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Effect of livestock and vegetation structure on Carabidae (Coleoptera) diversity in dehesas of the Iberian Peninsula

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Abstract: The response of carabid beetles to extensive livestock farming and vegetation structure in two traditionally managed 'dehesa' ecosystems was investigated. From March 2011 to January 2012, sampling was done, using pitfall trapping, on two forestry farms located in the Sierra de Hornachuelos Natural Park (Córdoba, Spain), both with hunting use, but one of them also with a heavy livestock load. On each forestry farm, two sampling plots were selected according to the vegetation structure. Faunal differences were proved through the ecological indices, and the faunal uniqueness was checked by the Coldwell and Coddington Complementarity Analysis. To identify the most influential factor on the carabid biodiversity, a Generalised Linear Mixed Model (GLMM) was performed. Results show that abundance and richness are higher in the plots with open vegetation, similarly like the number of recorded tribes. Nevertheless, the ecological indices do not reflect any significant differences. The complementarity between different vegetation structures exceeds that of the exploitation types. In fact, the GLMM analysis indicated that the livestock itself does not have a significant effect on the fauna. In addition, all exclusive, rare or endemic species came from the closed vegetation plots, suggesting that these areas may act as a reservoir of unique species in terms of biodiversity.

Keywords: biodiversity; carabids; forestry farm; ground beetles; oak forest

Currently, research is conducted to improve the understanding of the effect of different management practices carried out in wood pastures on their productivity, biodiversity and ecosystem services (Torralba et al. 2018). In this regard, our research group has focused on studying the Carabidae assemblages inhabiting oak forests (with trees and scrubs) and 'dehesas' (open grasslands and scattered oak trees) to assess the effect of anthropic practices (livestock presence and vegetation management) on soil biodiversity in a natural area of special conservation interest.

The original mixed Mediterranean oak forest, where holm oaks and cork oaks predominated, is now a simplified forest system to a large extent, more or less cleared of its different vegetation strata, but always used for grazing as the main form of exploitation. The transformation has been slow and gradual, and the geological and climatic processes occurring over time, together with human interventions, are the fundamental elements responsible for such a situation (Pardo 2023). This transformation was intensified after the Last

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Glacial Maximum (Bodi et al. 2012), when the climate became progressively warmer, favouring a sedentary lifestyle with agriculture and livestock as means of subsistence (Peña, Zapata 2012). These changes were very evident in the Mediterranean Basin, with the clearing of forests and development of pastures for livestock (Boticario 2011), combined with the use of fire as a management tool; these interventions were also applied very significantly in the south of the Iberian Peninsula (Carrion et al. 2022). So then, the history of the dehesas has been continuously determined by the dynamics of constant changes in the extent and spatial distribution of the mosaic formed by pastures, scrubland and trees, which are associated with intensification or changes in land use (Plieninger, Wilbrand 2001). This progressive transformation also has repercussions on the diversity and identity of the constituent organisms, the scope of which must be assessed as a priority in order to manage them appropriately for the sake of conservation.

On this concern, soil fauna is considered a good bioindicator of forest and agricultural soils disturbance, since its populations vary according to its physical, chemical and biological conditions (Rodríguez-Pajares et al. 2025). Accordingly, it seems evident that the type and intensity of territory exploitation can be assessed through the spatial and temporal analysis of edaphic communities.

The family Carabidae is among the most representative groups of soil beetles that are part of the Mediterranean ecosystem and have a great indicator potential (Rainio, Niemelä 2003); it includes beetles familiarly known as ground beetles because they are closely linked to the soil, being common predators in both forest ecosystems and agricultural landscapes, always developing their biological cycles in the edaphic environment. This intimate relationship can be enhanced by the hypogea habitat of the immature stages, which makes them very sensitive to environmental modifications. Both the substantial alterations and slight changes in soil can lead to structural changes of communities and to variations in terms of biodiversity (Kotze et al. 2011).

Overall, carabid beetles are considered valid bioindicators because their taxonomy is well known, they colonise a wide range of habitats, are very sensitive to environmental changes and can be sampled by standardised procedures. Literature summarising these issues is detailed in Borchard et al. (2014).

