Ground Coleoptera activity-density across crop types in agricultural ecosystems of the Thessaly Plain (Greece) and its implications for Lesser Kestrel (*Falco naumanni*) prey availability

Christos Christakis*, Maria Makri, Athanassios Sfougaris

Laboratory of Ecosystem and Biodiversity Management, Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Fytokou street, 38446, Volos, Greece

*Corresponding author e-mail: cchristakis@uth.gr

Received: 5 November 2025 / Accepted: 24 April 2026

Abstract. Species of the order Coleoptera play diverse ecological roles in agricultural ecosystems, and in many cases their populations can be monitored as biodiversity indicators. This study investigates the activity-density and diversity of ground Coleoptera in agricultural ecosystems of the Thessaly Plain, Greece, during the breeding season of the Lesser Kestrel (*Falco naumanni*), given that many Coleoptera species are known to be part of its diet. This study focuses on Coleoptera activity-density and its implications for potential prey availability, rather than direct prey use. A total of 18 Coleoptera families were recorded, with Carabidae, Anthicidae, Silphidae, Tenebrionidae, Elateridae, and Scarabaeidae being the most abundant. The results indicate significant variations in Coleoptera activity-density across different crop types and sampling periods, with legumes, cereals, and fallow lands hosting the highest values. In contrast, intensive crops such as cotton and maize exhibited lower activity-density. The study's results highlight the importance of preserving habitat heterogeneity in agricultural landscapes to promote biodiversity conservation.

Keywords: Coleoptera, ground beetles, Thessaly plain, pitfall traps, Lesser Kestrel

1. Introduction

Arthropods are the most diverse and abundant group of organisms, covering over 3/4 of the world's biodiversity. They are found in every type of environment (air, water, soil), undertaking critical ecological roles, such as pollination and decomposition (Kim, 1993). Arthropod species in agroecosystems are herbivores, decomposers, predators and pollinators, contributing to ecosystems' balance (Jeanneret et al., 2005). The species of the Coleoptera order are a typical example. The Scarabaeidae, Silphidae and Dermestidae families recycle organic matter, while the Carabidae, Coccinellidae and Dytiscidae families are effective predators of herbivorous insects, contributing to their population control (Kim, 1993).

However, intensive agriculture led to significant changes in Arthropod communities, since their presence and diversity are directly affected by the structure of the rural landscape (Duelli et al., 1999; Mancini et al., 2023; Rumohr et al., 2023; Fiser et al., 2025). The reduction of agricultural landscape heterogeneity, the complete absence of uncultivated land, the extensive use of agrochemicals and the mechanical soil disturbance have led to significant arthropod population loss (Woodcock et al., 2005). Ploughing terminates the nymphic stages of Carabidae (Holland & Reynolds, 2003), while herbicides reduce the availability of their food and shelter (Menalled et al., 2007). Nevertheless, Carabidae species play an important role in weeds and herbivorous insects control, thus are valuable allies of farmers (French & Elliott, 1999) and extensive cultivation practices and organic farming have been associated with greater abundance and diversity of their populations (Pfiffner & Luka, 2003). Carabidae use crops as feeding habitats and uncultivated margins as wintering shelters. In large agricultural fields, a predominance of species resistant to high soil disturbance is observed, while small species tend to prevail over larger ones (Burel et al., 1998). Exposure to insecticides negatively affects other Coleoptera also, such as Elateridae, Curculionidae and Staphylinidae (Wilson et al., 1999). Accordingly, Staphylinidae benefit from reduced tillage and limited pesticide use. At the same time, the presence of natural vegetation can contribute to the maintenance of their populations, as it provides favorable micro-environmental conditions (Krooss & Schaefer, 1998). In addition, Staphylinidae play an important role in controlling the populations of herbivorous crop pests (Krooss & Schaefer, 1998). A typical example of Arthropod adaptation to the agricultural landscape changes is the Mediterranean dung-eating beetles. Due to the sparsity of large herbivorous mammals in forests, these species have adapted to exploit domestic animal waste (Zamora et al., 2007). However, the presence of drug residues in animal feces has been associated with inhibition of the development of their larvae (Wilson et al., 1999).

Many studies have examined Coleoptera populations as biodiversity indicators in different ecosystems, through both qualitative and quantitative approaches (Makwela et al., 2023). Da Silva et al. (2020) investigated the diversity of ground beetles in oak forests and crops in the Mediterranean basin, recording 101 different species. They recorded the highest abundance and diversity of species in agroecosystems and open grasslands. Hummel et al. (2021), in a similar study carried out in agroecosystems of Canada, observed an increase in Coleoptera diversity metrics with increasing percentage of cereals in intercropping systems. However, the diversity of Carabidae, Staphylinidae and other Coleoptera families in agroecosystems in Western Germany appears to be higher in uncultivated areas compared to cereals, confirming the importance of uncultivated areas as refuges for farmland biodiversity (Rischen et al., 2021).

Lesser Kestrel (*Falco naumanni*) is a bird of prey of agricultural ecosystems in the western Palearctic (Bustamante, 1997). It is a small migratory falcon, which usually nests during its breeding season in agricultural buildings within settlements and forages in adjacent open agricultural areas (Bustamante, 1997; Franco et al., 2005; Perez et al., 2011). The region of Thessaly in central Greece hosts approximately 70% of the national Lesser Kestrel population and was classified as “vulnerable” in Greece (Legakis & Maragos, 2009) until 2023, when it was reclassified as "Least Concern" (LC) (NECCA, 2024). Extensively managed cereal fields, fallow lands, pastures-meadows and field margins in agricultural areas are usually considered the main foraging habitats of the species (Donazar et al., 1993; Parr et al., 1997; Tella et al., 1998; Franco and Sutherland, 2004; De Frutos et al., 2010; Gustin et al., 2014), while in Thessaly it mainly prefers fallow land, legumes and cereal crops (Christakis & Sfougaris, 2021). Arthropods, mainly Coleoptera and Orthoptera, are the main prey taxa of the species (Negro, 1997; Cramp et al., 1992; Rodriguez et al., 2010; Christakis et al., 2023).

The breeding success of the Lesser Kestrel is directly dependent on the abundance and availability of its prey (Kopij, 2002). The diversity of Arthropods, and therefore of the Lesser Kestrel prey in agroecosystems, is directly related to the agricultural practices (Jeanneret et al., 2005). The intensity of farming practices seems to negatively affect the abundance and diversity of prey, highlighting the need for sustainable agricultural land management (Woodcock et al., 2005; Christakis et al., 2025) for the benefit of the Lesser Kestrel and biodiversity in general.

The purpose of this paper is to assess ground Coleoptera activity-density across the main crop types of the Thessaly Plain during the breeding season of the Lesser Kestrel. This study focuses on potential prey availability rather than direct trophic interactions, as no concurrent data on prey selection, diet composition, or foraging behavior were collected. Therefore, the study aims to explore how agricultural practices and crop types may influence the availability of ground Coleoptera as a potential food resource within agroecosystems.

2. Study area

The study area is a representative agricultural ecosystem of the Thessaly plain, dominated by large-scale crop cultivations (Figure 1). Its total area is approximately 150km². According to the local Municipality, at the time of the study 36% of the total municipal area, which includes the study area, consisted of pastures, while cereal crops covered 27.8%. Irrigated cotton crops occupied 20.3% of the total area, maize 1.7%, while 1.4% of the area was fallow land. All other crops added up to approximately 7% of the total area.

