Proximity to corridors benefits bird communities in vegetated interrow vineyards in Mendoza, Argentina

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ARTICLE INFO

ABSTRACT

Management under ecological schemes and increasing habitat heterogeneity, are essential for enhancing biodiversity in vineyards. Birds provide several contributions to agriculture, for example pest control, recreation and enhancing human mental health, and have intrinsic value. Birds are also ideal model organisms because they are easy to survey, and species respond differently to agricultural land use at different scales. Vegetated borders of crops are key for many species of birds, and distance to the border have been found to be an important factor in vineyard-dominated agroecosystems. We evaluate if there are differences in the bird assemblage, between the interior compared to borders within vineyards, using a hierarchical community occupancy model. We hypothesized that occupancy of birds is greater in environments with greater heterogeneity, which in this study was considered to be contributed by the proximity to vegetated corridors. We expected that vineyard borders close to corridors will have higher bird occupancy than the center of the vineyard. The research was conducted in three vineyards with biodiversity-friendly management practices, in Gualtallary, Mendoza, Argentina. Bird surveys were conducted over three breeding seasons from 2018 to 2020. Occupancy and richness of the bird community was more closely associated with the borders adjacent to the corridors than with the interior of the vineyards, as we initially predicted, although the assemblage of birds did not differ much. More than 75% of the registered species consume exclusively or partially invertebrates. Biodiversity-friendly management and ecological schemes, together with vegetated corridors provide multiple benefits for biodiversity conservation. These approaches not only minimize the use of agrochemicals but also prioritize soil cover with spontaneous vegetation, which supports a diverse community of insectivorous bird species, potentially contributing to pest control.

1. Introduction

To reconcile the conservation of biodiversity and its contributions to agricultural production, it is essential to understand the conditions that foster synergies and mitigate trade-offs between them (Bennett et al., 2009; Bommarco et al., 2013; Díaz et al., 2018; IPBES, 2019). In agricultural ecosystems, biodiversity provides numerous contributions to people, and their quality of life, with positive effects on production (Díaz et al., 2018; Dainese et al., 2019; IPBES, 2019).

Perennial crops, such as vineyards, tend to be less disturbed than annual crops, and depending on the degree of intervention, the effects on biodiversity may not be comparable (Bruggisser et al., 2010). However, the general patterns observed regarding biodiversity responses to management in vineyards are largely comparable with those reported

for other crops (Paiola et al., 2020). In general, biodiversity-friendly management or management under ecological schemes, and habitat heterogeneity, both at landscape and local scales, are key elements for improving vineyard biodiversity (Assandri et al., 2016; Paiola et al., 2020; Bosco et al., 2021; Belkhiri et al., 2023). Vineyards have large areas without cultivars between the vine rows (i.e., interrows). Interrow vegetation cover in vineyards, especially native vegetation, is an important driver of biodiversity, strengthening the idea that high biodiversity and wine production do not necessarily exclude each other (Winter et al., 2018; López García et al., 2019; Beaumelle et al., 2023). The cultivation of grapes is not enhanced by wild insect pollination, although the latter does favor spontaneous vegetation in the inter-rows. This is in line with the general recommendation about the importance of maintaining at least 20% of native vegetation in agroecosystems as a

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crucial pathway toward sustaining both biodiversity and nature's contributions to people (Garibaldi et al., 2021). Most of the research addressing biodiversity in vineyards has been highlighted in Europe, North America (mostly California), in Oceania and South Africa, leaving an information gap in Asia and South America (Paiola et al., 2020), and particularly in arid ecosystems.

Birds provide several ecosystem services or contributions for agriculture, such as pest control, pollination, and seed dispersal, among others (Sekercioglu, 2006; Whelan et al., 2008, 2015; Sekercioglu et al., 2016). Birds are efficient predators of arthropods in agroecosystems. Around 50% of species feed on arthropods and the remaining half consume invertebrates at least occasionally, such as granivorous passerines that feed their nestlings with insects during the breeding season (Sekercioglu, 2006; Whelan et al., 2015; Nyffeler et al., 2018). In addition to their economic contributions, birds also contribute to recreation and human mental health, and have intrinsic value (Díaz et al., 2018). On the other hand, some species are considered a problem for agriculture, for example pigeons or parrots that cause damage to vineyards, other fruit trees or annual crops (Bernardos and Farrell, 2012Bernardos et al., 2012; Whelan et al., 2015; Sekercioglu et al., 2016; Calamari et al., 2018a). Added to their contributions, birds are ideal model organisms to assess the effects of environmental perturbations because they are relatively easy to survey and respond rapidly to changes, compared to other vertebrate groups (Goijman et al., 2015; Whelan et al., 2015).