In forest environments, changes in carabid assemblages ensuing from anthropisation can be expressed by variations in the number, composition and abundance of the species. In addition, the populations of the commonly considered 'specialist' species of large size and low dispersal power decrease while those of the 'generalist' species of smaller size but with good flight capability become larger (Rainio, Niemelä 2003). Land fragmentation, soil water content (Eyre, Luff 1990) and vegetation structure (Halme, Niemelä 1993) are among the main factors affecting the number and abundance of carabid species. Therefore, the carabids are particularly valuable bioindicators for understanding ecosystem responses and sustainability in forest and landscape management (Kosewska et al. 2023), which is the main goal of our study.

Concerning the agrarian ecosystems, although some species are mainly granivorous, seed-eating, or they feed on diverse plant material (Lindroth 1961–1969), most carabids are polyphagous predators, acting as potential control agents for pests such as aphids, slugs, and adults and larvae of lepidopterans (Lovëi, Sunderland 1996). Research dealing with the effect of crop type (Cárcamo, Spence 1994), soil management (Thomas 2002) or conservation practices (Rischen et al. 2021; Knapp et al. 2022) on the carabid biology indicates a great impact affecting overall activity, as well as density, diversity, community composition, and predation potential. These reasons explain why carabids are also increasingly used in the environmental assessment of crop fields (Pizzolotto 2022).

Like many other arthropod groups, carabids are currently suffering a global decline (Weiss et al. 2024). According to a meta-analysis performed on European carabids, the main factors responsible for such decline are indirect effects of 'anthropogenic activity' (pollution, land use, etc.), intensive agriculture and climate change (Rumohr et al. 2023).

Considering the bioindicator potential of the Carabidae, both in forest and in agricultural ecosystems, this research was conducted with the aim of studying the effect of the presence of extensive livestock and vegetation type on the carabid fauna, as a tool to assess the influence of anthropogenic interventions on soil biodiversity in a natural area of special interest from an environmental conservation perspective.

MATERIAL AND METHODS

The study was carried out on two forestry farms located in the Sierra de Hornachuelos Natural Park (southern Iberian Peninsula, Figure 1), subjected to different intensities and types of livestock management.

Concretely, sampling was done in two localities: Loma de los Jarales (geographic coordinates 37°56'44''N, 05°07'21''W; altitude 500 m a.s.l.; municipality of Villaviciosa and Hornachuelos, Córdoba; Figures 2 and 3) and Los Lagares (geographic coordinates 37°55'00''N, 05°04'26''W; altitude 370 m a.s.l.; municipality of Almodóvar del Río, Córdoba; Figures 4 and 5), both with hunting use but the latter also has heavy livestock load (mainly cattle). The factor 'livestock load' has been included in the analysis because grazing shapes the landscape differently from wild fauna (Serrano-Montes et al. 2019).

Two different sampling plots were selected on each forestry farm according to the type of vegetation: the so-called 'open vegetation' plot, whose vegetation was mainly typical holm oak [*Quercus ilex* subsp. *ballota* (Desf.) Samp.] pastures and cork oaks (*Q. suber* L.). The second type was the 'closed vegetation' plot, where corks and holms coexist with a well-developed scrubland mainly dominated by *Pistacia lentiscus* L., *Phlomis purpurea* L. and different species of *Genista* and *Cistus*. The distance between plots was longer than 200 m to avoid edge effects (Picaud, Petit 2007).

Ten pitfall traps, 12 cm in diameter and 15 cm high, containing a volume of 250 cm^3 (mL) of ethanol (70%) as bait and preservative, were installed at each sampling plot. The traps were buried at the ground level and partially covered with stones and plant debris to protect them from flooding but allowing beetles to enter. Depending on the weath-

