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Intermediate fragmentation surrounding vineyards favours the Coleoptera community within the crop

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Abstract

1. Insects of the order Coleoptera play an essential role in agricultural sustainability by supporting many ecosystem services (such as biological control, nutrient cycling or pollination). In agroecosystems, the Coleoptera community may be influenced by the surrounding landscape, which can provide living resources, like food or shelter, during different seasons, originating spillover movements between different environments.
2. The present study aimed to evaluate the response of the Coleoptera community to the landscape surrounding vineyards at different buffers. For that, Coleoptera were sampled in six wine protected designation of origin (PDO) regions of Portugal (35 vineyards), and landscape configuration and composition metrics were calculated at buffers of 500, 750, 1000, 1500 and 2000 m radii around the vineyards.
3. In total, 2954 Coleoptera individuals belonging to 36 families were collected. The most abundant families were Chrysomelidae, Coccinellidae and Latridiidae. Results indicated that intermediate habitat fragmentation levels, particularly in semi-natural areas and vineyards, favoured Coleoptera biodiversity in vine-producing regions. Moreover, the range of activity of Coleoptera seems to be larger than 1000 m.
4. This work constitutes an important contribution to understanding the response of the Coleoptera community to the landscape context in vineyards in Portugal and contributes to the theoretical framework about the influence of habitat fragmentation on biodiversity.

KEYWORDS
beneficial arthropods, ecosystem services, landscape composition, landscape configuration, low-impact practices., *Vitis vinifera*, wine regions

INTRODUCTION

Vineyards have configured the culture and landscape of the Mediterranean basin through the centuries; currently, this crop is rapidly expanding across regions with a Mediterranean climate (Paiola et al., 2020). In Portugal, vineyards contribute significantly to agriculture, the economy and society. Vineyards currently occupy around 190,322 hectares in vine-growing areas designed for wine and total production of 6,061,243 hectolitres (hl) (Instituto da Vinha e do Vinho, 2018). More than 30 wine protected designation of origin (PDO) Portuguese regions are historically distinguished by specific environmental characteristics, such as climate, soil and varieties (Fraga et al., 2012).

Agricultural crops, such as vineyards, hold specific arthropod communities that vary across the year's seasons. The surrounding landscape can influence this variation (Stoms, 1994). In vineyards, various functional guilds, including predators, are influenced by landscape (Christine et al., 2019). Moreover, different organisms have different ranges of distances in which they perform their activity. Therefore, the spatial scale used for the landscape quantification (i.e., distance from the crop) can determine the perceived effect of landscape on biodiversity (Whittaker et al., 2005). For example, some studies found that the abundance and diversity of beneficial arthropods within vineyard ecosystems are positively influenced by the large-scale habitat heterogeneity (Franin et al., 2016; Pérez-Bote & Romero, 2012; Ramos et al., 2019).

Arthropod pests are responsible for important production losses in crops. In the case of the vineyards, the crop attracts many arthropod pests that can reduce yield or, in severe cases, cause plant death (Gonçalves et al., 2017; Sharma et al., 2018). Commonly, these pests are controlled using insecticides (Paiola et al., 2020). However, several natural enemies can contribute to pests' reduction in vineyards. Among them, the order Coleoptera takes especial importance (Altieri et al., 2010; Gonçalves et al., 2013; Gonçalves et al., 2017). In vineyards, some Coleoptera species have been indicated as potential natural enemies of mealybugs, mites and moth pests (Altieri et al., 2010; Thomson & Hoffmann, 2013). Moreover, Coleoptera stands out for its high taxonomic and functional variety (Marinoni, 2001) and, therefore, the provision of multiple ecosystem services besides biological control, such as nutrient cycling, bioturbation, plant growth enhancement, secondary seed dispersal, pollination or trophic regulation (Nichols et al., 2008). Beetles can also perform ecosystem disservices such as intraguild predation, granivory or crop consumption, only increasing the importance of studying their population dynamics.

These organisms may be enhanced through the conservation or manipulation of the environment. One common strategy of habitat manipulation, particularly for conservation biological control (CBC), is establishing or maintaining vegetation ground covers. Plants can provide food resources, alternative hosts, and prey and shelter or oviposition places to natural enemies (Landis et al., 2000). The positive effect of vegetation (not only in the interrow but also adjacent to the crop) on the richness and abundance of natural enemies is described in many studies (e.g., Álvarez et al., 2019; Franin et al., 2016; Geldenhuys et al., 2021; Gonçalves et al., 2020; Paiola et al., 2020; Sáenz-Romo et al., 2019; Shapira et al., 2018; Thomson & Hoffmann, 2009; Thomson & Hoffmann, 2013). In vineyards, the presence of vegetation was related to an increase (i) in functional diversity of insectivorous birds (Lourenço et al., 2021), (ii) in beneficial arthropods (Gonçalves et al., 2020) and (iii) in pest predation, parasitism and reduction of pests (e.g., Rusch et al., 2017; Thomson & Hoffmann, 2009; Thomson & Hoffmann, 2013).

