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RESEARCH ARTICLE

No more silent (and uncoloured) springs in vineyards? Experimental evidence for positive impact of alternate inter-row management on birds and butterflies

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Abstract

1. Agricultural intensification is a main threat to biodiversity, and vineyards are particularly concerning because of their increasing extent and intensive management. Management strategies that mitigate vineyard impacts on biodiversity are urgently needed.
2. In a major wine area in northern Italy, we tested in a 3-year experiment the effect of alternate management of vineyard ground cover (mowing or tillage depending on the usual management system adopted by each farmer). After a first year (2017) with no implementation (baseline), in the two subsequent spring–summer periods (2018 and 2019), alternate management was adopted in a varying number of sites, providing an ideal BACI design. Birds and butterflies were selected as target groups, and surveyed by means of 200-m linear transects scattered over both conventional and organic vineyards, with and without alternate management.
3. We evaluated whether the implementation of alternate management resulted in an increase in species richness per transect. We also evaluated the effect of alternate management, year and land cover on different functional avian guilds (functional insectivores, seed eaters, potential grape eaters), considering both richness and abundance.
4. For both birds and butterflies, we found a positive effect of alternate management on the number of species per transect. The implementation of alternate management also promoted richness and abundance of functional insectivores and abundance of seed eaters; a positive but less supported association was also found between alternate management and richness and abundance of potential grape eaters. The most relevant land cover for the supply of ecosystem services by birds was likely shrubland cover, which increased richness and abundance of insectivores and seed eaters, while not supporting potential grape eaters.

Farmers reported no adverse effects of alternate management, and a positive impact on farm perception by consumers.

5. *Synthesis and applications*. The very easy-to-implement alternate inter-row management has the potential to rapidly increase the suitability of vineyards for biodiversity, while enhancing ecosystem services and attractiveness of farms for nature-based recreation, contributing to their multi-functionality. Alternate management could contribute to shape, for example, new interventions within the coming Common Agricultural Policy, and its benefits may be maximized by sympathetic landscape strategies.

KEYWORDS
biodiversity, conservation, ecosystem services, farming, ground vegetation, mowing, tillage, vineyards

1 | INTRODUCTION

Agricultural land-use and agricultural intensification are among the main, global, threats to biodiversity and ecosystem services (Crist et al., 2017; Williams, Clark, et al., 2020). In nearly all continents, and especially in Europe, many taxa are severely suffering because of farming intensification: the populations of many species of birds (Donald et al., 2001; Korner et al., 2018; Reif & Hanzelka, 2020), butterflies (Habel et al., 2019; Van Dyck et al., 2009) and other groups (e.g. Storkey et al., 2012) collapsed in the last decades throughout most of the continent. Within this context, vineyards represent an important threatening factor and a particular conservation urgency (Viers et al., 2013; Winkler et al., 2017). Vineyards are among the most impacting crops in areas with Mediterranean climate (Viers et al., 2013), and they are steadily expanding across many regions thanks to climate change, which results in milder climates allowing to grow vines at higher elevation or latitudes (Hannah et al., 2013), and thanks to the economic remuneration they provide.

Within vineyards, both sustainable farming practices and the conservation of the remaining semi-natural habitats are crucial to enable biodiversity survival and, especially, habitat specialists and other more demanding species (Paiola et al., 2020). Farming practices impact on the availability and accessibility of food items and on habitat suitability for several species (Bosco, Arlettaz, et al., 2019; Bosco, Wan, et al., 2019; Kratschmer et al., 2018; Winter et al., 2018), affecting also functional characteristics of biological communities (e.g. birds; Barbaro et al., 2021). On the other side, semi-natural habitats provide crucial habitats for many other species (Muñoz-Sáez et al., 2020; Paiola et al., 2020) and increase carbon storage (Williams, Morandé, et al., 2020).

With this work, we focused on management strategies at the field level. Previous studies suggested the positive effect of less intensive management of ground vegetation on biodiversity and ecosystem services (Bosco, Arlettaz, et al., 2019; Guyot et al., 2017; Hall et al., 2020; Kratschmer et al., 2019; Nascimbene et al., 2013; Winter et al., 2018). Low-intensity management often leads to heterogeneous grassland sward in vineyards and orchards, with beneficial effects for several animal species (e.g. Assandri et al., 2017a; Vickery & Arlettaz, 2012), and the resulting partial ground cover may enhance also ecosystem services provided by birds (Barbaro et al., 2021; Rusch et al., 2015). We therefore designed a simple management protocol targeted at lowering intensity and maintaining heterogeneity in ground vegetation during the spring–summer period, and proposed it for adoption to wine grovers in one of the most relevant areas for wine production of northern Italy. In collaboration with local wine-growers, who implemented in their vineyards the proposed measures, we tested the effect of this management protocol on two target groups in a 3-year experiment. Birds and butterflies were selected as target groups to evaluate the effects on biodiversity, thanks to their sensitivity and indicator/flagship values (Fraixedas et al., 2017; van Strien et al., 2009).

