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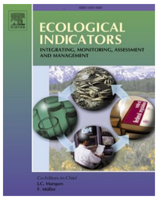

# Effect of vineyard characteristics on the functional diversity of insectivorous birds as indicator of potential biocontrol services

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## ABSTRACT

Insectivorous birds have a large potential to provide biocontrol services in vineyards, thus contributing to the sustainability of this agroecosystem. Bird communities are influenced by vineyard management practices and surrounding landscape, which may influence their role as ecosystem service providers. Functional diversity indices are indicators of bird community composition, and thus may reflect potential biocontrol services. We surveyed 31 vineyard plots in southern Portugal to assess vineyard characteristics (management intensity and landscape context) that may influence functional insectivorous birds in vineyards, using seven functional diversity indices as potential biocontrol indicators. We used eight characteristics of vineyard plots to define three vineyard types for our case-study: TREE – smaller vineyard plots surround by a more diverse landscape, with larger proportion of tree-habitats; AGRI – vineyard plots with medium size and greater cover by herbaceous vegetation, mostly surrounded by agricultural habitats (pastureland, crops); and VINE – vineyard plots of larger size and higher inter-row herbaceous vegetation, often surrounded by other vineyard plots. Five potential biocontrol indicators seemed to vary according to vineyard type. The richness of functional insectivorous birds, functional dispersion, functional richness, and Rao's functional diversity were all higher in vineyard TREE type compared to both AGRI and VINE types. The functional divergence was higher in vineyard TREE type than in VINE type, but similar to AGRI type. Accordingly, TREE type vineyards hold bird communities with more diverse and widespread ecological functions. This implies that smaller vineyard plots, in more heterogeneous landscapes, with neighbouring woodlands seem to have a higher potential of biocontrol services provided by insectivorous birds as suggested by using functional diversity indices as indicators.

## 1. Introduction

Wine and grape production plays an important role in the regional economy of several countries, being no longer restricted to European Mediterranean-climate countries (Bisson et al., 2002; Jones et al., 2005; Winkler et al., 2017). Simultaneously, vineyards should also assume some relevance in biodiversity conservation in a changing world, progressing towards more sustainable practices – the so called "vinecology", which integrates ecological and viticultural practices (Hannah et al., 2013; Viers et al., 2013). Complex agricultural landscapes, which encompass cultivated land and semi-natural areas, show reduced pest abundance associated with greater abundance of natural predators (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Veres et al., 2013). Vineyards are intensively managed landscapes, and they are susceptible to several diseases and pests responsible for considerable economic losses (Fuller et al., 2014; Daane et al., 2018). Several arthropod species may reach the pest threshold in vineyards, affecting mostly leaves or grapes (Bournier, 1976; Esmenjaud et al., 2008; Bostanian et al., 2012).

For a long time, agricultural arthropod pests have been fought using a panoply of chemicals, with severe health or environmental consequences in many cases, or limited success in others (Oberemok et al., 2015). In recent decades, farming and wine production have been

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increasingly changing their regimes from conventional to integrated pest management (IPM) and organic farming (Bisson et al., 2002; Viers et al., 2013; Pertot et al., 2017; Daane et al., 2018). This change has been also encouraged by the consumers' concern for wine quality and the environmental sustainability of its production (Bisson et al., 2002; Zucca et al., 2009; Tempesta et al., 2010; Daane et al., 2018). Pests' natural predators (both vertebrate and invertebrate predators) can contribute to balance the numbers of arthropods responsible for damages in crops, delivering an ecosystem service known as biological control, pest control, or biocontrol (Letourneau et al., 2009; Wenny et al., 2011). Birds have a large potential for pest control, because many species are insectivorous, they have high diversity of functional roles (e.g. variety of foraging habitats and behaviour), and they are common in most habitats (Wenny et al., 2011; Whelan et al., 2015). Moreover, there is evidence suggesting that birds provide a biocontrol service in vineyards (Jedlicka et al., 2011, 2014b, 2017; Benayas and Meltzer, 2017), as well as in other crops (Mols and Visser, 2007; Garfinkel and Johnson, 2015; García et al., 2018).

Functional diversity indices provide a more detailed and reliable information on ecosystem services than species richness alone (Flynn et al., 2009; Philpott et al., 2009; Cadotte et al., 2011) . Functional indices, such as functional richness or functional evenness in particular, have been pointed out as indicators of potential biocontrol services provided by birds (Philpott et al., 2009; Barbaro et al., 2014, 2017). Bird insectivory seems to increase with functional richness or functional evenness, demonstrating the importance of trait complementation associated with diverse bird communities (Philpott et al., 2009; Barbaro et al., 2014, 2017). Several functional diversity indices, including its three main components – functional richness, functional evenness, and functional divergence, have been proposed to help understanding how environmental constraints affect communities and the ecosystem services provided by these (Mason et al., 2005; Villéger et al., 2008; Laliberté and Legendre, 2010; Schleuter et al., 2010; Mouillot et al., 2013). However, many of these relationships between functional indices and the ecosystem services provided by communities need further evidence, clarification, and quantification (Mouchet et al., 2010; Cadotte et al., 2011; Matuoka et al., 2020).

