wet oligotrophic grassland
G4.9	Mixed deciduous woodland with Cupressaceae or Taxaceae
G5.7	Coppice and early-stage plantations
X18	Wooded steppe

Species observed in habitat E1.2 exhibited lowest degree of overlap with other habitats (Table 7). This indicates minimal repetition across habitats. In contrast habitat G3.5 showed the lowest H' value, which reflects the highest level of species repetition. The observed pattern suggests that species found in habitat G3.5 are more widely distributed across multiple habitats.

Assessment of species richness and individual abundance of the habitats revealed that the E1.2 habitat presented the highest diversity, both in terms of species number and total individual count (Fig. 7). Habitat diversity was evaluated using three different indices, which yields consistent results.

Species similarity among the habitats were examined, and their relative distances are illustrated in Fig. 7. In the dendrogram of this analysis, the initial separation clusters clustered habitats G1.7 and E1.2 together, whereas all other habitats formed a distinct group. The species compositions of habitats E1.2 and G1.7 exhibited more significant dissimilarity than did those of the remaining habitats (Fig. 7). In the innermost section of the dendrogram, habitats G3.5 and X18 were identified as the most similar in terms of species composition. When habitats are evaluated via the Shannon index, Habitat E1.2 has the most distinct and richest diversity, whereas Habitat G4.9 has the lowest diversity. A similar assessment based on distance and flatness yielded comparable results,