The tested measure addressed inter-row management in vineyards, taking into account both the usual management practice of vineyard ground adopted by the farmer and the biodiversity needs. It imposed alternate mowing of ground vegetation in the case of vineyards with perennial ground cover: grassland was cut on every second inter-row, alternating the inter-rows mown from one to the subsequent cut. The recommended interval between two subsequent cuts on the same inter-row was 50–60 days (to allow birds breeding on the ground to successfully conclude nesting attempts), but some farmers mowed at shorter (30–35 days) intervals. In the case of vineyards with tillage management, the measure required alternate tillage, which was therefore applied to every second inter-row only, so that half of the inter-rows, one every two, are covered by grass (for all the spring–summer season). Around 2 months after the first tillage, some farmers tilled again the same inter-rows, but the majority tilled the unmanaged ones. By means of alternate mowing or tillage, heterogeneity in ground cover was ensured.

Alternate management was prescribed for the period April–September and its effect was evaluated by means of a BACI (before and after control-impact) design. Figure 1 shows some examples of management before and after measure implementation.

2 | MATERIALS AND METHODS

2.1 | Study area

The work was carried out in Oltrepò pavese, northern Italy, within the Pavia province (Lombardy). This area is located at the interface between the Mediterranean and the Euro-Siberian regions, holds an exceptionally high biological diversity (Bogliani et al., 2003; Gariboldi & Gatti, 2019) and a high share of vineyards in the hilly area (Brambilla & Ronchi, 2020). While lowland areas are mostly covered by arable land and mountains by woodlands with pastures interspersed, the foothill and hills are largely covered by vineyards, which have been expanding in recent decades, progressively reducing the remaining semi-natural habitats (Brambilla, Gustin, et al., 2017). The study area is located in the central (hilly) portion of Oltrepò, roughly between 100 and 500 m above sea level. The climate is temperate, with rainfall and temperature varying with elevation (increasing and decreasing, respectively). This area has been used for wine production for centuries, and currently *c.* 15,000 ha are covered by vineyards (see Figure 2). Most of vineyards (in general and within our sample sites) are under a conventional management, but the share of organic farming is slightly increasing.

Survey sites were distributed across the 'vineyard belt' on the hilly portion of Oltrepò, encompassing all the environmental gradients in the area, from heterogeneous landscapes with several patches of semi-natural habitats, to valleys almost uniformly covered by vineyards, and from sites close to the lowland to other ones located at the highest elevation within the belt. Both conventional and organic vineyards were sampled (both as treatment and as control sites). Sampling sites may be assigned, based on geographical position and elevation, to four main groups, corresponding to four sub-areas (Figure 2).

2.2 | Study design and data collection

We investigated the biological response to the experimental alternate inter-row management along linear transects located at control and treatment sites, before and after the implementation of alternate management, hence adopting a BACI approach (Christie et al., 2019; Stewart-Oaten et al., 1986): after a first year (2017) with no implementation, in the two subsequent spring–summer periods (2018–2019) the recommended alternate management was adopted in a varying number of sites, providing an ideal set up to test its effectiveness on target groups. Most transects intersect a plurality of vineyards belonging to different owners (vineyard parcels are often rather small, extending over one or a few hectares), and hence alternate management sometimes was not applied all over the vineyards surrounding a transect, but only on part of those. For birds, we considered transects as treatment ones when at least 30% of the vineyard extent within a 100-m buffer around the transect was interested by alternate management in May and June. For butterflies, the same minimum amount of 30% of vineyard with alternate management was considered within a 20-m buffer around the transect and for the period June–September. Actually, in nearly all experimental transects, alternate management was practised over the entire growing season (as requested to farmers), and only in a very few transects farmers performed alternate management over areas and periods not enough to meet the above criteria.

We censused birds and butterflies each year along transects 200 m long, following methods previously adopted in vineyard-dominated ecosystems in the study area (Brambilla, Ilahiane, et al., 2017) and elsewhere (Assandri et al., 2016, 2017b; Barbaro et al., 2021; Puig-Montserrat et al., 2017; Rollan et al., 2019; Van Swaay et al., 2008). Slight differences in the number of transects

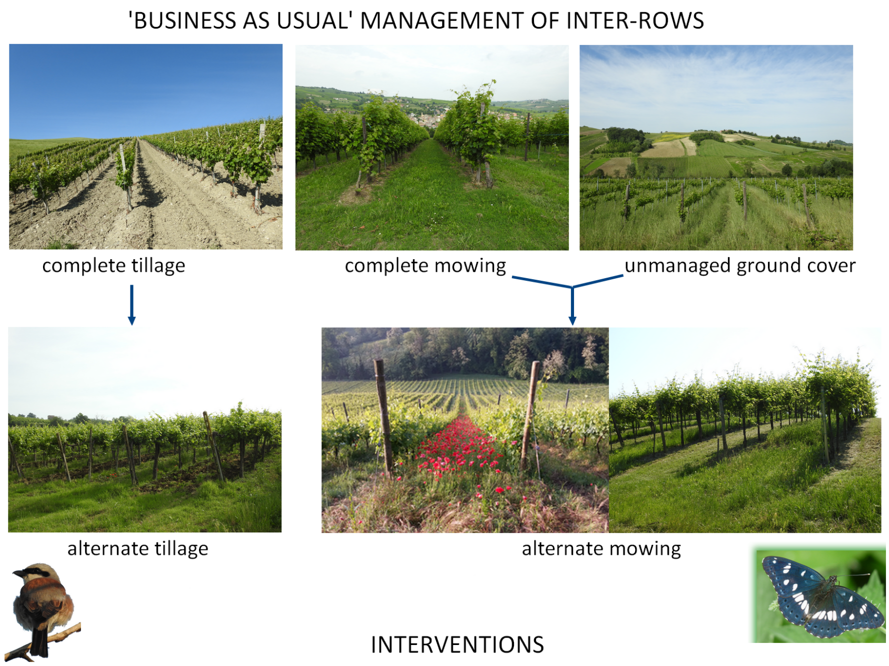

FIGURE 1 Examples of management adopted by farmers in vineyards: Business-as-usual (above) mostly involves homogeneous treatment, whereas experimental management is based on alternate mowing or tillage. Example species are *Lanius collurio* (bottom left) and *Limenitis reducta* (bottom right).