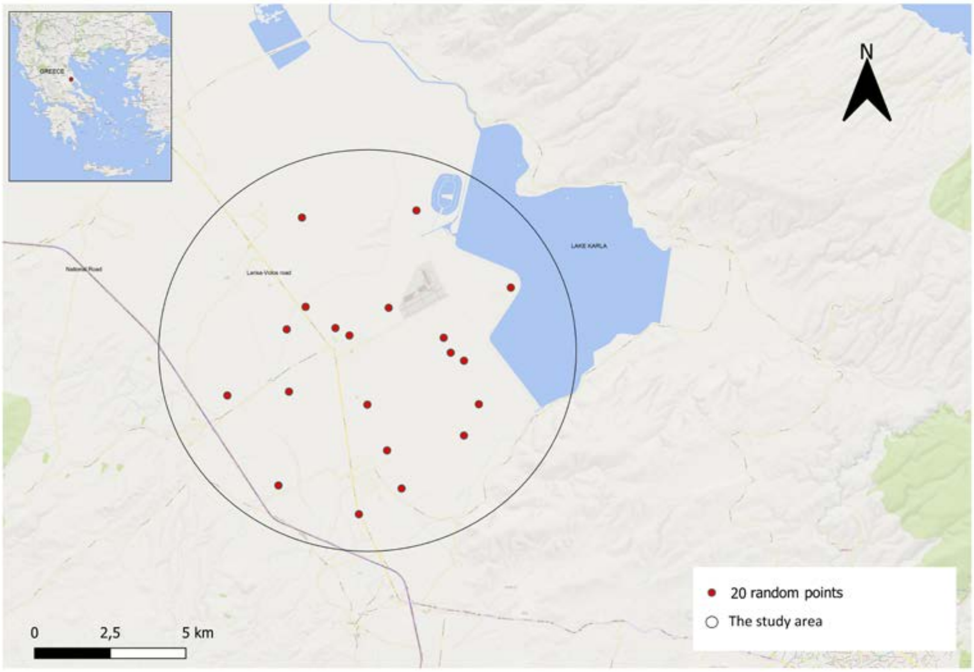

Figure 1. The study area.

3. Materials and Methods

3.1 Sampling stations

Twenty sampling stations were selected within the study area using GIS software, with a minimum distance among them of ≥500m. At each sampling station, the nearest crops were identified and served as sampling points in the three sampling periods and two years of the study. The main crop types of the area sampled were cereals, legumes (mainly alfalfa), cotton, maize, as well as fallow/uncultivated fields.

3.2 Pitfall Traps

Pitfall traps are a simple and economical method for sampling ground arthropods, primarily kinetic species such as Coleoptera, Spiders, and Ants, in areas with low vegetation (Woodcock, 2005; Skvarla et al., 2014). They are cylindrical containers at ground level that passively collect organisms continuously throughout the total installation period (Ausden & Drake, 2006). A preservative liquid, such as car antifreeze (ethylene glycol or propylene glycol), is often used to reduce decomposition and escapes, with the requirement of a protective cover due to the solution toxicity to larger animals (Weeks & McIntyre, 1997; Woodcock, 2005). The efficiency of traps is affected by factors such as season, weather conditions and vegetation (Greenslade, 1964). It should be noted that pitfall traps provide estimates of activity-density rather than absolute abundance, as captures depend not only on population size but also on species mobility and behavior (Woodcock, 2005). Therefore, the results should be interpreted with caution when referring to actual population size or prey availability.

Sampling was carried out in three distinct periods, reflecting critical stages of the Lesser Kestrel's biological cycle: (a) pair formation period (late March to early May), (b) breeding, egg incubation and chick rearing period (Breeding- mid May to late June), and (c) nest abandonment period, before autumn migration (Post Breeding- July and August).

Five pitfall traps were placed in a straight line in each selected field of the sampling stations, 10m apart. Each pitfall trap consisted of a 1L plastic container (mouth diameter 13cm, bottom 9.5cm), which was placed flush on the ground level. Each trap contained 330ml of solution [≈250ml water and ≈80ml paraflu type automotive coolant (25% w/w ethylene glycol)] (Schmidt et al., 2006), as well as a speck of unscented soap to reduce the surface tension of the liquid. A plastic cover was placed over each trap for larger animal protection and rain overflow. The traps remained active for one week. During collection, the organisms were isolated and placed in a labeled zip-lock bag. The collected material was stored in a freezer (-20°C) until further analysis in the laboratory. The remaining contents of the traps were collected in a special container for safe disposal.

3.3 Captured animals' identification

The organisms collected by the pitfall traps were isolated, counted and identified using a stereoscope (Novex RZB-SF 65.550), appropriate identification keys and laboratory equipment (Willemse, 1985; Chatenet, 1986; Chinery, 1993; Willemse, 1993; McGavin, 2000). Coleoptera were classified at the family level.

3.4 Data analysis

The analysis was conducted at the sampling point level, and the proportional representation of crop types at the landscape scale was not explicitly incorporated into the statistical analysis. Therefore, the results reflect relative differences among crop types under the sampling design rather than their overall contribution to landscape-level prey availability.

All data of pitfall trap sampling were transformed to individuals/100 days, according to: N'=(N/t*d)*100, where N is the number of individuals, t is the number of active traps and d the number of active days.

Normality and homogeneity of variance tests were performed. For non-normal data distributions, a logarithmic transformation was applied. For data with a normal distribution and homogeneous variance, one-way ANOVA and Tukey's post-hoc test were used. In case of unequal variance, a Welch ANOVA was applied, while Kruskal-Wallis and post-hoc Mann-Whitney test were performed when both conditions were not met. A modified t-test was used for diversity metrics, and a two-way ANOVA to assess the effects of "sampling period" and "cultivation type" on Coleoptera data.

Diversity was estimated using metrics (Hammer, 2015) that take into account both the richness of taxa and relative abundance (table 1).

Table 1. Diversity metrics

Metric	Equation	Description
Dominance index (D)	$D = \sum i \left(\frac{n_i}{n}\right)^2$ ni is the number of individuals of taxon i	Estimates the dominance of a taxon in the community (values 0-1)

Simpson index (1-D)		Estimates the evenness of taxa (values 0-1)
Shannon index (H)	$H = -\sum i \frac{n_i}{n} \ln \frac{n_i}{n}$ ni is the number of individuals of taxon i	Combines the number of individuals and taxa richness (0 for communities with 1 taxon, high values for rich communities)
Equitability (J)	$J = {}^{H}/_{H_{max}} = {}^{H}/_{\ln S}$	
Buzas and Gibson's evenness	${}^{e^H}/_{S}$ S is the species number	

Data analysis and figures were performed with Microsoft Excel 365, IBM SPSS Statistics v25 and PAST (v4.02).

4. Results

4.1 Coleoptera activity-density

A total of 1820 pitfall traps were placed in 364 fields (5 traps/field) during the three sampling periods for 2014 and 2015. Of these, 1720 pitfall traps were deemed suitable for further analysis. A total of 38,967 Coleoptera were collected, in all crop types and during all samplings. Specifically, during the 1st sampling of 2014, 3817 Coleoptera, during the 2nd sampling, 7886 Coleoptera and during the 3rd sampling, 6903 Coleoptera were collected. Similarly, in 2015, 5119 Coleoptera, 10,005 Coleoptera and 5237 Coleoptera were collected respectively.