The surrounding landscape can also affect Coleoptera and non-agricultural habitats close to crops, which are typically considered to increase beneficial insect populations (Thomson & Hoffmann, 2013). However, the effects of non-agricultural crops may be not positive in all cases. For example, natural and semi-natural areas near vineyards have a minor influence on beneficial insect abundance (Christine et al., 2019). This has been attributed to frequent disturbances, such as soil management and/or use of phytosanitary products in perennial crops (like the grapevines) (Rusch et al., 2017), which could make the conditions of noncrop areas close to the vineyards more attractive and favourable to the arthropods than the vineyards (Paredes et al., 2013; Uzman et al., 2020).

Despite the increment of investigation in the last decades about biodiversity patterns and ecosystem services in vineyards (Paiola et al., 2020; Ramos et al., 2019), and the recognized role of Coleoptera as an important group of insects in this crop (e.g., Caprio et al., 2015; Geldenhuys et al., 2021; Jiménez-García et al., 2019; Sáenz-Romo et al., 2019; Thomson & Hoffmann, 2009; Thomson & Hoffmann, 2013), the knowledge about this group in Portuguese vineyards is still deficient. In Portugal, published data about Coleoptera mainly focus on the Demarcated Region of Douro and mostly on the ground beetle's community of vineyards (Carlos et al., 2019; Gonçalves et al., 2019; Sharma et al., 2018) or Coleoptera in other crops, such as olives, almonds, chestnuts or citrus (Benhadi-Marín et al., 2011; Magro & Hemptinne, 1999; Santos et al., 2012).

In this context, in this work, the response of the Coleoptera community to the landscape structure at different scales was analysed in vineyards with low-impact management practices from several Portuguese wine producer regions and the Coleoptera community described.

MATERIAL AND METHODS

Study area

The study was conducted in Portugal, in six different wine PDO Regions, namely Bairrada, Beira Interior, Douro, Trás-os-Montes and Península de Setúbal, representing a total of 35 vineyards (Figure 1). All vineyards were under low-impact producing systems (integrated or organic), and the vegetation ground cover was maintained in the inter-rows during the sampling periods. Details about temperature and precipitation in each sampled region and date, coordinates, area, orientation (north, south, east, west), altitude, spacing between vines and among rows, grapevine varieties, vine training method (i.e., unilateral or bilateral), applications of phytopharmaceutical products, production mode and soil management of each vineyard are specified in Table S1.

Sampling methods

Sampling occurred using a standard entomological sweep net of 38 cm diameter. Individual samples consisted of 50 sweeps of the canopy and 10 sweeps of the herbaceous vegetation ground cover for each vineyard and sampling date, randomly selected in the field, distributed over 1 ha and separated at least by 25 m. The number of sweepings in the canopy was higher than in the herbaceous vegetation to avoid the underrepresentation of canopy arthropods derived from branches, which hindered the sampling. Each sweep was performed by moving the entomological sweep 180 degrees. The net contents were transferred into a plastic bag, and 0.3 ml of diethyl ether was added with a syringe to kill the arthropods immediately. Twenty samples (10 for the canopy and 10 for the vegetation ground cover) were