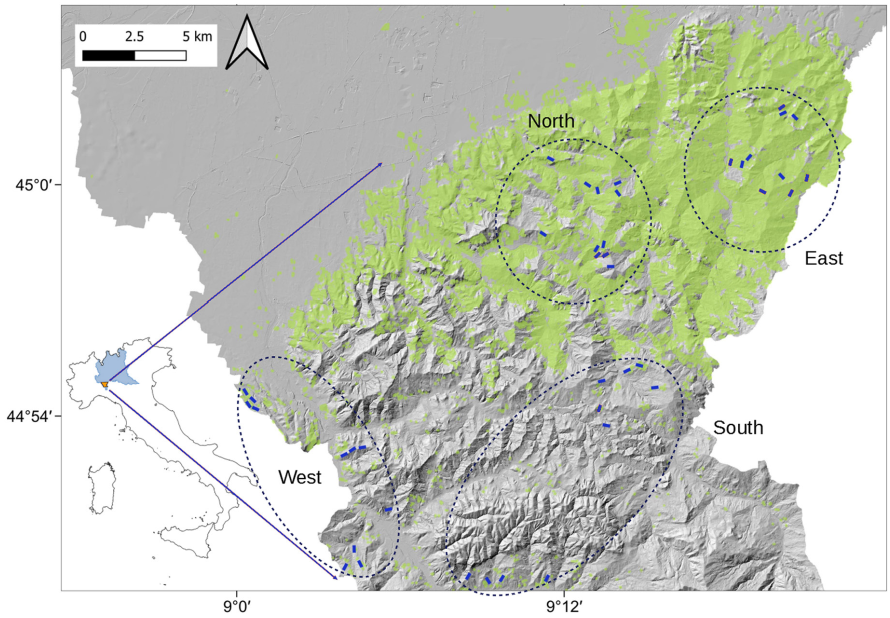

FIGURE 2 Spatial location of the study transects (in blu) in Oltrepò, in relation to vineyard distribution (in green); the four sub-areas considered in the analyses are shown by dotted ovals and labelled by relative approximate position. The inset shows the location of the study area (orange) in Lombardy (pale blue), and the location of the latter in Italy. Background: Hillshade derived from a digital terrain model (DTM) produced by the Lombardy regional government.

surveyed each year occurred for butterflies, because of logistic constraints (see Figure S1); 43 transects were surveyed in 2017 and 2018, and 35 in 2019; sites with alternate management implementation were 14 in 2018 (10 conventional and four organic) and eight in 2019 (six conventional and two organic). Birds were surveyed along the same 45 transects all years (largely corresponding with those adopted for butterfly census; Figure S2); intervention sites were 12 (four organic and eight conventional) in 2018 and eight in 2019 (three organic and five conventional). A few control sites ($N =$ six for both taxa) were located in grassland areas close to vineyards, but not within vineyards, to include sites not subject to possible large-scale variations in vineyard management due to season-specific weather conditions. Birds were counted within a 100-m buffer from the transect, and butterflies within a 5-m buffer. Bird counts mirrored previous approaches adopted within and outside the study area in similar environments (Assandri et al., 2016; Assandri et al., 2017a; Brambilla, Ilahiane, et al., 2017; Rollan et al., 2019). Avian counts were carried out twice per year per transect: they were initially visited between half May and early June, while a second visit was done in June/first few days of July. Bird counts started at dawn and lasted until 9–11 (exceptionally 12) a.m., according to weather and period (with census time longer in cool days in early season, and shorter in hot days), as to maximize detection probability for songbirds and the other non-raptorial breeding species. Individuals just flying over the transect were discarded (see Assandri et al., 2019 and under Analysis). Butterfly census was carried out four times per year along each transect, in May, June, July and September, to cover the flying period of most species. In a few cases, it was not possible to carry out the May census because of heavy rainfall. Censuses were made between 9.30 and 17 (with slight variations depending on daily weather); each single butterfly (imago) within 5 m from the transect was identified (using binoculars or trapping it with entomological net when needed, and releasing it soon after identification). Surveys were carried out in accordance with owners; no particular permission or ethical approval was needed for fieldwork.

Within the 100-m buffer from the transect, we estimated the proportional cover of some land-cover categories potentially relevant for birds: vineyards, broadleaved woodland, grassland, shrubland and sparse vegetation. Land-cover variables were evaluated in GIS, by combining a land-use map (DUSAF database; http://www.geoportale.regione.lombardia.it/) and field observations, and were updated in the case of variations between different years (actually rather limited, but still occurring somewhere). The software QGIS was used for this part and for map production (QGIS Development Team, 2022).