Among Coleoptera, the Carabidae family showed the highest relative activity-density, accounting for approximately 31.3% of total captures (individuals/100 days), followed by Anthicidae, Silphidae, Tenebrionidae, Elateridae, and Scarabaeidae, while all other families contributed less (Figure 2).

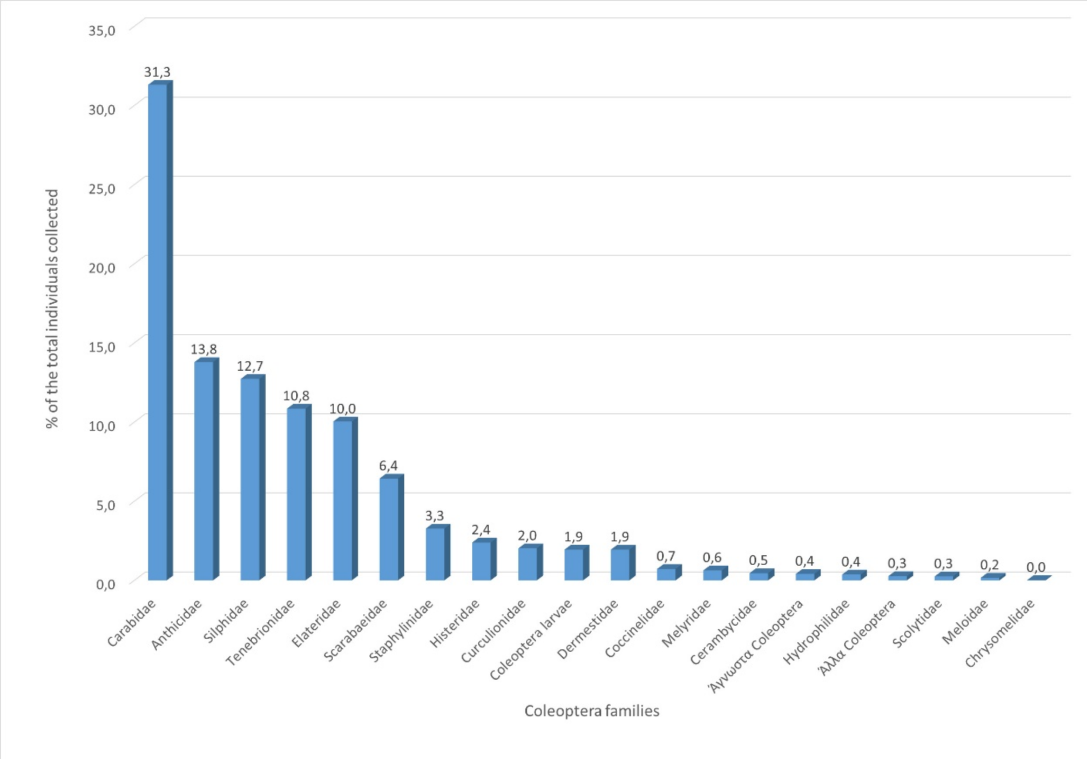

Figure 2. Total relative activity-density of Coleoptera families.

Activity-density of Coleoptera varied significantly among sampling periods, with the highest value recorded during the second sampling of 2015 and the lowest during the first sampling of 2014 ($U=167.5$, $p<0.05$). Significant differences were also observed among crop types. Legumes showed the highest total activity-density (43,725.88 individuals/100 days), followed by cereals (30,031.36 individuals/100 days) and fallow/uncultivated fields (20,243.17 individuals/100 days), while cotton exhibited lower values (18,590.97 individuals/100 days). Maize showed the lowest activity-density (3048.43 individuals/100 days); however, this result should be interpreted with caution, as sampling in maize was limited to the first sampling periods of the study.

No statistically significant differences were detected in the activity-density of Coleoptera families among sampling periods or between years ($F=1.043$, $df=113$, $p>0.05$; $F=0.3796$, $df=37$, $p>0.05$). Across all sampling periods, Carabidae consistently represented the dominant family (Figure 3).

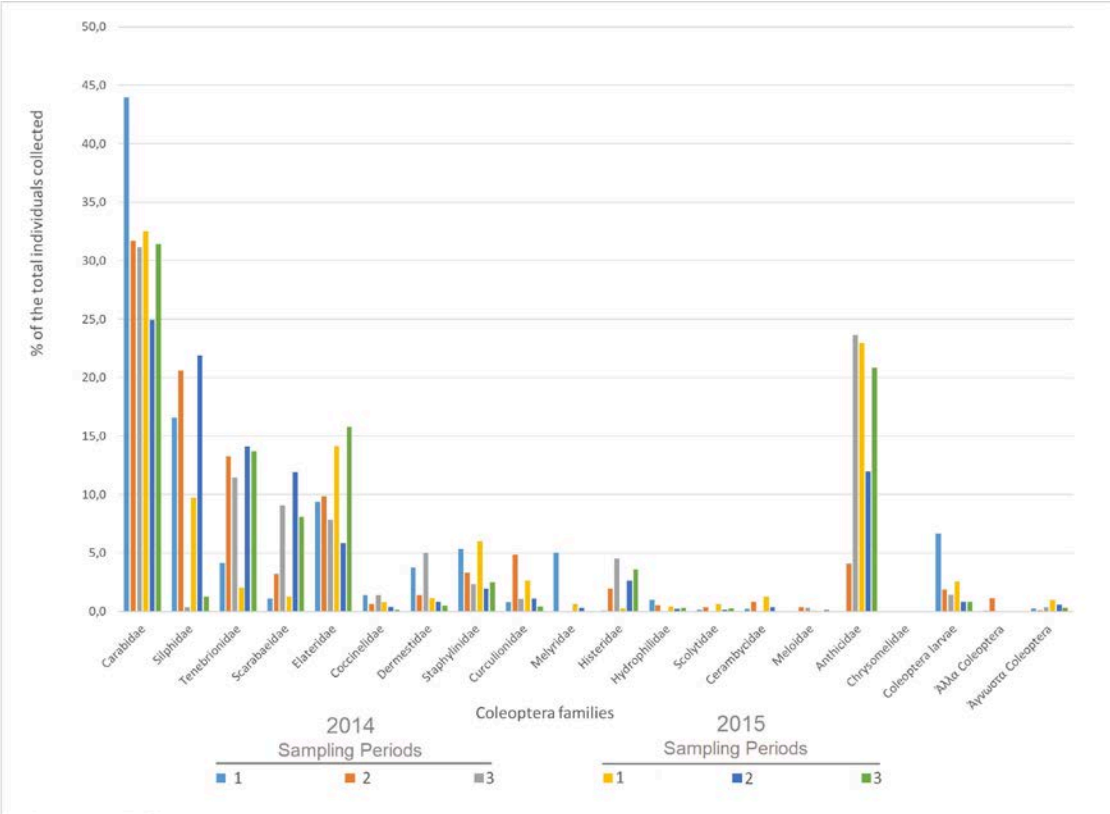

Figure 3. Percentages of individuals collected per sampling period.