Compared to conventional farming, both integrated pest management and organic farming can have a positive contribution to biodiversity and to natural pest control, while reducing pesticide use, particularly in vineyards (Crowder et al., 2010; Caprio et al., 2015; Assandri et al., 2017; Muneret et al., 2017; Puig-Montserrat et al., 2017; Katayama et al., 2019). Besides farming regimes (e.g. conventional, IPM, organic farming), which differ mostly in approaches to control pests, also other factors related to management options (i.e. farm or vineyard scale) and landscape characteristics may influence the potential biocontrol services by birds, as detailed next.

Concerning management options, planting or maintaining semi-natural woody vegetation (marginally or embedded in vineyards) is a practice that can favour generalist bird species (Assandri et al., 2016; Pithon et al., 2016; Barbaro et al., 2017) . The abundance and richness of bird communities may benefit in particular from marginal habitats and singular elements such as riparian habitats, hedgerows, tree rows, isolated trees and rural buildings (Jedlicka et al., 2014; Assandri et al., 2016, 2017a, 2017b; Muñoz-Sáez et al., 2020). Trellising systems that promote taller canopies, lower vine densities, and lower disturbance (limiting grass mowing in April and May, and reducing visits to vineyards) can also increase the use of vines by nesting birds (Assandri et al., 2017b, 2017c). In addition, the management of ground vegetation in vineyards (e.g. mowing or using herbicides), associated with the farming regime and soil conservation techniques, can influence the composition of bird communities (Arlettaz et al., 2012; Duarte et al., 2014; Guyot et al., 2017; Bosco et al., 2019). Finally, placing nest boxes in vineyards can increase the abundance of insectivorous bird species, and thus the potential biocontrol (Jedlicka et al., 2011).

Regarding the landscape context of vineyards, habitat heterogeneity at local and landscape scales may influence bird community (Assandri et al., 2016; Barbaro et al., 2017). Specifically, the increase in vineyard cover reduces the abundance and species richness of birds, whereas most bird species detected in vineyards are associated to its adjacent semi-natural habitats, such as woodlands or grasslands (Assandri et al., 2016, 2017a; Pithon et al., 2016; Steel et al., 2017; Muñoz-Sáez et al., 2020).

The above-mentioned vineyard characteristics can influence bird communities and therefore should also influence the functional indices that can work as indicators of potential biocontrol services. Accordingly, our main objective was to use functional diversity indices to assess the influence of vineyard characteristics on the potential biocontrol services provided by insectivorous birds. Considering the current knowledge, our main working hypothesis is that the neighbouring semi-natural habitats should increase the functional diversity of insectivorous birds in vineyards, which in turn may increase the potential biocontrol services provided by these species. Such results can help support management practices in vineyards to increase the potential for biocontrol of arthropods that can cause damages to vines and grapes.

## 2. Methods

### 2.1. Study area

The study was carried out in the district of Évora, located in Alentejo, south Portugal (38.5° N, −7.9° W), one of the most important wine production regions in the country, with many vineyards classified under Protected Designation of Origin (Alentejo DOC). Vineyards occupy 2% of the area of the district of Évora, where the main land uses are: agroforestry systems dominated by cork and holm oaks – (regionally known as "montado", 40%); pasture land (34%); woodland (8%); olive groves (5%); and crop land (5%) (Direção Regional de Agricultura e Pescas do Alentejo, 2013). The landscape is dominated by plains with a few low hills (altitude range 12 and 653 m a.s.l., but mainly between 200 and 400 m a.s.l.). The region has a typical Mediterranean climate, with mild winters and hot and dry summers (Peel et al., 2007) – mean annual temperature varies between 14.8 and 16.1 °C; while mean accumulated annual precipitation varies between 486.7 and 832.8 mm (IPMA, 2019). We selected 31 vineyard plots, representing different management practices and landscape contexts (Fig. 1. The maximum distance between vineyard plots was 55 km, and altitude ranged between 188 and 361 m (a.s.l.). All vineyards were under either two farming regimes: integrated pest management (IPM; $n = 17$), or organic ($n = 14$). We have no detailed information on the use of plant protection chemicals (including copper and sulphur) in each vineyard plot.

### 2.2. Bird communities

We used point counts to sample bird communities, recording all birds heard and seen during 10 min, within a radius of 100 m from the observer, except those birds flying over and clearly not using the vineyard and surrounding habitats (e.g. soaring raptors, flying waterfowl). We selected one point count for each of the 31 vineyard plots, located in the centre of each plot and separated among them by at least 500 m to ensure independence. Species detectability was likely similar among the vineyards due to only very small differences in overall plot structure and topography. Points counts were performed by one experienced observer (RL), during the first three hours after sunrise, and in days without rain or moderate/strong wind. Each point count was sampled three times in 2018: (1) the first visit was carried out in April, targeting at early-season breeding species, and corresponded to the beginning of leaf growth in vines; (2) the second visit took place in June (late-season breeders), and corresponded to the beginning of grape development; and (3) the third visit was conducted in September, covering the bird migratory period, and immediately before grape harvesting.