Finally, we also asked the farmers adopting the proposed measures whether they faced constraints and opportunities in relation to the implementation of alternate management. Constraints could derive from an increment in costs or efforts associated with that specific management option, or with the increase in undesired species, whereas opportunities might arise from the potential positive impact on the farm perception by the public, as well as from potential increase in ecosystem services (e.g. through increase in biological control). A quantitative analysis of such aspects was out of the scopes of our work, but an exploratory inquiry in that sense was deemed as necessary to assess the general impact of field-scaled measures on production and farmers' activity.

2.3 | Analyses

For both model groups, we evaluated whether the implementation of alternate management had any effect on the number of species at survey sites, which was thus selected as a measure of species richness. For butterflies, in the case of the relatively few individuals identified only at the genus level (e.g. *Pieris* sp.), we considered them as species occurring in a site only when no other species belonging to the same genus was found at that site during that survey. For birds, we considered the overall number of species censused at a site over the two visits, after excluding raptors, aerial foragers almost invariably observed flying over the transect, and migrant or very irregular species (Assandri et al., 2019). Barn swallow *Hirundo rustica* and house martin *Delichon urbicum* were considered only when actively foraging within an altitude of 20 m from the ground. A total of 17 species had been excluded from the analyses (see Table S1 for details and reasons for exclusion). To address the potential ecosystem services or disservices associated with bird occurrence and abundance, we performed another set of analyses for birds, to explore the link between alternate management and land cover, and the richness and abundance of three different avian functional guilds: (a) functional insectivores that could contribute to pest control, (b) seed eaters potentially involved in weed control and (c) species potentially creating disservices by acting as grape eaters. Following Barbaro et al. (2021), we included in the first group vineyard-dwelling species that are insectivorous in the breeding period and mainly forage on leaves or hunt in flight within vineyards. Seed-eater birds included species that mostly feed on seeds during the breeding season. Potential grape eaters were birds that have been reported or observed feeding on grapes within the study area or in other south European vineyards. The list of species for each group was derived from Barbaro et al. (2021), with minor adjustments to adapt to the local context, and is reported in Table S1. For each species, abundance was calculated as the maximum number of individuals counted at a transect in a given year.

To evaluate the effect of alternate management, we therefore considered the number of species (or the abundance of birds belonging to different avian guilds) per transect as the response variable, and alternate management, temporal and spatial factors as predictors. Regarding the latter, we added to the model sub-area, year and their interaction, to take into account the potential occurrence of different spatial patterns between years. For butterflies, we also considered month and its interaction with year, to correct for the effect of month on butterfly richness, taking into account potential inter-annual variations in month effect due to weather and/or different season progression. For birds, also the land-cover variables (weakly correlated between each other: $r < |0.5|$) measured within the censused areas (100-m buffer around the transect) were added to the models (see under Study design and data collection) as proportional cover, and were scaled before the analyses.

For all analyses, we adopted generalized linear mixed models (GLMMs), with transect identity as grouping (random) factor and the above described variables as predictors. Model validation was carried out using different validation functions available in the packages PERFORMANCE and DHARMA (testing for overdispersion, outlier occurrence, zero-inflation, location of quantiles via qgam), and testing for spatial autocorrelation by means of Moran's *I*. For butterflies, the latter was evaluated for each month within each single year, while for birds, it was evaluated for each year. We carried out an AICc-based model selection, considering the most supported (ΔAICc<2) among all possible models, excluding those with uninformative parameters (Arnold, 2010), and obtaining an averaged model with the remaining ones (or keeping the most supported one when there were no other supported models). In the Results section, we present all the supported models (ΔAICc < 2) and the first non-supported (ΔAICc > 2) one for all analyses, and the most supported or averaged models (Tables 1 and 2). Family was set to Poisson for all butterfly and bird analyses, except for the abundance of potential grape eaters (negative binomial), because of unacceptable patterns in the model's residuals when using a Poisson distribution. Within each models' set, the most supported one was used to calculate model's R^2 (using the lognormal conditional R^2). All analyses have been carried out in R (R Development Core Team, 2020), using the packages NLME (Pinheiro & Bates, 2021), MUMIN (Bartoń, 2020), LME4 (Bates et al., 2015), APE (Paradis & Schliep, 2019), GLMMTMB (Brooks et al., 2017), PERFORMANCE (Lüdecke et al., 2020), SJPLOT (Lüdecke et al., 2021) and DHARMA (Hartig, 2020).

3 | RESULTS

3.1 | Changes in species richness and measure implementation

A total of 88 bird species (of which 17 were excluded from analyses) and 72 butterflies were counted within the respective predefined buffers along transects (Table S1). Overall, the number of bird species was higher in 2017 (79 total/65 target species) than in 2018 (72/60) and 2019 (72/62), whereas it peaked in 2018 (61 species) for butterflies (54 in 2017 and 60 in 2019). The mean number of bird species per transect was higher in 2019 and lower in 2018 than in 2017; the average number of butterfly species per month per

TABLE 1 The two most supported models for the number of butterfly species per transect. The symbol '+' indicates the inclusion of a factorial variable in the model. For alternate management, the estimate reported refers to the effect of management implementation compared to lack of it. Effects in bold are those that have 95% confidence intervals of estimate not encompassing zero (at least for one category for the variable 'month' and the interaction between 'sub-area' and 'year')