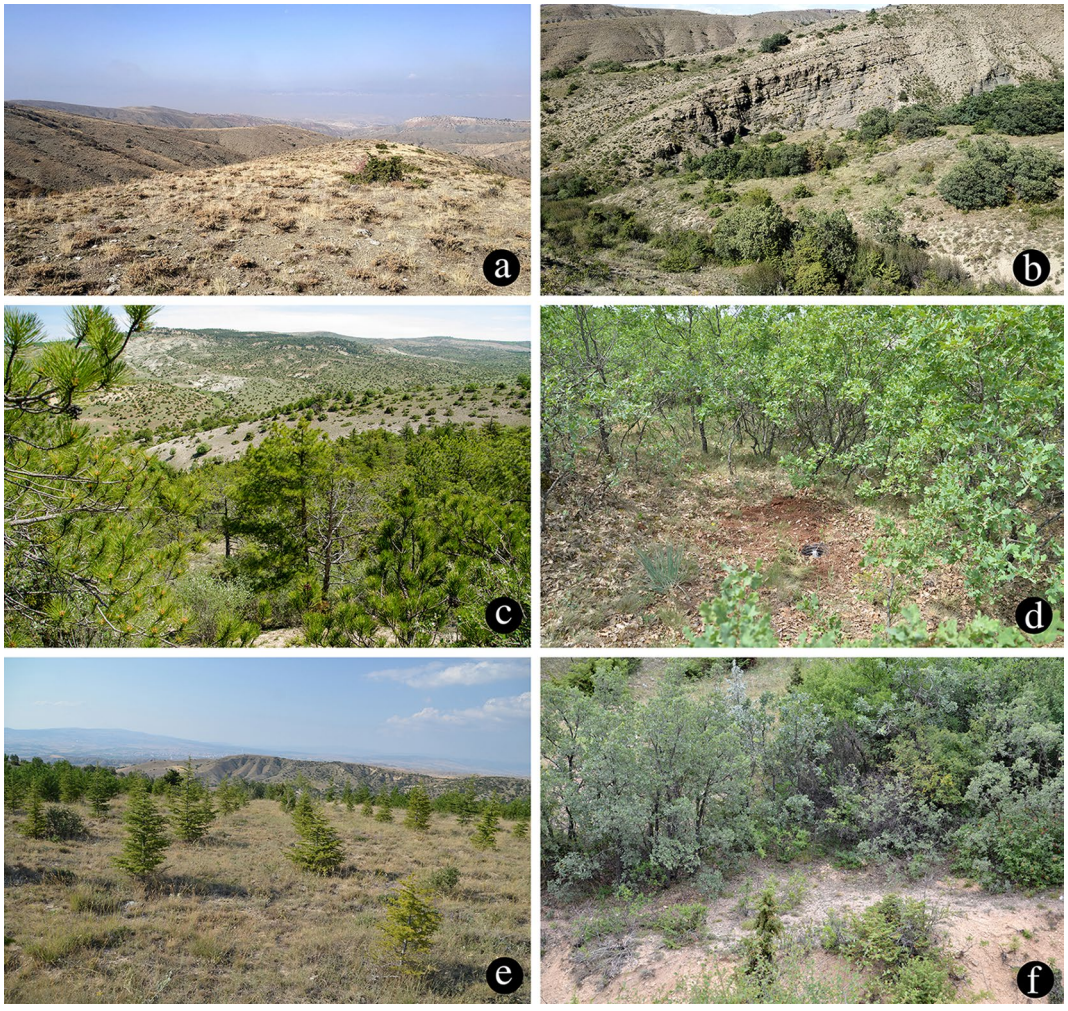


Fig. 3 General view of the EUNIS habitat types. (**a**) E1.2, (**b**) X18, (**c**) G3.5, (**d**) G4.9, (**e**) G5.7, and (**f**) G1.7

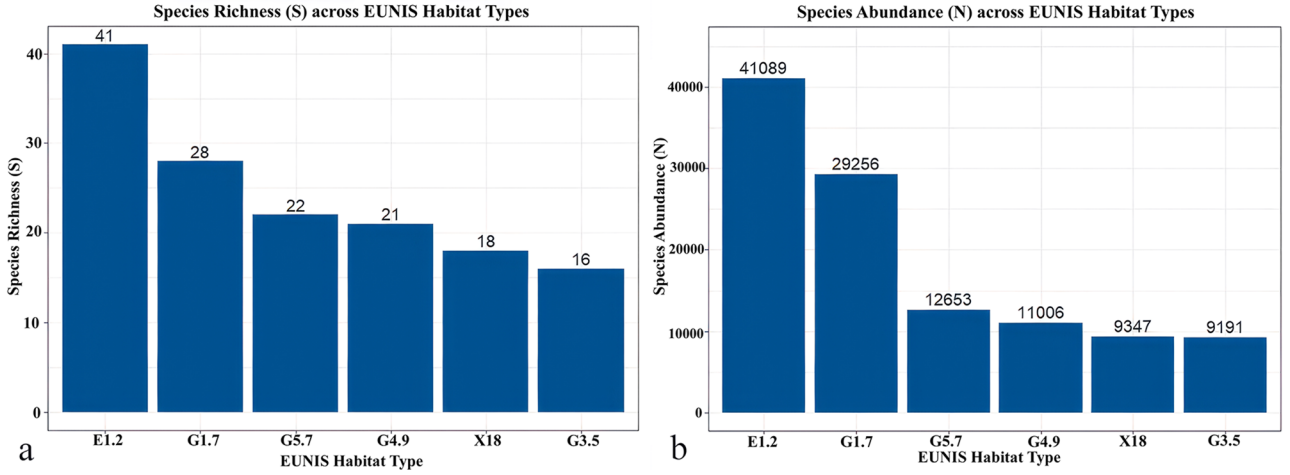


Fig. 4 Assessment of EUNIS habitat type preferences of taxa in terms of (**a**) Richness of species (S). (**b**) Abundance of species (N)

