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Vineyard Edges Increase Bird Richness and Abundance and Conservation Opportunities in Central Chile

Andrés Muñoz-Sáez [1,2,3]

[1] Laboratorio de Agroecología, Biodiversidad, & Sostenibilidad, Departamento de Producción Agrícola, Facultad de Ciencias Agronómicas, Universidad de Chile, Santiago 8820808, Chile; andrmunoz@uchile.cl; Tel.: +562-9785727 (ext. 212)
[2] Center of Applied Ecology and Sustainability (CAPES), Santiago 7820244, Chile
[3] Sociedad Científica Chilena de Agroecología, Los Ángeles 4440000, Chile

Abstract: Agricultural landscapes significantly impact biodiversity, particularly within vineyard ecosystems where the configuration of native vegetation and vineyard edges plays a pivotal role. This study investigated the structure of bird communities across vineyards, their edges, and adjacent native vegetation, utilizing generalized linear mixed models to analyze the influence of surrounding land covers at varying scales of 100 m and 1000 m radii across these three landscape types on bird richness and abundance and functional groups. The results highlight that native vegetation is crucial for supporting endemic bird species, with 41% of all observed species found across all three habitat types and a significant 66.7% shared between native vegetation and edge habitats. In particular, insectivores and carnivores, key to biodiversity conservation and ecosystem service provision, showed higher abundances in areas with extensive native vegetation, underscoring its vital role in maintaining ecological functions. Edges not only enhanced the general bird richness and abundance but also served as crucial habitats for granivores and omnivores, influencing ecosystem dynamics through changes in the trophic guild community structure. These findings underscore the importance of conserving native vegetation within vineyard landscapes to foster a diverse avian community that contributes to enhancing ecosystem services. These results provide an opportunity to intensify restoration initiatives on vineyard edges and enhance our understanding of how certain species adapt to agriculture. This can be considered a vital nature-based solution for sustainable agriculture, promoting biodiversity conservation alongside productive agroecological practices in vineyard ecosystems.

Keywords: agroecosystems; Aves; mediterranean-type ecosystems; trophic guilds; wildlife-friendly farming

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1. Introduction

Maintaining the well-being of nature and people is a central goal of global sustainability efforts. Agriculture plays a central role in food production and biodiversity loss [1,2]. Agricultural land expansion, overuse of agrochemical inputs, and loss of landscape diversity through monocultures are considered among the most significant contributors to global biodiversity loss [3,4]. A global population of 9.8 billion people is predicted by 2050, and, in the absence of improved food access, equitable food distribution, and reduced food waste, food production will need to increase between 25 and 70% by that time, challenging innovative food systems to reach both long-term sustainability and production goals [5,6].

Ecosystem services are directly related to community composition and the relative abundance of species [7,8]. In agricultural systems, the critical services of pest predation, pollination, nutrient cycling, water recycling, and cultural services are promoted by biodiversity [8,9]. Birds are critical organisms in agroecosystems, providing essential services such as pest predation and seed dispersion [10]. In vineyards, birds promote pest management at multiple trophic levels, such as insectivorous birds, which consume arthropods that are considered pests as well as beneficial insects, and birds of prey, which hunt frugivore birds that consume grapes [11–13].

Agroecosystems act as filters that retain the species that can inhabit them. Some species adapt and use resources in agroecosystems, while others do not [13,14]. Edges between natural ecosystems and agroecosystems influence communities differently in tropical forests, where edges have been shown to lose species compared to interior forests, while the opposite happens in temperate forests across the globe [15]. However, these global trends differ across taxa and landscape scales, affecting community composition and, consequently, ecosystem function and services [13]. In arable agroecosystems with a higher edge density, ecosystem services provided by arthropods have been shown to increase crop yield, pollination, and biological pest control [16]. Edges can increase complementary and supplementary resources and opportunities for spillover effects (e.g., unintended consequences beyond the targeted area) that also depend on species' biological traits, such as diet, dispersal abilities, and foraging behavior, among others [16]. Natural or semi-natural habitats had no effect on seed predation by birds and rodents in agroecosystems [17]. Indeed, retaining native vegetation within vineyards helps conserve endemic and insectivore birds in vineyards [18]. However, service and disservice provisions change among cereal fields with different amounts of natural grasslands, including some cases where the consumption of beneficial fauna by predators is similar to or higher than the consumption of weeds and harmful arthropods [19]. The net effect or balance between services and disservices provided should be considered to provide management recommendations for biodiversity in agricultural fields and landscapes [20].

Globally, vineyards are one of the major industries in Mediterranean-type ecosystems. New areas are increasingly adopting grape production for local wine consumption and expanding to new regions due to climate change [21]. Agriculture is one of the main economic drivers of Chile, and vineyards cover around 140,000 hectares with a monetary value of USD 2000 million [22]. Vineyards are expanding into new areas in southern Chile, which harms this biodiversity hotspot [23]. The Chilean wine industry has its own voluntary sustainability code that includes a section that aims to protect biodiversity [24]; however, without evidence and standardized methods to test sustainable practices, it is difficult to establish vineyards' effects on biodiversity or management interventions to mitigate these effects. To assess the impacts of agricultural landscapes on biodiversity, evidence on the ground through field observations is needed to evaluate changes in community composition and the impact on specific species communities.