Significant differences were observed among crop types in terms of total Coleoptera activity-density ($F=37.25$, $df=1719$, $p<0.05$). Similarly, the activity-density of different Coleoptera families varied significantly among crop types ($F=5.443$, $df=99$, $p<0.05$) (Figure 4).

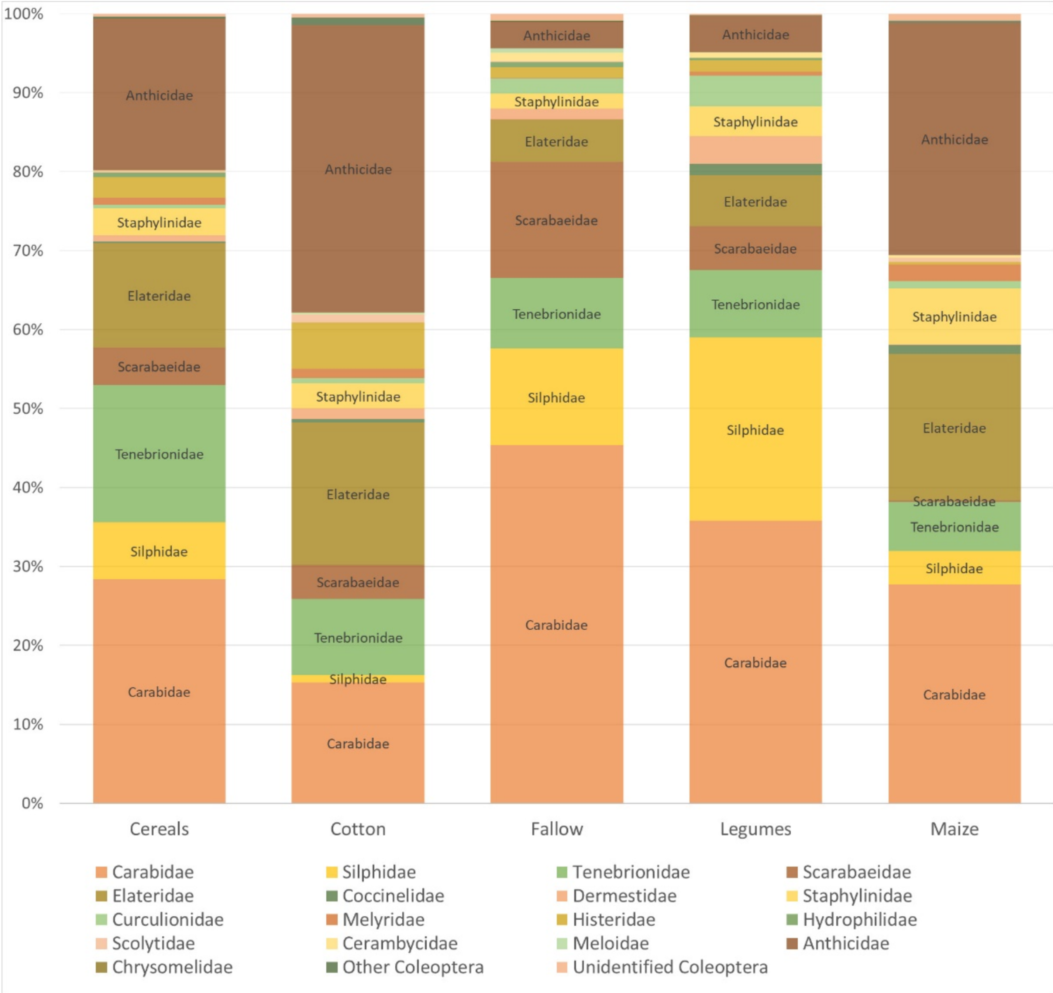

Figure 4. Total relative activity-density of Coleoptera in different crop types.

Across crop types, Carabidae was consistently the dominant family, although the relative contribution of other families varied depending on crop type and sampling period. In cereals and legumes, Carabidae predominated in most sampling periods, with occasional increases in Anthicidae, Tenebrionidae, and Silphidae. In legumes, Silphidae showed a notable peak during one sampling period (37.5%). In cotton and maize, community composition was more variable. Anthicidae dominated in several sampling periods, particularly in maize (up to 55.8%), while Carabidae and Elateridae also contributed substantially. Fallow and uncultivated fields exhibited a more heterogeneous assemblage, with Carabidae generally dominant, but with occasional high contributions from Scarabaeidae and Silphidae (both exceeding 30% in specific sampling periods). Overall, while Carabidae dominated across all crop types, differences in community composition were evident, reflecting variation in habitat conditions and agricultural practices.

Finally, two-way ANOVA was performed to assess the effects of sampling period and crop type on Coleoptera activity-density, as well as their interaction (Figure 5). Both sampling period (F=40.173, df=5, p<0.05) and crop type (F=48.272, df=4, p<0.05) had a statistically significant effect on Coleoptera activity-density. In addition, a significant interaction between the two factors was detected (sampling × crop type: F=4.839, df=18, p<0.05).

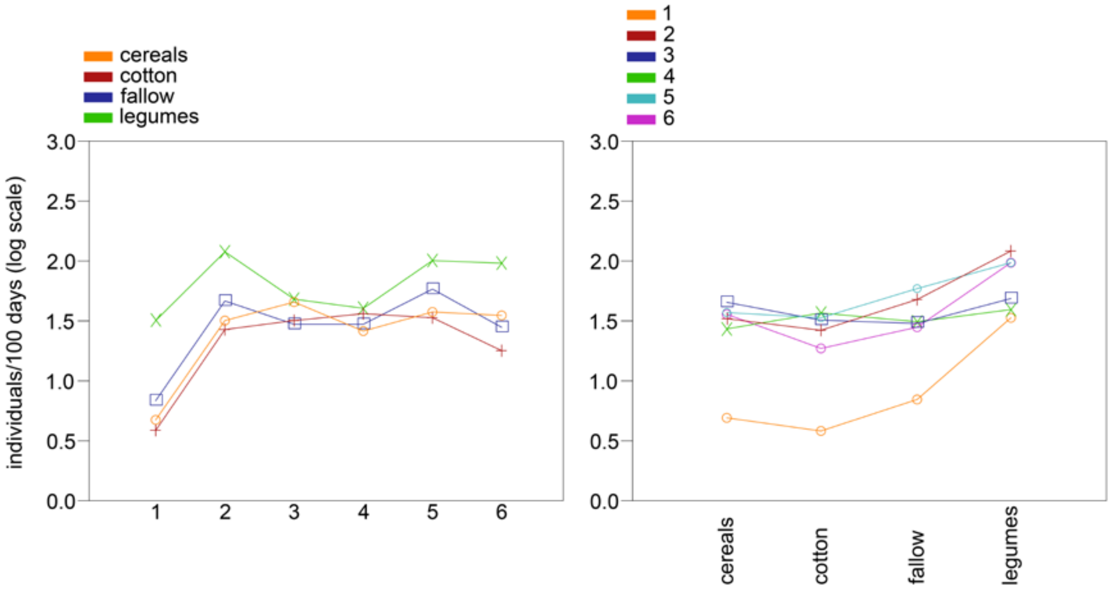

Figure 5. Interaction plots showing the effects of sampling period and crop type on Coleoptera activity-density. Left panel: variation of activity-density across sampling periods for each crop type. Right panel: variation among crop types across sampling periods. Sampling periods correspond to: 1–3 (first year: pair formation, breeding, nest abandonment) and 4–6 (second year: pair formation, breeding, nest abandonment). The y-axis represents Coleoptera activity-density (individuals/100 days) on a logarithmic scale.