For each point count, we calculated seven indicators of potential

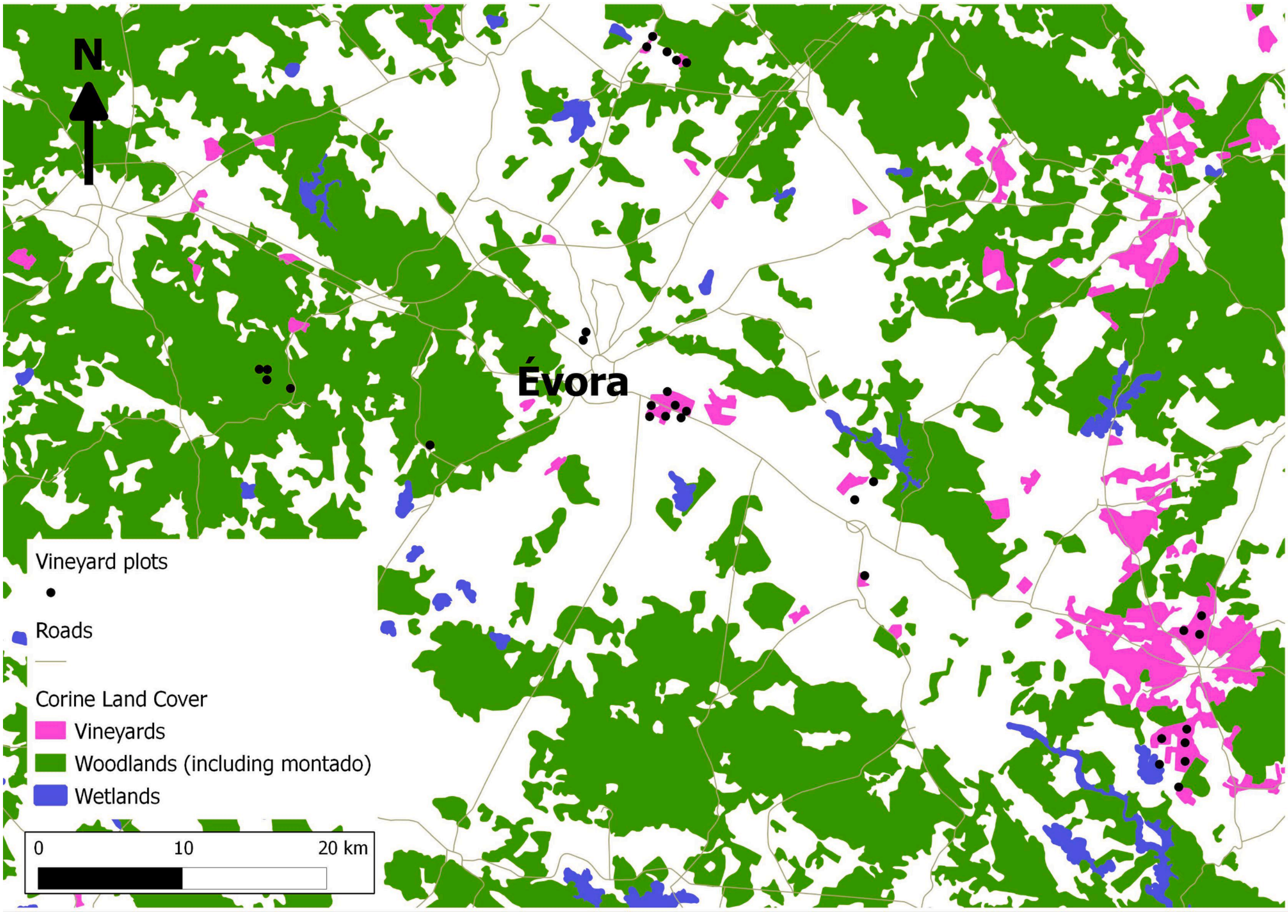

**Fig. 1.** Location of vineyard plots in the district of Évora, southern Portugal.

biocontrol service (Philpott et al., 2009; Barbaro et al., 2014, 2017): (1) abundance of functional insectivorous birds, i.e. species that potentially exert an arthropod biocontrol service in vineyards (ABIS); (2) richness of functional insectivorous birds (RIIS). We classified as functional insectivorous birds, all the species that forage on vineyards, are predominantly foliage gleaners or hawkers, and are insectivorous during spring and summer. Besides abundance and richness of functional insectivorous birds, we also used five multidimensional indices of functional diversity to characterize bird communities, since different indices can have a complementary role as surrogates of the potential for biocontrol by insectivorous birds (Mason et al., 2005; Schleuter et al., 2010; Mouillot et al., 2013; Barbaro et al., 2017): (3) functional richness (FRIC); (4) functional evenness (FEVE); (5) functional divergence (FDIV); (6) functional dispersion (FDIS); and (7) Rao's quadratic entropy (RAOQ). These indices were calculated for each point count using a species-by-trait matrix with five traits that may reflect differences in biocontrol potential: diet of adults during the spring and summer periods; foraging guild; phenology (breeding cycle); clutch size; body mass (Table S1 in Supplementary Material ESM1). Functional richness indicates "the amount of niche (or functional) space filled by species that compose the community"; functional evenness indicates the "evenness of abundance distribution in filled niche (or functional trait) space"; functional divergence (FDIV) indicates "how abundance is distributed in niche space (or functional trait axis), within the range occupied by the community" (Mason et al., 2005; Villéger et al., 2008); functional dispersion indicates "the mean distance in multidimensional trait space of individual species to the centroid of all species" (Laliberté and Legendre, 2010); Rao's quadratic entropy "measures the pairwise functional differences between species" (Botta-Dukát, 2005). We used the R library FD 1.0–12 (Laliberté et al., 2015) to calculate the functional diversity indices following Mason et al. (2005), Villéger et al. (2008), Laliberté and Legendre (2010), and Botta-Dukát (2005).