Sustainable vineyard management for biodiversity conservation and production requires evidence to guide decision making by producers, wine industry organizations, public policy, and environmental and conservation groups. This study aims to evaluate community composition changes in vineyard landscapes along a vineyard–vineyard edge–native vegetation gradient. It assesses which bird functional groups utilize the landside types of vineyards, edges, and native vegetation while accounting for the proportion of different land covers in the surrounding area (proportions of different land covers). Quantifying community composition and trophic guilds that use vineyard habitats and surrounding native vegetation is an important prerequisite to understanding the services and disservices birds provide in vineyard landscapes and their potential contribution to reaching sustainability goals.

2. Materials and Methods

2.1. Study Area

Vineyard landscapes in central Chile are characterized by their Mediterranean-type climate and are part of a biodiversity hotspot [25,26]. The main native vegetation corresponds to sclerophyllous forests and shrublands that correspond to hard-leaf vegetation adapted to dry summer conditions [27]. Agroecosystems support about 50% of the species in central Chile [18]. Meanwhile, vineyard landscapes in the same area can support 48 species [18]. The survey sites (n = 122) were located in the southern metropolitan region (Figure 1), Maipo Valley, which is a premium wine-producing area [23]. The survey sites were distributed on farms (n = 11). The natural treatments in this study were the vineyards (*Vitis vinifera* Linnaeus, 1753), native vegetation, and the abrupt transition between them, which corresponded to the edge zone (Figure 1). At each farm, at least 2 survey sites were in vineyards (V, at least 250 m from the edge) and 2 were at the edges (E) of vineyards and in native vegetation (N, at least 250 m from the edge). In total, there were 38 survey sites in vineyards, 44 at edges, and 40 in native vegetation. All survey sites were at least 250 m apart to avoid double counting the same birds [28], consistent with previous studies conducted in the same area and other Mediterranean-type vineyard landscapes [14,29].

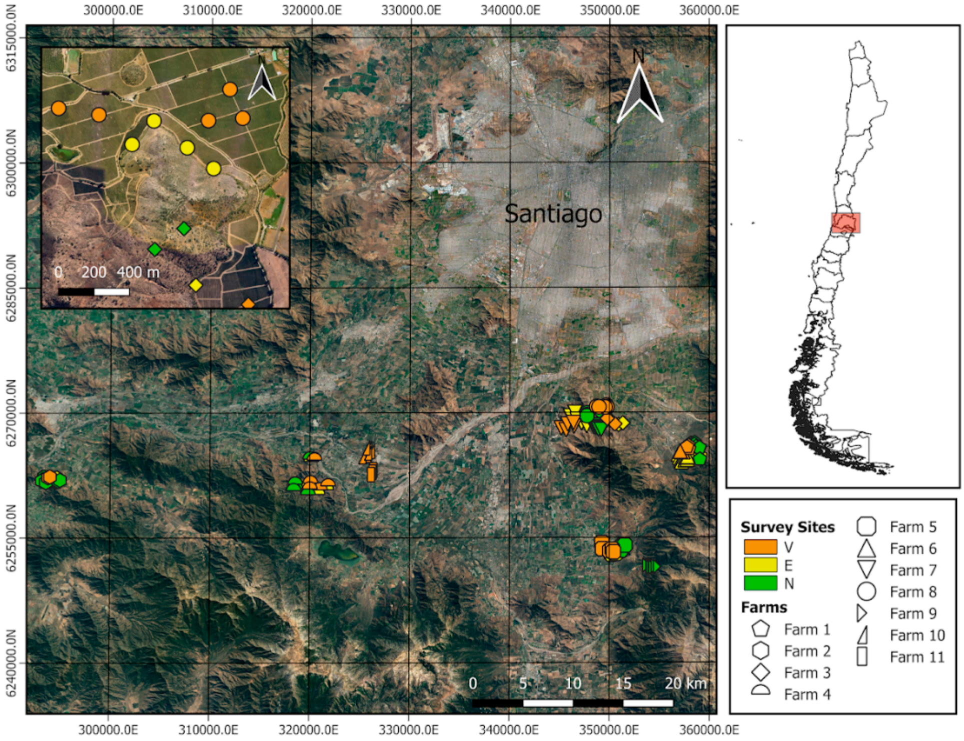


Figure 1. Study area in central Chile. Bird survey sites (n = 122) are shown. The closer caption shows survey site types in native vegetation (N, green), edges (E, yellow), and vineyards (V, orange) on 11 farms. The transition between the native vegetation and the vineyards corresponded to edges (yellow dots) (upper-left inset). Metropolitan region in central Chile (upper-right inset).