4.2 Coleoptera Diversity

Overall, cereals, legumes and fallow/uncultivated land presented the highest number of taxa (19 families), of which most Coleoptera individuals were collected in legumes, followed by cereals. Maize crops collected fewer individuals (2 fewer samplings) but also fewer Coleoptera families along with cotton crops (17). Regarding the diversity metrics, fallow land showed the highest Dominance index D and respectively the lowest Simpson index (1-D), which can be attributed to the dominance of a few taxa, such as Carabidae. On the other hand, the Shannon diversity index (H) showed the highest value in cereals, while the Evenness/ Equitability metrics (e^H/S and J) gave higher values in cotton. Fallow/uncultivated fields exhibited the least diversity and uniformity, regarding Coleoptera (Table 2).

Table 2. Diversity metrics of Coleoptera collected per crop type.

	Crop type				
Metric	Cereal	Cotton	Fallow	Legumes	Maize
Taxa_S	19	17	19	19	17
Individuals	29630	18590	19748	42467	3047
Dominance_D	0.1743	0.205	0.2555	0.2032	0.2087
Simpson_1-D	0.8257	0.795	0.7445	0.7968	0.7913
Shannon_H	1.998	1.945	1.829	1.987	1.845
Evenness_e^H/S	0.388	0.4116	0.3279	0.384	0.3722
Equitability_J	0.6784	0.6867	0.6213	0.6749	0.6512

5. Discussion

This study investigates the activity-density and diversity of ground Coleoptera in agricultural ecosystems of the Thessaly Plain during the breeding season of the Lesser Kestrel (*Falco naumanni*), a species that is known to include many Coleoptera in its diet. Crop types examined, as well as the three sampling periods of each year of the study, showed variations in Coleoptera activity-density and diversity. These variations were associated with both crop types and sampling periods, as well as their interaction.

The most abundant Coleoptera families collected in pitfall traps were Carabidae, Anthicidae, Silphidae, Tenebrionidae, Elateridae and Scarabaeidae, out of a total of 18 families recorded. Carabidae, one of the most numerous families of Coleoptera with over 40,000 species, are found in a variety of habitats, contributing in organic matter decomposition and population control of herbivorous insects, such as aphids in legume crops (Anlas and Tezcan, 2010). Some species of the family consume seeds, which affects their distribution and abundance in different habitats (Grez et al., 2004). The family Tenebrionidae includes herbivorous species that utilize soil organic matter, a key factor for their survival. Similarly, the family Elateridae consists mainly of herbivorous species, while the Silphidae includes saprophagous insects found in forests and managed grasslands (Skalski and Pospiech, 2006). The Anthicidae family, which showed increased activity-density during the third sampling period, is also saprophagous, with a rapid reproductive cycle, and represents over 50% of Coleoptera in cultivated areas (Grez et al., 2004).

Variations in Coleoptera activity-density, which may influence prey availability for the Lesser Kestrel among the sampling periods of the study are usually related to crop development and agricultural practices (Rodriguez et al., 2014). Many Coleoptera that are key prey species are vulnerable to agricultural interventions (Porhajasova et al., 2022). The use of pesticides in the spring, significantly reduces the population of ground Coleoptera (Carmona and Landis, 1999; Mihoub et al., 2010), and harvesting affects their distribution and abundance (Franco et al., 2004). Arthropods living within arable crops are particularly sensitive to crop type and the timing of agricultural practices (Holland, 2003). Moreover, crop phenology plays an important role in shaping potential food availability for the Lesser Kestrel (Rodriguez et al., 2014).

In this study, pitfall traps in legumes and cereals recorded a high diversity of Coleoptera families, in agreement with Gardi et al. (2006). Carabidae, Tenebrionidae and Elateridae were the dominant families in these crops. The family Carabidae appeared in greater activity-density in legumes compared to cereal, potentially related to increased availability of food resources such as aphids. Legumes showed consistently high activity-density of ground beetles, due to the positive effects of soil organic matter (McLaughlin & Mineau, 1995, Parisi et al., 2005). Furthermore, as legumes fields are not tilled for 3-4 consecutive years, stable microclimate conditions favorable to ground beetles are maintained (Krooss & Schaefer, 1998). In addition, many Carabidae species consume seeds, which determine their distribution and abundance in crops (Grez et al., 2004). Tenebrionidae are herbivorous and depend on soil organic matter, while Elateridae also includes herbivorous species (Skalski & Pospiech, 2006). Overall, the three dominant families of ground beetles in cereal and legume crops were Carabidae, Elateridae and Tenebrionidae, suggesting that these crops may support higher activity-density of ground beetles. In contrast, cotton fields showed lower activity-density of ground beetles in the first two sampling periods for both years, with an increase observed during the later stages of the crop cycle.

The intensification of agriculture in Thessaly and the Mediterranean in general has led to elimination of perennial crop rotations and fallows, thus reducing the seasonal uncultivated areas that function as biodiversity refuges (Wang et al., 2021). However, the results of this study indicate that fallow land hosts relatively high Coleoptera activity-density and richness, supporting its role as a biodiversity hotspot (Weibull & Östman, 2003). Furthermore, the diversity of natural vegetation in fallow land is associated with increased abundance and diversity of Carabidae and other Coleoptera (Torok et al., 2010).

As Coleoptera represent a major component of the Lesser Kestrel’s diet in the Thessaly plain (Christakis et al., 2023) and the species predominantly forages within cultivated landscapes in the same areas (Christakis & Sfougaris, 2021), agricultural habitats supporting high abundances of Coleoptera may contribute to increased prey availability within agricultural landscapes. In this study, the highest Coleoptera activity-density was recorded in legumes, fallow/uncultivated fields and cereals, especially during its breeding period. Various studies confirm that the species prefers semi-natural agro-ecosystems (Donazar et al., 1993, Ursua et al., 2005, Garcia et al., 2006), but in the study area these are limited and often unsuitable due to the dense vegetation, which makes predation difficult. Nevertheless, fallow land near the colonies of the species are characterized as important habitat, as it is a source of prey and contribute to prey enrichment of neighboring crops (Weibull & Ostman, 2003). Cereals are considered particularly favorable habitats (Parr et al., 1997, Franco & Sutherland, 2004, Gustin et al., 2014), while legumes have also been identified as important foraging options (Donazar et al., 1993, Ursua et al., 2005, Christakis & Sfougaris, 2021). Intensive crops, such as cotton, showed low prey activity-density, particularly in the first samplings of each year. As a result, these crops are likely to be less suitable for foraging (De Frutos et al., 2010, Christakis & Sfougaris, 2021). However, in some cases, Lesser Kestrels may use them occasionally, especially when low plant height or farming practices make prey easier to access (Rodriguez et al., 2014). Furthermore, during the post-breeding period, when cotton reaches a height of 20–30 cm, the abundance of available prey increases, making these fields potentially more suitable for foraging (Ursua et al., 2005). Maize appeared to be less suitable for the Lesser Kestrel, due to the density and height of the plants. Dense vegetation makes it difficult for the species to maneuver and provides shelter for prey, thus reducing its accessibility

(Cioccarelli et al., 2022). In the present study, it was not possible to estimate the total Coleoptera prey availability in the maize crops, as access to them was difficult during the breeding and post-breeding periods. In the early stages of the breeding season, when vegetation is low and sparse, the use of these crops by the species may be possible, although Coleoptera activity-density was estimated to be low. In general, the species avoids maize crops for foraging (Ursua et al., 2005), but can exploit any habitat when prey is available and accessible, even for a short period of time (Rodriguez et al., 2014). Overall, legumes, cereals and fallow fields may represent habitats with higher Coleoptera activity-density at the field scale for foraging by the Lesser Kestrel, in contrast to intensive crops, which may offer more limited foraging opportunities, except during specific periods or under specific conditions.