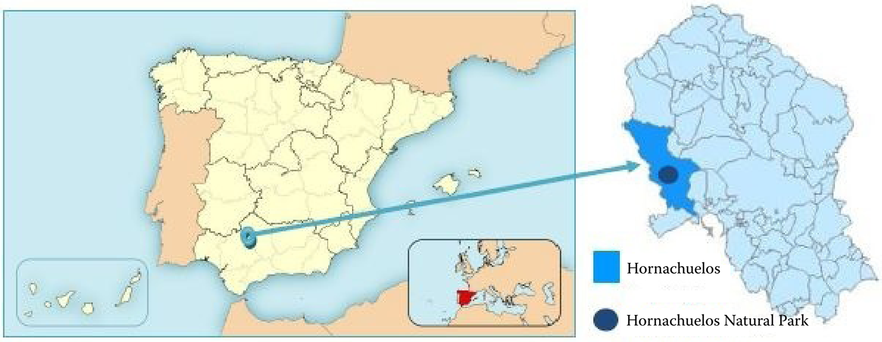

Figure 1. Location of the research area

Figure 2. Loma de los Jarales forestry farm – open vegetation sampling plot

Figure 3. Loma de los Jarales forestry farm – closed vegetation sampling plot

Figure 4. Los Lagares forestry farm – open vegetation sampling plot

er, the traps remained in place for five to twelve days. The process was repeated five times from March 2011 to January 2012.

Once in the laboratory, the caught specimens were identified, sexed, counted, labelled and definitively preserved, following the usual procedures in entomology.

The species of the greatest interest were classified according to the criteria defined in Laguna (2025).

- 'Exclusive' or with habitat rarity (very stenoic autoecology of the species). In our case, it is represented in only one of the four inventories to be compared.
- 'Rare or sporadic', with demographic rarity (low abundance or very poorly represented in the overall catalogue of the study area). In our case, there are fewer than five specimens recorded in all samplings.
- 'With restricted distribution' or with biogeographic rarity (species with reduced distribution). In our case, strictly Iberian (endemisms) or also located in North Africa (Ibero-Maghrebis).

In addition to specific identification and quantification, the results are analysed at the tribe level due to the correlation between taxonomic tribes and life strategies in the Carabidae (Talarico et al. 2016).

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Figure 5. Los Lagares forestry farm – closed vegetation sampling plot

The ecological indicators of richness (number of species), abundance (number of individuals of each species) and Shannon diversity (Bobbitt 2021) of the carabid communities were calculated and statistically compared by bootstrap tests (1 000 randomisations) using the PAST 2.17 program package (Hammer et al. 2001).

To estimate the faunal uniqueness of the surveyed environments, complementarity analysis was carried out using the Colwell and Coddington (1994) index, based on the number of exclusive species of each sampling area. Differences in carabid beetle assemblages were graphically displayed using non-metric multidimensional scaling (NMDS) based on Bray-Curtis dissimilarities. Species abundance data were subjected to square-root transformation prior to the analysis to reduce the influence of highly dominant species.

Finally, a Generalised Linear Mixed Model (GLMM) was used to identify which factor affects the carabid biodiversity to the largest extent. The presence of livestock and understory were included as fixed factors, the count was considered the response variable, and the species was the grouping component. The Akaike Information Criterion (AIC) was used to select the model that best fits the data distribution. A negative binomial distribution was chosen to model the data because it showed the best overall fit, handling data overdispersion (variance > mean) better.

The analysis was performed using the R Core Team (2020) software; the R packages used in the statistical analyses are: lme4, glmmTMB, emmeans, readxl, dplyr, tidyr and ggplot2 for the NMDS; and vegan, ggrepel, showtext, RColorBrewer, readxl and ggplot2 for the GLMM. The scripts would be available upon request to the authors.

RESULTS

During the sampling cycle, 631 specimens were recorded, belonging to 25 species of 11 tribes of the Carabidae (Table 1).

Results indicate that on the two forestry farms, both abundance and richness are higher in the plots with open vegetation, highlighting the number of individuals collected in Loma de los Jarales (370) and the number of species recorded in Los Lagares (19). The plot with closed vegetation of Los Lagares shows the poorest results with 52 specimens and only 5 species.

In line with these results, the number of represented tribes is also higher in the carabid fauna recorded in the open vegetation plots. Together, the open vegetation plots host 10 tribes (only the tribe Nebriini is missing), almost twice as many as in the closed vegetation ones. No quantitative differences were detected between forestry farms, when considering open and closed vegetation plots together, accounting for 9 tribes in both cases, although qualitative differences were found: Nebriini and Platynini are only present in Loma de los Jarales, while Zabrini and Harpalini were recorded exclusively in Los Lagares. The most disadvantaged plot in terms of tribal diversification is again the plot with closed vegetation of Los Lagares.