2.2. Bird Surveys

At each survey site, two auditory and visual bird counts were conducted by the same person during the spring–summer (November–February) season of 2021–2022. The second survey was conducted 43 (±25) days after the first one. All bird sightings and their vocalizations were documented through 10 min point counts with a 50 m radius at the survey sites from 7:00 am to 12:00 pm under fair weather conditions, without including bird flyovers [28]. This study aimed to evaluate habitat quality in vineyard landscapes by examining bird species richness, abundance, and feeding behavior rather than breeding success. The feeding behavior of all birds in the study was categorized based on previous studies in the same area and using the standardized names provided by the American Ornithologist Union [30,31], providing a comprehensive overview of avian community composition and habitat use.

2.3. Land Cover Classification and Analyses

Recent multispectral satellite imagery (Sentinel-2, 2023, spatial resolution of 10 m^2) was used to classify landscape variables in the study area. An unsupervised classification was used to generate the land cover map, using two commonly employed methods for unsupervised classification relying on statistics derived from spectral pixel data: K-means and the Iterative Self-Organizing Data Analysis Technique (ISODATA) [32]. The key principle in the K-means classification method involves identifying distinct classes and allocating pixels to the nearest cluster center, utilizing data from all accessible spectral bands. The ISODATA pixels are categorized into evenly distributed groups, and then any remaining pixels are clustered according to a predefined threshold [32]. After on-screen visualization and the use of expert criteria, the K-means method was selected for valleys and low-elevation areas, while the ISODATA was selected to classify mountain areas. This analysis was performed in QGIS [33–35].

After processing, each image's confusion matrix was created to compare the computer's classification of pixels against actual ground truth data (1117 points randomly assigned). This matrix shows correct identifications and misclassifications by the classifier [35]. The Kappa coefficient measures classification accuracy; these accuracy rates range from 0 to 1, in which 1 represents 100 percent accuracy. Kappa statistics represent the agreement between the classified and reference pixels. Values lower than 40% are ranked as poor or very poor agreement, while values from 70 to 85% show very good agreement, and values higher than 85% represent excellent agreement between the classified and reference pixels [35].

The extent of each land cover type (water, forest, shrubland, grassland, bare soil, urban, hedgerows, annual crops, orchards/vineyards, and farm buildings) was quantified at a 100 m and 1000 m radius at each survey site. A Pearson correlation matrix of the selected variables used in the bird detection prediction models was created (Appendix A Table A2). Using highly correlated predictors in a GLMM can reduce precision, unstable coefficients, and interpretation difficulties due to multicollinearity. Multicollinearity occurs when independent variables in a regression model are highly correlated, resulting in unreliable coefficient estimates and potential numerical issues in model fitting [36,37]. Before bird model analysis, all continuous variables were standardized to have a mean of 0 and a standard deviation of 1 to facilitate comparisons among explanatory variables.

2.4. Bird Models

All statistical analyses were conducted using R (4.3.3), and generalized linear mixed models (GLMMs) were employed to investigate the impact of land cover proportion on various bird variables, including total detections, species richness, detections within guilds (insectivores, granivores, omnivores, carnivores), and specific endemic species [18] (Appendix A Table A1). To generate the GLMMs, the maximum abundance of the two surveys was used to avoid problems of double counting and inflated abundance estimates in repeated surveys [38]. To mitigate issues associated with modeling rare species, our analysis focused on bird species with more than 5 observations at at least 5 different survey sites over all the 244 bird surveys [18,38]. Fixed effects comprised site types (native vegetation, edge, vineyard; a factor with 3 levels) and the proportion of land covers at the landscape scale (continuous). Random effects in the models included the starting time of the bird survey (a factor with 176 levels) and the survey site (a factor with 122 levels) nested within the farm where the survey was conducted (a factor with 11 levels), as in other studies [18].

A response was considered significantly associated with an environmental variable when the 95% model-averaged (mean ± SE) confidence interval (95% CI) did not encompass zero. Model averaging was conducted on models with ΔAICc < 2 using the dredge command and model.avg command of the MuMIn package [39]. This approach allowed us to account for uncertainty across multiple models rather than selecting the single best model, resulting in more robust predictions [36]. GLMMs were performed using the lme4 package [40] with a Poisson log-link distribution to model the relationship between species guild detections and site land covers. Overdispersion was assessed using the DHARMa package [41], and spatial autocorrelation was assessed using Moran's I test using the package spdep [42]. No significant overdispersion was detected, and the spatial distribution of survey sites did not impact species total detections or guilds, except for richness, where a spatial lag variable was included in the model to adjust for this spatial dependence. A post hoc Tukey analysis was conducted using the multcomp package [43] to perform pairwise comparisons among land site types (native vegetation, edges, and vineyard) in the full GLMMs. Data visualization was carried out using ggplot2 [44].