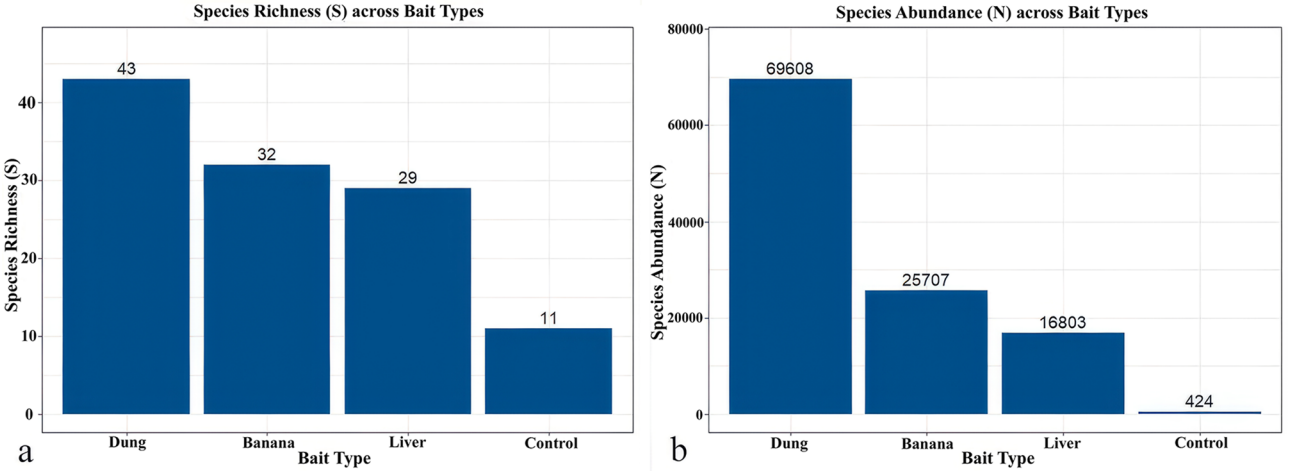


Fig. 5 Assessment of bait preference with respect to (**a**) Richness of species (S). (**b**) Abundance of species (N)

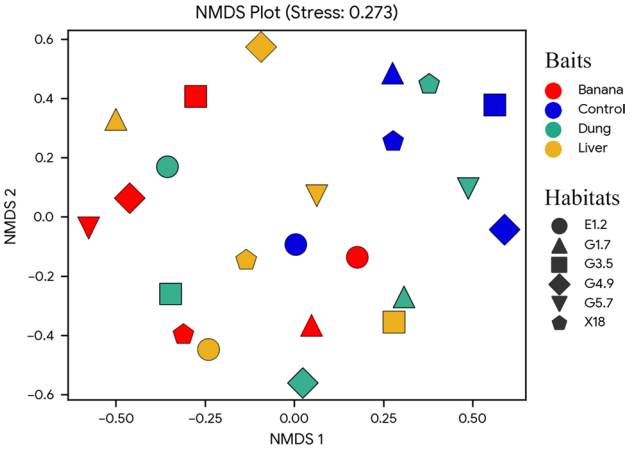


Fig. 6 NMDS ordination of dung beetle communities based on Bray-Curtis dissimilarity. Each point represents a habitat × food sampling unit; colors indicate bait types and symbols represent habitats. Distances among points reflect differences in species composition. Stress = 0.273

Table 4 Poisson generalized estimating equations (GEE) results for the effect of habitat type on insect abundance, with E1.2 used as the reference habitat. Negative coefficients indicate lower abundance compared to the reference habitat

Habitat	Coefficient (Coef)	Std. Error	z-value	P-value	Interpretation (compared to E1.2)
Intercept (E1.2)	5.325	0.755	7.050	<0.001	Reference habitat (highest abundance)
G1.7	−0.339	0.071	−4.768	<0.001	Significantly lower than E1.2
G3.5	−1.497	0.215	−6.963	<0.001	Significantly lower than E1.2
G4.9	−1.317	0.091	−14.530	<0.001	Significantly lower than E1.2
G5.7	−1.178	0.160	−7.382	<0.001	Significantly lower than E1.2
X18	−1.480	0.163	−9.068	<0.001	Significantly lower than E1.2

Table 5 Results of the Poisson generalized estimating equations (GEE) model showing the effect of bait type on insect abundance. Dung was used as the reference category, and coefficient estimates are presented on the log scale

Variable (Bait type)	Coefficient (Coef)	Std. Error	z-value	P-value	Interpretation (compared to dung)
Intercept (Dung)	5.447	0.854	6.376	<0.001	Mean abundance in dung-baited traps (log scale)
Banana	−1.421	0.173	−8.222	<0.001	Significantly lower than dung
Liver	−0.997	0.065	−15.419	<0.001	Significantly lower than dung
Control	−5.101	0.139	−36.787	<0.001	Much lower than dung

identifying E1.2 as the most homogeneous habitat and G3.5 as the most heterogeneous.

SHE analysis is an index used to compare different communities. By applying this index, multiple variables can be assessed when comparing habitats (Fig. 8). Habitat E1.2 presented the highest values in terms of both homogeneity and diversity.

A study evaluating species richness via the Shannon diversity index reported that grasslands and deciduous forests present significantly greater species richness than coniferous forests do [53]. The findings of this study are consistent with these earlier results.

These findings suggest that conserving grazing species may indirectly enhance dung beetle populations, thereby contributing to habitat restoration and ecosystem functioning.

