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Field-scale management strongly affects avian communities and the potential for bird-mediated ecosystem services and disservices in vineyards

Mattia Brambilla [a,*], Giacomo Assandri [b], Maurizio Odicino [a]

[a] University of Milan, Department of Environmental Science and Policy, Milan, Italy
[b] Dipartimento di Scienze e Innovazione Tecnologica, Università del Piemonte Orientale "Amedeo Avogadro", Alessandria, Italy

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ABSTRACT

Reconciling biodiversity and agriculture is crucial for conservation and sustainable production. Viticulture impacts on ecosystems, and birds, which are highly sensitive to human-induced changes, play key roles in vineyards. Birds may be affected by in-field management, but most studies have focused on larger spatial scales. Understanding field-level effects is fundamental: adjusting field-scale management to accommodate biodiversity needs can be feasible and easy to incorporate into conservation schemes. We analysed the effects of parcel (homogeneous management unit of vineyards) characteristics/management on the abundance of avian functional groups and species richness. We sampled bird communities and vineyards characteristics (both management- and landscape-related ones) along 43 linear transects in Italy, in May-June 2024. We grouped birds into woody vegetation-dwelling insectivores, ground/grass-dwelling insectivores, seed eaters, and potential grape eaters. We modelled species richness and abundance of different groups (occurrence for granivores) in relation to parcel characteristics. Irrigation was negatively associated with species richness, vegetation-dwelling insectivores and granivores. Row tillage and use of herbicides along rows negatively impacted on vegetation-dwelling insectivores, likely reducing habitats and resources. Alternate mowing promoted granivores and reduced potential grape eaters. Ground vegetation promoted granivores when 10–25 cm-high, and potential grape eaters and species richness at 25–40 cm-height. Bare ground cover positively affected granivores and species richness, likely increasing food accessibility. Alternate mowing (every second inter-row), retaining some bare ground patches and reducing row tillage and herbicide applications represent a win-win solution, promoting both bird conservation and potential ecosystem services provided by avian species to viticulture.

1. Introduction

Biodiversity and agriculture are intrinsically linked to each other. Wild species play irreplaceable functions in agroecosystems, and provide many ecosystem services, but also some disservices, in farmed areas (Pejchar et al., 2018). Agriculture creates and maintains habitats suitable for some species, but also dramatically impacts many organisms and ecosystems, being one of the main causes of species decline and ecological degradation (Crist et al., 2017). Reconciling biodiversity and agricultural practices is therefore crucial and needed both for conservation purposes and sustainable production.

Vineyards represent one of the most impacting crops worldwide (Viers et al., 2013). They are often highly intensive and homogeneous crops, established in biodiversity-rich areas, where they may exert a strong impact on wild species and ecosystem balance. The intense management is also leading to frequent agronomical and soil erosion issues (Prosdocimi et al., 2016). Integrating nature-based solutions into vineyard management and viticulture agroecosystems is key to achieving a sustainable grape production (Rusch, 2025).

Birds are highly sensitive to human-induced landscape and habitat changes, responding positively or negatively to anthropogenic pressures, depending on species and contexts (Fraixedas et al., 2020). In vineyards, where they are affected by both landscape and field characteristics (Assandri et al., 2016; Barbaro et al., 2021; Bouvier et al., 2024), birds can represent both allies and threats for grape production. Avian species may indeed contribute to key ecosystem services in agricultural areas (Gaston, 2022; Nyffeler et al., 2018; Pejchar et al., 2018; Roseo et al., 2024) and, in vineyard landscapes, they are involved in insect pest control (Barbaro et al., 2017), weed control (Whelan et al., 2008), and cultural ecosystem services (Assandri et al., 2018b;

* Correspondence to: University of Milan, Department of Environmental Science and Policy, Via Celoria 26, Milan I-20133, Italy.
E-mail address: mattia.brambilla@unimi.it (M. Brambilla).

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Brambilla and Ronchi, 2020; Zielonka et al., 2024b). On the other hand, some species may feed on grape (Barbaro et al., 2021), possibly leading to ecosystem disservices, i.e. reduction in grape production or quality (Anderson et al., 2013).

The in-field management strongly impacts ground vegetation in vineyards (Nascimbene et al., 2013) and, in turn, affects biodiversity and ecosystem services (Winter et al., 2018). Management is indeed particularly relevant in determining bird occurrence/abundance, by driving the availability of insect prey and of seeds, but also the possibility to find and obtain the food items, i.e. accessibility (Bosco et al., 2019a, 2019b; Schaub et al., 2010; Winter et al., 2018). Too high and dense vegetation may prevent access to food for many species, especially insectivores (Vickery and Arlettaz, 2012). In fact, many birds in vineyards seem to prefer intermediate conditions, with heterogeneous ground vegetation, where patches with taller and denser vegetation 'produce' the food, which is easily collected in areas with lower and/or sparser vegetation (Brambilla and Gatti, 2022). This kind of 'kitchen-dining room' sward system (Vickery and Arlettaz, 2012) may be easily obtained in vineyards by alternating inter-row management, i.e. by mowing vegetation or tilling the ground every second row. Experimental implementations of alternate management of ground vegetation in commercial vineyards resulted indeed in an increase in the number of bird (and butterfly) species in vineyards, also promoting the richness and/or abundance of avian functional groups most prominent for ecosystem services, i.e. insectivores and seed eaters (Brambilla and Gatti, 2022). Alternated tillage compared to more intensive management has been reported to promote more diverse plant communities, with higher ground coverage (Fiera et al., 2020).

Field-scale agricultural management practices, therefore, may strongly affect vineyard use by birds (Guyot et al., 2017). However, most studies focussing on the topic until now had been carried out at larger spatial scales than the parcel (i.e., the homogeneous unit of a crop, vineyard in this case, with the same characteristics and subject to the same management), working over sampling units of some hectares (Barbaro et al., 2021; Brambilla and Gatti, 2022), while vineyard parcels frequently cover a few thousands of square meters. In addition, there are still many aspects related to the parcel that deserve investigation and that can contribute to driving vineyard use by birds and, in turn, also the potential for ecosystem services and disservices. Understanding such effects is key to reconciling production and biodiversity, and it is also particularly important from a practical point of view. Indeed, while changing landscape composition and configuration is often difficult, modifying or adjusting parcel-scale management can be feasible, and can be easily incorporated into agri-environmental schemes and subsidies that have the potential to be adopted and implemented over large spatial scales through national or international programmes, like e.g. the European Union's Common Agricultural Policy (CAP).

With this work, we aim to fill some knowledge gaps on the effects of fine-scale management of vineyards on birds. We develop a parcel-level approach to explore the impact on different avian functional groups and bird species richness exerted by the most relevant factors shaping fine-scale habitat characteristics in vineyards (Fig. 1): i) different types of mowing of ground vegetation (considering both inter- and under-row vegetation cover); ii) soil management (e.g., tillage, ploughing); iii) height of ground vegetation; vi) use of herbicides; and v) use of irrigation systems. Based on previous works, we expect i) significant effects of ground vegetation and soil management, with positive outcomes of alternated management (Brambilla and Gatti, 2022); ii) variable effects of vegetation cover/bare soil on different functional groups (Barbaro et al., 2021; Guyot et al., 2017); iii) variable effects of the height of ground vegetation (Vickery and Arlettaz, 2012); iv) a negative effect of herbicides (Zielonka et al., 2024a); and v) a potential negative effect of irrigation (Cabodevilla et al., 2021). Furthermore, we expect a positive effect of the parcel area on bird metrics, but such an effect could potentially reach a plateau or turn into negative after a given threshold, because very large parcels may be less suitable to birds, which are generally associated to the occurrence or proximity of natural or semi-natural vegetation in vineyard landscapes (Assandri et al., 2016; Rösch et al., 2024).

Understanding how such key factors drive vineyard use by birds is crucial to identify management practices to maximise the potential for conservation and ecosystem services, while reducing disservices. Given that those are standard practices, recommendations may be easily developed and implemented through schemes and subsidies.