Bird species respond differently to agricultural land use at different scales, depending on their life-history traits such as foraging type or habitat specialization (Gavier-Pizarro et al., 2012; Goijman et al., 2015; Calamari et al., 2018b). Many species depend on both the local and landscape scale, and habitat conditions, even with potentially opposite responses to land cover and management depending on the scale and landscape context (Assandri et al., 2016, 2017; Barbaro et al., 2017; Macchi et al., 2020; Bosco et al., 2021). Some studies of grape cultivation report that the surrounding landscape affects birds to a greater extent than the vineyard itself (Pithon et al., 2016; Assandri et al., 2017; Belkhiri et al., 2023). Within vineyards, management promoting soil covered by vegetation increases richness and abundance of birds, especially for insectivores, and some granivores (Duarte et al., 2014; Brambilla and Gatti, 2022), potentially increasing suitability of habitat for ground nesting species (Buehler et al., 2017; Bosco et al., 2021), and foraging habitat for a variety of ground-foraging species. In addition, vegetated borders of crops are key for many species of birds (Goijman and Zaccagnini, 2008; Di Giacomo and López de Casenave, 2010; Goijman et al., 2020). This positive association with borders is especially observed in granivorous passerines and other ground-feeding granivores and insectivores, while branch-feeding insectivores and aerial foragers are less associated (Di Giacomo and López de Casenave, 2010; Goijman et al., 2015, 2020). Distance to the border was also found as important factor in vineyard dominated agroecosystems (Belkhiri et al., 2023).

The current area of vineyards in Argentina in 2022 (207,047 ha) is 4.9% less than that registered in 2010 (INV, 2023). The trend in Argentina indicates that properties are getting bigger, with an average size of the vineyard of 5.8 ha and 9.0 ha in 1990 and 2022, respectively. A large percentage (71.2%) of the total surface implanted in the country is in Mendoza, a desert province in the country west. In Mendoza there are three large artificially irrigated areas, or productive oases, from north to south. Despite the fact that the total area has decreased in Mendoza since 2010, the trend was the opposite towards 2022 in the region of Uco Valley, center oasis, with surfaces between 8933 and 10, 434 ha, representing increases between 18.5% and 25.3%, in addition to an increase of vineyard size. This process of expansion of the agricultural frontier has come at the cost of the removal of natural fields in the direction towards the foothills, on the foothills. The process was facilitated by a great technological change, mainly in the cultivation of vines for the production of fine wines (for example, expansion of monocultures,

more specific and efficient machinery for harvesting and handling the vines). This region is distinguished today by the generalization of the monoculture of a few perennial species (around 60% of the vines). These changes, which led to a homogenization of the landscape, have been also noted to have led to environmental problems, such as an increased risk of flooding in urban areas downstream (Lauro et al., 2018; McMartin et al., 2018). Due to this situation and the increasing prices of more environmentally friendly produced wines, some companies and local farmers have recently shifted from conventional farming practices, such as pesticide use and bare interrows, to more environmentally sustainable methods. However, there still hasn't been any government incentive for the adoption of environmentally friendly practices.

Our objective is to evaluate if there are differences in the bird assemblage, at a local scale, between the interior compared to borders within vineyards, in vineyards with biodiversity-friendly management (i.e., management with vegetation cover in interrows). We used a hierarchical community occupancy model, an ideal model structure for situations where bird species are rare and have low detectability, which is the present study case. Our hypothesis is that occupancy of the bird assemblage is greater in environments with greater heterogeneity. In this study, we specifically consider that the environmental heterogeneity is contributed by vegetated corridors, and therefore we predict that vineyard borders close to natural vegetation corridors will have higher bird occupancy than the center of the vineyard. Furthermore, we believe that it is important to explore the potential contributions of birds associated with vineyards, which will be possible by knowing the assemblage of birds in the study system.

2. Materials and methods

2.1. Study site

The study was carried out in three sites (vineyards) close to each other (between 790 and 2024 m apart), in Gualtallary, department of Tupungato, province of Mendoza, Argentina (Fig. 1). The vineyards have vertical trellis systems, are mowed in the interrow space and are dripped irrigated, with moderate slopes in the W-E direction. They have an adjacent dry streambed (henceforth "corridors") covered with natural vegetation and permanent covers in the interrows. All sites have biodiversity-friendly management, but they differ in their management (organic or not), the age of the vineyards, in the proportion of spontaneous vegetation in interrows, and in the size and layout of corridors adjacent to fields.