Interc.	Sub-area	Month	Alternate management	Year 2018	Year 2019	Sub-area: year	*df*	logLik	AICc	Delta
1375	+	+	**0.25 ± 0.11**	−0.20 ± 0.14	**−0.27 ± 0.13**	+	17	−949.59	1934.6	0.00
1383	+	+		−0.01 ± 0.12	−0.15 ± 0.12	+	16	−952.23	1937.7	3.13

TABLE 2 Models of species richness (estimates for included predictors and relative standard error) for the entire avian community, and models for species richness and bird abundance for the three functional guilds of vineyard-dwelling birds considered in the study. For each category, the most supported (ΔAICc < 2) models (after the removal of uninformative parameters) and the first non-supported model (ΔAICc > 2) are reported, followed by averaged models obtained by full and conditional averaging, respectively (see text for details). The symbol '+' indicates the inclusion of factorial predictors in the model. Effects in bold in the averaged models are those that have 95% confidence intervals of estimate not encompassing zero (at least for one category for the variable 'sub-area'). 'Int' stands for model intercept, 'broad_w' for broadleaved woodland and 'sparse_veg.' for sparse vegetation (see text for details)

	Int.	Year 2018	Year 2019	Sub-area	Alternate management	broad_w	Shrubland	Vineyards	sparse_veg.	Grassland	*df*	logLik	AICc	Δ
Species richness														
All species	2.79	−0.13	0.03		0.17	0.05	0.09	−0.06			8	−375.93	769.0	0.00
	2.68	−0.13	0.04	+	0.17		0.11				9	−374.79	769.0	0.02
	2.79	−0.14	0.04		0.19		0.09	−0.09	−0.05		8	−376.19	769.5	0.52
	2.79	−0.13	0.04		0.15	0.07	0.12				7	−377.45	769.8	0.79
	2.79	−0.13	0.04		0.16		0.09	−0.08			7	−377.51	769.9	0.90
	2.79	−0.13	0.04		0.15		0.12				6	−379.70	772.0	3.05
	2.77 ± 0.07	**−0.13 ± 0.06**	0.04 ± 0.05	+	**0.17 ± 0.07**	0.02 ± 0.03	**0.10 ± 0.03**	−0.04 ± 0.05	−0.01 ± 0.02			Full average		
	2.77 ± 0.07	**−0.13 ± 0.06**	0.04 ± 0.05	+	**0.17 ± 0.07**	**0.06 ± 0.03**	**0.10 ± 0.03**	−0.05 ± 0.03	−0.07 ± 0.04			Conditional average		
Functional insectivores	1.76	−0.16	0.12		0.20	0.16	0.21				7	−302.98	620.8	0.00
	1.76	−0.11	0.16			0.15	0.20				6	−304.57	621.8	0.94
	1.75				0.18	0.14	0.17	−0.09			6	−307.20	627.1	6.22
	1.76 ± 0.07	−0.14 ± 0.09	0.13 ± 0.09		0.13 ± 0.13	**0.15 ± 0.05**	**0.21 ± 0.05**					Full average		
	1.76 ± 0.07	−0.14 ± 0.09	0.13 ± 0.09		0.20 ± 0.11	**0.15 ± 0.05**	**0.21 ± 0.05**					Conditional average		
Seed eaters	1.12					−0.09	0.12		−0.15		5	−243.30	497.1	0.00
	1.13						0.12		−0.13		4	−244.71	497.7	0.67
	1.12					−0.11		−0.12	−0.15		5	−243.88	498.2	1.17
	0.90			+		−0.12			−0.12		7	−241.83	498.5	1.48
	1.12							−0.09	−0.13		4	−245.99	500.3	3.23
	1.08 ± 0.11			+		−0.07 ± 0.07	0.08 ± 0.07	−0.02 ± 0.05	**−0.14 ± 0.06**			Full average		
	1.08 ± 0.11			+		−0.10 ± 0.06	**0.21 ± 0.05**	**−0.12 ± 0.05**	**−0.14 ± 0.06**			Conditional average		
Potential grape eaters	1.19					0.09		0.10			4	−235.57	479.4	0.00
	1.20									−0.09	3	−237.22	480.6	1.18
	1.20							0.08			3	−237.27	480.7	1.28
	1.16				0.22	0.07					4	−236.37	481.1	1.61
	1.17				0.21						3	−237.52	481.2	1.78
	1.20										2	−238.83	481.7	2.30
	1.19 ± 0.06				0.06 ± 0.12	0.04 ± 0.05		0.05 ± 0.06		−0.02 ± 0.04		Full average		
	1.19 ± 0.06				0.21 ± 0.12	0.08 ± 0.05		**0.10 ± 0.05**		−0.09 ± 0.05		Conditional average		

TABLE 2 (Continued)