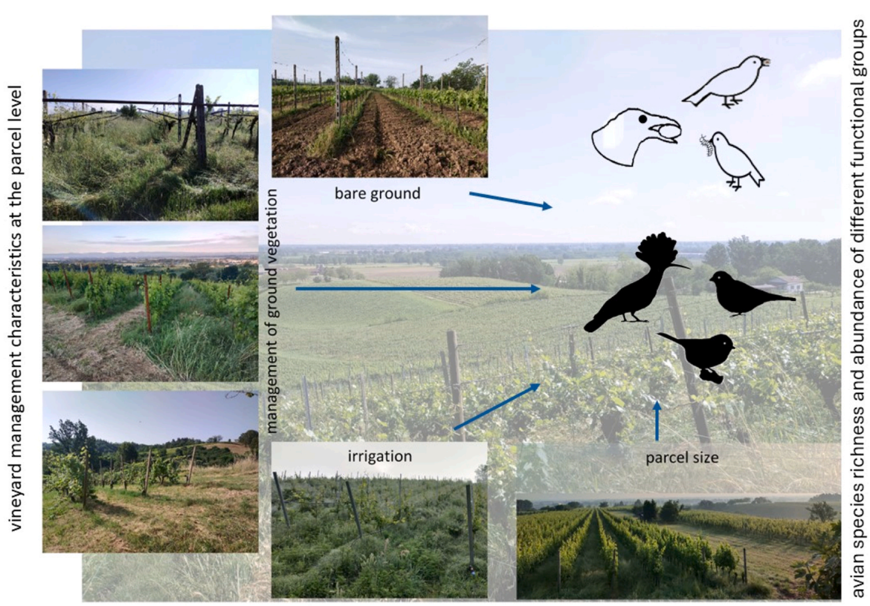

Fig. 1. A schematic summary of the most relevant impacts of management practices assessed in the study, and of the target avian functional groups considered (vegetation-dwelling insectivores, ground and grassland-dwelling insectivores, seed eaters, and potential grape eaters). All pictures have been taken in the study area in 2024.

2. Materials and methods

2.1. Study system

The work was carried out in northern Italy, in a vineyard-dominated landscape located in Colle di San Colombano, in southern Lombardy (extreme coordinates NW: 9.43,45.16; SE: 9.50,45.21, EPSG 4236). This is an isolated, low (elevation range 70–146 m asl) hill, stretched over a NW-SE direction and standing above the surrounding lowland area in the Po plain (c. 60–70 m asl around the site). This area had never been considered by previous studies focusing on vineyards and/or breeding birds. Given the isolation of the site, the expected avian species richness is lower than in other areas surrounded by more suitable landscapes for vineyard and farmland birds. This makes this site perfectly complementary to avian-rich and more diverse areas, to test if the positive effect of e.g. alternated management found in those areas (Barbaro et al., 2021; Brambilla and Gatti, 2022) still holds even within poorer avian communities.

The landscape of the hill is a mosaic of vineyards interspersed with other crops (hay meadows, small cereal fields, and small orchards), broadleaved woodlands, and small urban areas. Vineyards are found all over the hill, but reach their highest share towards the south-eastern portion of the area. Most of the parcels cover a few thousand square meters each. Vineyard management is rather heterogeneous: different mowing/tilling regimes, use of herbicides and irrigation are randomly combined without a clear spatial pattern, with very different management options frequently found close to each other. Therefore, we randomly scattered sampling sites all over the area occupied by vineyards.

2.2. Fieldwork

We sampled bird communities during the breeding season along 43 linear transects scattered over the vineyard landscapes of the entire hill (Fig. 2), within a 100 m-buffer, following previous research on vineyard birds (Assandri et al., 2017a; Brambilla et al., 2017; Rollan et al., 2019). Transects were located on pre-existing paths or unpaved roads and measured 200 m (30 transects) or 100 m (13 transects) in length (in the case of smaller vineyards, transects were 100 m-long to avoid sampling other environments). Transect buffer did not overlap (minimum distance = 200 m) with very limited exceptions in morphologically complex areas (the proportion of overlapping buffers was <1 % of the overall buffers' extent), where we paid attention to count each parcel only once in the analyses. Each transect was surveyed twice, once in May (17−24) and once in June (3−14), covering the core of the breeding period of most species. Surveys were carried out from dawn to the first hours of the morning, and variable clusters of neighbouring transects were randomly visited through each survey to minimise possible patterns due to temporal autocorrelation. All birds observed or heard were considered and accurately mapped on detailed aerial orthophotos (Google satellite) using the NaturaList app (www.biolovision.net). Overflying birds were noted as such. Transect surveys were carried out by the same expert observer (MB), walking at a slow pace, with the help of binoculars (Swarovski EL 10 × 42) and avoiding rainy and windy days.

We identified four categories of birds as potentially more relevant for ecosystem services and disservices in vineyards, based on i) possible contribution to pest control (Barbaro et al., 2021; Korányi et al., 2025), distinguishing between insectivorous birds foraging on different vegetation substrates (Granata et al., 2025), ii) possible contribution to weed control (Kelly and Mccallum, 1990; Wenny et al., 2011) or seed dispersal (García et al., 2024), and iii) possible grape predation (Barbaro et al., 2021). The four categories (Table S1) were therefore woody vegetation-dwelling insectivores (21 species observed along the transects, of which 11 actually found in vineyards), ground or grass-dwelling insectivores (5 species in vineyards out of 10 species observed), seed eaters (11 out of 12 species observed), and potential grape eaters (8 species); a few species were included in more than one group. We used previously available information (Barbaro et al., 2021; Brambilla and Gatti, 2022; Tobias et al., 2022) and considered species-specific ecological habits within the region to assign species to the different groups; see Table S1 in supplementary material for the list of species

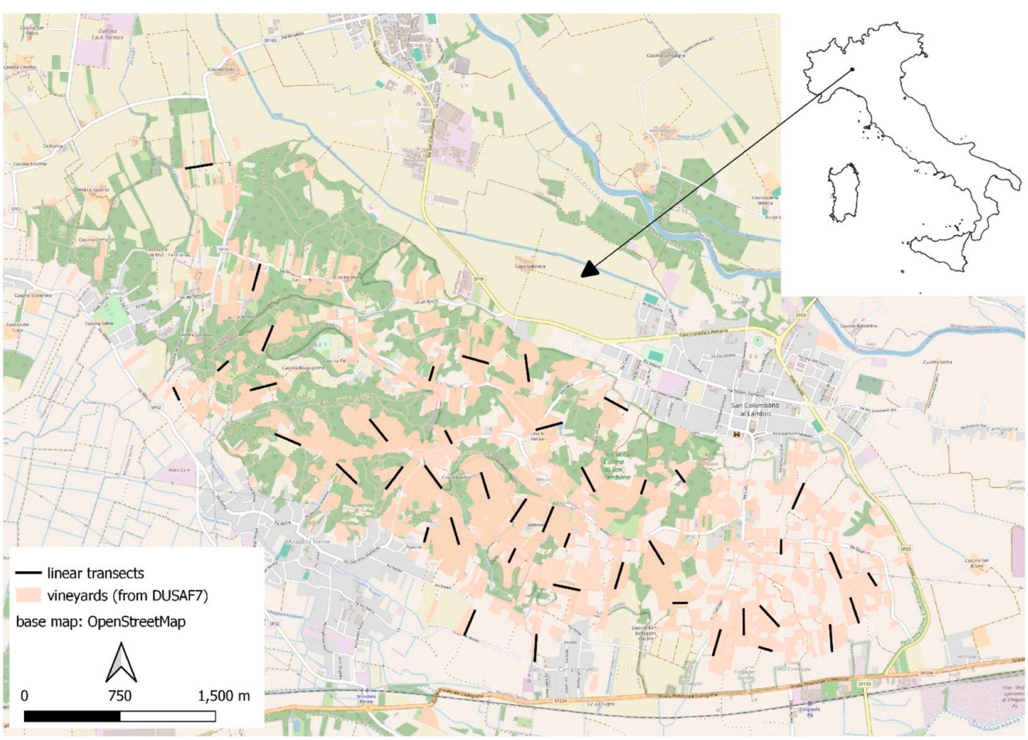

Fig. 2. Location of linear transects within the study area. The upper right inset shows the location of the study area within Italy. Vineyard cover is derived from the land-use/land-cover map DUSAF7 (see text).

detected in the study area (within and outside vineyards) and the subdivision in subgroups.