The first vineyard with 92 ha (V1, 33°23'48" S; 69°15'18" W; 1360 m a.s.l.) has organic management (i.e., without added agrochemicals), it has one adjacent 40 m wide corridor and has been planted with perennial grasses and legumes (*Vicia sativa*) in the interrow space (López García et al., 2019). Of the three sampled sites, this is the one with the least presence of flowering species in the interrows. The proportion of native and exotic species in the adjacent corridor is similar. This vineyard is the oldest, and it was established in 1992. The second vineyard with 339 ha (V2, 33°22'36" S; 69°14'15" W; 1330 m a.s.l.) has greatest proportion of natural vegetation in the interrows, composed of native and exotic dicotyledons in similar proportions, and grasses to a lesser extent, and less frequency of mowing than the others (López García et al., 2019). They use herbicides and insecticides only when they consider it necessary. This vineyard was established between 2008 and 2009, and presents four dry corridors of variable width (range from 20 m to 100 m, we focused in a 40 m corridor). The third vineyard with 32 ha (V3, 33°23'15" S; 69°14'46" W; 1350 m a.s.l.), is the newest, established in 2016, also with natural vegetation in the interrows, composed by a greater coverage of native dicotyledons and a lower amount of exotic dicotyledons and grasses (López García et al., 2019). Here they do not use herbicides, but they do use insecticides when they consider it necessary. It has two adjacent corridors of 20–30 m width.
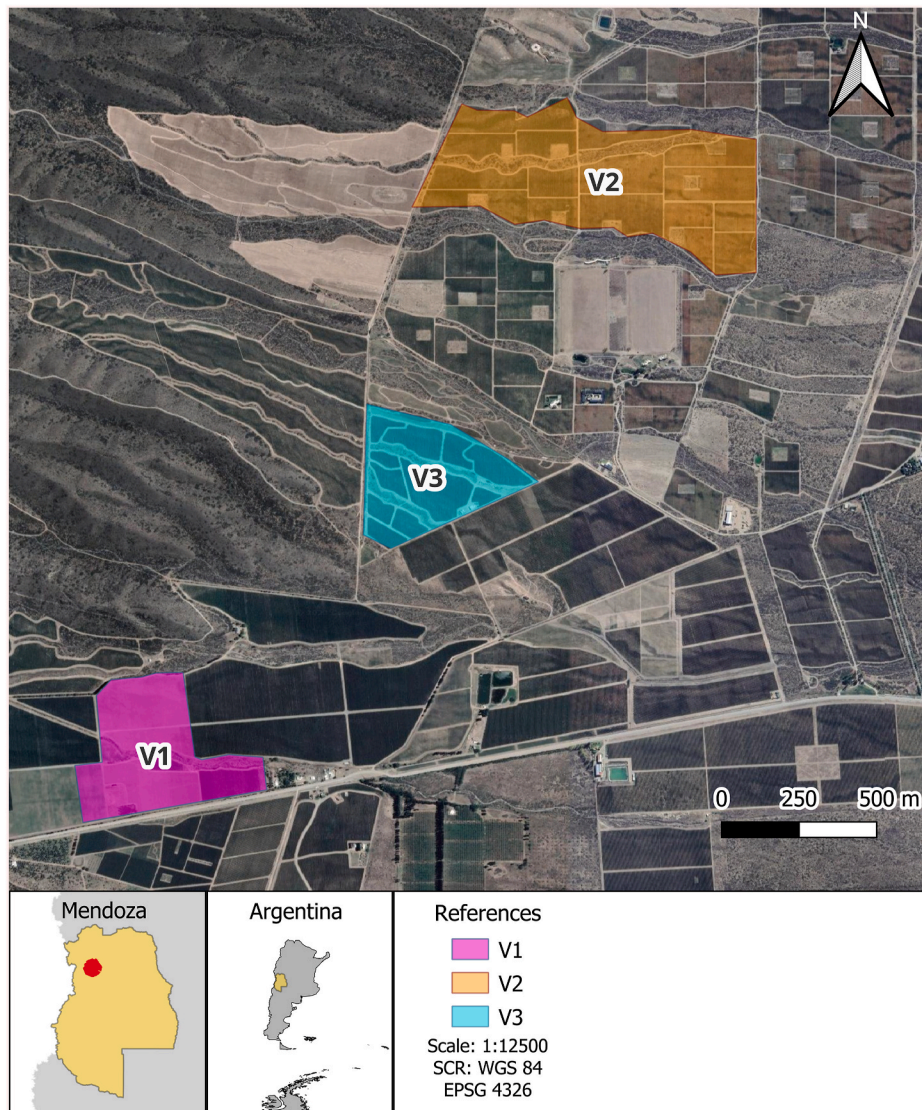
Fig. 1. Study area. Vineyards where bird sampling was conducted 2018–2020, in Gualtallary, Mendoza, Argentina.

We are aware of the importance of the context of the vineyard, so all the sites studied were immersed in the similar landscapes (within 2000 m), and therefore we assumed that we could concentrate on the local scale.

2.2. Data collection

We surveyed birds during three breeding seasons, in early summer (beginning of December), from 2018 to 2020. We chose this time of year because the less conspicuous resident birds make a greater number of displays and there are not yet large movements of vineyard workers (which affect bird detection). One of the vineyards (V1) was only surveyed the first two years, because the third year the vineyard was removed by the managers. Each year we surveyed 42 points (21 in borders close to the corridors and 21 in the interior of the vineyards), adding up to 126 surveys. We randomly allocated the first point, and then located the rest every 200 m (Goijman et al., 2020). Border points were distributed close to a single corridor per vineyard. We recorded all bird species seen or heard during 5 min at each survey point (observational unit) up to approximately 50 m, by visual/aural estimate. We conducted surveys two consecutive times at each point, between 07:00 and 10:00 (first daily visit) and 16:00–19:00 (second daily visit).

2.3. Classification of avian groups

We classified species into groups according to their main foraging guild and foraging site based on Lopez de Casenave et al. (2008) and de la Peña (2011) in order to explore the potential contributions of birds associated with vineyards (Table 1). We considered the main foraging guild for the classification, but in most cases, the species does not strictly consume only one diet category. For example, most of the granivorous species consume insects during the breeding season to feed their chicks, with the exception of pigeons and doves.

Table 1
Avian species observed in borders and interior of vineyards in Gualtallary, Mendoza, Argentina.