3. Results

This study documented 3385 individual birds from 244 separate bird counts, encompassing 48 species (45 native and 3 exotic). The introduced species (exotic) were *Passer domesticus*, *Columba livia*, and *Callipepla californica*. Nearly half of the species (41%) are shared between vineyards (V), edges (E), and native vegetation (N), followed by 12 species (25%) that are shared between E and N (Figure 2). Six species were found only in N (*Phrygilus patagonicus*, *Falco peregrinus*, *Coragyps atratus*, *Cathartes aura*, *Scelorchilus albicollis*, *Patagioenas araucana*), three only in E (*Glaucidium nana*, *Falco femoralis*, *Nothoprocta perdicaria*), and three only in V (*Bubulcus ibis*, *Passer domesticus*, *Columba livia*) (Figure 2). The most abundant bird species in N was an insectivore (*Elaenia albiceps*, 103 individuals/Ha); in E, the most abundant were an omnivore and a granivore (*Curaeus curaeus*, n = 147 individuals/Ha, and *Diuca diuca*, 147 individuals/Ha, respectively); and in V, the most abundant was a granivore (*Zenaida auriculata*, 142 individuals/Ha). All species detected were classified as least concern [45].

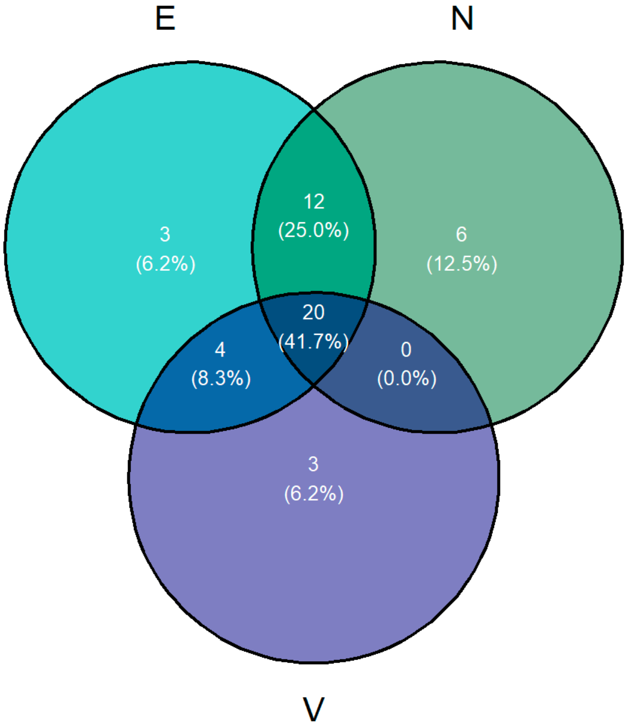
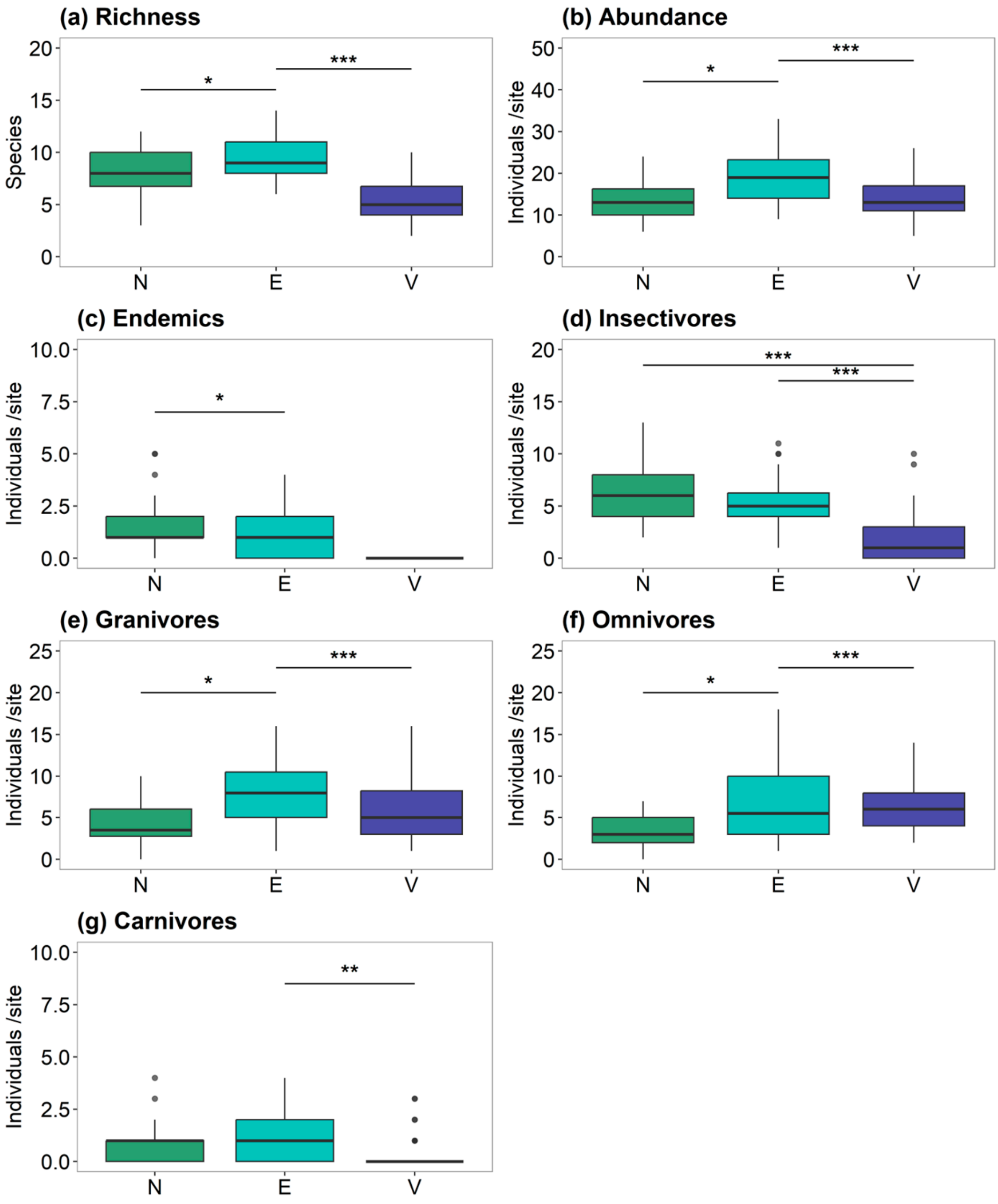