At each transect, we also recorded the characteristics and shape of vineyard parcels in the field, and mapped their spatial configuration on GIS (using QGIS; QGIS Developmen Team, 2022). We recorded a set of pre-defined variables that characterise the practices and management adopted by the farmer on each individual parcel. Variables described ground vegetation management (mowing, alternated mowing) at rows and inter-rows, soil operations (light tilling, digging, other type of tillage), occurrence of irrigation systems (all being drip (droplet) systems, made of pipes and tubes that distribute water through emitters along the vine row), use of herbicides on rows and/or inter-rows, use of pheromone traps, the height of ground vegetation (according to the percentage cover of four classes of vegetation height), the share of bare ground (%), and the occurrence of roses planted at row head (which could offer additional shelter or perching sites). All those variables were recorded directly in the field through visual assessment, during each survey day, to have a perfect correspondence between bird and vineyard data. In QGIS, and separately for May and June, we estimated the parcel size (extent in square meters). In some cases, management over a vineyard was homogeneous during a visit but not during the other one; in these cases, the resulting number of parcels was different across the two periods, to accurately reflect the parcel characteristics. To consider the possible landscape effects, for each parcel we computed the distance from the main non-vineyard habitats of the area, i.e. woodland, shrubland, cropland, grassland, and urban areas. Distances were calculated in QGIS based on a detailed land-use/land-cover map made available by Lombardy regional authorities (DUSAF 7; https://www.cartografia.servizirl.it/arcgis1/services/territorio/dusaf7/MapServer/WMSServer?_jsfBridgeRedirect=true). Variables are summarised in Table 1.

Table 1
Management variables recorded at the parcel-scale. All variables were independently measured in May and June, and parcel boundaries always matched the management implemented at a given time.

Variable	Description	Rows or inter-rows	Values
mowing of ground vegetation	combined assessment of ground vegetation mowing over rows and inter-rows	combined	0: no mowing; 1: only rows; 2: only inter-rows; 3: both rows and inter-rows mown
alternate mowing	mowing performed every second row or inter-row	separately assessed	0: no; 1: yes
tillage	light, superficial tillage interesting only the first cm of the soil	separately assessed	0: no; 1: yes
soil digging	deeper tillage	separately assessed	0: no; 1: yes
other soil tillage	other types of tillage	separately assessed	0: no; 1: yes
herbicides	recent use of herbicide	separately assessed	0: no; 1: yes
pheromone traps	use of pheromone traps	combined	0: no; 1: yes
roses	roses planted at row head	only for rows	0: no; 1: on < 50 % of rows; 2: on > 50 % of rows
bare ground	cover of bare ground in the vineyard	combined	% cover on vineyard ground
irrigation	presence of irrigation systems	only for rows	
height of ground vegetation	percentage cover of vegetation of different sward height (total: 100 %)	combined	% cover for < 10 cm, 10–25, 25–40, > 40 cm
parcel size	parcel extent (also as a quadratic term)	-	m^2
woodland	distance to the nearest forest patch	-	m
shrubland	distance to the nearest shrubland patch	-	m
cropland	distance to the nearest non-vineyard cultivated area	-	m
grassland	distance to the nearest grassland	-	m
urban areas	distance to the nearest built up area	-	m

2.3. Analyses

Flying over individuals not related to vineyard parcels (i.e., all raptors, waterbirds, aerial insectivores, and all individuals of any species just overflying transects) were discarded from the analysis. Migratory species that do not breed in the area (*Clamator glandarius*, *Hippolais icterina*, *Curruca curruca*) and all individuals observed outside vineyards were also discarded. We considered all bird observations in vineyards, and associated each observation with the parcel where it took place (separately defined for May and June, see above). Then, we modelled the abundance of different functional groups (the sum of individuals of species belonging to a functional group) and the species richness per parcel (both on a given date) as a response to the parcel characteristics. We removed variables with values different from zero in less than 5 % of parcels: soil tillage variables (apart from tillage, i.e. light tilling, at rows), pheromone traps, and roses.

We used GLMM (generalized linear mixed models) to model the effect of management and landscape variables on the abundance of each functional group. All analyses were carried out in R (R Development Core Team, 2020). We entered transect as a random intercept in models to correct for the possible non-independence of data collected in neighbouring parcels located along the same linear transect. Given that the huge number of parcels (453, considering both first and second surveys) implied a high proportion of zeros, for the two insectivore categories, we randomly selected 106 unused parcels (106 corresponding to the highest number of parcels with birds, found for grape eaters) and discarded the other parcels without any observations. For species richness, we randomly selected 157 unused parcels (equivalent to 157 parcels with at least one observation). For seed eaters, given that most records were related to single individuals, we modelled the use vs. non-use of parcels by those birds, i.e. converting the abundance data into a binary variable (binomial error, logit link). To reduce the number of predictors and possible collinearity issues, we adopted a two-step procedure. We initially subdivided predictors into three groups (landscape – all distances to other habitats; management variables; height of the grassland sward) and fitted one model for each group. Parcel size was entered, together with its quadratic term, in all models, to take into account the possible overwhelming effect due to the parcel extent.

From those three models, we selected all predictors with an effect with $P < 0.3$ (we chose a high value to reduce the risk of leaving out potentially relevant predictors, balancing with the need to reduce the number of terms presented to the model). Then, we considered all selected variables as potentially contributing, in any possible combinations with the other factors, to explain parcel use. Therefore, the possible variable combinations were treated as alternative hypotheses, for which we evaluated the relative support based on Akaike's Information Criterion corrected for small sample size (AICc), computed using the dredge command in MuMIn (Barton, 2020). Then, we compared models based on the respective value of the AICc, removed models containing uninformative parameters (Arnold, 2010), and performed a conditional averaging of the remaining ones with $\Delta AICc < 2$ (see Table S2 in the supplementary material for alternative models for each dependent variable).

All variables were scaled before modelling; multicollinearity was checked using the variance inflation factor (VIF) and highly collinear variables (VIF>4) were left out from the model (actually, only the percentage cover of ground vegetation higher than 40 cm for granivores, potential grape eaters and species richness). Models were fitted using a negative binomial error (log link), as Poisson models proved to be overdispersed. As stated above, only for granivores, we used a logistic binomial model (as there were very few parcels with observation values > 1). All models were fitted using glmmTMB (Brooks et al., 2017) and were tested for consistency with assumptions about residuals' distribution, occurrence of outliers and zero-inflation, using the functions implemented in the DHARMa and performance packages (Hartig, 2020; Lüdecke et al., 2020); all assumptions were verified for all models (tests performed on a full model). Marginal and conditional R^2 values were computed using the r2 command in the performance package (Lüdecke et al., 2020) on the final model (when only one was selected), or on a model including all the variables comprised in the averaged model.

3. Results

Sixty-nine species had been observed, for a total of 2280 observations, related to 3259 individuals; of those, 453 observations (43 species and 1177 individuals) occurred in vineyards. Thirty-three species and 471 individuals were retained for the analyses after removing excluded species and overflying individuals. The most abundant species were long-tailed tit *Aegithalos caudatus* and common nightingale *Luscinia megarhynchos* among vegetation insectivores, common blackbird *Turdus merula* and common hoopoe *Upupa epops* among ground-dwelling insectivores, European serin *Serinus serinus* and red-legged partridge *Alectoris rufa* among seed eaters, and common starling *Sturnus vulgaris* and hooded crow *Corvus corone cornix* among potential grape eaters.