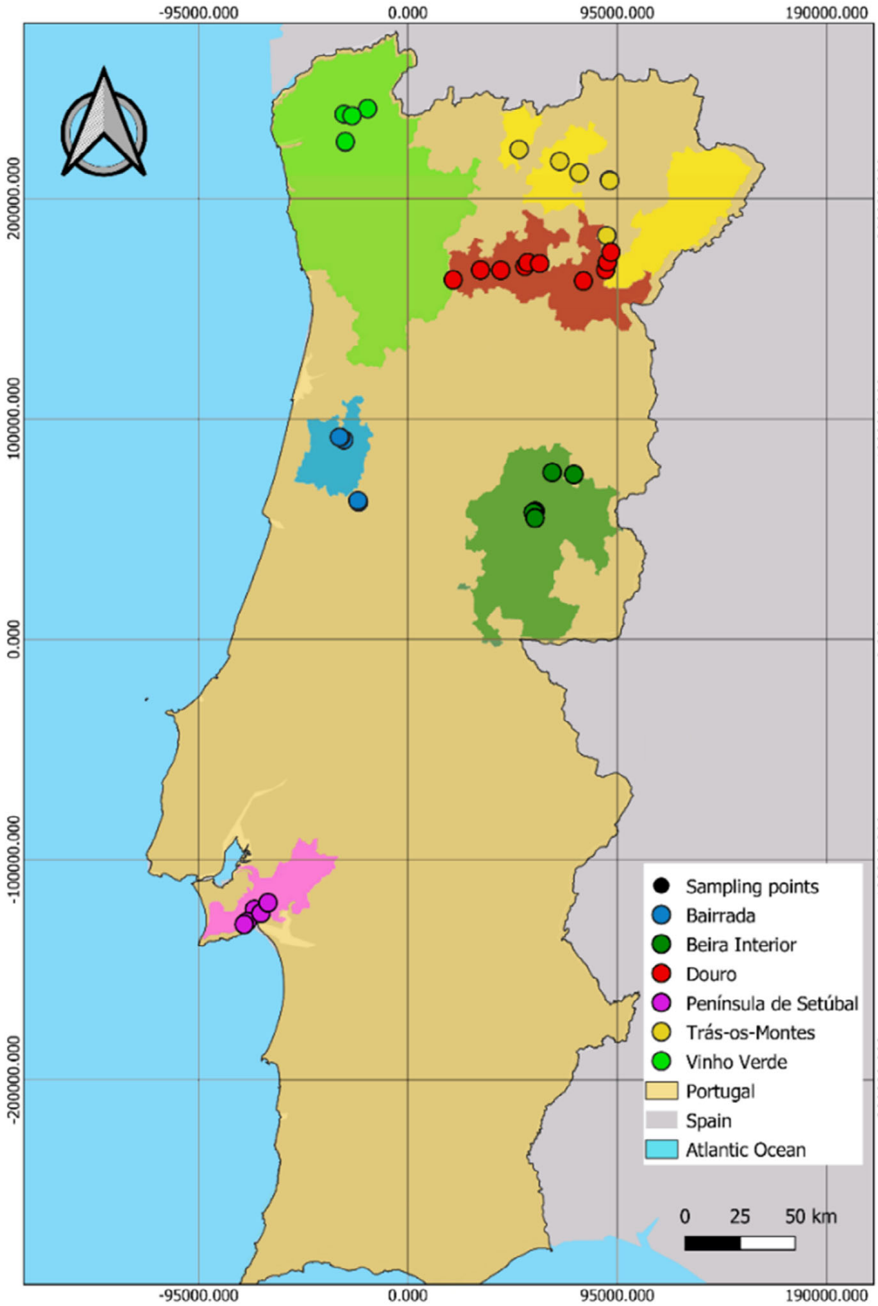

FIGURE 1 Map of Portugal with the studied wine PDO regions and the location of the sampled vineyards. The map was projected in ETRS89/PT-TM06.

taken within each site on three dates (early July—representing a period with favourable conditions for arthropods, mid-September, and mid-October 2019—representing a period when overall arthropod abundance is lower). In the laboratory, all samples were frozen at −20°C. Arthropods were separated under a stereomicroscope and conserved in ethanol 96% until further identification. The adults of the order Coleoptera were identified up to the family taxonomic level with an entomological key (Harde & Severa, 1984). All specimens were stored in the collection of the Mountain Research Center (CIMO) at the Polytechnic Institute of Bragança, Bragança, Portugal.

Landscape analysis

Buffers construction

Five circular areas (buffers) with 2000, 1500, 1000, 750 and 500 m radii were nested around each study site (Figure 2). To avoid overlapping between nearby territories contained within buffers and elude spatial autocorrelation, several vineyards were excluded. A total of 25 vineyards were selected for the buffer construction and further data analysis. Land-use classes occurring across study sites were

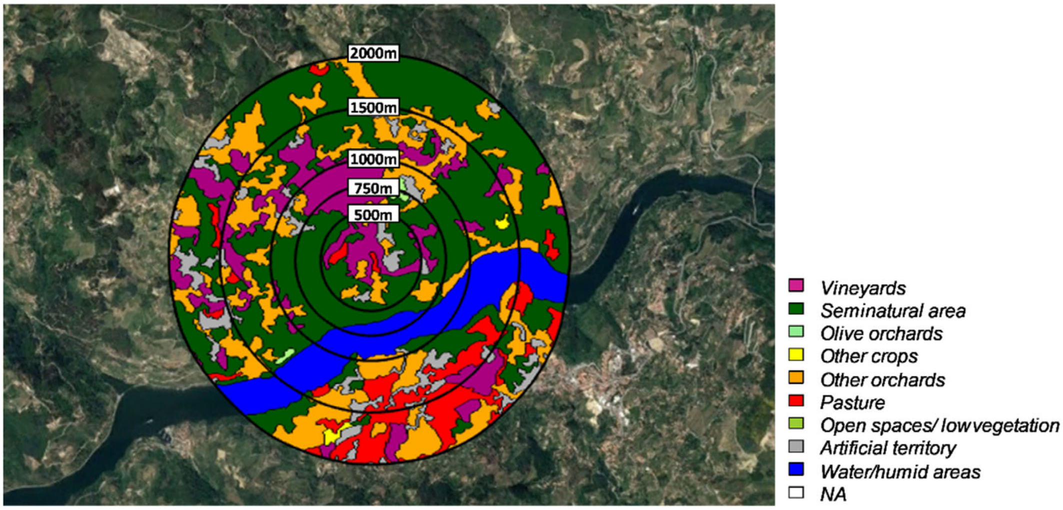

FIGURE 2 Illustration of one of the sampled vineyards. Land uses and buffers used for the landscape metrics are indicated.