Our current understanding of the role of scarabs in soil fertility and habitat dynamics is derived primarily from studies conducted in pastures and grasslands. However, the significance of these processes in other habitat types remains insufficiently explored. Dung beetles play a key role in soil enrichment in nitrogen-deficient environments by facilitating the incorporation of mammalian dung into the soil, thereby increasing its structure and nutrient content [54]. The Bray–Curtis dendrogram presented in our study has provided insights into the similarity among habitat types based on scarab assemblages.

When the baits in the traps were evaluated via Shannon index analysis, the highest diversity was recorded in dung, whereas the lowest diversity was observed in the liver (Table 7) (H' Log Base 10); in terms of species richness, dung was identified as the most species-rich attractant (Shannon Hmax Log Base 10). Species dissimilarity (J) was also tested, revealing that dung has the most distinct species composition (Table 8, Fig. 9).

Control traps consistently presented the lowest species counts and sample numbers. Specimens found in empty traps may have either missed the intended attractant

Table 6 Bray-Curtis cluster analysis (single link) of habitat preference [18]

Step	Clusters	Distance	Similarity	Joined 1	Joined 2	Similarity Matrix						
							E1.2	X18	G1.7	G3.5	G5.7	G4.9
1	5	4,811738	95,18826	2	4	E1.2	*	37,06	81,7859	36,4707	47,0899	42,1659
2	4	9,640045	90,35995	2	6	X18	*	*	48,4004	95,1883	82,9545	89,6182
3	3	12,98026	87,01974	2	5	G1.7	*	*	*	47,65	60,1875	51,4629
4	2	18,21413	81,78587	1	3	G3.5	*	*	*	*	83,6111	90,36
5	1	39,81245	60,18755	1	2	G5.7	*	*	*	*	*	87,0197
						G4.9	*	*	*	*	*	*

Table 7 Habitat assessment with the Shannon index [18]

Index	E1.2	G1.7	G4.9	G5.7	X18	G3.5
Shannon H' Log Base 10	0,474	0,325	0,305	0,184	0,176	0,093
Shannon Hmax Log Base 10	1,613	1,415	1,322	1,362	1,204	1,176
Shannon J'	0,294	0,23	0,231	0,135	0,146	0,079

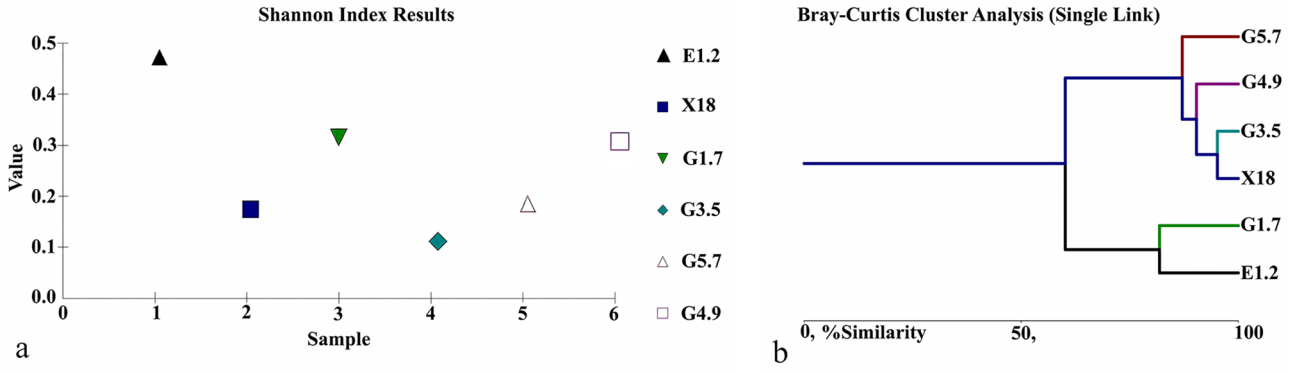


Fig. 7 (**a**) Shannon index plot of the EUNIS habitat assessment. (**b**) Dendrogram of the Bray–Curtis cluster analysis of EUNIS habitats (single link) [18]