Figure 2. Venn diagram showing the number of species and proportion of total species observed (%) over three different site types: native vegetation (N), vineyards (V), and/or edges (E) between them.

The survey site type (N, E, V) significantly impacted abundance, richness, and trophic guilds, with a general trend of higher values at edges, except for endemics and insectivores, which were more abundant in the native vegetation. Bird abundance (Figure 3b) was highest in E (23.82 ± 2.14) compared to V (15.68 ± 1.36, $p = 0.006$) and N (13.38 ± 0.78, $p < 0.001$). Similarly, richness (Figure 3a) was greater in E (9.41 ± 0.31) compared to N (8.00 ± 0.35, $p = 0.037$) and V (5.58 ± 0.30, $p < 0.001$). For endemic species, low numbers and a high variation across sites made comparisons challenging, but a significant difference was observed between N and E (Figure 3c, $p = 0.\ 037$).



(a) Richness

(b) Abundance

(c) Endemics

(d) Insectivores

(e) Granivores

(f) Omnivores

(g) Carnivores

Figure 3. Comparison (mean ± SE) of the three site types (N, native vegetation; E, edge; V, vineyard) for (**a**) species richness and (**b**) abundance of birds and summed (**c**) endemic, (**d**) insectivore, (**e**) granivore, (**f**) omnivore, and (**g**) carnivore species' detections. Asterisks indicate significance of post hoc Tukey test on the generalized linear mixed model: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; (.), $p < 0.1$.

Trophic guilds showed distinct patterns among the sites (Figure 3). Insectivores (Figure 3d) were most abundant in N (6.18 ± 0.44) and significantly more abundant in E (5.39 ± 0.37) compared to V (1.90 ± 0.40, $p < 0.001$ for both comparisons with V). Granivores (Figure 3e) were most numerous in E (12.39 ± 1.98), with a significantly higher abundance than in N (4.90 ± 0.62, $p < 0.001$) and V (7.32 ± 0.93, $p = 0.012$ for V-N comparison). Omnivores (Figure 3f) were most abundant in V (7.71 ± 1.05) compared to N (3.25 ± 0.30, $p < 0.001$) and were also significantly more abundant in E (7.16 ± 0.85) compared to N ($p < 0.001$). Finally, carnivores (Figure 3g) showed similar abundances in N (0.75 ± 0.15) and E (0.98 ± 0.16, $p = 0.827$) but were more abundant in E compared to V (0.37 ± 0.13, $p = 0.008$).

Land covers were used as predictors of bird abundance in the GLMMs. The land cover classification showed a Kappa index of accuracy of 81.5%, indicating a very good classification in comparison with the real categories. The user accuracy showed an 85.9% accuracy, indicating that 959 of the 1117 points were correctly assigned, which is considered accurate [32,35]. Due to the high correlation between some variables (Pearson > 0.5), the variables hedgerows, annual crops, orchards/vineyards, and farm buildings were eliminated to avoid multicollinearity issues, selecting only the variables that were ecologically meaningful for birds [36,46].

The generalized linear mixed model (GLMM) results, summarized in Table 1 and Supplementary Table S1, highlight the influence of different landscape variables on bird richness, abundance, and trophic guild composition. According to the variance inflation factor (VIF) results, the multicollinearity among the predictor variables is minimal across the models (all VIF values < 2.5), indicating that each variable provides unique information for explaining bird community variation.

Table 1. Generalized linear mixed model results for evaluating the influence of landscape variables on bird species richness, overall abundance, and abundance by trophic guilds (species detected summed and grouped by guilds). Significant effects ($p < 0.05$) are shown in bold.