### 2.3. Characterization of the vineyard plots

To understand the effect of vineyard characteristics that may influence potential biocontrol by insectivorous birds we used eight variables at two scales. First, we considered a fine scale of 100 m radius around the point count, which was the limit of detection of individual birds that we considered in point counts. At this scale (100 m radius buffer) we recorded: (1) vineyard cover (vineC) – percentage of the buffer occupied by vineyards; (2) herb height (herbH) – mean height of herbaceous vegetation; and (3) herb cover (herbC) – percentage of the buffer with herb cover. Second, as birds are mobile animals, we looked for variables that could show the effect of the landscape surrounding the vineyard plot (i.e. farm management), and thus we used a buffer of 300 m radius around the point count. This radius encompasses the home range size of most of the species detected in vineyard plots and that were included in the analysis (Cramp et al., 1977–1994). At this scale we calculated: (4) vineyard proportion (vine3) – percentage of the buffer occupied by vineyards; (5) riparian vegetation (rip3) – total length of corridors of riparian vegetation within the buffer; (6) tree habitat proportion (tree3) – percentage of the buffer occupied by woodlands and other non-riparian habitats with trees; (7) proportion of semi-natural habitats

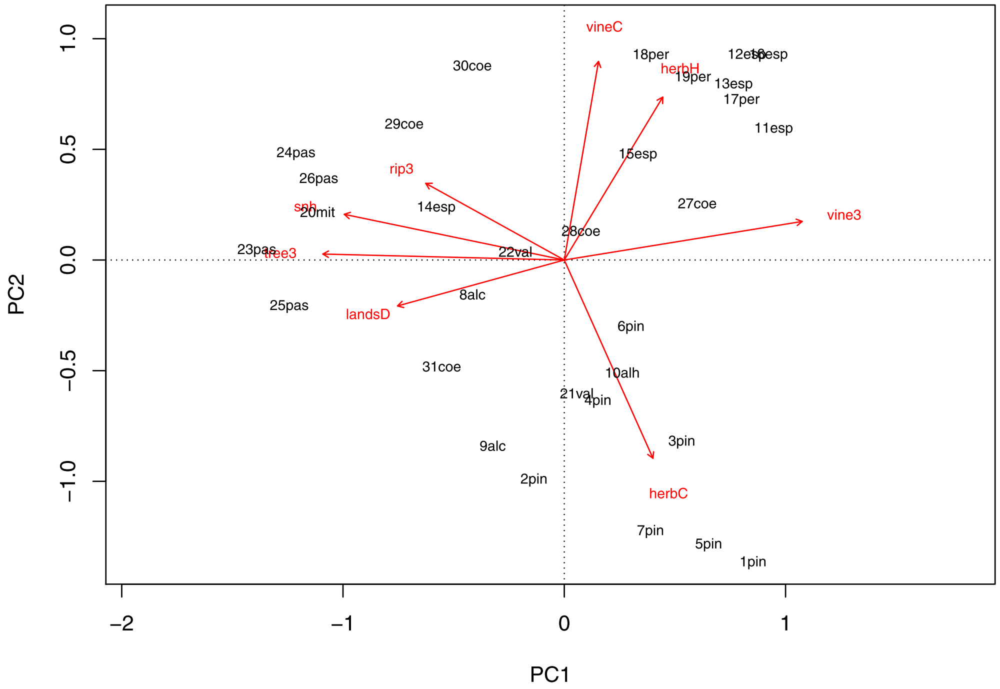

**Fig. 2.** PCA plot showing the characterization of vineyard plots (with a unique ID) according to eight landscape descriptors (see Table 1 for acronyms of explanatory variables).

(snh) – percentage of the buffer occupied by oak woodlands and riparian vegetation; and (8) landscape diversity (landsD) – Shannon's diversity index for the different type of land uses. Herb height was calculated by averaging three representative measurements of the inter-row herbaceous vegetation within the 100 m buffer, while the remaining variables were determined using satellite images with field confirmation.

### 2.4. Data analysis

As a first step, we looked for types of vineyards that could group the main characteristics: vineyard size, neighbouring habitat (agricultural or semi-natural), presence and height of herbaceous vegetation. We used a principal components analysis (PCA) to perform a multivariate analysis of the eight explanatory variables characterizing each vineyard plot. Following Borcard et al. (2011), we then combined the PCA results (ordination) with the results from a clustering procedure using the same eight explanatory variables (Euclidean distance of standardized variables followed by Ward clustering) to define three vineyard types.

We used linear mixed effects models to investigate potential relationships between the seven indicators of potential biocontrol and the three vineyard types. We used each indicator (i.e. functional diversity indices) as response variable, the vineyard type as explanatory variable, and the vineyard plot as random factor. The variables ABIS and RIIS were square-root transformed to normalize their distribution. Models were validated using diagnostic plots (Zuur et al., 2009). We checked for spatial autocorrelation in the model residuals using correlograms and Moran's I, and discarded the potential effects of spatial autocorrelation in the analyses due to some aggregation of vineyard plots. All analyses were performed using the statistical software R 3.6.3 (R Core Team, 2020), with the packages vegan 2.5–6 (Oksanen et al., 2019), nlme 3.1–139 (Pinheiro et al., 2019), spdep 1.1–2 (Bivand and Wong, 2018), ncf 1.2–9 (Bjornstad, 2020), gplots 3.0.1.1 (Warnes et al., 2019).