obtained from the polygon map "Carta de Uso e Ocupação do Solo de Portugal Continental para 2018" (COS2018). The different types of land use and their percentage cover (area) within each circle were assessed to determine the landscape composition and configuration. Buffers were generated in R software version 4.1.0 (R core team, 2021), using the *buffer* and *intersect* functions from the "raster" package (Hijmans, 2021). The function *aggregate* from the "raster" package was used to aggregate all polygons with the same land use, and then the function *msexplode* from "rmapshaper" package (Teucher & Russell, 2021) was used to generate an individual polygon from each patch. The *area* function from "raster" was used to calculate the area (ha) of the polygons. The intersection process originated several polygons smaller than 25 m^2 in the buffer edges. Those small polygons were merged to a larger adjacent polygon to reduce metric misspecifications (resolution of orthophotos for the generation of the COS2018 is 25 m^2) ArcGIS, version 10.3.1 (ESRI, Redlands, California) was used. Land-use classes considered to calculate the landscape metrics were vineyards, semi-natural areas (SNH), olive orchards, other crops, other orchards, pasture, open space/low vegetation (bared areas), artificial territory and water/humid areas.

Landscape variables

At the landscape level, that is, including all reclassified land classes (habitat types), the calculated landscape metrics for quantifying the landscape configuration were the mean patch size (MPS), which is the mean area of patches (hectares), and the mean perimeter area ratio (MPAR), which quantifies the shape complexity, resulting from the sum of each patch perimeter/area ratio divided by the number of patches (metres/hectare). For the landscape composition at the landscape level, the Simpson's diversity index (SEI), which represents the probability that any types selected at random would be different types, was calculated (McGarigal & Marks, 1995). At the class level, the area (hectares) covered by vineyards and SNH was considered for further analysis.

Data analysis

Coleoptera's response to landscape context

The response of the Coleoptera richness and abundance to the landscape at the different buffers were analysed using a generalized mixed model (GLMMs) (separated models for richness and abundance, and one model for each buffer—2000, 1500, 1000, 750 and 500 m—and month). All full models included the following explanatory variables: the coordinates of the sampling sites (longitude and latitude) as proxies for environmental conditions related to location, the landscape diversity index (SEI), the landscape complexity (MPAR and MPS), areas of vineyards (Vin) and semi-natural vegetation (SNH), the month (July, September and October) and the habitats (two levels: vegetation ground cover and canopy). The interactions between landscape complexity (MPAR) and the areas of SNH and vineyards were also included.

Before running the models, the absence of collinearity among explanatory landscape variables was confirmed using the variance inflation factor (VIF). Maximum VIF was 2. 91, 2.77, 2.82, 2.86 and 2.95 for variables in 2000, 1500, 1000, 750 and 500 m buffers.

The Poisson (for count data) and negative binomial—quadratic parameterization (nbinom2)—to account for overdispersion distributions (Bolker 2021) were used for the models. The distribution used for each model is indicated in Data S1. The backward selection was performed until all explanatory variables were significant or the model validation failed. Then, the most explanatory model (keeping the highest number of explanatory variables) within <2 ΔAIC was selected. The individual AIC values are not interpretable as they contain arbitrary constants and are much affected by sample size, and AIC is rescaled to:

$$\Delta i = \mathrm{AICi} - \mathrm{AICmin},$$

where AICmin is the minimum of the different AICi values (i.e., the minimum is at i = min). Models having Δ i ≤ 2 have substantial support(evidence), those in which 4 ≤ Δ i ≤ 7 have considerably less support, and models having Δ i > 10 have essentially no support (Burnham & Anderson, 2004). The function glmmTMB from the "glmmTMB" package was used for the model's fit (Brooks et al. 2017). Models were validated using the simulateResiduals function from DHARMa package (Hartig, 2021).

RESULTS

Description of Coleoptera community

A total of 2954 individuals of the order Coleoptera belonging to 32 families and four subfamilies were collected (Table S2). The most abundant families were Chrysomelidae with 753 individuals (representing 25.49% of the total individuals), Coccinellidae with 325 individuals (11%) and Latridiidae with 301 individuals (10.19%). From all individuals collected, 80.33% belonged to the herbaceous layer. Generally, Coccinellidae, Phalacridae, Chrysomelidae and Latridiidae were abundant in the vegetation ground cover in July, Staphylinidae was abundant in October, and Chrysomelidae in October and September (Table S2).

Coleoptera's response to landscape variables

The model outputs are shown in Table S3.

Richness

The complex shape of small areas of SNH increased the richness of Coleoptera families, whereas the complex shape of large areas of SNH reduced the richness (positive SNH:MPAR interaction) at the 2000 and 1000 m buffers (Figure 3). Moreover, landscapes with larger land patches (MPS) favoured greater beetle richness at the same buffers. Larger vineyards also favoured greater beetle richness (at the 1500, 750 and 500 buffers). A tendency of positive effect and negative effect of MPAR and SNH were detected at the 1500 buffer (Figure 3).