	Int.	Year 2018	Year 2019	Sub-area	Alternate management	broad_w	Shrubland	Vineyards	sparse_veg.	Grassland	*df*	logLik	AICc	Δ
Abundance														
Functional insectivores	2.30	−0.24	−0.01		0.17	0.19	0.28	−0.13			8	−376.35	769.8	0.00
	2.30	−0.20	0.02			0.18	0.27	−0.14			7	−378.00	770.9	1.04
	2.30	−0.24	−0.01		0.18	0.21	0.34				7	−378.62	772.1	2.28
	2.30 ± 0.07	**−0.23 ± 0.07**	**0.00 ± 0.07**		0.11 ± 0.11	**0.18 ± 0.05**	**0.27 ± 0.06**	**−0.14 ± 0.06**				Full average		
	2.30 ± 0.07	**−0.23 ± 0.07**	**0.00 ± 0.07**		0.17 ± 0.09	**0.18 ± 0.05**	**0.27 ± 0.06**	**−0.14 ± 0.06**				Conditional average		
Seed eaters	1.50			+		−0.18	0.13	0.29		0.17	9	−349.37	718.2	0.00
	1.80				0.18	−0.18			−0.09	0.14	6	−352.95	718.6	0.38
	1.82					−0.18			−0.09	0.13	5	−354.15	718.8	0.58
	1.51			+		−0.18		0.18		0.14	8	−351.06	719.3	1.08
	1.82					−0.18				0.10	4	−355.53	719.4	1.19
	1.58			+	0.17	−0.21					7	−352.59	720.1	1.88
	1.63			+		−0.21					6	−353.71	720.1	1.90
	1.82					−0.19					3	−357.06	720.3	2.13
	1.67 ± 0.18			+	0.05 ± 0.10	**−0.19 ± 0.07**	0.03 ± 0.06	0.09 ± 0.14	−0.03 ± 0.05	0.11 ± 0.08		Full average		
	1.67 ± 0.18			+	0.18 ± 0.11	**−0.19 ± 0.07**	0.13 ± 0.07	0.15 ± 0.11	−0.09 ± 0.05	**0.14 ± 0.06**		Conditional average		
Potential grape eaters	2.47	−0.25	0.06		0.28	0.18		0.29			8	−476.16	969.5	0.00
	2.47	−0.17	0.11			0.17		0.30			7	−477.31	969.5	0.04
	2.46	−0.16	0.12					0.26			6	−478.50	969.7	0.18
	2.46					0.17		0.29			5	−479.73	969.9	0.45
	2.46							0.26			4	−480.89	970.1	0.62
	2.46	−0.15	0.12				−0.21				6	−479.55	971.8	2.29
	2.46 ± 0.13	−0.13 ± 0.15	0.06 ± 0.12		0.06 ± 0.14	0.11 ± 0.12		**0.28 ± 0.11**				Full average		
	2.46 ± 0.13	−0.19 ± 0.14	0.10 ± 0.13		0.28 ± 0.18	0.17 ± 0.11		**0.28 ± 0.11**				Conditional average		

transect mirrored the general trend in species richness (highest in 2018, lowest in 2017).

Butterfly species richness per transect was affected by spatial and temporal factors (sub-area, month, year, and the interaction between sub-area and year), and by a positive effect of alternate management (Table 1; Figure 3). R^2 of the most supported model was equal to 0.42. Similarly, also bird species richness per transect across years was consistently and positively associated with interventions (Table 2; Figure 3), as well as with year (less favourable conditions in 2018) and shrubland cover (with positive effect); secondary effects were related to broadleaved woodland (positive effect), vineyards and sparse vegetation (negative effect), and sub-area (Table 2). R^2 of the most supported model was equal to 0.41. Model validation was achieved in all cases (no overdispersion, no outliers, no zero-inflation, acceptable residuals' patterns); spatial autocorrelation was never found in models' residuals, with the only exception of butterfly species' richness for July 2017 (Moran's *I* higher than expected at $p < 0.05$).

3.2 | Species richness and abundance for different avian functional groups

Both the richness (most supported models' R^2: 0.46) and the abundance (R^2: 0.76) of functional insectivores increased with the implementation of alternate management. In addition, both increased with broadleaved woodland and shrubland cover and decreased in 2018, while the abundance decreased with vineyard cover. Seed eaters (R^2: 0.10 for richness, 0.55 for abundance) increased with shrubland and grassland cover, and decreased with broadleaved forest and sparse vegetation (both richness and abundance). In addition, vineyards exerted contrasting effects on abundance (positive) and species richness (negative), while abundance varied also across sub-areas and with alternate management (positive effect). The species

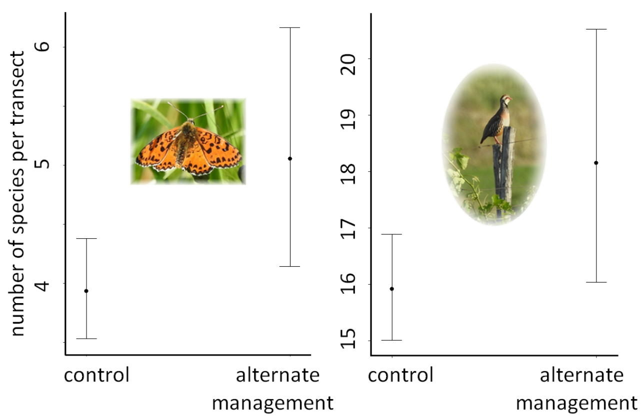

FIGURE 3 Marginal effect (with 95% confidence intervals) of the implementation of alternate management on the number of butterfly (left) and bird (right) species, in control and experimental transects, according to the relative most supported models for overall species richness. Species shown are *Carcharodus alceae* and *Alectoris rufa*.

richness of potential grape eaters (R^2: 0.05) and their abundance (R^2: 0.62) were positively related to broadleaved woodland and vineyard cover, and secondarily to the implementation of alternate management, while richness was negatively affected by grassland cover; the abundance of potential grape eaters varied also with year (being lower in 2018). All the effects are summarized in Table 2, and are visually represented in Figure S3. Model validation was achieved in all cases (no overdispersion, no outliers, no zero inflation, no deviation in residuals' distribution from expected patterns), with the partial exception of a few models showing significantly different simulated and observed dispersion; however, in the latter cases, the ratio between observed and simulated values was rather close to 1 (~0.8) and residual patterns look very good. Spatial autocorrelation was never found in models' residuals, with the only exception of richness of seed-eating birds for 2019 (Moran's *I* higher than expected at $p < 0.05$).