## 3. Results

### 3.1. General description of bird communities in vineyards

In total, we counted 2350 bird individuals in the 93 point counts (3 visits in each of the 31 sampling sites), with a mean of 25.3 ± 12.0 (mean ± SD) individuals per point count. We identified 65 species (belonging to 22 families) using the vineyards or the surrounding habitats within a 100 m radius (mean ± SD per point = 11.3 ± 3.6 species). We considered 41 species as functional insectivorous birds in vineyard ecosystems (Table S1 in Supplementary Material ESM1). The species with greatest mean abundance per point were Corn Bunting *Emberiza calandra* (2.0 ± 2.4 inds./point), Linnet *Linaria cannabina* (1.8 ± 2.8 inds./point), Thekla's Lark *Galerida theklae* (1.5 ± 1.9 inds./point), Goldfinch *Carduelis carduelis* (1.4 ± 1.6 inds./point), Serin *Serinus serinus* (1.1 ± 1.4 inds./point), and Stonechat *Saxicola rubicola* (1.1 ± 1.1 inds./point). Corn Bunting and Thekla's Lark were also the two most abundant species of functional insectivorous birds in vineyards.

### 3.2. Characterizing vineyard plots into vineyard types

The PCA used the define vineyard types had 42% of variance explained by the axis PC1, and 21% explained by axis PC2 (cumulative proportion of explained variance = 63%). Only axis PC1 and PC2 had eigenvalues above the mean. Analysing the PCA plot (Fig. 2), vineyard plots were grouped according to characteristics in three types: (1) TREE – vineyard plots of smaller size, with higher landscape diversity and larger proportion of tree-habitats, semi-natural habitats (mostly woodlands), and riparian vegetation in the neighbourhood (Table 1); (2) AGRI – vineyard plots with medium size and smaller proportion of tree-habitats, mostly surrounded by agricultural habitats (pastureland, crops), and with greater cover by herbaceous vegetation; (3) VINE –

**Table 1**

Mean ± SD (range) of the eight explanatory variables according to the three vineyard types defined for our case-study.

| Explanatory variable | VINEYARD TYPES | | |
|---|---|---|---|
| | TREE (surrounded by tree habitats) | AGRI (surrounded by agricultural habitats) | VINE (extensive vineyards) |
| vineC – Vineyard cover (%) | 66.9 ± 13.9<br>(40.0–80.0) | 60.3 ± 18.9<br>(25.0–80.0) | 81.4 ± 6.8<br>(70.0–90.0) |
| herbH – Herb height (m) | 0.17 ± 0.10<br>(0.05–0.33) | 0.12 ± 0.04<br>(0.05–0.18) | 0.29 ± 0.09<br>(0.18–0.48) |
| herbC – Herb cover (%) | 10.4 ± 5.3<br>(5.0–18.3) | 30.5 ± 9.4<br>(16.7–43.3) | 12.6 ± 5.7<br>(5.0–20.0) |
| vine3 – Vineyard proportion (%) | 30.5 ± 13.6<br>(11.9–62.5) | 64.1 ± 21.4<br>(35.4–97.4) | 89.5 ± 10.4<br>(69.6–99.1) |
| rip3 – Riparian vegetation (length, m) | 389 ± 314<br>(0–905) | 187 ± 271<br>(0–816) | 259 ± 286<br>(0–818) |
| tree3 – Tree habitat proportion (%) | 53.1 ± 22.1<br>(12.0–80.0) | 13.0 ± 15.6<br>(0.3–53.9) | 3.2 ± 3.4<br>(0.0–9.1) |
| snh – Proportion of semi-natural habitats (%) | 37.1 ± 29.5<br>(0.0–80.0) | 1.8 ± 2.1<br>(0.0–5.6) | 0.6 ± 1.2<br>(0.0–3.4) |
| landsD – Landscape diversity (Shannon index) | 0.482 ± 0.157<br>(0.217–0.676) | 0.366 ± 0.181<br>(0.052–0.628) | 0.152 ± 0.123<br>(0.023–0.337) |

vineyard plots of larger size and often surrounded by other vineyard plots, and in our case-study showing larger height of herbaceous vegetation inter-row. The cluster analysis for grouping the vineyard plots using the eight characteristics resulted in 12 plots classified as TREE vineyard type, 10 as AGRI vineyard type, and nine as VINE vineyard type (Figs. S1, S2 in Supplementary Material ESM1). The TREE vineyard type had 11 exclusive functional insectivorous bird species, whereas the VINE type had two and the AGRI type had one exclusive functional insectivorous species (see details in Table S1 in Supplementary Material ESM1).

### 3.3. *Relation between vineyard types and indicators of potential biocontrol*

Five of the seven indicators of potential biocontrol by insectivorous birds varied significantly according to vineyard type (see model parameters and p values in Table S2 in ESM1). The richness of functional insectivorous birds (RIIS), functional dispersion (FDIS), functional richness (FRIC), and Rao's functional diversity (RAOQ) were all higher in vineyard TREE type when compared to both AGRI and VINE types (Fig. 3, Table 2). The functional divergence (FDIV) was higher in vineyard TREE type than in VINE type, but similar to AGRI type. The abundance of functional insectivorous birds (ABIS) and functional evenness (FEVE) did not vary between vineyard types.