The diversity of habitats that traditionally are characterized by agricultural land has been significantly reduced due to modern intensive farming practices (Fuller, 2012). The increased use of agrochemicals and the intensive agricultural land management have led to a dramatic decline of wildlife in cultivated areas (Pfiffner & Luka, 2003) and furthermore a strong influence on both arthropod species composition in cultivated areas and farming bird communities at a larger scale (Weibull & Östman, 2003). In this regard, an important strategy for the conservation of the Lesser Kestrel and other biodiversity is to maintain a mosaic of cultivations of varying farming intensity, combined with uncultivated margins of vegetation around its breeding colonies. This agricultural mosaic may enhance the availability of ground Coleoptera and arthropods in general, which are known to constitute key prey items of the species. Important management measures for maintaining low-intensity habitats in agroecosystems include crop rotation, reducing the use of toxic pesticides, implementing annual non-cultivation periods for fields and maintaining a significant percentage of arable land with cereals and legumes. This approach can contribute to the harmonious coexistence of agriculture with the preservation of biodiversity, while potentially supporting the conservation of the Lesser Kestrel and other species of agrobiodiversity.

A key limitation of this study is that pitfall traps measure activity-density rather than absolute abundance. As such, the recorded values reflect both the number of individuals and their movement patterns, which may vary across habitats and environmental conditions. Consequently, the observed differences among crop types should be interpreted as relative differences in Coleoptera activity-density, which may influence potential prey availability, rather than direct estimates of population size. Furthermore, the proportional extent of each crop type within the landscape was not incorporated into the analysis. As a result, while differences in Coleoptera activity-density among crop types are clearly demonstrated, these findings do not directly translate into landscape-level prey availability for the Lesser Kestrel. The ecological importance of each crop type should therefore be interpreted in relation to both its relative activity-density and spatial distribution within the agricultural mosaic. In addition, the hierarchical structure of the data (traps nested within fields and sampling periods) was not explicitly incorporated into the statistical analysis. Finally, the identification of Coleoptera at the family level may limit the resolution of ecological interpretation compared to species-level analyses.

6. Conclusion

This study assessed the activity-density of Coleoptera in agricultural ecosystems of the Thessaly Plain during the breeding season of the Lesser Kestrel (*Falco naumanni*). A total of 18 Coleoptera families were recorded, with Carabidae, Anthicidae, Silphidae, Tenebrionidae, Elateridae, and Scarabaeidae being the most abundant. The activity-density of these families varied across crop types and sampling periods. Legume and cereal crops showed the highest Coleoptera activity-density, while cotton fields had the lowest. Fallow and uncultivated areas also exhibited significant activity-density and diversity, supporting their role as biodiversity refuges. The results of the study suggest that legume fields, fallow lands, and cereals may represent habitats with higher Coleoptera activity-density at the field scale during the Lesser Kestrel breeding season. In contrast, intensive crops such as cotton and maize may offer more limited foraging opportunities, except during specific periods or under particular conditions. Maintaining a mosaic of crop types with different management intensities may enhance the activity-density of ground Coleoptera and other arthropods, which are known to constitute key prey items for the Lesser Kestrel, while promoting overall farmland biodiversity. However, these findings should be interpreted with caution, as activity-density does not necessarily reflect effective prey availability, which is also influenced by factors such as prey accessibility and vegetation structure.

Funding

The study was carried out within the framework of the project LIFE11NAT/ GR/001011 project [Conservation and management of the Lesser Kestrel (*Falco naumanni*) in three Special Protection Areas (SPAs) of Greece].

References

Anlas, S., & Tezcan, S., 2010. Species composition of ground beetles (carabidae, coleoptera) collected by hibernation trap-bands in agricultural landscapes, Bozdaglar mountain of western Turkey. Acta Biologica Universitatis Daugavpiliensis 10(2):193-198.

Ausden, M, & Drake, M., 2006, Invertebrates, [in] Ecological census techniques: a handbook, W.J. Sutherland (ed), Cambridge University Press, New York, pp. 214-249.

Burel, F., Baudry, J., Butet, A., Clergeau, P., Delettre, Y., Le Coeur, D., Dubs, F., Morvan, N., Paillat, G., Petit, S., Thenail, C., Brunel, E., & Lefeuvre J. C., 1998, Comparative biodiversity along a gradient of agricultural landscapes. Acta Oecologica, 19(1):47-60. https://doi.org/10.1016/S1146-609X(98)80007-6

Bustamante, J., 1997, Predictive models for Lesser Kestrel *Falco naumanni* distribution, abundance and extinction in southern Spain. Biological Conservation 80(2):153-160. https://doi.org/10.1016/S0006-3207(96)00136-X

Carmona, D. M., & Landis, D. A., 1999, Influence of Refuge Habitats and Cover Crops on Seasonal Activity-Density of Ground Beetles (Coleoptera: Carabidae) in Field Crops. Environmental Entomology 28(6):1145-1153. https://doi.org/10.1093/ee/28.6.1145

Chatenet, G. D., 1986, Guide des coleopteres d'Europe, Tome 1, Delachaux et Niestlé, Paris, France

Chinery, M., 1993, Insects of Britain and Western Europe, Collins Field Guide, Harper Collins, New York, USA.

Christakis, C. E., & Sfougaris, A. I., 2025, Lesser Kestrel (Falco naumanni) ground prey abundance during its breeding season in central Greece. Acta Biologica Szegediensis 68(2):142–150. https://abs.bibl.u-szeged.hu/index.php/abs/article/view/3508

Christakis C., & Sfougaris, A., 2021, Foraging habitat selection by the Lesser Kestrel Falco naumanni during the different phases of breeding and the post breeding period in central Greece. Ornithological Science 20(2):175-183. https://doi.org/10.2326/osj.20.175

Christakis, C., Makri, M., Alivizatos, H., & Sfougaris, A., 2023, Lesser Kestrel *Falco naumanni* diet during different phases of breeding and post breeding periods in central Greece. Avocetta 47:2023F002 https://doi.org/10.30456/AVO.2023103

Cioccarelli, S., Terras, A., Assandri, G., Berlusconi, A., Grattini, N., Mercogliano, A., Pazhera, A., Sbrilli, A., Cecere, J. G., Rubolini, D., & Morganti, M., 2022, Vegetation height and structure drive foraging habitat selection of the lesser kestrel (Falco naumanni) in intensive agricultural landscapes. PeerJ 10:e13979 https://doi.org/10.7717/peerj.13979

Cramp, S., Perrins, C. M., & Brooks, D. J., 1992, Handbook of the birds of Europe the Middle East and North Africa: the birds of the Western Palearctic, Oxford University Press, Oxford.