Scientific name	Code	Common name	Main foraging guild	Foraging site
Falconiformes				
Milvago chimango	MILCH	Chimango Caracara	Insectivore-Carnivore	Ground
Falco femoralis	FALFE	Aplomado Falcon	Insectivore-Carnivore	Ground-Air
Strigiformes				
Athene cunicularia	ATHCU	Burrowing Owl	Insectivore-Carnivore	Ground-Branch
Piciformes				
Colaptes melanochloros	COLME	Green-barred Woodpecker	Insectivore	Ground-Trunk
Columbiformes				
Zenaida auriculata	ZENAU	Eared Dove	Granivore*	Ground
Patagioenas maculosa	PATMA	Spot-winged Pigeon	Granivore*	Ground
Columbina picui	COLPI	Picui Ground Dove	Granivore*	Ground
Columba livia	COLLI	Rock Pigeon	Granivore*	Ground
Tinamiformes				
Nothura maculosa	NOTMA	Spotted Nothura	Granivore	Ground
Apodiformes				
Streptoprocne zonaris	STRZO	White-collared Swift	Insectivore	Air
Passeriformes				
Spinus barbatus	SPIBA	Black-chinned Siskin	Granivore	Ground-Grass panicle
Sicalis luteola	SICLU	Grassland Yellow-finch	Granivore	Ground
Zonotrichia capensis	ZONCA	Rufous-collared Sparrow	Granivore	Ground
Phrygilus gayi	PHRGA	Gray-hooded Sierra Finch	Granivore	Ground
Rhopospina fruticeti	RHOFR	Mourning Sierra Finch	Granivore	Ground
Molothrus bonariensis	MOLBO	Shiny Cowbird	Granivore	Ground
Passer domesticus	PASDO	House Sparrow	Granivore	Ground
Agelaioides badius	AGEBA	Grayish Baywing	Granivore	Ground
Catamenia analis	CATAN	Band-tailed Seedeater	Granivore	Ground-Grass panicle
Rauenia bonariensis	PIPBO	Blue-and-yellow Tanager	Granivore-Frugivore	Ground-Branch
Tyrannus melancholicus	TYRME	Tropical Kingbird	Insectivore	Air
Tyrannus savana	TYRSA	Fork-tailed Flycatcher	Insectivore	Air
Pyrocephalus rubinus	PYRRU	Vermilion Flycatcher	Insectivore	Air
Knipolegus aterrimus	KNIAT	White-winged Black-tyrant	Insectivore	Air
Pygochelidon cyanoleuca	PYGCI	Blue-and-white Swallow	Insectivore	Air
Troglodytes aedon	TROAE	House Wren	Insectivore	Branch-Trunk
Pseudoseisura lophotes	PSELO	Brown Cacholote	Insectivore	Ground
Mimus patagonicus	MIMPA	Patagonian Mockingbird	Insectivore	Ground
Turdus chiguanco	TURCH	Chiguanco Thrush	Insectivore	Ground
Leistes loyca	LEILO	Long-tailed Meadowlark	Insectivore-Granivore	Ground

Orders, scientific and common names are indicated, and main foraging guild and foraging site. (*) denotes strictly granivores, while the other granivores consume invertebrates in the breeding season.

2.4. Occupancy modeling

We used a hierarchical multi-species single-season occupancy model under a Bayesian framework to assess how avian occupancy differed between border and interior of vineyards, and how these differences related to species (Dorazio and Royle, 2005; Royle and Dorazio, 2008Royle and Dorazio, 2009; Zipkin et al., 2009). Occupancy estimation accounts for imperfect detection probabilities of each species ($p < 1$). Multi-species occupancy models are an extension of the single-species occupancy model (Mackenzie et al., 2002) where the parameters of each species are treated as random effects, and species-specific effects are drawn from a common distribution (community-level distribution) (Dorazio and Royle, 2005). In this context, hierarchical models are valuable because they improve inference by sharing information across species regardless of their relationships (i.e., reduce prediction error or uncertainty intervals), which becomes especially important for those species less frequently detected in the community (Sauer and Link, 2002). We further extended the multi-species occupancy model to use all data collected across multiple vineyards and years, considering them as random effects to account for the possible sources of variability contributed by them (Goijman et al., 2015). We focused our interest on understanding species-level responses allowing the identification of a posteriori responses common within guilds to make inferences on potential contributions of birds to vineyards. We did not group the species a priori since the grouping criteria could be varied and influence the results observed at the community level (Pacifici et al., 2014).

Our hierarchical model consisted of two sub-models: an ecological process model for occupancy of each species and an observation process model for detection, conditional on occupancy (Royle and Dorazio, 2008). Our ecological process model assumes occupancy as a binary state $z_{j,\ i,\ e}$ for each species $i = 1, 2, …, N$ at site $j = 1, 2, …, J$ and vineyard-year combination $e = 1, 2, …, E$; where $z_{j,\ i,\ e} = 1$ when the species is present, and zero otherwise. $Z_{j,\ i,\ e}$ is a latent variable that represents the true state of occurrence of each species i at point j in vineyard-year e; and the Bernoulli parameter ψ is the expected value of z, called the probability of occupancy. Due to the fact that true occurrence is imperfectly observed, this is incorporated through the observation process model $y_{j,k,i,e} \sim$ Bern $[z_{j,i,e} \times p_{j,k,i,e}]$, where $p_{j,k,i,e}$ is the probability that species i at point j in farm e is detected at repetition $k = 1, 2$; and $p_{j,k,i,e} = 1$ when the species is detected, and zero otherwise.

We modeled occupancy probability to incorporate vineyard and year as a random effect (Goijman et al., 2015). Our occupancy model was:

$$\log it\left(\psi_{j,i,e}\right) = \alpha_{i,e} + \beta_i \times \text{cov}_{j,e}$$

where α is estimated for each species i and vineyard-year e; *cov* corresponds to border (*cov* = 1) and center of the vineyard (*cov* = 0) of each site j and vineyard-year e respectively.