## 4. Discussion

Our study indicates that vineyards can hold a functionally diverse bird community, which may provide useful biocontrol services, however the strength and diversity of these services may be influenced by the landscape characteristics of each vineyard plot. The potential differences in biocontrol services provided by birds may be better estimated by using functional diversity indices. Indeed, insectivorous birds have been increasingly recognized as potential predators of arthropod species that can damage grapes or vines (Jedlicka et al., 2011, 2014b; Barbaro et al., 2017; Benayas and Meltzer, 2017). Therefore, a healthy community of insectivorous birds should be part of a natural insurance against vineyard pests.

Functional insectivorous species accounted for a considerable proportion of the local bird community (41 of 65 species: 63%), even though we used a small sampling area (100 m radius) centred on vineyard plots. The only similar study available for comparison has been carried out in vineyards in Aquitaine region, France, where 27 out of 56 species (48%) were functional insectivorous birds (Barbaro et al., 2017). The overall bird community in our study area was within the range of the number of species when compared to other studies carried out in European vineyards, despite methodological differences in bird sampling: Málaga, Spain (30 species in Spring, (Duarte et al., 2014); Aquitaine, France (56 species in Spring, (Barbaro et al., 2017); Trento, Italy (59 species in Spring, (Assandri et al., 2016); Valais, Switzerland (66 species all year, Guyot et al., 2017); Loire, France (93 species in Spring, (Pithon et al., 2016). Therefore, although data are not directly comparable, these numbers suggest that in vineyards across Europe, insectivorous birds have the potential to provide biocontrol services, which could be assessed more in depth by using functional diversity indices as indicators.

Our study suggests that bird communities may be influenced by the characteristics of vineyards, in particular their management practices and the surrounding landscape, which in turn determine the indices of functional diversity, and consequently can act as indicators of potential biocontrol by insectivorous birds. Apparently, smaller vineyard plots, in more heterogeneous landscapes, with neighbouring woodlands (in our study classified as TREE type) seem to have greater functional diversity of birds, which should mean a higher potential of biocontrol services provided by insectivorous birds. This finding reinforces the notion that birds tend to avoid extensive vineyards and that maintaining the heterogeneity of vineyards, namely by conserving riparian habitats, hedgerows, trees, stone walls, and rural buildings, is a way to benefit bird communities and can also increase the potential for biocontrol services (Jedlicka et al., 2014; Pithon et al., 2016; Assandri et al., 2016, 2018). Even small woodland patches seem to have a high potential to deliver ecosystem services in agricultural landscapes, including biocontrol of pests (Valdés et al., 2020). However, not all studies agree on the role of semi-natural habitats on biocontrol services in vineyards, as in some particular cases the effect on biocontrol was not evident or negative (Muneret et al., 2019). Further evidence is required to help clarify when, how, and which semi-natural habitats (e.g. small woods and riparian habitats) contribute to biocontrol services provided by birds and other animal groups.

Our results were not conclusive regarding the management of the inter-row herbaceous vegetation. The practice of maintaining herbaceous vegetation has been recognized as favouring birds, notwithstanding for some species it may also be relevant the presence of areas of bare soil or where vegetation is short (Duarte et al., 2014; Arlettaz et al., 2012; Bosco et al., 2019). In agreement, bird functional diversity may be higher in areas that combine different heights of herbaceous vegetation, although this needs further confirmation from field data.

Overall, insectivorous bird communities and their potential to deliver biocontrol services seem to be dependent on several interacting factors. Besides the characteristics we used to identify vineyard types, also other factors have been reported to influence bird communities in vineyards, namely, the proportion of bare soil, distance between rows, vine age, human disturbance, and farming regime (Arlettaz et al., 2012; Duarte et al., 2014; Assandri et al., 2017b, 2017c; Barbaro et al., 2017). Moreover, the presence and abundance of functional insectivorous birds in vineyards may be influenced by factors at different scales, including fine-scale (vineyard plot), *meso*-scale (landscape surrounding the vineyard plot), and broad-scale (regional characteristics). Therefore, the effect of vineyard characteristics may be complex to dissect, requiring specific study designs and extensive study areas. However, the effect of some vineyard characteristics on the presence of cavity-nesting bird species may be attenuated by methods to promote their breeding, such as nest boxes (Jedlicka et al., 2014; Benayas and Meltzer, 2017).