Abundance

Similar to the richness, the complex shape of small areas of SNH increased the abundance of Coleoptera, whereas the complex shape of large areas of SNH reduced it (a positive tendency of SNH:MPAR interaction) at 2000. This pattern was also detected for the interaction between landscape complexity (MPAR) and the area of vineyards at the same buffer. The landscape complexity favoured the Coleoptera abundance at 1500 and 1000 m (although the trend was inverted for the

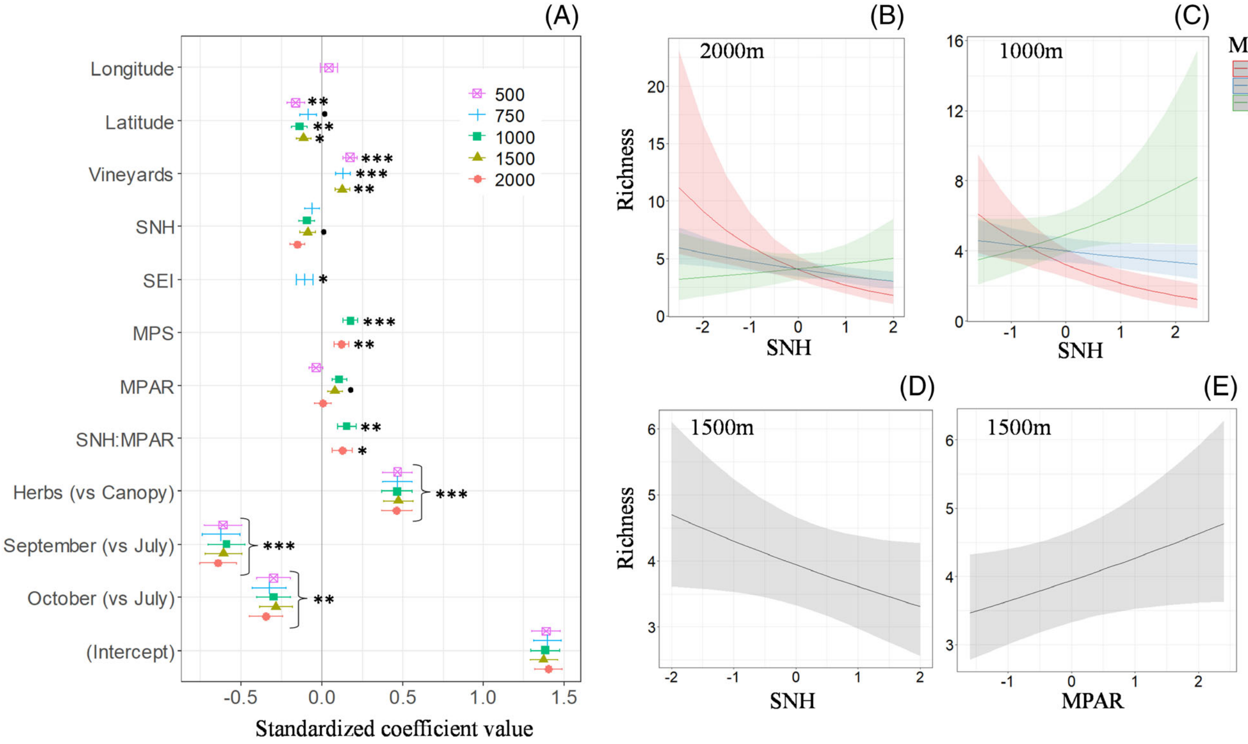

FIGURE 3 Response of Coleoptera family richness to landscape variables, longitude, latitude, strata (herb and vine canopy) and date (July, September and October) (GLMM). (A) Standardized coefficient value (±SE) (***<0.001; **<0.01; *<0.05; ·<0.1); (B) Interaction effect of MPAR and SNH at the 2000 m buffer; (C) Interaction effect of MPAR and SNH at the 1000 m buffer; (D) SNH effect at 1500 buffer; (E) MPAR effect at 1500 buffer. SNH, Semi-natural habitat; SEI, Simpson's diversity index; MPS, Mean patch size; MPAR, Mean perimeter area ratio