Different functional groups showed different responses to landscape and management factors, with models generally having decent marginal (between 0.12 and 0.44) and conditional (between 0.13 and 0.53) R^2 values. All the effects (coefficients plus the relative standard errors) of the conditionally averaged models are reported in Table 2, together with R^2 values. Distance to grassland and distance to shrubland negatively predicted species richness, and distance to shrubland also predicted the occurrence of seed eaters: more species and more frequent granivorous birds can be found close to shrublands and the former also closer to grasslands. On the other side, distance to grassland was positively related to the abundance of both insectivore groups, which was therefore higher far from grasslands.

The occurrence of irrigation systems was negatively associated with species richness, the abundance of vegetation-dwelling insectivores and the occurrence of seed eaters. Tillage and herbicide use (both at vine rows) had negative impacts on vegetation-dwelling insectivores, and no effect on the other metrics. Alternate management of ground vegetation had a positive effect on the occurrence of granivores and a negative influence on the abundance of potential grape eaters.

The height of the ground vegetation sward had a varying effect on different metrics. The cover of vegetation of height comprised between 10 and 25 cm promoted seed eaters' occurrence, that between 25 and 40 cm, the abundance of potential grape eaters and species richness. The cover of bare ground had a positive effect on seed eaters' occurrence and species richness.

Finally, the parcel size had a largely positive effect, linearly positive for ground/grassland-dwelling insectivores, and with a (much smaller) quadratic effect on all other metrics. This suggests that the abundance of most groups and the species richness increased with parcel size but that the effect weakens at larger extents. In fact, data inspection revealed a likely general peak around 1.5 ha of parcel extent, but the modelled effect was generally not very different from a linear one (quadratic term much smaller than the linear one; see Figs. S1-S5 in the Appendix), suggesting that the relationship tends to weaken or reach a plateau rather than turning into negative after a given threshold. Main management effects are summarised in Fig. 3.

4. Discussion

Many wild species contribute to key functions to support agricultural

Table 2
Conditional average model (estimate ± standard error) for the abundance (number of individuals observed within a parcel) of each avian functional group (occurrence for granivores). For both insectivore groups and species richness, the number of parcels with no observation was randomly reduced (see text for details). "alternate mowing" here refers to the inter-row. Irrigation, row tillage, row herbicide and alternate mowing are dummy variables (0/1) and the coefficient refers to the effect of the respective occurrence/implementation in the parcel. Effects in bold are those for which the 95 % confidence intervals did not encompass zero. Marginal and conditional R^2 values are reported (see text).

Group	N	intercept	d_grassland	d_shrubland	irrigation	row tillage	row herbicide	alternate mowing	sward 10–25 cm	sward 25–40 cm	bare ground	parcel area	parcel area²	mar. R^2	con. R^2
vegetation insectivores	138	-1.15 ± 0.34	0.42 ± 0.22		-1.57 ± 0.96	-1.89 ± 1.00	-1.09 ± 0.73					**1.11 ± 0.36**	**-0.18 ± 0.08**	0.44	0.53
ground/grass insectivores	133	-1.52 ± 0.30	0.29 ± 0.16									**0.39 ± 0.15**		0.12	0.13
granivores	453	-2.83 ± 0.29		-0.46 ± 0.24	-1.13 ± 0.86			1.07 ± 0.61	0.31 ± 0.18		0.25 ± 0.15	**0.98 ± 0.30**	-0.16 ± 0.09	0.20	0.22
grape eaters	453	-0.98 ± 0.20						-1.06 ± 0.58		**0.28 ± 0.12**		**0.95 ± 0.20**	**-0.09 ± 0.03**	0.20	0.43
no. species	314	-0.35 ± 0.09	-0.14 ± 0.08	-0.13 ± 0.08	-0.42 ± 0.26					0.10 ± 0.07	0.12 ± 0.07	**0.66 ± 0.10**	**-0.09 ± 0.02**	0.21	0.27

d_: distance to
sward: height of the grassland sward / ground vegetation

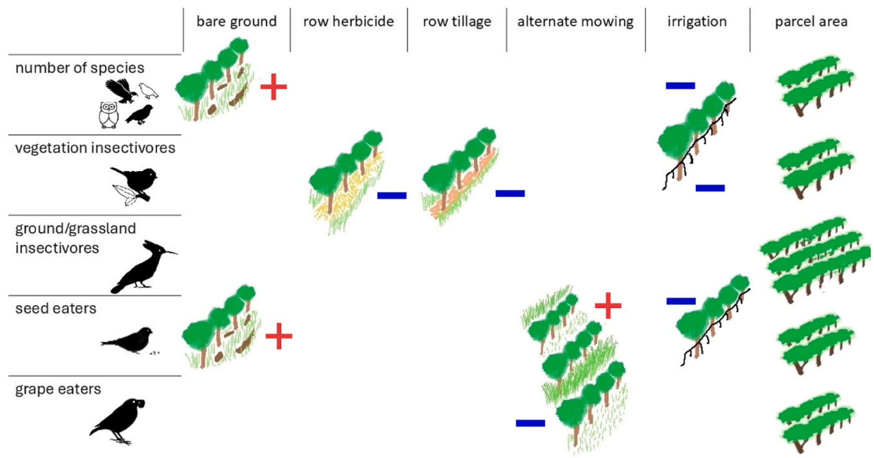

Fig. 3. Graphical summary of the management effects found for different avian metrics. A red plus symbol indicates a positive effect, a blue minus symbol a negative one. For parcel area, the effect is linearly positive for ground/grassland insectivores, and quadratic for all other metrics (see text).

production and, especially, sustainable production, and at the same time, a huge range of organisms is impacted by farming practices and land cover changes associated with agriculture. In our study area, avian species richness peaked when vineyards were close to grassland and shrubland patches, and the proximity to the latter also supported the occurrence of granivores. This is consistent with the importance of natural habitats around vineyards to promote pest control (Korányi et al., 2025; Paredes et al., 2021). Hedgerows, woodlands, shrublands and other natural or semi-natural habitats increase pest predation by birds and/or bats in and around vineyards, or at least support populations of those key insect predators (Assandri et al., 2017b; Barbaro et al., 2017; Chávez et al., 2025; Korányi et al., 2025; Paiola et al., 2020). On the other side, insectivores were more abundant far from grasslands, possibly because vineyards might represent alternative habitats to grassland for foraging insectivores (which are often rather degraded in the study's lowland context).

Results also revealed the likely importance of management factors. Our expectations about the possible relevance of ground vegetation and soil management, vegetation cover, height of ground vegetation, use of herbicides, and irrigation, were largely met, with each of those key factors affecting at least one of the functional groups we considered. Vineyard characteristics driven by management practices often interact with natural/semi-natural habitats in driving predation pressures (Rusch et al., 2017) or contribute *per se* in increasing the potential for pest control (Barbaro et al., 2021). In addition, management is known to significantly affect other animal groups (Ancillotto et al., 2023; Beaumelle et al., 2023; Biella et al., 2025; Granata et al., 2023; Zielonka et al., 2024a), and hence it could have both direct and indirect effects on birds.

In our study system, factors such as irrigation, row tillage, herbicide use, alternate mowing, and bare ground extent, all directly or indirectly related to ground vegetation, affected at least one of the metrics we considered. In fact, the structure and composition of ground vegetation may represent a potentially important mediator of management effects. Different types of tilling or mowing regimes (Fiera et al., 2020; Nascimbene et al., 2013), irrigation (Melloul et al., 2024), and different practices in general (Winter et al., 2025), may affect plant communities, shaping their diversity and composition. In turn, different plant communities may result in different availability of key resources for birds, such as seeds, arthropods and microhabitats. Exploring the effects of tillage, alternate management, irrigation, and other practices on birds via effects on vegetation (e.g. through structural equation modelling, see e.g. Anderle et al., 2025; Melloul et al., 2024) represents a promising approach to shed light on the links between management, plant communities and avian species and related services/disservices.