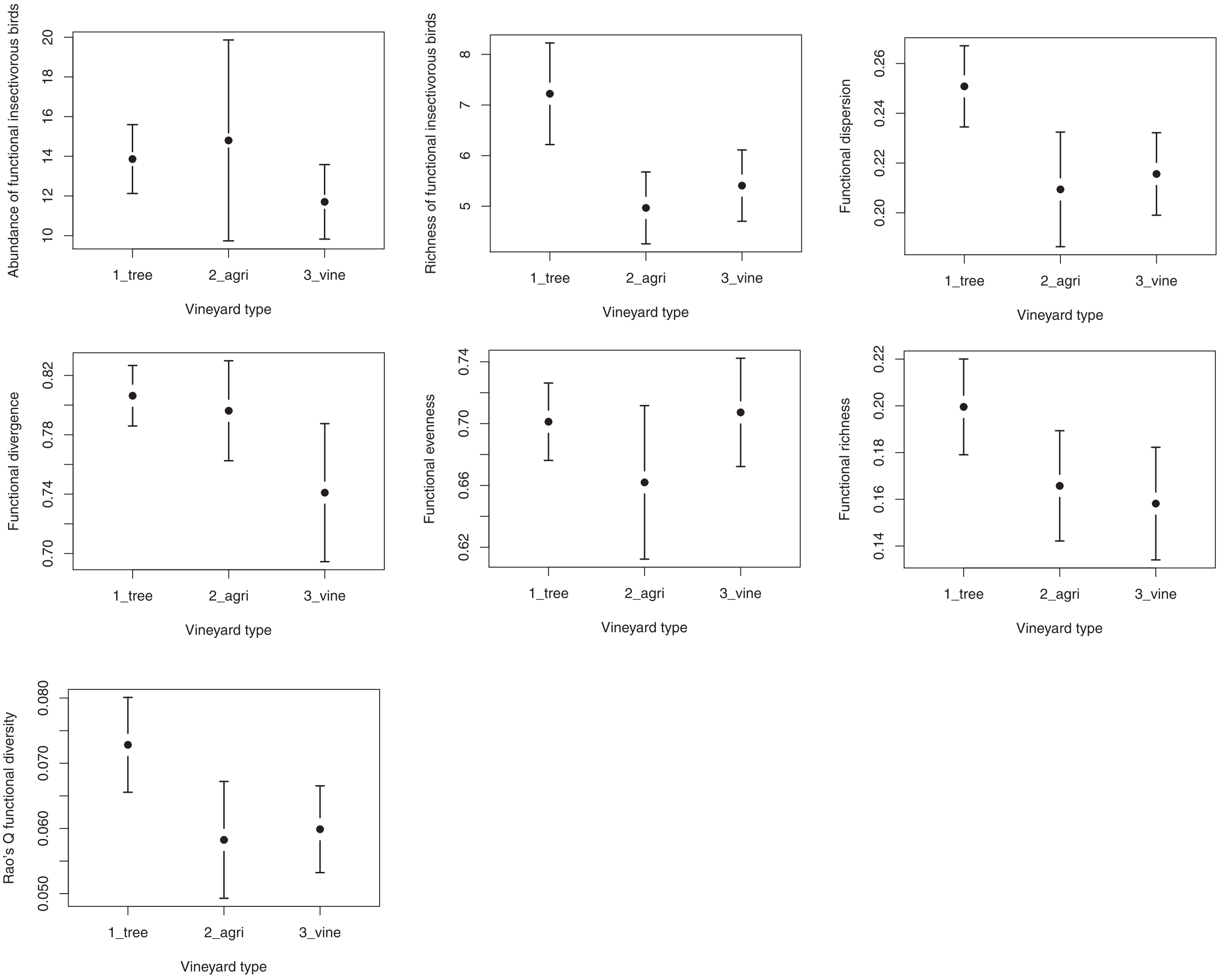

**Fig. 3.** Variation of the seven diversity indices used as indicators of potential biocontrol by insectivorous birds (ABIS – Abundance of functional insectivorous, RIIS – Species richness of functional insectivorous, FDIS – Functional dispersion, FDIV – Functional divergence, FEVE – Functional evenness, FRIC – Functional richness, RAOQ – Rao's quadratic entropy) according to the three vineyard types defined in our case-study. Mean value for the studied vineyard plots with 95% confidence intervals.

Our approach provides a multidimensional functional perspective of the bird community, indicating how different components of functional diversity relate to each other and how they respond to the environment (Mason et al., 2005; Villéger et al., 2008; Mouillot et al., 2013). This functional approach is beneficial as it provides a more comprehensive understanding of the potential of birds as providers of ecosystem services, namely as natural predators of potential arthropod pests (Barbaro et al., 2014, 2017). Five of the seven indices varied similarly according to vineyard type. Smaller vineyard plots, in more heterogeneous landscapes, with neighbouring woodlands (i.e. TREE type) seem to be associated with greater richness of functional insectivorous birds, and accordingly a higher number of insectivorous species should provide greater biocontrol services. Functional dispersion was also higher in the TREE vineyard type, indicating that bird abundance is more dispersed across different functional roles when vineyards have these characteristics. This fact should promote biocontrol across a broader spectrum of prey, which may cover more species among those known to cause damages in vineyards. Functional divergence was smaller in the VINE type compared to the two other types, suggesting that large vineyards have a more limited number of functional roles provided by birds. Functional richness was higher in vineyard plots with TREE type characteristics, indicating that more heterogeneous vineyards may have a greater amount of niche spaces filled, which should provide a more widespread biocontrol service among prey types. The higher Rao's Q functional diversity associated with the TREE type also suggests a diversification of functional roles played by the community of birds in smaller and more heterogeneous vineyards.