Da Silva, P. M., Aguiar, C. A. S., Niemela, J., Sousa, J. P., & Serrano, A. R. M., 2008, Diversity patterns of ground-beetles (Coleoptera: Carabidae) along a gradient of land-use disturbance. Agriculture, Ecosystems & Environment 124(3–4):270-274. https://doi.org/10.1016/j.agee.2007.10.007

De Frutos, A., Olea, P., Mateo-Tomas, P., & Purroy, F. J., 2010, The role of fallow in habitat use by the Lesser Kestrel during the post-fledging period: inferring potential conservation implications from the abolition of obligatory set-aside. European Journal of Wildlife Research 56:503–511. https://doi.org/10.1007/s10344-009-0338-4

Donazar, J., Negro, J., & Hiraldo, F., 1993, Foraging habitat selection, land-use changes and population decline in the Lesser Kestrel *Falco naumanni*. Journal of Applied Ecology 30(3):515-522. https://doi.org/10.2307/2404191

Duelli, P., Obrist, M. K., & Schmatz, D. R., 1999, Biodiversity evaluation in agricultural landscapes: above-ground insects. Agriculture, Ecosystems and Environment 74(1-3):33–64. https://doi.org/10.1016/S0167-8809(99)00029-8

Fiser, C. M., Haan, N. L., & Landis, D. A., 2025, Long-term agricultural management reduces abundance and alters community structure of ground beetles (Coleoptera: Carabidae), Agriculture, Ecosystems & Environment 379:109337. https://doi.org/10.1016/j.agee.2024.109337

Franco, A., & Sutherland, W. J., 2004, Modeling the foraging habitat selection of Lesser Kestrels: conservation implications of European Agricultural Policies. Biological Conservation 120(1):63–74. https://doi.org/10.1016/j.biocon.2004.01.026

Franco, A., Catry, I., Sutherland, W., & Palmeirim, J., 2004, Do different habitat preference survey methods produce the same conservation recommendations for Lesser Kestrels. Animal Conservation 7(3):291–300. https://doi.org/10.1017/S1367943004001465

Franco, A., Marques, J. T., & Sutherland, W. J., 2005, Is nest-site availability limiting Lesser Kestrel populations? A multiple scale approach. Ibis 147(4):657-666. https://doi.org/10.1111/j.1474-919x.2005.00437.x

French, B. W., & Elliott, N. C., 1999, Temporal and spatial distribution of ground beetle (Coleoptera: Carabidae) assemblages in grasslands and adjacent wheat fields. Pedobiologia 43(1):73-84. https://doi.org/10.1016/S0031-4056(24)00493-1

Fuller, R. J., 2012, Birds and habitat: relationships in changing landscapes, Cambridge University Press, New York.

Garcia, J. T., Morales, M. B., Martinez, J., Iglesias, L., De-la-Morena, E. G., Suarez, F., & Vinuela, J., 2006, Foraging activity and use of space by lesser Kestrel Falco naumanni in relation to agrarian management in central Spain. Bird Conservation International 16(1):83–95. https://doi.org/10.1017/S0959270906000013

Gardi, C., Tomaselli, M., Parisi, V., Petraglia, A., & Santini, C., 2002, Soil quality indicators and biodiversity in northern Italian permanent grasslands. European Journal of Soil Biology 38(1):103−110. https://doi.org/10.1016/S1164-5563(01)01111-6

Greenslade, P. J. M., 1964, Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). Journal of Animal Ecology 33(2): 301-310. https://doi.org/10.2307/2632

Grez, A. A., Zaviezo, T., & Reyes, S., 2004, Short-term effects of habitat fragmentation on the abundance and species richness of beetles in experimental alfalfa microlandscapes. Revista Chilena De Historia Natural 77:547-548.

Gustin, M., Ferrarini, A., Giglio, G., Pellegrino, S. C., & Frassanito, A., 2014, Detected foraging strategies and consequent conservation policies of the Lesser Kestrel *Falco naumanni* in Southern Italy. Proceedings of the International Academy of Ecology and Environmental Sciences 4 (4):148-161.

Holland, J. M., 2004, The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems and Environment 103(1):1–25. https://doi.org/10.1016/j.agee.2003.12.018

Holland, J. M., & Reynolds, C. M., 2003, The impact of soil cultivation on arthropod (Coleoptera and Araneae) emergence on arable land. Pedobiologia, 47(2):181–191. https://doi.org/10.1078/0031-4056-00181

Hummel, J. D., Dosdall, L. M., Clayton, G. W., Harker, K. N., & O'Donovan J. T., 2012, Ground Beetle (Coleoptera: Carabidae) Diversity, Activity Density, and Community Structure in a Diversified Agroecosystem, Environmental Entomology 41(1):72–80. https://doi.org/10.1603/EN11072

Jeanneret, P., Pfiffner, L., Pozzi, S., & Walter, T., 2005, Impact of low input meadows on arthropod diversity at habitat and landscape scale. Grassland Science in Europe 9:237-239.

Kim, K., 1993, Biodiversity, conservation and inventory: why insects matter. Biodiversity and Conservation 2:191-214. https://doi.org/10.1007/BF00056668

Kopij, G., 2002, Food of the Lesser Kestrel (*Falco naumanni*) in its winter quarters in South Africa. Journal of Raptor Research 36(2):148-152. https://digitalcommons.usf.edu/jrr/vol36/iss2/12

Krooss, S., & Schaefer, M., 1998, The effect of different farming systems on epigeic arthropods: a five-year study on the rove beetle fauna (Coleoptera: Staphylinidae) of winter wheat. Agriculture, Ecosystems and Environment 69(2):121-133. https://doi.org/10.1016/S0167-8809(98)00093-0

Legakis, A., & Maragou, P., 2009, The Red Book of Endangered Animals of Greece, Greek Zoological Society, Athens, Greece

Makwela, M. M., Slotow, R., & Munyai, T. C., 2023, Carabid Beetles (Coleoptera) as Indicators of Sustainability in Agroecosystems: A Systematic Review. Sustainability 15(5):3936. https://doi.org/10.3390/su15053936

Mancini, F., Cooke, R., Woodcock, B. A., Greenop, A., Johnson, A. C., & Isaac, N. J. B., 2023, Invertebrate biodiversity continues to decline in cropland Proceedings of the Royal Society B 290:20230897 https://doi.org/10.1098/rspb.2023.0897

McGavin, G. C., 2000, Insects, Spiders and Other Terrestrial Arthropods Dorling Kindersley- Handbooks, Dorling Kindersley, London, UK.