Management practices affecting vegetation growing under the vines are indeed particularly significant (Bosco et al., 2022), and ground vegetation characteristics in vineyards affect plants (Nascimbene et al., 2013), pollinators (Biella et al., 2025; Granata et al., 2023), birds (Barbaro et al., 2021), bats (Cistrone et al., 2025), and overall biodiversity and ecosystem services (Giffard et al., 2022; Mamabolo et al., 2025; Rocher et al., 2024; Winter et al., 2018), as well as carbon content (Liebhard et al., 2024). Alternate management, specifically, has recently emerged as a highly favourable option for butterflies and birds (increasing species richness of both, abundance and diversity of insectivores, and abundance of seed-eating birds) in another area of Italy characterised by rich and diverse communities (Brambilla and Gatti, 2022), and for plants in Romania (Fiera et al., 2020). Alternate management may also mitigate the loss of carbon content in the soil due to tillage in contexts where water scarcity does not allow year-round vegetation cover (Liebhard et al., 2024). Here, alternate mowing (there was virtually no alternate tillage in our study area) promoted granivores and discouraged potential grape eaters, confirming the high potential of alternate management for biodiversity and for bird-mediated ecosystem services in vineyards (Brambilla and Gatti, 2022), even in depauperate avian communities, where it does not result in increased species richness.

Our study also provides the likely first insight into the effects of other parcel-scale management attributes (not yet or very scarcely investigated) on breeding birds. The negative effect on vegetation-dwelling insectivores of tilling the vine row or treating it with herbicides is not surprising, considering the degradation and/or depletion of key microhabitats and resources (such as invertebrates; Bosco, Wan, et al., 2019) they cause, and previously reported results (Buehler et al., 2017). We also found a less expectable effect of drip irrigation systems. Irrigation is typical of modern, intensive vineyards in the Mediterranean region, and may impact on biological communities (Cabodevilla et al., 2021), also outside vineyards, leading to widespread bird declines (Cabodevilla et al., 2022). The presence of an irrigation system in the parcel has a negative impact on species richness, the abundance of vegetation-dwelling insectivores, and the occurrence of granivores. This effect, which to the best of our knowledge has never been reported, could be due to fine-scale alteration due either to the surplus of water, which may affect vegetation (Melloul et al., 2024), leading e.g. to a denser sward (even if irrigation should be used only in the case of scarce natural precipitation), to physical impediments or structural alterations due to the network of cables along vines, or to different soil humidity leading to less favourable conditions for some species. Alternatively, it could be that irrigated vineyards are simply more intensively managed than non-irrigated ones (cf. Cabodevilla et al., 2021), leading to a general decrease in parcel suitability for birds. However, in terms of ground management they did not differ from other parcels and varied from complete cover of untilled vegetation to partial herbicide use and complete mowing.

The availability of some bare ground promoted species richness and the occurrence of granivores. Bare patches favour the detectability and accessibility of food resources, such as seeds or invertebrates (Schaub et al., 2010). While some bare soil and low-density vegetation patches may increase foraging suitability for many species (Vickery and Arlettaz, 2012), even outside farmed landscapes (Alessandrini et al., 2022), high cover values of bare ground lead to reduced biodiversity (Bosco et al., 2019a, 2019b). In our parcels, bare ground covered on average 2.8 % (± 0.4 SE), and high values of bare soil are very rare in the study area.

The height of the grassland sward is a key determinant of habitat selection in many avian species (Andreatta et al., 2025; Bettega et al., 2025), and may condition the use or avoidance of different crops (Hološková and Reif, 2024). In our study system, the percentage cover of medium-low (10–25 cm-height) ground vegetation promoted granivores' occurrence, while the percentage cover of medium-high (25–40 cm-height) sward favoured potential grape eaters and species richness. Further studies are needed to identify the right conditions that promote species diversity and key functional groups while not favouring possible grape eaters.

The role of parcel size deserves further investigation. Smaller parcels are associated with higher heterogeneity and more margins and edges, promoting bird communities (Assandri et al., 2016). In our analyses focused on parcel-level observation, a higher number of birds could be expected in larger parcels because of sampling reasons. We found a positive effect of parcel size and a weaker negative contribution of its quadratic term on all metrics but the abundance of ground and grassland dwelling insectivores, which showed a purely positive linear response. This suggests that larger parcels may be more tolerated by species tied to open or semi-open habitats, like most ground and grassland-dwelling birds. For such species, larger parcels could provide benefits, by e.g. reducing edge effects, to which many of them are sensitive (Besnard and Secondi, 2014). A similar pattern was recently found for an insectivorous bat (Cistrone et al., 2025). For all the other groups, the inclusion of the quadratic term suggested that very large parcel size might offset the increased sampling.

5. Study limitations

Our study also comes with some limitations. First, compared to other areas, Colle di San Colombano lacks several species typically found in many agroecosystems dominated by vineyards (e.g., skylark *Alauda arvensis*, corn bunting *Emberiza calandra*; Barbaro et al., 2021). While this suggests that patterns common to previous studies may really apply to most vineyard-dominated landscapes, this also implies that with more diverse, richer communities, some results might be different. Second, we did not have information about the use of pesticides and fertilisers. While it is unlikely that vineyards in the area undergo very different treatments in that sense, as they belong to relatively few farms, we cannot exclude that some hidden differences might contribute to local variations not properly accounted for in our work.

Third, the effect of parcel size is likely related to sampling issues (see above), and we cannot exclude that a decreased detectability of birds on larger parcels might contribute to flattening the relationship between avian metrics and parcel size above a given threshold. This possible detection effect is mitigated by the fact that we restricted observations and analyses to a 100 m-buffer from the transect. At the same time, such a restriction also artificially reduced the extent of the largest parcels. Such effects are virtually common to all other studies on birds in agricultural systems that are based on standardised methods (i.e., linear transects, point counts); other approaches, such as mapping carried out through accurate exploration of parcels (Assandri et al., 2018a), could help disentangle the effects of parcel size from those of variation in detectability.

Fourth, most of the effects highlighted by models were not particularly strong (see Table 2). This could be a statistical effect due to the generally low abundance found in vineyard parcels, or to the fact that the impact of many factors is not particularly marked. Paired with the relatively low number of species and individuals that dwell in vineyard parcels of the study area, this calls for further exploration of the previously unreported effects. Finally, we have evaluated the effect of vegetation sward height considering the percentage of vegetation within a given height class, because ground cover was almost always nearly total. In more heterogeneous conditions, different effects could be potentially associated with varying actual (and not proportional) cover of ground vegetation of different height.

6. Conclusions

Our results confirmed the relevance of vineyard management characteristics, in addition to landscape structure. While some specific effects (e.g. that of irrigation systems and parcel size) require further investigation to be fully understood, the importance of other management practices, consistent with previously published evidence at larger spatial scales, opens the way to easy-to-implement parcel-scale recommendations and prescriptions. Schemes encouraging alternate mowing (every second inter-row) and the occurrence of some bare ground patches, while reducing as much as possible row tillage and the use of herbicides, would promote both bird conservation and the potential for ecosystem services provided by avian species to viticulture, leading to win-win situations for famers and biodiversity.

CRediT authorship contribution statement

Giacomo Assandri: Writing – review & editing, Visualization, Validation, Methodology. **Mattia Brambilla:** Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Maurizio Odicino:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation.

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. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2025.110185.

Data availability

Data are available in Milan University Dataverse at the following address: https://doi.org/10.13130/RD_UNIMI/76RY7Q.

References

Alessandrini, C., Scridel, D., Boitani, L., Pedrini, P., Brambilla, M., 2022. Remotely sensed variables explain microhabitat selection and reveal buffering behaviours against warming in a climate-sensitive bird species. Remote Sens. Ecol. Conserv. 8, 615–628. https://doi.org/10.1002/RSE2.265.