**Table 2**
Mean value ± SD (range) of the seven indicators of potential biocontrol by insectivorous birds according to three vineyard types defined in our case-study.

| Indicators of biocontrol | TREE (n = 36) | AGRI (n = 30) | VINE (n = 27) |
|---|---|---|---|
| Abundance of functional insectivorous (ABIS) | 13.9 ± 5.1<br>(4–22) | 14.8 ± 13.6<br>(3–78) | 11.7 ± 4.7<br>(1–20) |
| Species richness of functional insectivorous (RIIS) | 7.2 ± 3.0<br>(1–12) | 5.0 ± 1.9<br>(2–9) | 5.4 ± 1.8<br>(1–9) |
| Functional dispersion (FDIS) | 0.25 ± 0.05<br>(0.12–0.31) | 0.21 ± 0.06<br>(0.04–0.30) | 0.22 ± 0.04<br>(0.11–0.31) |
| Functional divergence (FDIV) | 0.81 ± 0.06<br>(0.66–0.89) | 0.80 ± 0.09<br>(0.61–0.96) | 0.74 ± 0.12<br>(0.53–0.96) |
| Functional evenness (FEVE) | 0.70 ± 0.07<br>(0.48–0.85) | 0.66 ± 0.13<br>(0.37–0.89) | 0.71 ± 0.09<br>(0.45–0.85) |
| Functional richness (FRIC) | 0.20 ± 0.06<br>(0.01–0.27) | 0.17 ± 0.06<br>(0.03–0.26) | 0.16 ± 0.06<br>(0.04–0.27) |
| Rao's quadratic entropy (RAOQ) | 0.073 ± 0.021<br>(0.015–0.105) | 0.058 ± 0.024<br>(0.006–0.098) | 0.060 ± 0.01<br>(0.020–0.095) |

In turn, two indices – abundance of functional insectivorous birds and functional evenness – did not seem to vary between vineyard types. The similar abundance of functional insectivorous is not surprising, since birds are a diverse taxonomic group with many species adapted to most habitat types (Seoane et al., 2004; Laiolo, 2005). This could suggest that the potential for biocontrol by insectivorous birds would be similar across vineyard types. However, high functional diversity (as indicated by other indices) should be beneficial as it may ensure a more effective biocontrol on different species and life stages of potential pests. Higher bird functional evenness is associated with greater biocontrol services in more heterogeneous vineyard landscapes (Barbaro et al., 2017). In our study, functional evenness did not seem to vary among vineyard types. Although not conclusive, it is indicative that the relationships between functional composition of bird communities and biocontrol services still need clarification, since many drivers may be playing a relevant influence (from fine-scale characteristics of vineyard plots to regional landscape characteristics and climate). As future steps for research, we consider relevant to evaluate the relationship between functional diversity indices and effective biocontrol, i.e. quantifying the abundance of arthropod pests. In addition, it is also useful to establish clear implications of management measures on functional diversity, which would allow a more evident translation of practical farming options on potential benefits on biocontrol services provided by birds.

Complementary to the perspective of how can birds help wine and grape production as natural predators of pests, is the perspective of how can vineyards help bird conservation. The decline of European insectivorous birds results mostly from agricultural intensification, with loss of grasslands (Bowler et al., 2019). Widespread landscape transformation is today an unquestionable reality, however, vineyards can still be managed to also benefit biodiversity. Vineyards can be used by birds as feeding and nesting areas, and they may represent suitable alternative habitats for some species with unfavourable conservation status (e.g. Isenmann and Debout, 2000; Arlettaz et al., 2012; Assandri et al., 2017). In our study area, vineyards can act as alternative habitat for the Rufous-tailed Scrub-robin *Cercotrichas galactotes*, a regionally vulnerable insectivorous species that breeds mostly in Mediterranean shrublands. However, the majority of bird species occurring in vineyards in our study area were common species, as found in other vineyards (Pithon et al., 2016; Assandri et al., 2017; Barbaro et al., 2017; Steel et al., 2017). Notwithstanding, biocontrol services are largely provided by the common and abundant insectivorous bird species, so the factors driving their abundance and richness assume greatest relevance in this context.

We reinforce the idea that the potential for pest control by insectivorous birds can represent a valuable ecosystem service in wine and grape productions. This is especially true under the current scenario of increasing awareness of consumers for the health and environmental consequences of food production (Bisson et al., 2002; Winkler et al., 2017). State of the art knowledge on vineyard management for promoting natural control of enemies (e.g. Assandri et al., 2017; Barbaro et al., 2017; Steel et al., 2017; Bosco et al., 2019), including our study, indicates that wine and grape producers may adapt management practices to benefit functional insectivorous birds. These measures include promoting landscape heterogeneity in vineyards, by incorporating semi-natural structures such as riparian galleries, stone walls, or tree patches. This could be achieved with simultaneously increasing landscape multifunctionality, including adding value to products and diversifying production and services (Winkler et al., 2017).

A functional diversity approach to bird communities in vineyards (but also in other agricultural landscapes) can give to ecologists and farmers more accurate indicators of ecosystem functioning and services (Cadotte et al., 2011; Barbaro et al., 2017. In turn, birds can feedback to wine producers by lending their attractive image in promoting wines, and providing added-value (Fig. S3 in Supplementary Material ESM1).

## CRediT authorship contribution statement

**Rui Lourenço:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Pedro F. Pereira:** Methodology, Investigation, Writing - review & editing. **Amália Oliveira:** Methodology, Writing - review & editing. **Joana Ribeiro-Silva:** Methodology, Writing - review & editing. **Diogo Figueiredo:** Writing - review & editing, Funding acquisition. **João E. Rabaça:** Writing - review & editing, Funding acquisition. **António Mira:** Conceptualization, Methodology, Supervision, Project administration, Funding acquisition. **J. Tiago Marques:** Conceptualization, Methodology, Writing - review & editing, Project administration.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2020.107251.

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