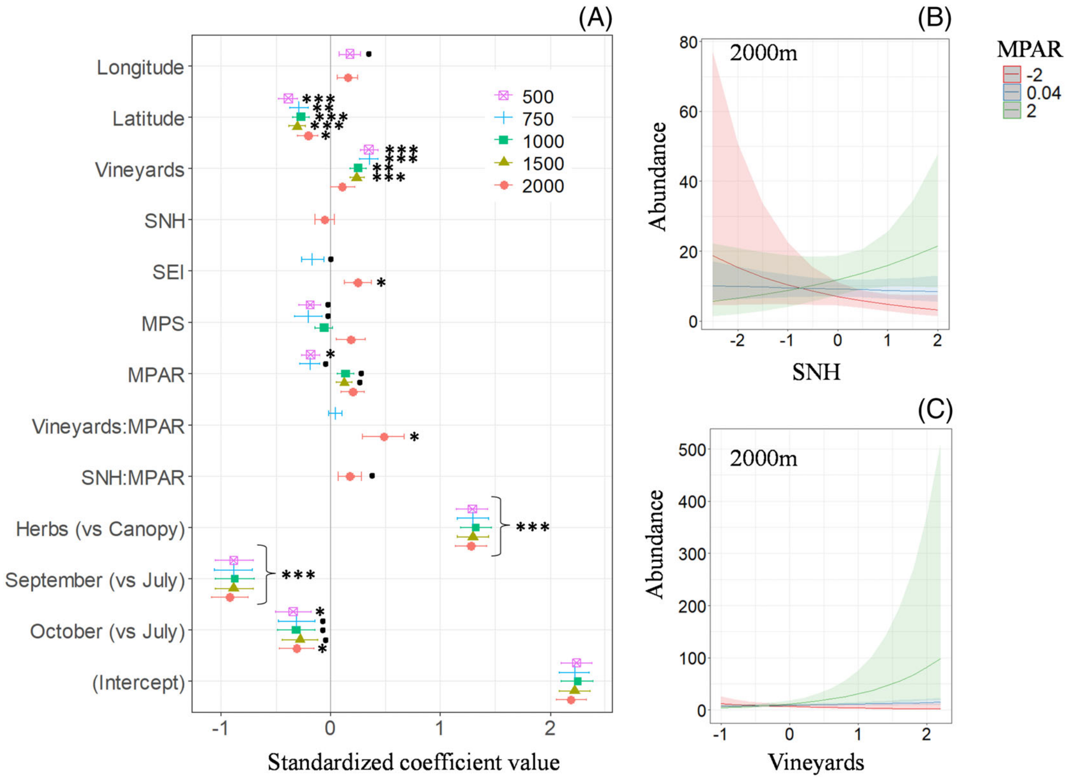

FIGURE 4 Response of Coleoptera abundance to landscape variables, longitude, latitude, strata (herb and vine canopy) and date (July, September and October) (GLMM). (A) Standardized coefficient value (±SE) (***<0.001; **<0.01; * < 0.05; ·<0.1); (B) Interaction effect of MPAR and SNH at the 2000 m buffer; (C) Interaction effect of MPAR and vineyards at the 2000 m buffer. SNH, Semi-natural habitat; SEI, Simpson's diversity index; MPS, Mean patch size; MPAR, Mean perimeter area ratio

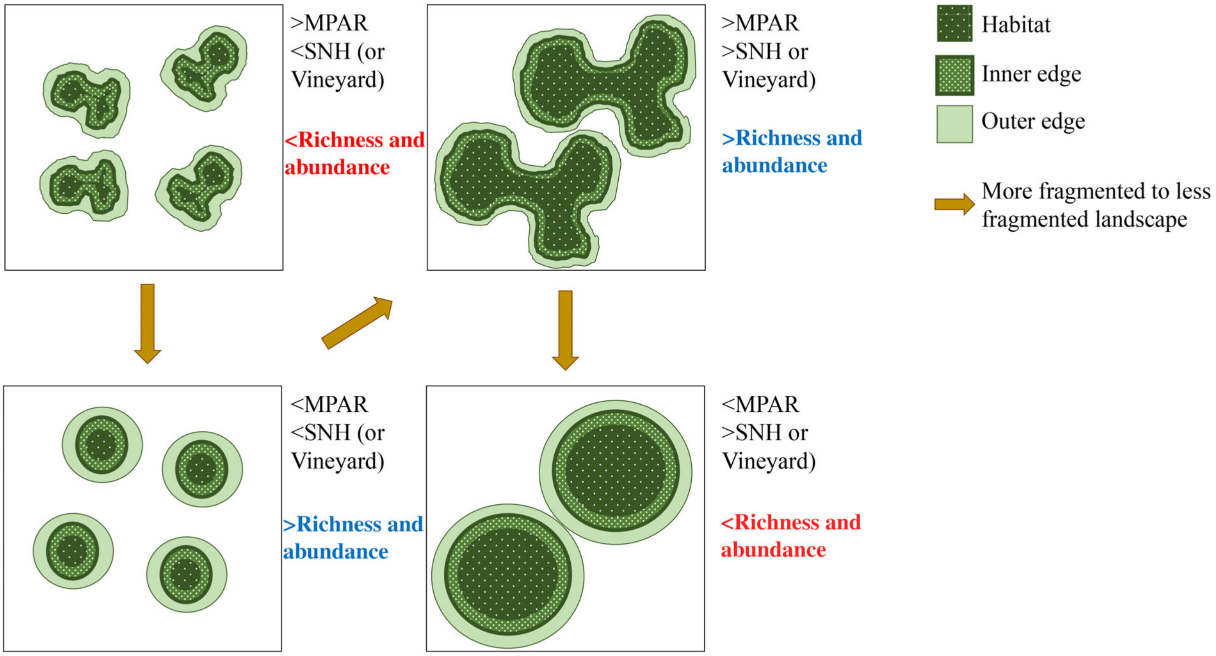

FIGURE 5 Scheme representing the fragmentation of habitat understood as the combined effect shape complexity (MPAR, Mean perimeter area ratio) and patch size (SNH, semi-natural habitat or vineyard) on the richness and abundance of Coleoptera

smallest buffers, 750 and 500 m). The patch size (MPS) was also related with a lower Coleoptera abundance at the smallest buffers. Generally, the area of vineyards favoured the richness. Moreover, the diversity of land uses (SEI) favoured a higher abundance of Coleoptera at the largest buffer (Figure 4).