Ancillotto, L., Scaramella, C., Dartora, F., Migliozzi, A., Russo, D., 2023. Organic farming sustains bats in Mediterranean farmland. Agric. Ecosyst. Environ. 342, 108230. https://doi.org/10.1016/J.AGEE.2022.108230.

Anderle, M., Ceresa, F., Hilpold, A., Marsoner, T., Roilo, S., Scanferla, J., Dellavedova, R., Tappeiner, U., Brambilla, M., 2025. Direct and indirect ecological drivers of bird communities in intensively cultivated landscapes. J. Environ. Manag. 393, 127169. https://doi.org/10.1016/j.jenvman.2025.127169.

Anderson, A., Lindell, C.A., Moxcey, K.M., Siemer, W.F., Linz, G.M., Curtis, P.D., Carroll, J.E., Burrows, C.L., Boulanger, J.R., Steensma, K.M.M., Shwiff, S.A., 2013. Bird damage to select fruit crops: the cost of damage and the benefits of control in five states. Crop Prot. 52, 103–109. https://doi.org/10.1016/j.cropro.2013.05.019.

Andreatta, D., Bazzi, G., Nardelli, R., Siddi, L., Cecere, J.G., Chamberlain, D., Morganti, M., Rubolini, D., Assandri, G., 2025. Remote sensing reveals scale-specific effects of forage crop mowing and landscape structure on a declining farmland bird. J. Appl. Ecol. N./a. https://doi.org/10.1111/1365-2664.14865.

Arnold, T.W., 2010. Uninformative parameters and model selection using akaike's information criterion. J. Wildl. Manag. 74, 1175–1178. https://doi.org/10.1111/j.1937-2817.2010.tb01236.x.

Assandri, G., Bogliani, G., Pedrini, P., Brambilla, M., 2016. Diversity in the monotony? Habitat traits and management practices shape avian communities in intensive vineyards. Agric. Ecosyst. Environ. 223, 250–260. https://doi.org/10.1016/j.agee.2016.03.014.

Assandri, G., Bogliani, G., Pedrini, P., Brambilla, M., 2017a. Assessing common birds' ecological requirements to address nature conservation in permanent crops: lessons from Italian vineyards. J. Environ. Manag. 191, 145–154. https://doi.org/10.1016/j.jenvman.2016.12.071.

Assandri, G., Bogliani, G., Pedrini, P., Brambilla, M., 2017b. Insectivorous birds as 'non-traditional' flagship species in vineyards: applying a neglected conservation paradigm to agricultural systems. Ecol. Indic. 80, 275–285. https://doi.org/10.1016/j.ecolind.2017.05.012.

Assandri, G., Bernardi, A., Schmoliner, A., Bogliani, G., Pedrini, P., Brambilla, M., 2018a. A matter of pipes: Wryneck *Jynx torquilla* habitat selection and breeding performance in an intensive agroecosystem. J. Ornithol. 159, 103–114. https://doi.org/10.1007/s10336-017-1479-y.

Assandri, G., Bogliani, G., Pedrini, P., Brambilla, M., 2018b. Beautiful agricultural landscapes promote cultural ecosystem services and biodiversity conservation. Agric. Ecosyst. Environ. 256, 200–210. https://doi.org/10.1016/j.agee.2018.01.012.

Barbaro, L., Rusch, A., Muiruri, E.W., Gravellier, B., Thiery, D., Castagneyrol, B., 2017. Avian pest control in vineyards is driven by interactions between bird functional diversity and landscape heterogeneity. J. Appl. Ecol. 54, 500–508. https://doi.org/10.1111/1365-2664.12740.

Barbaro, L., Assandri, G., Brambilla, M., Castagneyrol, B., Froidevaux, J., Giffard, B., Pithon, J., Puig-Montserrat, X., Torre, I., Calatayud, F., Gaüzère, P., Guenser, J., Macià-Valverde, F.-X., Mary, S., Raison, L., Sirami, C., Rusch, A., 2021. Organic management and landscape heterogeneity combine to sustain multifunctional bird communities in European vineyards. J. Appl. Ecol. 1–11. https://doi.org/10.1111/1365-2664.13885.

Barton, K., 2020. MuMIn: multi-model inference. R package version 1.43. 17 9–14.

Beaumelle, L., Giffard, B., Tolle, P., Winter, S., Entling, M.H., Benítez, E., Zaller, J.G., Auriol, A., Bonnard, O., Charbonnier, Y., Fabreguettes, O., Joubard, B., Kolb, S., Ostandie, N., Reiff, J.M., Richart-Cervera, S., Rusch, A., 2023. Biodiversity conservation, ecosystem services and organic viticulture: a glass half-full. Agric. Ecosyst. Environ. 351, 108474. https://doi.org/10.1016/J.AGEE.2023.108474.

Besnard, A.G., Secondi, J., 2014. Hedgerows diminish the value of meadows for grassland birds: potential conflicts for agri-environment schemes. Agric. Ecosyst. Environ. 189, 21–27. https://doi.org/10.1016/j.agee.2014.03.014.

Bettega, C., Luciani, P., Roseo, F., Pedrini, P., Leonardi, S., Brambilla, M., 2025. Preserving short-sward natural grasslands may provide suitable foraging habitat for a climate-threatened alpine species along ski-pistes. Anim. Conserv. N./a. https://doi.org/10.1111/acv.70002.

Biella, P., Ramazzotti, F., Parolo, G., Galimberti, A., Labra, M., Brambilla, M., 2025. Vineyard footprint on pollinators is mediated by flower vegetation, organic farming, seasonal and weather factors, a case study from North Italy. Agric. Ecosyst. Environ. 378, 109297. https://doi.org/10.1016/j.agee.2024.109297.

Bosco, L., Wan, H.Y., Cushman, S.A., Arlettaz, R., Jacot, A., 2019b. Separating the effects of habitat amount and fragmentation on invertebrate abundance using a multi-scale framework. Landsc. Ecol. 34, 105–117. https://doi.org/10.1007/s10980-018-0748-3.

Bosco, L., Arlettaz, R., Jacot, A., 2019a. Ground greening in vineyards promotes the Woodlark *Lullula arborea* and their invertebrate prey. J. Ornithol. 160, 799–811. https://doi.org/10.1007/s10336-019-01666-7.

Bosco, L., Siegenthaler, D., Ruzzante, L., Jacot, A., Arlettaz, R., 2022. Varying responses of invertebrates to biodynamic, organic and conventional viticulture. Front. Conserv. Sci. 3. https://doi.org/10.3389/fcosc.2022.837551.

Bouvier, J.-C., Lavigne, C., Sentenac, G., Boivin, T., 2024. Environmental filtering and landscape composition drive multifaceted diversity of bird assemblages in vineyards. J. Appl. Ecol. 61, 746–758. https://doi.org/10.1111/1365-2664.14587.

Brambilla, M., Gatti, F., 2022. No more silent (and uncoloured) springs in vineyards? Experimental evidence for positive impact of alternate inter-row management on birds and butterflies. J. Appl. Ecol. 59, 2166–2178. https://doi.org/10.1111/1365-2664.14229.

Brambilla, M., Ronchi, S., 2020. Cool species in tedious landscapes: ecosystem services and disservices affect nature-based recreation in cultural landscapes. Ecol. Indic. 116, 106485. https://doi.org/10.1016/j.ecolind.2020.106485.

Brambilla, M., Ilahiane, L., Assandri, G., Ronchi, S., Bogliani, G., 2017. Combining habitat requirements of endemic bird species and other ecosystem services may synergistically enhance conservation efforts. Sci. Total Environ. 586, 206–214. https://doi.org/10.1016/j.scitotenv.2017.01.203.