4 | DISCUSSION

4.1 | Simple field-scale practices positively affect biodiversity

Landscape mosaics that include vineyards often support a rich biodiversity, including some rare species (Brambilla & Ronchi, 2020), even if most of the taxa inhabiting such landscapes seem to avoid or, at least, not to favour vineyards (Assandri et al., 2016; Brambilla, 2015; Pithon et al., 2016). Wine-growing areas represent one of the most intensive and impacting cultivations worldwide (Viers et al., 2013); both management practices and the conservation of residual patches of natural and semi-natural habitats must be pursued to promote biodiversity and ecosystem services in such intensive agri-environments (Paiola et al., 2020). Our work tested the effects of a simple management practice, implemented at the field scale, on birds and butterflies, which were selected as model groups because of their well-known sensitivity to environmental changes and habitat management. Results show the positive impacts of the adoption of alternate management (tillage or mowing) of inter-rows in vineyards, on both groups. Most of experimental vineyards were not completely tilled (as in Figure 1, upper left) before the measure implementation: frequently, tillage was applied to all the inter-rows, but some ground cover was left along wine rows. It is therefore likely that even greater benefits may be provided by converting completely tilled vineyards to alternate tillage parcels because of the expectable 'improvement effect' (Kleijn & Sutherland, 2003).

The effects of the field-scale alternate management were particularly relevant for butterflies, the entire community and the functional insectivores among birds. The factors year and sub-area were both relevant for butterflies, whereas for different bird groups only one of the two was included in the most supported models. This could be due to a plurality of factors, including the more spatiotemporally structured variations in dynamics of butterfly communities (Sutcliffe et al., 1996; Thomas, 1991). Birds frequently require habitat mosaics, especially in homogeneous landscapes such as vineyards (Assandri et al., 2017a), and hence species richness is often more dependent on landscape structure than on vineyard management (see Table 2 and Assandri et al., 2016). This was confirmed by the relevant effects of land-cover variables on richness and abundance of avian community and functional groups; however, the implementation of alternate management still played a role, especially for insectivores, increasing both richness and abundance and hence potentially contributing to pest control. Secondarily, alternate management may marginally and positively affect the abundance of seed eaters, and richness and abundance of grape eaters, but in this case the effect was poorly supported (Table 2).

The positive effect of alternate management, which promotes heterogeneity in ground cover and in the height of the sward layer under vineyards, is not surprising. For birds, the alternate management is likely to increase the suitability of nesting habitat (a crucial component during the breeding season) for only a handful of bird species nesting on the ground (Buehler et al., 2017), but it can improve foraging habitat for a variety of ground-foraging avian taxa (Assandri et al., 2017a). The availability of rows with different sward height close to each other is likely to enhance the availability of key invertebrate preys, which are abundant in unmanaged rows, and easily preyed in tilled or mown ones (Schaub et al., 2010; Vickery & Arlettaz, 2012). A partial grassland cover, especially in organic vineyards, also enhances avian functional diversity (Barbaro et al., 2021; Guyot et al., 2017; Rollan et al., 2019). However, the limited potential impact of alternate management on nesting habitats implies that its positive consequences for birds may be maximized through a sympathetic promotion of nesting opportunities, by means of, for example, nest-box deployment (Assandri, Bernardi, et al., 2018; Caprio & Rolando, 2017) and, especially, through the conservation or restoration of marginal elements and semi-natural habitats (Assandri, Bogliani, et al., 2018; Barbaro et al., 2017; Brambilla, Ilahiane, et al., 2017). For butterflies, alternate mowing is likely to offer floral resources during all the spring–summer, hence promoting feeding in inter-rows. The smaller spatial scale at which butterflies likely respond to habitat changes (and hence to dedicated management) could make them more sensitive to interventions taking place at a local scale. The maintenance of unmown grassland patches for all the reproductive season enhances the availability also of host plants and increases the chance of completing the life cycle. This could be achieved either by (a) keeping unmown a few inter-rows over a vineyard parcel (in 2020, one of the farmers left one unmanaged inter-row every 11, with apparently very positive outcomes for biodiversity; Figure S5) or (b) delay mowing on residual grassland patches and on marginal grassland strips (that should be recreated if completely wiped out).

Other studies carried out elsewhere and focusing on these or other groups reported consistent effects in vineyard ecosystems (Bosco, Arlettaz, et al., 2019; Kratschmer et al., 2018; Maurer et al., 2020). Partial mowing or tillage, which is a rather extensive management, would benefit also ground vegetation and related ecosystem services (Hall et al., 2020), and it is also likely to reduce shallow landslide risks within the study area, promoting slope stability (Bordoni et al., 2019).