Coleoptera across sampling dates and strata

Both richness and abundance of Coleoptera were significantly higher in July than in the autumn months (September and October), and in the herbaceous strata than in the vine canopies (Figures 3 and 4).

Coleoptera across location

Generally, the richness and abundance of Coleoptera increased to the south (Figures 3 and 4). A tendency of abundance increase to the east was detected at the 500 m buffer (Figure 4).

DISCUSSION

Coleoptera response to the surrounding landscape

In this work, landscape complexity in landscapes with large patches of SNH and vineyards at the largest buffers favoured a richer and more abundant Coleoptera community. However, landscape complexity in landscapes with smaller patches penalized the abundance and richness of the Coleopteran community. Pérez-Bote and Romero (2012) found that niche opportunities are likely higher in complex land uses but are reduced in simplified contexts. This agrees with our results when the landscape patches are large. However, in a landscape configurated by small patches, an increase in the patches' shape and complexity may be translated into an unaffordable increase in landscape fragmentation and a consequent reduction of biodiversity. Our results suggest that a high level of fragmentation (landscapes configurated by small and complex shaped patches) or low levels of fragmentation (landscape configurated by large and simple shaped patches) would show the lower richness and less abundant Coleoptera communities, whereas intermediate levels of fragmentation would favour this group (Figure 5). This contradicts the habitat amount hypothesis, i.e., species richness only depends on the total amount of habitat in a local landscape (Rybicki et al., 2019). In accordance, Rybicki et al. (2019), through a stochastic model, concluded that intermediate degrees of fragmentation might be beneficial for competitive communities when the amount of habitat is high, but if the total amount of habitat is small, the situation is reversed: fragmentation per se decreases species diversity.

Previous studies showed that the probability of Coleoptera habitat patch occupancy increases with reduced patch isolation and increases with patch size (Zagmajster et al., 2007). This may be related to a limitation of Coleoptera dispersion in an excessively fragmented habitat. Fragmentation of habitats encompasses several components, such as reduced potential habitat area and increased edge effects (Saunders et al., 1991). Larger patches have a larger core area that is unaffected by external factors, like the environmental and biotic changes associated with edges, which may act as barriers or corridors between populations (Holland et al., 1991).

In our study, the effect of the landscape complexity on the Coleoptera richness and diversity depended on the buffer size around vineyards, which is more noticeable at the largest buffers. Regarding the landscape composition (SEI), results indicated an increase of abundance at 2000 m, in accordance with other studies that also indicated that vine-growing areas surrounded by a more diverse crop habitat increased Coleoptera richness and activity density (Fiera et al., 2020; Franin et al., 2016). However, our results indicated a reduction of the richness and abundance at 750 m. The inconsistencies across buffers may be related to the fact that at the larger buffers landscape with high proportions of host habitat may be more attractive, triggering higher abundances due to long-distance dispersal (resource concentration hypothesis), whereas at the smaller scales, lower or higher abundances may result from dilution or concentration effects depending on the availability of host habitat on the selected buffer (Marrec et al., 2017), in other words, at the smaller buffers the whole area of distribution of the individuals may not be captured, resulting in the inconsistent results. This also agrees with Rybicki et al. (2019), which observed that the habitat amount hypothesis is sensitive to the scale at which the local landscape is defined.

Coleoptera community in vineyards

The Coleoptera diversity was higher in the vegetation ground cover in July at all buffers. These results agree with the literature that indicates that the vegetation maintained in the inter-rows is an important biodiversity hotspot within this agroecosystem (Fiera et al., 2020; Franin et al., 2016). In Mediterranean areas—characterized by mild, wet winters and warm to hot, dry summers (Lionello et al., 2006)—in North Hemisphere, September corresponds to the end of the summer. In the early autumn, the occurrence of precipitation promotes the development of natural plants (Marteinsdóttir et al., 2010), and multiple insects can find suitable habitats within (Carlos et al., 2019; Gonçalves et al., 2020; Ng et al., 2018; Sáenz-Romo et al., 2019). This may explain the lower diversity found in September when some Coleoptera migrate to more favourable places with a higher abundance of fresh plants (Rodrigues et al., 2013; Sloggett & Majerus, 2000) than vineyards. Also, the disturbance caused by grape harvesting may contribute to a reduction in the abundance of Coleoptera. Similarly, in Portugal, Carlos et al. (2019) found higher richness and abundance of ground-dwelling arthropods in July and lower in October, and the Douro region showed a greater activity density of all Coleoptera trophic groups in summer (Gonçalves et al., 2017).

The higher abundance of Coccinellidae and Phalacridae in September, and Chrysomelidae, Staphylinidae, and Latridiidae in

October, was probably related to the fact that those were the periods of favourable conditions for these families, that is, environmental conditions and food resources availability (Gonçalves et al., 2017).