Guild	Environmental Variables	Estimate (±SE) [†]	Z Value	p Value
Richness (N = 946; 48 species)	**Forest_1 km**	0.127 ± 0.036	3.553	**<0.001**
	Shrubland_1 km	0.090 ± 0.035	2.596	**0.009**
	Water_1 km	0.039 ± 0.033	1.186	0.236
Abundance (N = 2179; 48 species)	Forest_1 km	0.055 ± 0.048	1.156	0.248
	Water_1 km	0.085± 0.046	1.872	0.061
	Longitude (X)	0.065 ± 0.047	1.386	0.166
	Shrubland_1 km	−0.066 ± 0.049	1.348	0.178
	Annual_crop_100 m	0.025 ± 0.046	0.551	0.582
Endemics (N = 118; 5 species)	**Forest_1 km**	0.912 ± 0.164	5.566	**<0.001**
	Shrubland_1 km	0.557 ± 0.171	3.260	**0.001**
	Annual_crop_100 m	0.156 ± 0.119	1.312	0.189
	Water_1 km	−0.137 ± 0.152	0.898	0.369
	Longitude (X)	−0.213 ± 0.244	0.872	0.383
	Tree_hedgerow_100 m	0.072 ± 0.097	0.747	0.455
Insectivores (N = 556; 15 species)	Tree_hedgerow_100 m	−0.032 ± 0.057	−0.561	0.575
	Annual_crop_100 m	0.081 ± 0.048	1.675	0.093
	Water_1 km	0.123 ± 0.061	2.015	**0.044**
	Forest_1 km	0.341 ± 0.069	4.907	**<0.001**
	Shrubland_1 km	0.067 ± 0.082	0.818	0.4133
Granivores (N = 1019; 16 species)	**Water_1 km**	0.156 ± 0.079	1.979	**0.048**
	Latitude (Y)	−0.088 ± 0.075	1.159	0.246
	Annual_crop_100 m	0.073 ± 0.079	0.924	0.356
	shrubland_1 km	−0.078 ± 0.090	0.868	0.385
	tree_hedgerow_100 m	−0.065 ± 0.085	0.767	0.443
	Longitude (X)	0.052 ± 0.087	0.596	0.551
	forest_1 km	0.039 ± 0.081	0.481	0.630
Omnivores (N = 738; 7 species)	**Forest_1 km**	−0.163 ± 0.077	2.107	**0.035**
	shrubland_1 km	−0.182 ± 0.107	1.693	0.091
	Annual_crop_100 m	−0.060 ± 0.076	0.785	0.433
	Water_1 km	0.042 ± 0.076	0.548	0.583
Carnivores (N = 87; 6 species)	**Shrubland_1 km**	0.400 ± 0.203	1.973	**0.048**
	Water_1 km	0.313 ± 0.112	2.801	**0.005**
	Tree_hedgerow_100 m	0.121 ± 0.080	1.516	0.129
	Annual_crop_100 m	−0.277 ± 0.310	0.894	0.371
	Forest_1 km	0.162 ± 0.150	1.079	0.281

[†] SE: standard error.

Bird richness showed a significant positive relationship with the proportion of sclerophyllous forest (Estimate ± SE = 0.127 ± 0.036, Z = 3.553, $p < 0.001$) and shrubland (0.090 ± 0.035, Z = 2.596, $p = 0.009$) within a 1 km radius, reflecting the importance of these habitats for supporting diverse avian communities. To account for spatial autocorrelation, Moran's I tests were conducted, showing no significant spatial correlation for richness (Moran's I statistic = 0.023, $p = 0.255$).

Bird abundance was marginally positively associated with water at a 1 km radius (0.085 ± 0.046, Z = 1.872, $p = 0.061$), while no significant association was found with other landscape variables such as forest, shrubland, or crop cover at smaller scales (e.g., a 100 m radius). The Moran's I statistic for abundance (0.087, $p = 0.023$) suggested some degree of spatial correlation.

Endemic bird species showed strong positive associations with sclerophyllous forest (0.912 ± 0.164, Z = 5.566, $p < 0.001$) and shrubland (0.557 ± 0.171, Z = 3.260, $p = 0.001$) at a 1 km radius, indicating that these native habitats are crucial for conserving endemic avifauna. The spatial structure of endemic species distributions was not significant (Moran's I = −0.018, $p = 0.580$).

Among trophic guilds, insectivores were positively associated with sclerophyllous forest (0.341 ± 0.069, Z = 4.907, $p < 0.001$) and water at 1 km (0.123 ± 0.061, Z = 2.015, $p = 0.044$), showing their preference for forests and landscapes where water is available. Granivores were also positively influenced by water within 1 km (0.156 ± 0.079, Z = 1.979, $p = 0.048$). Omnivores exhibited a significant negative relationship with forest cover at 1 km (−0.163 ± 0.077, Z = −2.107, $p = 0.035$), suggesting that these species prefer less forested environments. Lastly, carnivores were positively associated with shrubland (0.400 ± 0.203, Z = 1.973, $p = 0.048$) and water (0.313 ± 0.112, Z = 2.801, $p = 0.005$) proportions, highlighting the role of these habitats in supporting higher-trophic-level bird species.