Table 1. Tribes (in capitals), specimens number, species number and tribes number of Carabidae collected in Loma de los Jarales and Los Lagares, differentiating the specimens number captured in the open and closed vegetation plots

CARABIDAE	JO	JC	LO	LC	Total
CARABINI					
Carabus rugosus Fabricius, 1792	1		1		2
C. lusitanicus Fabricius, 1801	19	7	2	12	40
NEBRIINI					
Leistus spinibarbis (Fabricius, 1775)		2			2
NOTIOPHILINI					
Notiophilus geminatus Dejean, 1831	11				11
N. marginatus Gené, 1839			1		1
N. quadripunctatus Dejean, 1826			2		2
TRECHINI					
Trechus diecki Putzeys, 1870		1		1	2
T. obtusus Erichson, 1837	6		2		8
BEMBIDIINI					
Bembidion ambiguum Dejean, 1831			1		1
B. tethys Netolitsky, 1826	16		2		18
PTEROSTICHINI					
Pterostichus globosus (Fabricius, 1792)	19	9	47	17	92
ZABRINI					
Amara aenea (DeGeer, 1774)			2		2
PLATININI					
Olisthopus hispanicus Dejean, 1825	1				1
SPHODRINI					
Platyderus emblema Marseul, 1871		1			1
Calathus granatensis Vuillefroy, 1866	292	45	65	21	423
HARPALINI					
Amblystomus niger (Heer, 1841)			1		1
LEBIINI					
Calodromius bifasciatus Dejean, 1825			1		1
Dromius agilis (Fabricius, 1887)			1		1
D. chobauti Puel, 1924		1			1
Metadromius rambourii (Piochard de la Brûlerie, 1868)	3		1	1	5
Mesolestes scapularis (Dejean, 1830)			1		1
Microlestes abeillei Brisout de Berneville, 1885			3		3
M. luctuosus Holdahus, 1904			5		5
Syntomus foveatus (Geoffroy, 1785)	2		3		5
Singilis alternans (Bedel, 1905)		1	1		2
Total specimens number	370	67	142	52	631
Total species number	10	8	19	5	25
Tribes number	8	6	9	5	11

JO – Loma de los Jarales open vegetation plot; LO – Los Lagares open vegetation plot; JC – Loma de los Jarales closed vegetation plot; LC – Los Lagares closed vegetation plot

The tribes Sphodrini, Pterostichini, Carabini and Lebiini account for 92% of the overall recorded abundance. Because of the great abundance of *Calathus granatensis* in the area, the tribe Sphodrini predominates in the four surveyed plots, and the tribe Pterostichini, represented only by *Pterostichus globosus*, reaches noticeable abundance levels in the two plots of Los Lagares (open and closed vegetation). The greatest faunal balance observed in Los Lagares is due not only to the presence of Pterostichini, but also to the good representation of Lebiini and Carabini in the open and closed vegetation plots, respectively.

Although four of the recorded tribes stand out for their abundance in the study area, only one (Lebiini) stands out in terms of richness (species number).

Breaking down the results of tribe Lebiini in the different plots, the one with open vegetation in Los Lagares (LO) has been by far the most favourable (only the species *D. chobauti* is missing), while the rest of the plots show quite homogeneous results.

The values of the Colwell and Coddington complementarity index (Table 2) calculated between the open and closed vegetation plots of each forestry farm were identical (80) and higher than those between plots of a similar type of vegetation of different forestry farms. In this sense, the greatest faunal homogeneity (minimum complementarity) was obtained between the two plots of closed vegetation, poor in species in both cases.

On the contrary, the most marked difference was established between the closed vegetation plot of Loma de los Jarales and the open vegetation plot of Los Lagares. In general terms, the complementarity of the types of environments (open/closed vegetation) exceeds that of the forestry farms (80 vs. 60).

In fact, the specific overlap between the carabids recorded on each forestry farm is double than that between plots with different types of vegetation (open vs. closed vegetation plots), with 10 and 5 common species, respectively. A large part of the faunal affinity between Los Lagares and Loma de los Jarales resides in their respective open vegetation plots, with 8 common species.