McLaughlin, A., & Mineau, P., 1995, The impact of agricultural practices on biodiversity. Agriculture, Ecosystems and Environment 55(3):201-212. https://doi.org/10.1016/0167-8809(95)00609-V

Menalled, F. D., Smith, R. G., Dauer, J. T., & Fox, T. B., 2007, Impact of agricultural management on carabid communities and weed seed predation. Agriculture, Ecosystems and Environment, 118(1-4):49–54. https://doi.org/10.1016/j.agee.2006.04.011

Mihoub, J. B., Gimenez, O., Pilard, P., & Sarrazin, F., 2010, Challenging conservation of migratory species: Sahelian rainfalls drive first-year survival of the vulnerable Lesser Kestrel *Falco naumanni*. Biological Conservation 143(4):839–847. https://doi.org/10.1016/j.biocon.2009.12.026

Natural Environment and Climate Change Agency (NECCA), 2024, The Greek Red List of Threatened Species. Athens, Greece. Available at https://redlist.necca.gov.gr, accessed 18/03/2025.

Negro, J., 1997, *Falco naumanni* Lesser Kestrel. Birds of the Western Palearctic Update 1:49-56.

Parisi, V., Menta, C., Gardi, C., Jacomini, C., & Mozzanica, E., 2005, Microarthropod communities as a tool to assess soil quality and biodiversity: a new approach in Italy. Agriculture, Ecosystems and Environment 105(1-2):323–333. https://doi.org/10.1016/j.agee.2004.02.002

Parr, S., Naveso, M., & Yarar, M., 1997, Habitat and potential prey surrounding Lesser Kestrel *Falco naumanni* colonies in central Turkey. Biological Conservation 79(2-3):309-312. https://doi.org/10.1016/S0006-3207(96)00086-9

Perez, I., Noguera, J., & Minguez, E., 2011, Is there enough habitat for reintroduced populations of the Lesser Kestrel? A case study in eastern Spain. Bird Conservation International 21(2):228-239. https://doi.org/10.1017/S0959270910000523

Pfiffner, L., & Luka, H., 2003, Effects of low-input farming systems on carabids and epigeal spiders – a paired farm approach. Basic and Applied Ecology 4(2):117–127. https://doi.org/10.1078/1439-1791-00121

Porhajasova, J. I., & Babosova, M., 2022, Impact of arable farming management on the biodiversity of Carabidae (Coleoptera). Saudi Journal of Biological Sciences 29(9):103371. https://doi.org/10.1016/j.sjbs.2022.103371

Rischen, T., Frenzel, T., & Fischer, K., 2021, Biodiversity in agricultural landscapes: different non-crop habitats increase diversity of ground-dwelling beetles (Coleoptera) but support different communities. Biodiversity and Conservation 30:3965–3981. https://doi.org/10.1007/s10531-021-02284-7

Rodriguez, C., Tapia, L., Kieny, F., & Bustamante, J., 2010, Temporal changes in Lesser Kestrel (*Falco naumanni*) diet during the breeding season in southern Spain. Journal of Raptor Research 44(2):120-128. https://doi.org/10.3356/JRR-09-34.1

Rodriguez, C., Tapia, L., Ribeiro, K., & Bustamante, J., 2014, Crop Vegetation Structure Is More Important than Crop Type in Determining Where Lesser Kestrels Forage. Bird Conservation International 24(4):438-52. https://doi.org/10.1017/S0959270913000129

Rumohr Q., Baden C.U., Bergtold M., Marx M.T., Oellers J., Schade M., Toschki, A., Maus, C., 2023, Drivers and pressures behind insect decline in Central and Western Europe based on long-term monitoring data. PLoS ONE 18(8):e0289565. https://doi.org/10.1371/journal.pone.0289565

Schmidt, M. H., Clough, Y., Schulz, W., Westphalen, A., & Tscharntke, T., 2006, Capture efficiency and preservation attributes of different fluids in pitfall traps. The Journal of Arachnology 34(1):159-162. https://doi.org/10.1636/T04-95.1

Skalski, T., & Pospiech, N., 2006, Beetles community structures under different reclamation practices. European Journal of Soil Biology 42(1):316-320. https://doi.org/10.1016/j.ejsobi.2006.07.026

Skvarla, M. J., Larson, J. L., & Dowling, A. P. G., 2014, Pitfalls and Preservatives: A review. Journal of the Entomological Society of Ontario 145:15-43. https://doi.org/10.21083/jeso.v145i0.3734

Southwood, T., & Henderson, P., 2000, Ecological Methods, 3η ed, Blackwell Science Ltd., New Jersey.

Tella, J. L., Forero, M. G., Hiraldo, F., & Donazar, J. A., 1998, Conflicts between lesser kestrel conservation and European agricultural policies as identified by habitat use analyses. Conservation Biology 12(3):593–604. https://doi.org/10.1111/j.1523-1739.1998.96288.x

Torok, P., Deak, B., Vida, E., Valko, O., Lengyel, S., & Tothmeresz, B., 2010, Restoring grassland biodiversity: Sowing low-diversity seed mixtures can lead to rapid favourable changes. Biological Conservation 143(3):806–812. https://doi.org/10.1016/j.biocon.2009.12.024

Ursua, E., Serrano, D., & Tella, J. L., 2005, Does land irrigation actually reduce foraging habitat for breeding lesser kestrels? The role of crop types. Biological Conservation 122(4):643–648. https://doi.org/10.1016/j.biocon.2004.10.002

Wang, M., Axmacher, J. C., Yu, Z., Zhang, X., Duan, M., Wu, P., Zou, Y., & Liu, Y., 2021, Perennial crops can complement semi-natural habitats in enhancing ground beetle (Coleoptera: Carabidae) diversity in agricultural landscapes. Ecological Indicators 126:107701. https://doi.org/10.1016/j.ecolind.2021.10770

Weeks, R.D., & Mclntyre, N.E., 1997, A comparison of live versus kill pitfall trapping techniques using various killing agents. Entomologia Experimentalis et Applicata 82(3):267-273. https://doi.org/10.1046/j.1570-7458.1997.00140.x

Weibull, A., & Ostman, O., 2003. Species composition in agroecosystems: The effect of landscape, habitat, and farm management. Basic and Applied Ecology 4(4):349–361. https://doi.org/10.1078/1439-1791-00173

Willemse, F., 1984, Fauna Graeciae I. Catalogue of the Orthoptera of Greece, Hellenic Zoological Society, Athens, Greece.

Willemse, F., 1985, Fauna Graeciae II. A Key to the Orthoptera Species of Greece, Hellenic Zoological Society, Athens, Greece.

Wilson, J. D., Morris, A. J., Arroyo, B. E., Clark, S. C., Bradbury, R. B., 1999, A review of the abundance and diversity of invertebrate and plant foods of granivorous birds in northern Europe in relation to agricultural change. Agriculture, Ecosystems and Environment 75(1-2):13–30. https://doi.org/10.1016/S0167-8809(99)00064-X

Woodcock, B. A., 2005, Pitfall trapping in ecological studies. [in:] Insect sampling in forest ecosystems, S. R. Leather (ed), Blackwell Science Ltd, Oxford: 37-57.

Woodcock, B., Westbury, D.B., Potts, S.G., Harris, S.J., Brown, V.K., 2005, Establishing field margins to promote beetle conservation in arable farms. Agriculture, Ecosystems and Environment 107(2-3):255–266. https://doi.org/10.1016/j.agee.2004.10.029

Zamora, J., Verdu, J. R., & Galante, E., 2007, Species richness in Mediterranean agroecosystems: Spatial and temporal analysis for biodiversity conservation. Biological Conservation 134(1):113-121. https://doi.org/10.1016/j.biocon.2006.08.011