These results underscore the importance of conserving native habitats, particularly sclerophyllous forests and shrublands, to maintain bird diversity and support trophic guilds within Mediterranean agricultural landscapes.

4. Discussion

Edges significantly influence bird communities within vineyard landscapes, enhancing both species richness and abundance compared to those found in native vegetation or vineyard interiors. This survey documented 3385 individual birds from 244 separate counts, encompassing 48 species, which included 45 native and 3 exotic species. Of the species recorded, 41% are shared between native vegetation, edges, and vineyards, with 32 species intersecting between sites of type E and N, constituting 66.7% of the total species. This significant overlap, including 12 species unique to E and N and 20 common across all sites, underscores the conservation potential of vineyard edges. These areas likely attract birds using diverse resources such as food, shelter, and nesting materials available at the edges [15,47,48]. The findings indicate that the natural resources at edges, the surrounding native vegetation, and the birds' tolerance to anthropized environments contribute to a varied community composition, supporting a higher abundance of insectivores, granivores, omnivores, and carnivores. These groups are crucial for assessing the contribution of birds to ecosystem services in agroecosystems [16,49]. Additionally, the results affirm the vital role of native vegetation around vineyards in conserving native bird species and providing essential ecosystem services [29,50].

Assessing bird communities in modified landscapes is crucial for ecological conservation [51]. Insectivorous birds benefit from native vegetation in vineyards, with other studies showing that nest boxes enhance predation services [29,50,52]. Granivores and omnivores, which are more abundant at edges, impact seed dynamics and grape yields, necessitating further research on their ecological roles [53,54]. Carnivores are also more abundant at edges, possibly influencing ecosystem services through intraguild predation. Future research should explore these interactions and their overall effects on vineyard ecosystems [20].

Sclerophyllous forests and shrublands are crucial for enhancing the richness and abundance of endemic, insectivorous, and carnivorous birds, underscoring the need for their conservation [29,55]. This aligns with broader restoration efforts aimed at boosting biodiversity and ecosystem services in agricultural landscapes, particularly during the UN Decade of Restoration [1,56]. Recent studies advocate for prioritizing restoration in underused agricultural areas [57]. Additionally, water availability is crucial, especially where vineyard irrigation is primarily carried out through drip systems; managing water sources like ponds and channels is vital for supporting diverse bird populations [58,59]

Recent reviews indicate that resource availability primarily drives community composition changes in working landscapes, although competition and interspecific interactions also play significant roles [29,51,60]. The structural composition, including multiple vegetation strata and interspecific interactions, significantly affects community dynamics and edge effects' intensity. Studies have shown that edge effects are more pronounced in forest bird communities adjacent to open pastures than those near eucalyptus plantations [61].

Other studies, such as Steel et al. (2017) [57], have confirmed increased bird richness at Chilean vineyard edges, along with higher activity for bats and flying insects, particularly near native vegetation [62–65]. The edge effect varies by species' mobility and tolerance to anthropogenic environments [51,61].

In vineyard interiors, only three birds were found, including two exotics (*Columba livia* and *Passer domesticus*) and a widespread egret (*Bubulcus ibis*), which have adapted to anthropogenic environments and are prevalent in agricultural systems [29]. Their presence suggests that they mainly forage rather than reproduce in these settings. These species contribute to biotic homogenization, potentially impacting ecosystem services [66,67]. Further research is needed to evaluate the extent of biotic homogenization, especially with vineyard expansion [23]. Additionally, the introduced *Callipepla californica*, found at edges and in native vegetation, may affect endemic species like *Nothoprocta perdicaria*, although their exact impact remains unclear [53].

This study, focused on the edge between native vegetation and vineyards, has limitations due to its specific setting. Future research should include diverse boundary types like vineyard–urban, vineyard–annual crop, and vineyard–grassland edges, which might differently impact bird communities [15,47]. It did not consider variations in agricultural practices (e.g., agroecological, organic, conventional) or labor intensity (e.g., the use of machinery), which are factors known to affect bird populations [47,68,69]. For the GLMMs, the maximum values among the two surveys were used, but other studies suggested that using the average or sum of those two replicates is preferable to using the maximum value, as it more accurately reflects the true average of the distribution [70]. Preliminary analysis of this dataset showed that the main results remained consistent with both approaches. The findings suggest that maintaining natural habitats in vineyards increases bird richness and abundance, but further studies should investigate breeding success to fully understand these effects [1,71,72].

Understanding some species' traits of adapting to anthropogenic conditions, such as agricultural fields, helps to improve conservation efforts and enhance field-level analyses [1]. Landscape planning for multifunctional vineyards, considering biodiversity conservation performance, ecosystem service quantification, and changes in agronomic management, could enhance the agroecological transition towards sustainable systems [73]. Enhancing birds that provide ecosystem services, such as insectivores and carnivores at edges, by changing agronomic practices, for example, avoiding spraying pesticides at edges, and enhancing artificial habitats, such as perches and bird boxes, could increase the abundance of these beneficial birds and their services, as a nature-based solution for food production [70–73].