Brooks, M.E., Kristensen, K., Benthem, K.J., van, Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Mächler, M., Bolker, B.M., 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R. J. 9, 378–400. https://doi.org/10.3929/ETHZ-B-000240890.

Buehler, R., Bosco, L., Arlettaz, R., Jacot, A., 2017. Nest site preferences of the Woodlark *(Lullula arborea)* and its association with artificial nest predation. Acta Oecologica 78, 41–46. https://doi.org/10.1016/j.actao.2016.12.004.

Cabodevilla, X., Arroyo, B., Wright, A.D., Salguero, A.J., Mougeot, F., 2021. Vineyard modernization drives changes in bird and mammal occurrence in vineyard plots in dry farmland. Agric. Ecosyst. Environ. 315, 107448. https://doi.org/10.1016/j.agee.2021.107448.

Cabodevilla, X., Wright, A.D., Villanua, D., Arroyo, B., Zipkin, E.F., 2022. The implementation of irrigation leads to declines in farmland birds. Agric. Ecosyst. Environ. 323, 107701. https://doi.org/10.1016/J.AGEE.2021.107701.

Chávez, F., Entling, M.H., Alcalá Herrera, R., Benítez, E., Möth, S., Reiff, J.M., Winter, S., Rösch, V., 2025. Strong benefits of hedgerows to bats in three European winegrowing regions. Ecosphere 16, e70143. https://doi.org/10.1002/ecs2.70143.

Cistrone, L., Schofield, H., Russo, D., 2025. Ground cover promotes enhanced bat activity in high-value insular vineyards. Agric. Ecosyst. Environ. 389, 109698. https://doi.org/10.1016/j.agee.2025.109698.

Crist, E., Mora, C., Engelman, R., 2017. The interaction of human population, food production, and biodiversity protection. Science 356, 260–264. https://doi.org/10.1126/science.aal2011.

Fiera, C., Ulrich, W., Popescu, D., Bunea, C.-I., Manu, M., Nae, I., Stan, M., Markó, B., Urák, I., Giurginca, A., Penke, N., Winter, S., Kratschmer, S., Buchholz, J., Querner, P., Zaller, J.G., 2020. Effects of vineyard inter-row management on the diversity and abundance of plants and surface-dwelling invertebrates in Central Romania. J. Insect Conserv 24, 175–185. https://doi.org/10.1007/s10841-019-00215-0.

Fraixedas, S., Lindén, A., Piha, M., Cabeza, M., Gregory, R., Lehikoinen, A., 2020. A state-of-the-art review on birds as indicators of biodiversity: advances, challenges, and future directions. Ecol. Indic. 118, 106728. https://doi.org/10.1016/j.ecolind.2020.106728.

García, D., Rumeu, B., Illera, J.C., Miñarro, M., Palomar, G., González-Varo, J.P., 2024. Common birds combine pest control and seed dispersal in apple orchards through a hybrid interaction network. Agric. Ecosyst. Environ. 365, 108927. https://doi.org/10.1016/j.agee.2024.108927.

Gaston, K.J., 2022. Birds and ecosystem services. Curr. Biol. 32, R1163–R1166. https://doi.org/10.1016/J.CUB.2022.07.053.

Giffard, B., Winter, S., Guidoni, S., Nicolai, A., Castaldini, M., Cluzeau, D., Coll, P., Cortet, J., Le Cadre, E., d'Errico, G., Forneck, A., Gagnarli, E., Griesser, M., Guernion, M., Lagomarsino, A., Landi, S., Bissonnais, Y.L., Mania, E., Mocali, S., Preda, C., Priori, S., Reineke, A., Rusch, A., Schroers, H.-J., Simoni, S., Steiner, M., Temneanu, E., Bacher, S., Costantini, E.A.C., Zaller, J., Leyer, I., 2022. Vineyard management and its impacts on soil biodiversity, functions, and ecosystem services. Front. Ecol. Evol. 10. https://doi.org/10.3389/fevo.2022.850272.

Granata, E., Pedrini, P., Marchesi, L., Fedrigotti, C., Biella, P., Ronchi, S., Brambilla, M., 2023. Environmental and management factors drive biological communities and ecosystem services in agroecosystems along an urban-natural gradient. Agric. Ecosyst. Environ. 357, 108693. https://doi.org/10.1016/J.AGEE.2023.108693.

Granata, E., Assandri, G., Franzoi, A., Pedrini, P., Brambilla, M., 2025. Management, topography and landscape contribute to shape bird communities in Alpine semi-natural grasslands. Biol. Conserv. 311, 111409. https://doi.org/10.1016/j.biocon.2025.111409.

Guyot, C., Arlettaz, R., Korner, P., Jacot, A., 2017. Temporal and spatial scales matter: Circannual habitat selection by bird communities in vineyards. PLoS ONE 12. https://doi.org/10.1371/journal.pone.0170176.

Hartig, F., 2020. DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. R package.

Hološková, A., Reif, J., 2024. Factors shaping insectivorous farmland bird abundance in intensively cultivated arable fields: insights through the former Iron Curtain. Agric. Ecosyst. Environ. 360, 108772. https://doi.org/10.1016/j.agee.2023.108772.

Kelly, D., Mccallum, K., 1990. Demography, seed biology, and biological control of Carduus nutans in New Zealand. The Biology and Control of Invasive Plants. British Ecological Society, Cardiff, United Kingdom, pp. 72–79.

Korányi, D., Zsebők, S., Báldi, A., Brambilla, M., Varga, M., Batáry, P., 2025. Forest cover enhances pest control by birds and bats independently of vineyard management intensity. J. Appl. Ecol. N./a. https://doi.org/10.1111/1365-2664.70094.

Liebhard, G., Guzmán, G., Gómez, J.A., Winter, S., Zaller, J.G., Bauer, T., Nicolai, A., Cluzeau, D., Popescu, D., Bunea, C.-I., Strauss, P., 2024. Vineyard cover crop management strategies and their effect on soil properties across Europe. Eur. J. Soil Sci. 75, e13573. https://doi.org/10.1111/ejss.13573.

Lüdecke, D., Makowski, D., Waggoner, P., Patil, I., 2020. performance: Assessment of Regression Models Performance version 0.4.5.

Mamabolo, E., Gaigher, R., Pryke, J.S., 2025. Unravelling the effects of vineyard inter-row vegetation on soil biodiversity in South Africa. Agric. Ecosyst. Environ. 393, 109842. https://doi.org/10.1016/j.agee.2025.109842.

Melloul, E., Rocher, L., Gros, R., Bischoff, A., Blight, O., 2024. Irrigation decreases flower cover and beneficial arthropod abundances in Mediterranean vineyards. Basic Appl. Ecol. 77, 1–7. https://doi.org/10.1016/j.baae.2024.03.003.

Nascimbene, J., Marini, L., Ivan, D., Zottini, M., Wrbka, T., 2013. Management intensity and topography determined plant diversity in vineyards. PLoS ONE 8, e76167. https://doi.org/10.1371/journal.pone.0076167.

Nyffeler, M., Şekercioğlu, Ç.H., Whelan, C.J., 2018. Insectivorous birds consume an estimated 400–500 million tons of prey annually. Sci. Nat. 105. https://doi.org/10.1007/S00114-018-1571-Z.

Paiola, A., Assandri, G., Brambilla, M., Zottini, M., Pedrini, P., Nascimbene, J., 2020. Exploring the potential of vineyards for biodiversity conservation and delivery of biodiversity-mediated ecosystem services: a global-scale systematic review. Sci. Total Environ. 706, 135839. https://doi.org/10.1016/j.scitotenv.2019.135839.

Paredes, D., Rosenheim, J.A., Chaplin-Kramer, R., Winter, S., Karp, D.S., 2021. Landscape simplification increases vineyard pest outbreaks and insecticide use. Ecol. Lett. 24, 73–83. https://doi.org/10.1111/ele.13622.