The reproduction and metabolic activity of Coccinellidae occur in the early summer when the temperature increases (Jalali et al., 2009; Kontodimas et al., 2004), and it is during this period that Coccinellidae has more activity as predators (Sáenz-Romo et al., 2019). In the case of herbivorous groups such as Phalacridae (Lima et al., 2010) and the subfamily Bruchinae—known as seed beetles (Beenen & Roques, 2010), there is more food available at the beginning of the summer, when seeds from the vegetation cover in the inter-rows are produced (Marteinsdóttir et al., 2010).

The higher abundance of Staphylinidae, Latridiidae and Chrysomelidae during autumn may be related to the reestablishment of the vegetation ground cover resulting from the first early autumn rains after the summer (Ruiz-Colmenero et al., 2011). Staphylinidae are generalist ground-dwelling predators (Wurst et al., 2013), and in vineyards, they contribute to regulating pests populations (Carlos et al., 2019). October is also suitable for the occurrence of Latridiidae, which are more widespread in the wetter periods and prefer wet and moist habitats (Bukejs et al., 2013). This group's adults and larvae mainly feed on mycelia and fungi spores and can commonly be found on the leaf litter (Bukejs et al., 2013; Yoshinami et al., 2018). Latridiidae contributes, in terms of ecosystem services, to the decomposition of organic matter (Bukejs et al., 2013). Chrysomelidae have phytophagous feeding habits, and some species are considered vineyards insect pests (Beenen & Roques, 2010; Enoiu et al., 2013; Vincent et al., 2018), sometimes originating serious damages (Yoshinami et al., 2018). They have been associated with weeds growing within the vineyards and feeding on the vine's foliage but not in the berries (Lesage et al., 2008; Vincent et al., 2018).

The identified Coleoptera families may be responsible for several functions in vineyards. Staphylinidae can feed on soil arthropods like nematodes and mites (Thomson & Hoffmann, 2009). Coccinellidae presents a wide diversity of habitats, dietary preferences and specificities (Sloggett & Majerus, 2000), such as aphids, coccids, mildew, and plant foliage, pollen or pollen flower nectar (Bouvet et al., 2019; Majerus, 2009). In this study, Carabidae abundance was generally low; nevertheless, this certain importance in the Douro region. Some studies found a relevant effect of this family on the biological control of aphids (Hemiptera) (Marteinsdóttir et al., 2010), dipterans, and eggs and larvae of the potato beetle (Leptinotarsa decemlineata) (Ruiz-Colmenero et al., 2011) or lepidopterans (Ruiz-Colmenero et al., 2011). Various families, found in low numbers, may have relevant functions in the vineyards. For example, Anthicidae, Cantharidae, Cucujidae or Malachiinae comprise predator or decomposer species (Crowson, 1986).

A tendency for richness and abundance increase was observed to the south (for most buffers) and of abundance to the east (only at 750 buffers). This could be related to differences in temperature and humidity along the year and locations, important factors for Coleoptera development and population dynamics (Jalali et al., 2009; Kontodimas et al., 2004).

CONCLUSIONS

This research indicates that intermediate levels of habitat fragmentation, particularly in semi-natural areas and vineyards, in vine-producing regions may favour Coleoptera biodiversity and, consequently, their provided ecosystem services. Moreover, the range of activity of Coleoptera, considering the whole order, seems to be larger than 1000 m. Generally, Coleoptera was more biodiverse in the vegetation ground cover at the beginning of the summer, whereas in autumn, the biodiversity was lower. The most relevant families and potential ecosystem services/undesired effects identified were Coccinellidae (predators), Phalacridae (herbivorous) and the subfamily Bruchinae (seed feeders) in the herbaceous layer at the beginning of the summer, and the families Staphylinidae (predators), Chrysomelidae (herbivorous and potential pests or weed controllers) and Latridiidae (decomposers) at the beginning of the autumn. This work constitutes an important contribution to understanding the Coleoptera community's response to the landscape context in vineyards from Portugal managed under low-impact practices. However, further studies should analyse its effect on specific ecosystem services, such as the reduction of pests or weeds, decomposition of organic matter and their potential undesired pest role.

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DATA AVAILABILITY STATEMENT

Data available on request from the authors

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1 Wine Regions climatic informations (IPMA, 2021), vineyards' sampling dates and management data of the plots. Tmin - medium of the minimum temperature; Tmax - medium of the maximum temperature; Total Prec. - total precipitation.

Table S2 Frequency (%) and number of individuals (n) of Coleoptera families collected on the canopy and vegetation ground cover in each region: Bairrada (B), Beira Interior (BI), Douro (D), Península de Setúbal (S), Trás-os-Montes (TM) and Vinhos Verdes (VV). Trophic groups: C – Carnivorous, D – Detritivores, F – Fungivorous, H – Herbivorous (Crowson, 1986).

Table S3 Response of Coleoptera family richness and abundance (GLMM) to landscape variables, longitude, latitude, strata (herb and vine canopy) and date (July, September and October) (GLMM). E: Standardize coefficient value; SE: Standard Error SNH: Seminatural habitat; SEI: Simpson's diversity index; MPS: Mean Patch Size; MPAR: Mean Perimeter Area Ratio. Between brackets is indicated the used distribution in each case.

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