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/agriculture14122098/s1, Table S1: Results of model averaging, spatial autocorrelation test, and overdispersion test.

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Data Availability Statement: The original data presented in the study will be openly available in FigShare at 10.6084/m9.figshare.26790547.

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Appendix A

Table A1. Land cover description of the categories used in the GLMM models.

Land Cover	Description
Tree_hedgerows_100 m	Linear trees that are used to separate properties, for shade, and as a wind breaker. These include exotic and native trees.
Annual_crop_100 m	Vegetables (lettuce, tomatoes, peppers) and cereal crops (wheat, corn), including naturally and naturalized grasslands (annual and perennial) mainly from the Poaceae family. Species include *Holcus lanatus*, *Dactylis glomerata*, *Festuca* sp.
Water_1 km	Watercourses include irrigation channels, ponds, and the Maipo River.
Forest_1 km	Native sclerophyllous forest trees over 2 m high, including species such as *Peumus boldus*, *Quillaja saponaria*, *Lithraea caustica*, *Cryptocaria alba*, *Crinodendron patagua*, and *Prosopis chilensis*, among others, as coexisting species.
Shrubland_1 km	Native shrubs less than 2 m high, including species such as *Vachellia cavens*, *Colliguaja odorifera*, and *Trevoa trinervis*, among others, and succulents (*Puya* sp., *Echinopsis chiloensis*) as coexisting species.

Table A2. The Pearson correlation matrix of the selected variables used in the bird detection prediction models.

	tree_hedgerow_100 m	annual_crop_100 m	water_1 km	forest_1 km	shrubland_1 km
tree_hedgerow_100 m	1	−0.0167	−0.044	−0.001	−0.064
annual_crop_100 m		1	0.044	−0.058	−0.100
water_1 km			1	−0.148	−0.087
forest_1 km				1	−0.302
shrubland_1 km					1

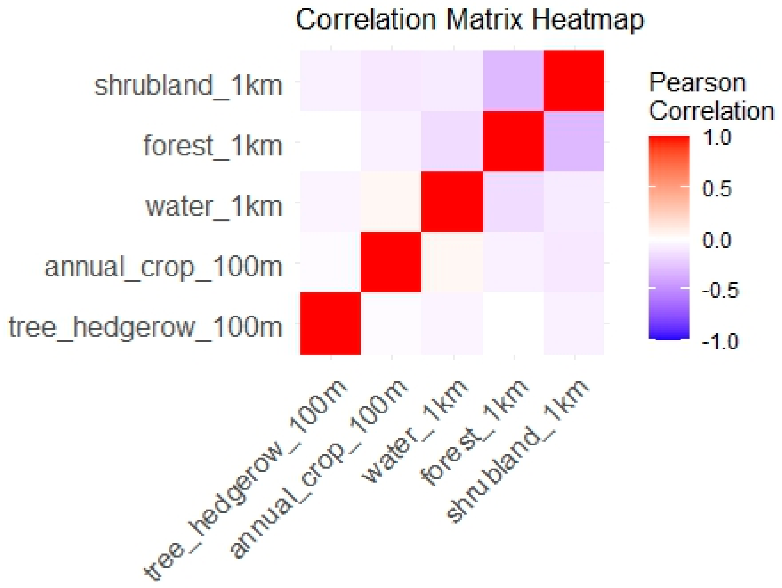

Figure A1. Heatmap Pearson correlation of the variables used in the analysis.

Table A3. Confusion matrix showing users' and producers' accuracy. Kappa indicates a very good classification in comparison with the real categories.

Confusion Matrix	Sclerophyllous Forest	Annual Crops	Orchards	Bare Soil	Shrubland	Urban	Farm Buildings	Grassland	Water	Hedgerows	Total	User's Accuracy (%)	Confusion Error (%)	Kappa (%)
sclerophyllous forest	415		2	5	31			1			454	0.914	0.086	
annual crops	2	104	7	1							114	0.912	0.088	
orchards		3	119				1				123	0.967	0.033	
bare soil	2			83	4						89	0.933	0.067	
shrubland	73		1	8	91					1	174	0.523	0.477	
urban			1	1		70					72	0.972	0.028	
farm buildings	1	2		2			53				58	0.017	0.983	
grassland	4			2	1			21			28	0.750	0.250	
water		2							3		5	0.600	0.400	
hedgerows										0	0	0.000	1.000	
Total	497	111	130	102	127	70	54	22	3	1	1117			
Producer's Accuracy (%)	0.835	0.937	0.915	0.814	0.717	1	0.981	0.955	1	0		0.859		
Error of omission (%)	0.165	0.063	0.085	0.186	0.283	0	0.019	0.045	0	1				
Kappa (%)														0.815

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