Further investigations should address the potential interaction between the field-scale management practice tested here, and the management regimes adopted, that is, organic vs. conventional, and tillage vs. mowing. In fact, the low sample size of our experiment did not allow us to perform a proper assessment of the impact of management regimes. Preliminary evidence showed contrasting patterns between different years (stronger effect in either organic or conventional vineyards, depending on the year, in both taxa; details not shown). Ideally, the potential interactions between management regimes and alternate tillage or mowing should be addressed using parcels as sampling units, within a stratified design, to quantify the very field-scale effects of management combinations under the same landscape conditions.

4.2 | From the farmers' side

No farmer reported adverse effects of alternate management. However, in a couple of circumstances, reportedly they were unable to implement alternate management because of access constraints created by excessive development of ground vegetation. Two farmers reported such an issue: surprisingly, the first for a wet spring, with heavy rainfall causing early and too fast vegetation growth, and the second for a drier year, reporting that the scarcity of rain prevented the standard dominance of annual plant species, leading to excessive growth of some perennial herbs, which complicated access to vineyards. The two farms (both organic), which adopted mowing and do not apply tillage, were located in different environments at different elevation, and local contexts markedly differed.

All the farmers who took part to the initiative received illustrative panels, which were placed in their farms to communicate to visitors their efforts to promote biodiversity (Figure S4), and were involved in a communication plan. Many of them reported beneficial effects in terms of attention gathered from visitors, and stated that taking part to this coordinated effort had likely increased their appeal and attractiveness (see also Galati et al., 2019). Therefore, initiatives targeted at local biodiversity not only did not exert adverse impacts on farmers, but also potentially enhance the appeal of their products, and promote farm attractiveness for nature-based recreation, contributing both to biodiversity conservation and farm multifunctionality. This is particularly relevant also because of the negative perception of vineyards by, for example, birdwatchers (Brambilla & Ronchi, 2020), due to the effect exerted by large vineyard cover on avian diversity (Pithon et al., 2016) and single species (Brambilla, Gustin, et al., 2017), which clearly limits the potential appeal of wine-growing areas for nature-based recreation, reducing the potential of vineyard areas for tourism (Brambilla & Ronchi, 2020; Fiedler et al., 2008).

Additional benefits to farmers may be provided by the potential increase in pest and weed control services. The implementation of the field-scale measure resulted in higher abundance of seed eaters and insectivores, and in a higher species richness of the latter. The positive effect of the alternate management on these key functional groups could promote the ecosystem services provided by birds in vineyards. On the other side, the potential impact of alternate management on species that can potential eat grapes is less clear; even if such an effect seemed positive, it is likely to be almost negligible (the estimate for the alternate management effect in fully averaged models is invariably much smaller than its standard error; Table 2).

5 | CONCLUSIONS

The adoption of the very simple alternate management tested in this study, which involves alternate mowing or tillage depending on farmer's standard management, has the potential to immediately increase suitability of vineyards for biodiversity while enhancing ecosystem services, thus mitigating viticulture impacts on species and ecosystems (Brambilla, Ilahiane, et al., 2017). Further refinements could better accommodate the needs of birds nesting in vineyards, especially by promoting the maintenance of unmown inter-rows for longer period to promote successful breeding of ground-nesting species such as woodlark *Lullula arborea* (Buehler et al., 2017), and butterflies laying on vineyard ground (all butterflies observed in the study vineyards were foraging, but apparently no species laid eggs in inter-rows). The mowing frequency in the inter-row could also be calibrated in a context-specific way, according to the potential occurrence of sensitive species of conservation relevance (Nascimbene et al., 2013), and similarly the composition of ground vegetation could be addressed to enhance the grape quality according to local context and varieties (Steiner et al., 2021). Complementing alternate management of inter-rows with interventions increasing the availability of nesting sites and unmown grassland strips may synergistically increase the suitability for birds and butterflies, respectively. All those simple but relevant field-scaled measures could be part of an intervention ‘package’ to be supported by means of, for example, agro-environmental-climatic interventions in Rural Development Programmes, in the framework of the coming new Common Agricultural Policy for European Union countries. Concomitant strategies acting at the landscape scale would maximize the potential for biodiversity and ecosystem services (Martin et al., 2019; Paiola et al., 2020). Our own results suggest indeed that increasing shrubland cover promotes species richness and abundance of insectivores and seed eaters, hence promoting also pest and seed control by wild birds, and the likely resilience of such services by increasing redundancy. At the same time, increasing shrubland cover would not favour birds potentially eating grapes. Important effects of landscape composition and/or configuration on vineyard bird species and communities (per se or in interaction with vineyard management) have been reported from the study area (Brambilla, Ilahiane, et al., 2017) as well as from many other regions (Assandri et al., 2016, 2017a; Barbaro et al., 2017; Barbaro et al., 2021).

Incorporating (and communicating the adoption of) biodiversity-friendly practices in vineyards, such as the alternate management tested in this study, could enhance the synergy between different ecosystem services and objectives. Biodiversity conservation, biological control, ecotouristic value and product appeal are indeed all likely to benefit from the implementation of these field-scaled measures, at least in the Old Mediterranean and the rest of Europe.

AUTHORS' CONTRIBUTIONS

Both authors conceived the idea and performed the fieldwork; M.B. analysed the data and wrote a first draft of the paper; both authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available via Unimi Dataverse https://doi.org/10.13130/RD_UNIMI/5ZXGIV (Brambilla & Gatti, 2022).

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