Pejchar, L., Clough, Y., Ekroos, J., Nicholas, K.A., Olsson, O., Ram, D., Tschumi, M., Smith, H.G., 2018. Net effects of birds in agroecosystems. Biosci. XX 1–9. https://doi.org/10.1093/biosci/biy104.

Prosdocimi, M., Cerdà, A., Tarolli, P., 2016. Soil water erosion on Mediterranean vineyards: a review. CATENA 141, 1–21. https://doi.org/10.1016/j.catena.2016.02.010.

QGIS Developmen Team, 2022. QGIS Geographic Information System.

R Development Core Team, 2020. A Language and Environment for Statistical Computing.

Rocher, L., Melloul, E., Blight, O., Bischoff, A., 2024. Effects of sown and spontaneous inter-row vegetation on weeds and beneficial arthropods in vineyards. Basic Appl. Ecol. 81, 17–24. https://doi.org/10.1016/j.baae.2024.10.001.

Rollan, À., Hernández-Matías, A., Real, J., 2019. Organic farming favours bird communities and their resilience to climate change in Mediterranean vineyards. Agric. Ecosyst. Environ. 269, 107–115. https://doi.org/10.1016/j.agee.2018.09.029.

Rösch, V., Chavez, F., Krey, L., Möth, S., Petrović, B., Richart-Cervera, S., Rusch, A., Tiedemann, M., Tolle, P., Weyandt, L., Winter, S., Entling, M.H., 2024. Semi-natural habitats are key to breeding bird diversity in intensified vineyard landscapes across Europe. Basic Appl. Ecol. https://doi.org/10.1016/j.baae.2024.10.010.

Roseo, F., Salvatori, M., Brambilla, M., Pedrini, P., Fedrigotti, C., Bertocchi, A., 2024. The landscape of fear in cattle farms? How the presence of barn swallow influences the activity of pest flies. J. Appl. Ecol. 61, 1269–1278. https://doi.org/10.1111/1365-2664.14635.

Rusch, A., 2025. Nature-based solutions to increase sustainability and resilience of vineyard-dominated landscapes. Basic Appl. Ecol. 82, 70–78. https://doi.org/10.1016/j.baae.2024.12.005.

Rusch, A., Delbac, L., Thiéry, D., 2017. Grape moth density in Bordeaux vineyards depends on local habitat management despite effects of landscape heterogeneity on their biological control. J. Appl. Ecol. 54, 1794–1803. https://doi.org/10.1111/1365-2664.12858.

Schaub, M., Martinez, N., Tagmann-Ioset, A., Weisshaupt, N., Maurer, M.L., Reichlin, T.S., Abadi, F., Zbinden, N., Jenni, L., Arlettaz, R., 2010. Patches of bare ground as a staple commodity for declining ground-foraging insectivorous farmland birds. PLoS ONE 5, e13115. https://doi.org/10.1371/journal.pone.0013115.

Tobias, J.A., Sheard, C., Pigot, A.L., Devenish, A.J.M., Yang, J., Sayol, F., Neate-Clegg, M.H.C., Alioravainen, N., Weeks, T.L., Barber, R.A., Walkden, P.A., MacGregor, H.E.A., Jones, S.E.I., Vincent, C., Phillips, A.G., Marples, N.M., Montaño-Centellas, F.A., Leandro-Silva, V., Claramunt, S., Darski, B., Freeman, B.G., Bregman, T.P., Cooney, C.R., Hughes, E.C., Capp, E.J.R., Varley, Z.K., Friedman, N.R., Korntheuer, H., Corrales-Vargas, A., Trisos, C.H., Weeks, B.C., Hanz, D.M., Töpfer, T., Bravo, G.A., Remeš, V., Nowak, L., Carneiro, L.S., Moncada R, A.J., Matysioková, B., Baldassarre, D.T., Martínez-Salinas, A., Wolfe, J.D., Chapman, P.M., Daly, B.G., Sorensen, M.C., Neu, A., Ford, M.A., Mayhew, R.J., Fabio Silveira, L., Kelly, D.J., Annorbah, N.N.D., Pollock, H.S., Grabowska-Zhang, A.M., McEntee, J.P., Carlos, T., Gonzalez, J., Meneses, C.G., Muñoz, M.C., Powell, L.L., Jamie, G.A., Matthews, T.J., Johnson, O., Brito, G.R.R., Zyskowski, K., Crates, R., Harvey, M.G., Jurado Zevallos, M., Hosner, P.A., Bradfer-Lawrence, T., Maley, J.M., Stiles, F.G., Lima, H.S., Provost, K.L., Chibesa, M., Mashao, M., Howard, J.T., Mlamba, E., Chua, M.A.H., Li, B., Gómez, M.I., García, N.C., Päckert, M., Fuchs, J., Ali, J.R., Derryberry, E.P., Carlson, M.L., Urriza, R.C., Brzeski, K.E., Prawiradilaga, D.M., Rayner, M.J., Miller, E.T., Bowie, R.C.K., Lafontaine, R.-M., Scofield, R.P., Lou, Y., Somarathna, L., Lepage, D., Illif, M., Neuschulz, E.L., Templin, M., Dehling, D.M., Cooper, J.C., Pauwels, O.S.G., Analuddin, K., Fjeldså, J., Seddon, N., Sweet, P.R., DeClerck, F.A.J., Naka, L.N., Brawn, J.D., Aleixo, A., Böhning-Gaese, K., Rahbek, C., Fritz, S.A., Thomas, G.H., Schleuning, M., 2022. AVONET: morphological, ecological and geographical data for all birds. Ecol. Lett. 25, 581–597. https://doi.org/10.1111/ele.13898.

Vickery, J., Arlettaz, R., 2012. The importance of habitat heterogeneity at multiple scales for birds in European agricultural landscapes. In: Fuller, R.J. (Ed.), Birds and Habitat: Relationships in Changing Landscapes. Cambridge University Press, pp. 177–204.

Viers, J.H., Williams, J.N., Nicholas, K.A., Barbosa, O., Kotzé, I., Spence, L., Webb, L.B., Merenlender, A., Reynolds, M., 2013. Vinecology: pairing wine with nature. Conserv. Lett. https://doi.org/10.1111/conl.12011.

Wenny, D.G., Devault, T.L., Johnson, M.D., Kelly, D., Sekercioglu, C.H., Tomback, D.F., Whelan, C.J., 2011. The need to quantify ecosystem services provided by birds. Auk 128, 1–14. https://doi.org/10.1525/auk.2011.10248.

Whelan, C.J., Wenny, D.G., Marquis, R.J., 2008. Ecosystem services provided by birds. Ann. N. Y. Acad. Sci. 1134, 25–60. https://doi.org/10.1196/annals.1439.003.

Winter, S., Bauer, T., Strauss, P., Kratschmer, S., Paredes, D., Popescu, D., Landa, B., Guzmán, G., Gómez, J.A., Guernion, M., Zaller, J.G., Batáry, P., 2018. Effects of vegetation management intensity on biodiversity and ecosystem services in vineyards: a meta-analysis. J. Appl. Ecol. https://doi.org/10.1111/1365-2664.13124.

Winter, S., Weitzl, R., Möth, S., Petrović, B., Aurelle, V., Tolle, P., Costes, T., Richart-Cervera, S., Rusch, A., 2025. Extensive vegetation management and semi-natural habitats increase plant alpha and gamma diversity in European vineyards. Basic Appl. Ecol. https://doi.org/10.1016/j.baae.2025.01.005.

Zielonka, N.B., Tubman, V., Dicks, L.V., Butler, S.J., 2024b. Increased bird sound diversity in vineyards enhances visitors' tour experience. People Nat. 6, 2325–2338. https://doi.org/10.1002/pan3.10721.

Zielonka, N.B., Shutt, J.D., Butler, S.J., Dicks, L.V., 2024a. Management practices, and not surrounding habitats, drive bird and arthropod biodiversity within vineyards. Agric. Ecosyst. Environ. 367, 108982. https://doi.org/10.1016/J.AGEE.2024.108982.