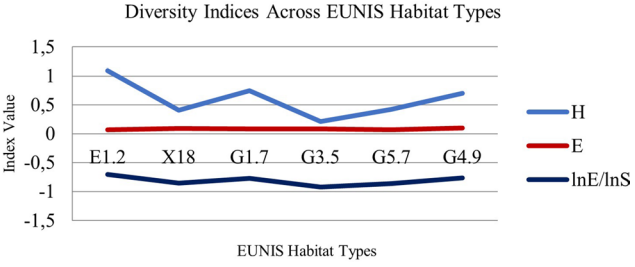


Fig. 8 Assessment of habitats with SHE analysis

Table 8 Attractant preference analysis of species with the Shannon index

Index	Dung	Banana	Liver	Control
Shannon H' Log Base 10	0,286	0,461	0,367	0,404
Shannon Hmax Log Base 10	1,633	1,505	1,462	1,041
Shannon J'	0,175	0,306	0,251	0,388

during landing or fallen while walking or been drawn to the antifreeze scent used in the traps. Attractant preferences were evaluated via the Bray–Curtis clustering method with the single-linkage index (Table 9). The analysis identified two main clusters, with dung forming a distinct primary group separate from the other baits (Fig. 9).

Among the baits in the pitfall traps, feces had the highest taxonomic diversity (S) and sample count (N) In contrast, the lowest number of species was detected in the liver, whereas the lowest sample count was detected in the banana (Table 7). Collectively, these results indicate that dung beetle community structure in this study is shaped primarily by food resource type rather than habitat differences. Both the NMDS ordination and quantitative analyses suggest that bait type plays a dominant role in determining species composition. In particular, dung bait attracted a distinct assemblage, clearly separated from other bait types, highlighting its strong and selective attractiveness to coprophagous taxa. Species-level attractiveness assessments revealed that certain species preferred specific baits significantly more. Accordingly, *Eudolus quadriguttatus, Caccobius histeroides, Euonthophagus gibbosus, Onthophagus (Furconthophagus)*

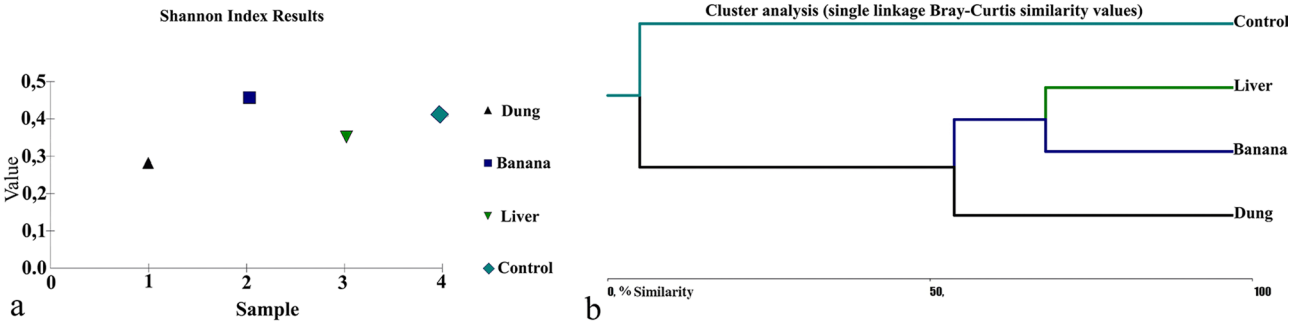


Fig. 9 (**a**) Assessment of food preferences with the Shannon index. (**b**) Dendrogram of the Bray–Curtis cluster analysis of foods (single link)

Table 9 Bray–Curtis clustering analysis according to attractor type (single link)

Step	Clusters	Distance	Similarity	Joined 1	Joined 2	Similarity Matrix				
							Dung	Banana	Liver	Control
1	3	32,10495	67,89505	2	3	Dung	*	33,4564	53,7545	1,208
2	2	46,24554	53,75446	1	2	Banana	*	*	67,8951	4,9109
3	1	95,0891	4,910896	1	4	Liver	*	*	*	3,2394
						Control	*	*	*	*

furcatus, *O. (Palaeonthophagus) fissicornis*, *O. (P.) verticicornis*, *Scarabaeus sacer,* and *S. typhon* were predominantly attracted to dung.