The NMDS analysis (Figure 6) clearly shows segregation on the four sampling plots, being in opposite positions on the plane without overlap, indicating high faunal differentiation between vegetation types (open/closed) and livestock presence (forestry farm); (stress = 0). Plots with open vegetation are closer to each other than those with different vegetation on each farm. Therefore, the open vs. closed vegetation factor has a greater influence on the composition of ground beetles than the forestry farm itself.

In addition to the observed high specific richness, ten exclusive species have been found in the open vegetation plot of Los Lagares, a number quite higher than in the remaining plots (Table 1). These species represent more than half of the inventory. In this sense, the level of the fauna exclusivity in the two plots with open vegetation, jointly considered, is four times higher than that recorded in the areas with closed vegetation (16 vs. 4 species), although all the exclusive species of the latter (*L. spinibarbis, P. emblema, D. chobauti* and *T. diecki*) are rare and

Table 2. Complementarity Index among sampling stations, the total obtained for the forestry farms and the total obtained for the vegetation types

	JO	JC	LO	LC
JO	–	3*	8*	4*
JC	80	–	4*	4*
LO	61.9	82.6	–	4*
LC	63.6	55.6	80	–
	J	L	O	C
J	–	10*	–	–
L	60	–	–	–
O	–	–	–	5*
C	–	–	80	–

*number of shared species; JO – Loma de los Jarales open vegetation plot; JC – Loma de los Jarales closed vegetation plot; LO – Los Lagares open vegetation plot; LC – Los Lagares closed vegetation plot; J – Loma de los Jarales; L – Los Lagares; O – open vegetation plot; C – closed vegetation plot

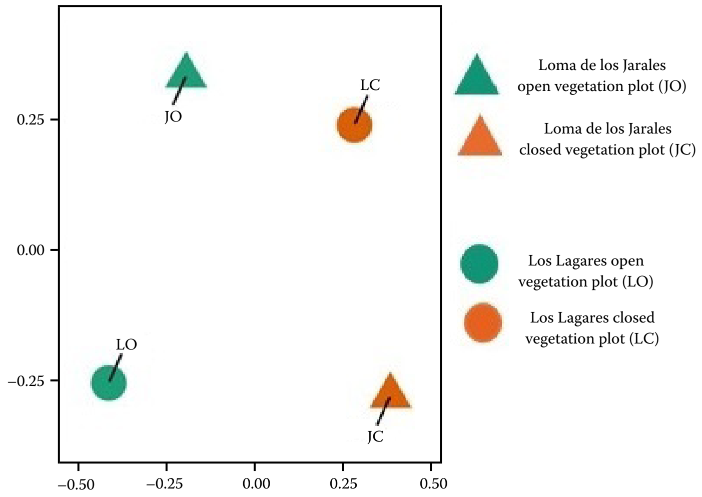

Figure 6. NMDS (non-metric multidimensional scaling) ordination (Bray-Curtis distance) of carabid assemblages found in open and closed vegetation plots of the two forestry farms (stress is goodness-of-fit)

endemic species. Indeed, the endemicity of carabids in the plots with closed vegetation is extreme, with numerous species of restricted distribution *sensu lato* (Table 3).

Having established that there are more faunal differences between plots with different vegetation types than between forestry farms, a direct comparison of the former was undertaken, us-

Table 3. List of species recorded in the sampling stations

JO	LO	JC	LC
*Carabus rugosus**	*C. rugosus**	*C. lusitanicus**	*C. lusitanicus**
*C. lusitanicus**	*C. lusitanicus**	*Leistus spinibarbis*	*Trechus diecki***
Notiophilus geminatus	*Notiophilus marginatus*	*Trechus diecki***	*Pterostichus globosus**
Trechus obtusus	*N. quadripunctatus*	*Pterostichus globosus**	*Calathus granatensis**
Bembidion tethys	*Trechus obtusus*	*Platyderus emblema**	*Metadromius rambourii***
*Pterostichus globosus**	*Bembidion ambiguum*	*Calathus granatensis**	
*Olisthopus hispanicus***	*B. tethys*	*Dromius chobauti***	
*Calathus granatensis**	*Pterostichus globosus**	*Singilis alternans**	
*Metadromius rambourii***	*Amara aenea*		
Syntomus foveatus	*Calathus granatensis**		
	Amblystomus niger		
	Calodromius bifasciatus		
	Dromius agilis		
	*Metadromius rambourii***		
	*Mesolestes scapularis***		
	Microlestes abeillei		
	M. luctuosus		
	Syntomus foveatus		
	*Singilis alternans**		