We used the mean of the posterior distribution and the associated 95% Bayesian credible intervals (95% CRI) of the beta coefficient to assess the effect of borders on occupancy. We considered as strong effects those in which zero was not included in the 95% CRI, because we can be confident that the parameter is either positive or negative.

However, we also present and discuss the effect of those parameters with 95% CRI those that slightly overlapped zero (i.e., $f > 0.90$, f being the proportion of the posterior with the same sign as the mean). We modeled detection for each species without specific covariates.

We fitted our model using Markov chain Monte Carlo (MCMC) methods via the package jagsUI (Kellner, 2015) in R 4.2.1 (R Core Team, 2022). We ran three chains of length 100,000 each and discarded the first 10,000 as burn in, adapting 50,000 iterations with a thinning rate of 10. We used weakly informative priors for all parameters (for details see Appendix A). We assessed MCMC convergence and mixing by visually inspecting trace plots and by calculating the Gelman–Rubin statistic for each parameter of interest, where values lower than 1.1 indicated convergence (Gelman and Rubin, 1992).

We estimated species richness at each site $N_{j,\ e}$ as a derived quantity of the community occupancy model, so that $N_{j,\ e} = \Sigma z_{j,\ e}$. In that manner this analysis accommodates imperfect detection, and yields an estimate of site/specific species richness conditional on the list of species that were detected at least once (Kéry and Royle, 2016). We compared species' richness between borders and interior of the vineyards with a nested ANOVA, considering the habitat nested within vineyards and years.

2.5. Species composition

In order to test for differences in the composition of the bird community between border and interior, and the vineyards, we used permutational multivariate analysis of variance (PERMANOVA) with 999 iterations, using the Adonis function in the vegan package (Oksanen et al., 2019). We used post-hoc Tukey pairwise comparisons to assess differences between vineyards and years, using the pairwiseAdonis package (Arbizu, 2017).

We plotted bird species composition of the community to show association with vineyards and habitats, through a non-metric multidimensional scaling (NMDS), using the Bray-Curtis index as a dissimilarity measure, with the metaMDS function in the vegan package (Oksanen et al., 2019). We assessed the proper choice of dimensions through a plot of stress (a measure of goodness-of-fit) vs. dimensionality. We chose to perform the final analysis with four dimensions (stress = 0.084). We also examined β-diversity to determine if we found marked differences and infer more deeply on the potential provision of contributions of birds to production (Mori et al., 2018). We used beta.multi and beta.pair in the betapart package to explore partitioned β-diversity between border and interior, and vineyards, respectively (Baselga et al., 2023).

All analyses were performed using R 4.2.1 (R Core Team, 2022).

3. Results

3.1. Bird occupancy and richness

We observed 30 bird species belonging to 7 orders; 12 of these species were classified as mainly insectivores, 15 as granivores (11 of which catch invertebrates in the breeding season to feed their chicks), and 3 as carnivores (Table 1). More than 75% of these species exclusively or partially consume invertebrates. Most registered species feed on the ground, and a smaller percentage feed in the air or on branches, or panicles. Detection probabilities (p) for most species were less than 50% (Appendix Fig. S1, Table S1). Only two species had higher detection probabilities: *Sicalis luteola* and *Zonotrichia capensis*.

Occupancy of the bird community was greater on the borders than inside the vineyard, and this was the general trend for most of the species (Fig. 2; Appendix Fig. S2, Table S1). Seven of those species showed a strong effect towards the borders (Fig. 2; Appendix Table S1). Those species consisted of two strictly insectivorous aerial foragers, *Tyrannus savana* and *Knipolegus aterrimus*, and five ground granivorous species, *Z. capensis*, *Passer domesticus*, *Agelaioides badius*, *Molothrus bonariensis*, and *Columbina picui*, with the last species being a strict granivore.

Species richness was significantly higher at the borders of all vineyards ($p < 0.0001$), compared to their interior, for all years (Fig. 3). Mean richness in V3 border was close to the mean of V1 and V2 center. Overall, richness was the highest in V1, followed by V2, and V3 had the lowest values.

3.2. Species composition

Species composition of the community was weakly different between borders and the interior of the vineyards ($F = 1.47$, df = 8; $r^2 = 0.095$; $p = 0.051$).

Likewise, β-diversity was low between border and interior, with only 33% of the species differing overall ($\beta_{\text{Sorensen}} = 0.33$).

Community composition was different between vineyards and years (Fig. 4; $F = 4.33$, df = 7; $r^2 = 0.244$; $p = 0.001$). Post-hoc tests between vineyards revealed that there were not differences within vineyards between years, but that there were significant differences between all vineyards (V2 vs. V3: $r^2 = 0.097$; $p_{\text{adj}} = 0.003$; V2 vs. V1: $r^2 = 0.16$; $p_{\text{adj}} = 0.003$; V3 vs. V1: $r^2 = 0.094$; $p_{\text{adj}} = 0.006$). V1 was the largest community, followed by V2, and V3 was last. β-diversity also differed between vineyards more than between border and center, especially V2 vs. V1 and V3, not so much V1 vs. V2 (V1–V3 $\beta_{\text{Sorensen}} = 0.54$; V2–V3 $\beta_{\text{Sorensen}} = 0.5$; V1–V2 $\beta_{\text{Sorensen}} = 0.35$).