The presence of many *Euonthophagus amyntas alces* specimens exclusively in dung traps suggests that this species specializes in dung. The genus *Oxythyrea* and the species *Protaetia (Netocia) trojana godeti*, *Protaetia (Netocia) vidua,* and *Protaetia (Philhelena) ungarica auliensis*, which are known to feed on plants, exhibited a clear numerical preference for banana. *Caccobius schreberi*, on the other hand, showed the greatest attraction to the liver. Since other taxa were captured in low or similar numbers, the primary attractant could not be determined. The number of samples captured by the same attractant varied across different transects. This suggests that as grazing increases dung availability in the surrounding habitats, the effectiveness of the baits in the traps decreases.

Although banana traps were initially expected to attract only phytophagous scarabs, prolonged exposure in the field led to fermentation and decay, subsequently attracting saprophagous scarabs as well. A study conducted in European forests and grasslands analyzed the seasonal activity patterns of dung beetles to elucidate their habitat preferences. The study reported that *Scarabaeinae* were predominantly found in grassland habitats, *Geotrupidae* were more abundant in forests, and *Aphodiinae* exhibited similar abundances in grassland and forest ecosystems. Additionally, significant differences in species diversity were observed between forest and grassland habitats [55]. Consistent with these findings, habitat class E, which includes steppe habitats, was richer in terms of species diversity than was habitat class G, which includes forest habitats.

The species *Onthophagus (Furconthophagus) furcatus* (Fabricius, 1781) was the most abundant species across all the studied habitats and attractant types. A study in La Mandria Park (Italy) investigated resource selection in dung beetles via pitfall traps and direct observation sampling methods. This study compared the effectiveness of pitfall traps and freely deposited dung pats. The results indicated that 61.5% of the captured species belonged to the Scarabaeidae family, followed by the Aphodiidae family at 32.5%. The study revealed that members of the Scarabaeidae family, which nest away from dung, preferred pitfall traps, whereas members of the Aphodiidae family, which naturally nest within dung, were more attracted to freely available dung pats. The use of two different sampling methods to evaluate these two families with distinct nesting behaviors was considered a methodological issue. Because the exposed surface area of feces placed in plastic containers decreases, the feces are less attractive to those living there. Additionally, pitfall traps and free dung pats have different chemical influences, attracting a significantly greater number of samples. The higher capture rate of Scarabaeidae in pitfall traps may be attributed to their behavior of relocating dung to alternative nesting sites [8]

Similar results were reported from southern Brazil to understand the effects of forest fragmentation, using dung, meat, and banana as baits. However, human feces are sometimes used as a source of dung. Consistent with our findings, dung attracted the greatest number of species, followed by meat, whereas banana attracted the fewest species [23]. In addition to the target taxa, pitfall traps also captured various non-target organisms. Species such as *Ophisops elegans*, *Lacerta trilineata*, *Bufotes variabilis*, *Calosoma sycophanta*, *Stenus* sp., and *Sorex* sp. often entered the traps to feed on insects that had already fallen in. This not only resulted in their accidental capture but also caused additional mortality among the trapped insects.

The improvement of pasture quality, restoration of degraded habitats, and enhancement of productivity can be achieved through the use of scarabs as bioindicators, population increases, and habitat restoration efforts. Scarabs play a crucial role in maintaining the health of pastures and steppes by supporting the mutual interactions between plants and mammals, ultimately contributing to the well-being of both [56]. Understanding food preferences and habitat selection of scarabs is crucial for understanding their ecological roles and making informed decisions in habitat management. The present study identified the current status of the Scarabaeidae family and examined their habitat and food preferences in pilot areas. Long-term monitoring can reveal temporal changes in habitat conditions and resource availability. If needed, determining which species dominate a given habitat would allow for the rearing and release of specific species in controlled environments to aid in habitat restoration. This approach can increase soil nitrogen retention and accelerate the restoration process. Scarabs act as

catalyst species in habitat restoration, and future studies should be built upon this foundation.

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Author contributions
Doğan Erhan Ersoy participates in the design of the experiments, performs the experiments, analyzes and interprets the data, provides materials and analysis tools, and is involved in writing the paper. Abdullah Hasbenli is the mentor of Ersoys' doctoral thesis and reviews the paper. All authors have read and agreed to the published version of the manuscript.

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Data availability
All the data were presented in the manuscript.

Declarations

Ethics approval and consent to participate
As experimental work with invertebrates do not require ethic approval according to the Türkiye law. Field research permission to conduct this research was obtained from the Republic of Türkiye Ministry of Agriculture and Forestry (Permit No. 72784983-488.04-114097).

Consent for publication
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Competing interests
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