Asterisks – the most restricted distribution species: *Iberian endemism, **Ibero-Maghrebi endemism; JO – Loma de los Jarales open vegetation plot; LO – Los Lagares open vegetation plot; JC – Loma de los Jarales closed vegetation plot; LC – Los Lagares closed vegetation plot

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ing the parameters of Carabidae richness and abundance.

Although these values are higher in the open vegetation plots than in those with greater vegetation cover, the diversity expressed by the Shannon Index does not reflect any significant differences (diversity *H*': 1.233 and 1.250 for open and closed vegetation plots, respectively; *P*-bootstrap = 0.929).

Finally, the GLMM (Table 4) only found significant differences in the effect of the type of vegetation. The presence of shrubs and bushes reduces the carabid abundance while the livestock itself does not have a significant effect on the fauna, once controlled for natural variability between species and dispersion in data.

The expected mean abundances for each combination of livestock and vegetation can be obtained from the fixed effects predicted by the model, resulting higher in the case of open vegetation plots than in the case of closed vegetation plots (Figure 7).

Table 4. Fixed effects estimate from the conditional GLMM model for Carabidae including intercept, livestock, vegetation, and their interaction

Conditional model	Estimate	SE	*Z* value	*P* (> |*Z*|)
Intercept	0.57759	0.45759	1.262	0.206855
Livestock/no livestock	–0.05377	0.45486	–0.118	0.905893
Vegetation/undergrowth	–1.75866	0.52701	–3.337	0.000847***
Livestock/no livestock/vegetation/undergrowth	0.36628	0.70167	0.522	0.601665

***very strong significance ($P \leq 0.001$); GLMM – Generalised Linear Mixed Model; SE – standard error

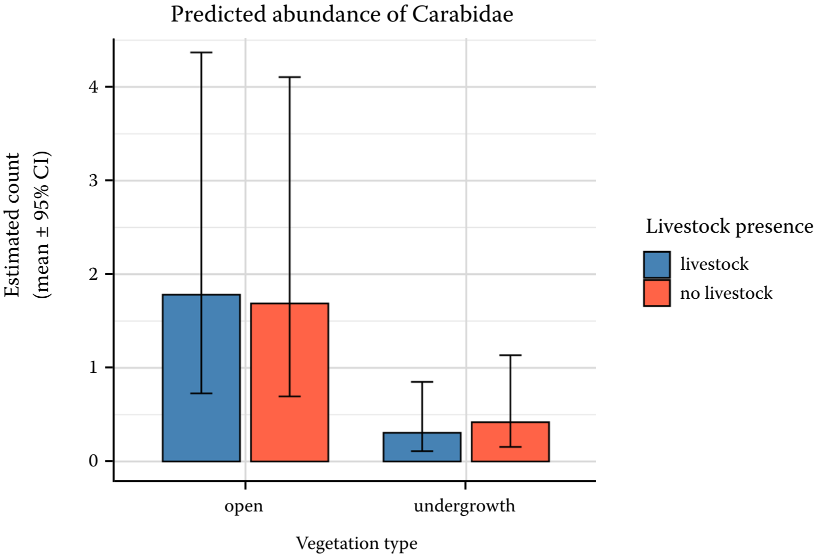

Figure 7. Fixed-effects predictions from the negative binomial GLMM

Bars represent the estimated mean abundance of Carabidae for each combination of vegetation type and livestock presence; error bars indicate 95% confidence intervals (CI)

DISCUSSION

The current fauna in the Mediterranean region is extraordinarily diverse and broadly adapted to the impacts of land management practised over a long time (Blondel et al. 2010). In the southern Iberian Peninsula, the forest landscape is dominated by wooded savannah-like pasture lands, called 'dehesas', a unique Mediterranean ecosystem combining high ecological value and noticeable socioeconomic services if under the proper management regime (Moreno et al. 2018). The literature review performed by Rodríguez-Rojo et al. (2022) concluded that different agronomic practices for the maintenance of this ecosystem may have a variable effect on biodiversity depending on their type and level of intensity. In addition, these authors advised that a hitherto unresolved issue is the impact of extensive livestock on vegetation structure and its combined effect on other biological components of the Dehesa, suggesting that delving into this topic could be useful as scientific support for decision-making in agricultural and conservation policies.