4. Discussion

Our findings provide some support for our main hypothesis, that higher levels of habitat heterogeneity drives patterns of occupancy by bird assemblages. Across all vineyards and the three survey seasons, occupancy and richness of the bird community was more closely associated with the borders adjacent to corridors than with the interior of the vineyards. Patterns for individual species such as *Tyrannus savanna*, *Knipolegus aterrimus*, *Z. capensis*, *Passer domesticus*, *Agelaioides badius*, *Molothrus bonariensis*, and *Columbina picui* were also similar to the general pattern. However, the assemblage of birds did not differ much between borders and interior. Bird assemblage and also richness differed between vineyards, with the greatest richness and complex assemblage in the organic vineyard with vegetation planted in interrows, followed by the vineyards with spontaneous vegetation.

As expected, proximity to vegetated corridors was a factor that determined a greater probability of species occupancy. Our results support the findings from other studies, that land use heterogeneity, in both permanent and annual agricultural systems, favors biodiversity (Assandri et al., 2016, 2017; López García et al., 2019; Paiola et al., 2020; Bosco et al., 2021; Brambilla and Gatti, 2022; Belkhiri et al., 2023). In our study, corridors are an important component of landscape heterogeneity, and their proximity favors occupancy of some species within vineyards closer to borders. Species most strongly associated with borders belong to different groups and foraging sites, so proximity to a corridor would help maintain functional diversity and the potential contributions from different functional groups (Sekercioglu, 2006; Whelan et al., 2008). Among the bird species that showed a preference for borders, two were aerial insectivores, four were terrestrial granivore/insectivores and one terrestrial granivore. Species richness was also greater at the borders, compared to the center of the vineyards. Although the community assemblage did not differ strongly between border and center, there were species that only used the borders, several of them insectivores. One management approach that could attract border-only species would be to place internal patches or "islands" of vegetation within the vineyard.