While the dehesa is considered a key support for biodiversity conservation in the Mediterranean region, it is immersed in long and complex uses of the territory, which causes conflicts between conservation and economic exploitation (Sánchez-Martín et al. 2019). It is remarkable that the main problem for the dehesa conservation derives from the disappearance or transformation of the traditional uses that generated and maintained it. The disappearance of traditional grazing (sheep), its replacement by other more intensive forms of livestock (cattle), conversion to crops or simply the abandonment of any management cause degradation or disappearance of the habitat and consequently of the biodiversity it harbours (SGPC 2022).

To address the effect of practices related to livestock farming and vegetation management on soil biodiversity of the dehesa, carabid beetles were selected because this group of insects is considered one of the most representative families of edaphic coleopterans and with greater indicator potential (Kosewska et al. 2023).

Observations of patterns of the species presence and abundance provide a framework that allows us to assess future changes that could hamper the conservation of local diversity. To understand the impact of livestock and vegetation structure, we provide qualitative and quantitative baseline information on Carabidae species recorded on two forestry farms with different use (with/without livestock), distinguishing also two structural types of vegetation (open/closed) on each of them. Faunistic variations could be assessed from the data in future, as well as related pressing issues, such as changes in management policies. It is true that the data collection in the field was carried out in the last decade, so the presented results correspond to a snapshot of a previous situation. This circumstance does not diminish the value of the information obtained; rather, on the contrary, the elapsed time is long enough to allow for the detection and interpretation of possible changes if new surveys are conducted in future.

The results obtained indicate that the vegetation type is more determinative for the carabid beetle fauna than the differences related to livestock farming. The differences observed in the various parameters considered, such as richness, abundance, diversification at different taxonomic levels, or faunistic uniqueness between what has been termed 'open' and 'closed' vegetation plots, exceed those established between the two forestry farms. The graphical representation of the position of each sampling plot in the ordination space (NMDS analysis) supports the highly complementary values obtained between open and closed vegetation plots (Colwell and Coddington index), confirming that faunal replacement is greater between vegetation types than between forestry farms with different types of livestock use.

In fact, the species richness, the most commonly used criterion of habitat characterisation due to its ease of assessment, clearly indicates that open spaces are the ones that contribute to the most specific variety. These areas, which are actually moderately open, support the fauna from both highly exposed environments and typically forested areas, blending as if they were true ecotones. These findings are consistent with those obtained by Mullen et al. (2008), in the sense that open habitats such as pastures, croplands and other areas without forest cover harbour a greater number of carabid species compared to forested environments. Similar results have also been found in other insect groups, i.e. it has been stated that the plant structure clearly drives the taxonomic and functional composition of ants (Frenette-Dussault et al. 2013) and grasshoppers (Van der Plas et al. 2012). Verdú et al. (2007) indicated that cattle farming maintains a diversified land mosaic, and these areas support more diverse dung beetle ensembles than homogeneous areas of closed and shrubby vegetation cover; Karacetin et al. (2022) also concluded that in areas with the mosaic structure of grazing and mowing, the butterfly diversity was higher.

Contrarily, recent studies in the Mediterranean area indicate that the carabid diversity is favoured by vegetation because the forested patches with shrubs act as shelter/refuge in agroforestry landscapes (Baptista et al. 2024).

As might be expected, in our study, the shared fauna (whether between plots, vegetation types, or forestry farms) is mainly contributed to by the common and most abundant species. Concretely, only the three species clearly dominant in the study area (*C. lusitanicus*, *P. globosus* and *C. granatensis*) were recorded in the four inventories.