Of all the recorded species in this study that use the vineyard, more than 75% exclusively or partially consume invertebrates. On the other hand, most species feed on the ground, whether granivores or insectivores. However, of all the invertebrate consumer species, 30% also feed on branches or trunks and another 30% in the air, covering the entire spectrum of strata where they prey on invertebrates, and possibly
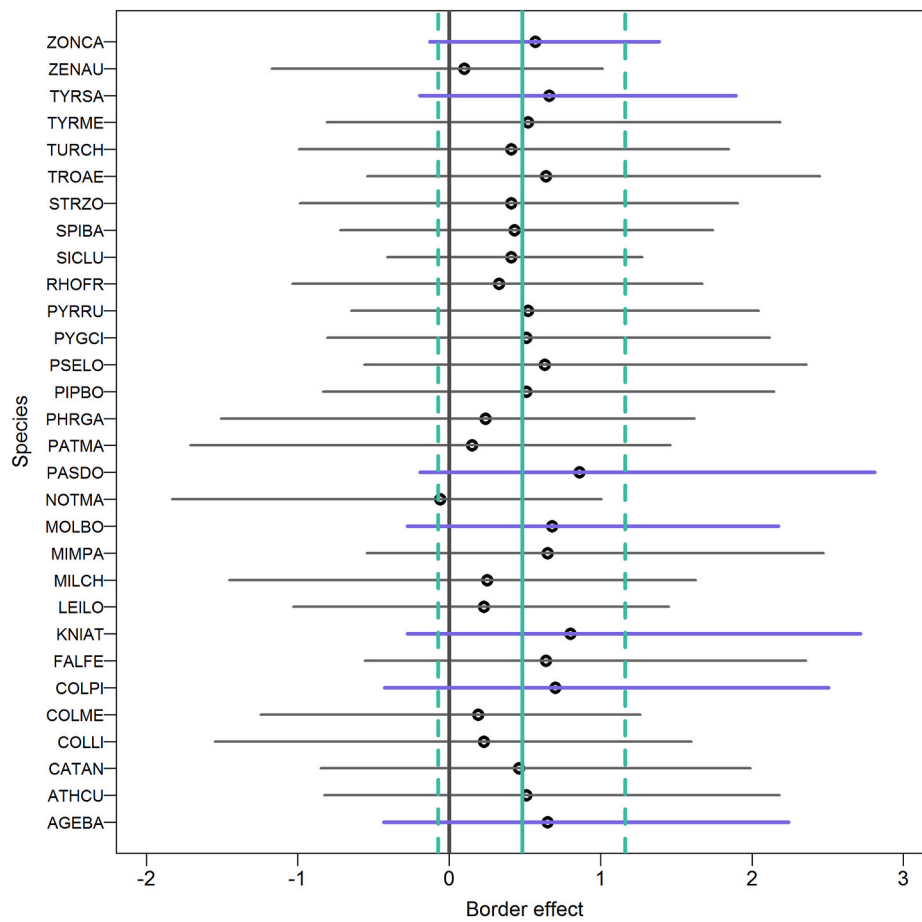
Fig. 2. Vineyard border effect on bird occupancy. Effect of border of the vineyards (relative to the inside) on bird species and community occupancy (posterior means and 95% CRI), in Gualtallary, Mendoza, Argentina. Posterior distributions to the right of zero represent species or which occupancy was higher on borders. Purple lines highlight strong effects (95% CRI that slightly overlaps zero, refer to the methods section for more details, and Table 1 for species codes).
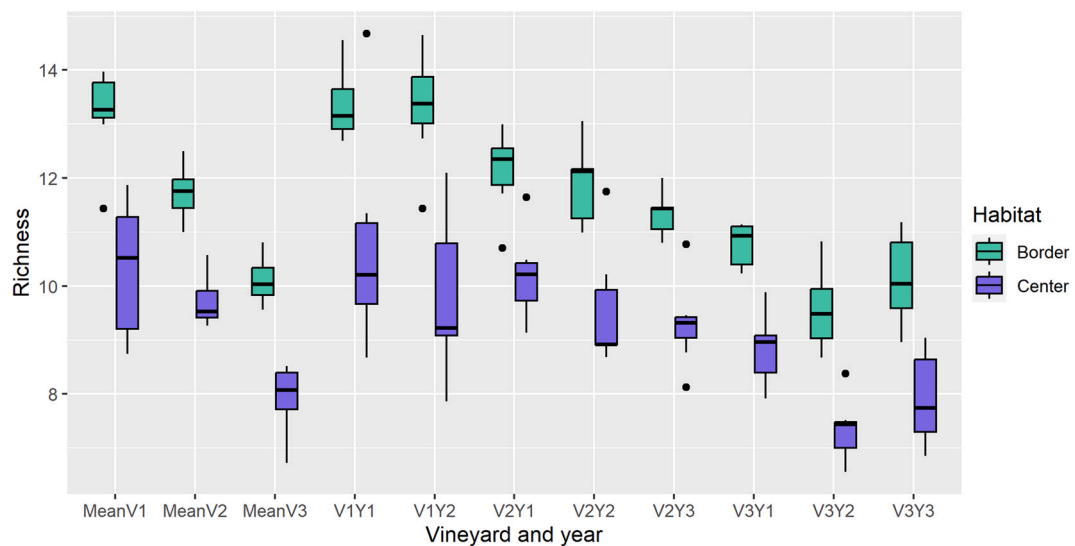
Fig. 3. Species richness in vineyards. Species richness in border and center at each vineyard and year (means, V1, V2, V3, Years 1–3). Boxes represent 25th and 75th percentiles (inter-quartile range, IQR), horizontal lines indicate the median, and whiskers 1.5IQR. Richness differed significantly between border and center ($p < 0.0001$).
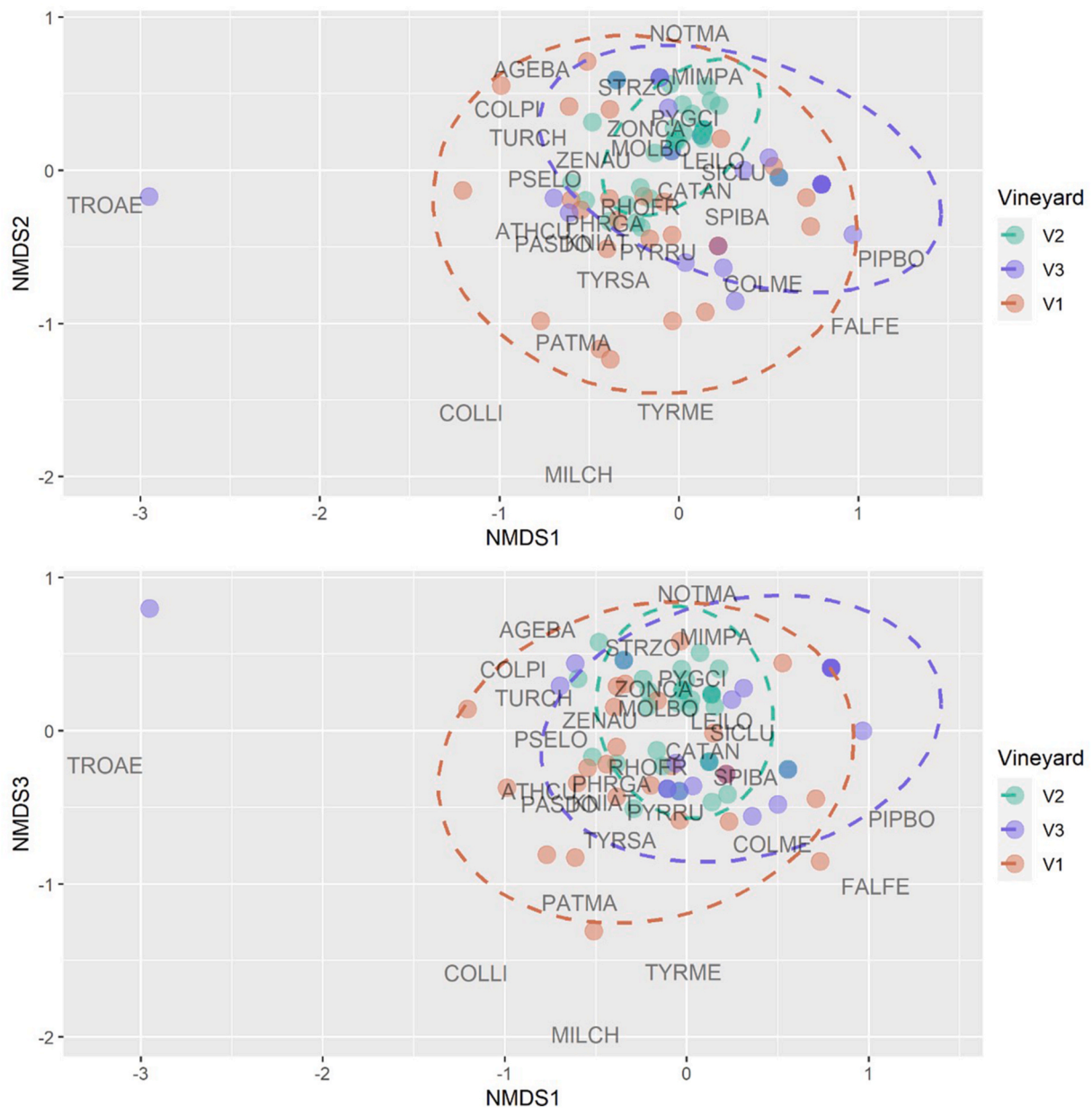
Fig. 4. Bird species' composition in vineyards. Non-metric multidimensional scaling (NMDS) plot illustrating the association among birds in vineyards in relationship to border and interior. No strong differences between years within vineyards, but significant differences between vineyards ($p < 0.006$). Top: NMDS borders 1 and 2. Bottom: NMDS borders 1 and 3.

increasing pest control contributions by birds (Sekercioglu, 2006; Whelan et al., 2008; Barbaro et al., 2017; Nyffeler et al., 2018). We also found some species that have been reported feeding on grapes, such as the four species of pigeons (*Zenaida aurticulata*, *Patagioenas maculosa*, *C. picui* and *Columba livia*) and three passerines (*P. domesticus*, *A. badius*, and *M. bonariensis*), causing a disservice (Whelan et al., 2015; Seker-cioglu et al., 2016). Currently in the study region, these species are not perceived by producers as a threat to grape production (unpublished results). Thus, heterogeneity that benefits birds does not harm pro-ducers, but more research is needed.

By finding the highest observed species richness and the highest bird functional diversity in the vineyard with planted vegetation cover and organic management, we deduce that the species occupy vineyards with high cover between rows, regardless of whether these covers are planted or natural, dicotyledonous or grasses. Although we did not find marked patterns in partitioned β-diversity to infer more about differences in the potential contributions by species such as pest control, between

vineyards (Mori et al., 2018). The patterns of richness and diversity found for beneficial insects in these same vineyards are opposite to the results of this study on birds. The greatest richness and local diversity of invertebrates is found in the vineyard with more frequent management interventions and coverage of native dicotyledons vineyards (López García et al., 2019), where the richness of birds is lower and higher β-diversity with the other two. These results are supported by other studies where it was found that birds respond more to the offer of shelter than to the invertebrates, especially insectivorous birds (Goijman et al., 2020). Other studies found higher bird abundance and richness (Rollan et al., 2019; Beaumelle et al., 2023), insectivorous and generalist func-tional diversity and abundance (Barbaro et al., 2021) in organic vine-yards with grass cover when compared to conventional ones, while others found no differences in richness and abundance (Assandri et al., 2016; Puig-Montserrat et al., 2017; Paiola et al., 2020). Differences on these findings, as well as the differences found in the assemblages and richness of birds between vineyards in this study, can be attributed to

the interaction with landscape context (Tscharntke et al., 2012; Tuck et al., 2014). These differences could also be attributed to the degree of vegetation cover in the interrows, which has been shown to have positive impacts on birds, especially for those that nest there (Duarte et al., 2014; Buehler et al., 2017; Brambilla and Gatti, 2022).

Farmland bird communities are determined by both landscape structure and agricultural management, and the interaction of these factors, and their multiple levels, are often difficult to disentangle (Batáry et al., 2011; Goijman et al., 2015; Assandri et al., 2016; Pithon et al., 2016; Barbaro et al., 2017, 2021). Landscape context interacts with vineyard management to shape bird functional diversity and pest control (Assandri et al., 2017; Barbaro et al., 2017, 2021; Paiola et al., 2020; Bosco et al., 2021), and could even be key to mitigate tradeoffs between vineyard management and vineyard yield in different management systems (Beaumelle et al., 2023). In order to better distinguish the effect of the context of the landscape from the effect of management, we consider that we should increase the scale of the study and include more vineyards, recording the surrounding landscape in future studies. The scope of the present study can shed light on some aspects, such as the differences between the use of the borders or interiors of the vineyard, and to generate a baseline of knowledge and guide future efforts, such as the study of the landscape context.

Most biodiversity studies in vineyards in other parts of the world focus on comparing organic and conventional management, without evaluating biodiversity-friendly management or ecological schemes, where not only the applications of agrochemicals are minimized, but also the soil cover with spontaneous vegetation is prioritized. The latter are proposals that must also be evaluated in terms of their contributions to biodiversity conservation. In this study we have seen that the vegetation cover and proximity to corridors, which adds heterogeneity within the fields, whether implanted or spontaneous, favors birds, and houses many insectivorous species that may be contributing to pest control (Nyffeler et al., 2018). In turn, these schemes have shown in other parts of the world that yield did not differ from conventional management, while it was lower in organic production (Döring et al., 2019; Katayama et al., 2019; Beaumelle et al., 2023). However, when evaluating the productive results of a vineyard, it is not only necessary to take into account the productive performance, but also how much in benefits provided by the biodiversity has been gained, as in these cases, soil protection and presence of beneficial organisms (Duarte et al., 2014; Paiola et al., 2020; Brambilla and Gatti, 2022; Beaumelle et al., 2023).

Funding

CRediT authorship contribution statement

Andrea Paula Goijman: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Agustín Zarco:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization.

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.

Acknowledgements

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.avrs.2024.100174.

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