Agreeing with the Martín-Piera (2000) criterion, regarding the usefulness of using high-ranking taxa to assess diversity affected by the uses and overexploitation of terrestrial ecosystems, the tribes of carabids present in the different studied vegetation plots were also analysed. It was found that the areas with dense vegetation are less suitable for the species establishment, resulting impervious to tribes adapted to more exposed environments (Harpalini, Zabrini, etc.). The predominance of the Sphodrini and Pterostichini is due to the abundance of dominant species such as *C. granatensis* and *P. globosus*, both generalist and good competitors in silvicultural ecosystems as well as in open environments. Given the correspondence between taxonomic tribes and life strategies (mainly expressed by feeding guilds and reproduction time) in Carabidae (Talarico et al. 2016), the broad taxonomic spectrum of assemblages recorded in plots with cleared vegetation reveals greater functional diversity than in areas with undergrowth. The diversification of roles – in this case, akin to tribes – is more relevant for the ecosystem functioning than the species composition itself (Giller et al. 2004), considering that certain species may have a redundant effect within the same community (Walker 1992), when this aspect is optimised in dehesas. At a higher taxonomic scale, the tribe with the highest indicator potential in the study area is the Lebiini, the most diversified and with a significant proportion of species inhabiting the bark of trees, which links it directly to the forest environment (Atienza et al. 1995). The plots with open vegetation contain more generalist fauna of limited interest from the point of view of conservation. On the other hand, very few species are restricted to closed vegetation plots (only 16% of the total richness of the area), but they are of greater interest in terms of their rarity, endemicity and, consequently, greater vulnerability. The affinity of these carabids to closed forests could raise doubts due to the small number of captures, but it is verifiable from the information available on their biology (Thiele 1977; Casale 2000).

The top representative of this type of fauna is *P. emblema*, the most endemic species of the recorded ones, known only from the western Sierra Morena (Hidalgo, Cárdenas 2024). Taboada et al. (2006) also found a few silvicolous species exclusive to forested zones. These authors indicated that the open habitat species are expected to thrive in the grasslands and that the generalist species are expected to be less influenced by differences between the two habitat types.

It is obvious that the vegetation cover influences the degree of sunlight/shade and, therefore, the soil temperature, particularly in drylands of the Mediterranean Region (Lozano-Parra et al. 2018). On the other hand, Tsafack et al. (2029) found that the climate (temperature and humidity) plays a greater role than soil and vegetation in determining the abundance, richness, and diversity of carabid assemblages.

On this concern, several studies have shown that temperature can be a major driver of carabid diversity (Saska et al. 2013), also affecting the activity and abundance of species (Honek 1997), with warmer areas generally exhibiting higher diversity (Robinson et al. 2018). This agrees with our observations and those of the authors mentioned above, finding greater diversity and abundance of carabids in plots with less vegetation and, therefore, with the soil more exposed to the sunlight.

Nevertheless, another feasible explanation for these observations could be related to the sampling method. When using pitfall traps, the catch is dependent not only on the actual density of the insects in the field, but also on other factors such as their own dispersal power, which is, in turn, dependent on temperature (Saska et al. 2013). While effective, pitfall traps have some limitations, including biases in species capture that depend on factors such as trap design, preservative used, and the activity patterns of beetles. The ease of this sampling technique and its reliability compared to other less standardised procedures have normalised its use, despite some limitations regarding the bias in the capture of the most active species (Holland 2002; Honbein, Connawy 2018).

Finally, it could be mentioned that carabid populations are suffering a global decline, with studies showing significant reductions in the population size and diversity of species (Pozsgai, Littlewood 2014). This decline is attributed to various factors, including climate change, habitat loss, and agricultural intensification. To protect these insects, conservation approaches are necessary, such as managing habitats with sustainable farming methods and monitoring carabid populations (Ramakrishna et al. 2024).

CONCLUSION

Regarding the effect of extensive livestock farming and vegetation structure on the biodiversity of carabid beetles, it can be concluded that the type of vegetation is more decisive in the singularity and diversity of fauna in the studied area of the Sierra Morena.

Dehesas harbour the carabid fauna typical of open areas together with forest species. For this reason, it is important to carry out good management, promoting their conservation or regeneration.

In the southern Iberian Peninsula, oak forests conserving the undergrowth are a reservoir of unique carabid species in terms of rarity and endemicity, resulting in 'key habitats' in the field of conservation in the face of the progressive loss of surface area in agroforestry landscapes.

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