Diversity in the monotony? Habitat traits and management practices shape avian communities in intensive vineyards.

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Abstract

Spreading of viticulture may pose serious threats to biodiversity and adequate policies targeted at decreasing its impact are urgently required. Current knowledge of viticulture effects on biodiversity is scarce and studies on bird communities in vineyards are even scarcer.

We surveyed avian assemblages in Trentino vineyards (North-East Italy) in both breeding and wintering seasons to evaluate the effect of: i) landscape, ii) management and iii) topographic-climatic characteristics on birds. We calculated four community indexes and modelled their relative variation according to 18 environmental variables belonging to the three above-mentioned groups.

Landscape models performed better than the others, except for winter evenness, for which management models were the most supported ones. Generally, models considering the three groups together explained more variation than models from an individual group.

Landscape (and agricultural) heterogeneity, extent of marginal habitats, density of traditional elements (hedgerows, tree rows, isolated trees and rural buildings) all had positive effects, whereas vineyard cover had negative impact on the value of the four community indexes. Organic management had no apparent effect on avian communities.

We detected a seasonal difference in the effects of environmental characteristics on bird communities, which suggested that local conservation efforts could be tuned according to the seasonal importance of vineyards in different regions. Key measures to promote biodiversity in vineyards include maintaining patches of residual habitats in the vineyard matrix and enhancing heterogeneity. Marginal features appeared particularly important in the homogeneous landscape of intensive vineyards.

Keywords – CAP, greening, landscape, organic, Trentino, viticulture

1. Introduction

Millennia of agricultural expansion have resulted in a substantial amount of terrestrial species surviving on land dedicated to food production (Krebs et al., 1999). At the same time, agricultural intensification is one of the main causes of biodiversity loss (Green et al., 2005), and thus sustainable management of farmland habitats has become a key topic of modern conservation biology (Chapin et al., 2000).

Considering the agricultural impacts on biodiversity, arable crops in temperate regions are among the most studied systems (Balmford et al., 2012), whereas permanent crops (*e.g.* orchards, vineyards, timber plantations) had received much less attention. As a result, knowledge of factors affecting biodiversity in permanent crops remains limited. In addition, permanent crops have not yet been included in any Agri-environmental Scheme in the recent Common Agricultural Policy (CAP) 2013 reform. The 30% of direct payments delivered to farmers according to three ‘greening measures’ (the most relevant of which is devoting 5% of the farm to Ecological Focus Areas), applies to only half of EU farmland and all permanent crops had been excluded (Pe’er et al., 2014).

Such exclusion is particularly concerning, as available evidences suggested that permanent crops are no more suitable for biodiversity than other crops. Intensification in olive orchards, traditionally considered to host a high level of biodiversity (Loumou and Giourga, 2003), produced strongly detrimental effect on plant biodiversity (Allen et al., 2006), whereas in fruit orchards different management strategies strongly affected bird assemblages (Myczko et al., 2013). Therefore a better understanding of the effect of management practices on biodiversity in permanent crops is urgently needed to inform evidence-based conservation practices (*sensu* Arlettaz et al., 2013).

Vineyard is a typical Mediterranean permanent crop, which can reach extreme levels of intensification (e.g. esempi di località). Despite the high economic value and the potentially high impact that such crops can have on the environment (ref.), very little attention has been paid to further investigate factors and management practices affecting vineyards biodiversity. In recent years, wine consumers and producers are however moving away from heavy vinification, extraction and oaking towards leaner, purer, more ‘natural’ styles. Landscape and biodiversity have therefore assumed a new role in viticulture, and this should be seen as a great opportunity for research and conservation efforts (Bisson et al., 2002; Viers et al., 2013).

Recent studies suggested that different taxonomic groups, occupying different trophic levels, may respond differently to disturbance intensity and types in vineyards (Bruggisser et al., 2010). A better understanding of management effects is therefore needed to implement well-focused conservation strategies.

Agricultural intensification caused major decreases in farmland bird populations in Europe (Donald et al., 2001). Despite the efficacy of birds as environmental indicators (Gregory et al., 2005), there are a very few studies on bird communities in vineyards (especially if compared with arthropods or plants), often limited to highly specific topics. Duarte et al. (2014) reported that soil conservation practices based on mechanically managed herbaceous corridors favour bird communities in vineyards. A study of Woodlark *Lullula arborea* in wineyards*,* found that this endangered ground-nesting bird favours a mixture of ground vegetation and bare ground (Arlettaz et al., 2012).

Sierro & Arlettaz (2003) suggested that, vineyards have the potential for harbouring interesting bird communities, but the availability of natural features and ground vegetation cover have to be well understood. The same authors also advocated for further studies with a fine-scale approach, which should also consider management type and intensity.

In this work, we studied avian communities in Italian vineyards in both breeding and wintering season, aiming at understanding the effects of habitat characteristics and management practices on birds. In particular, we first tried to disentangle which environmental levels (i.e. group of variables: landscape, management, topography-climate) affect avian assemblages in vineyards; and secondly to which are the specific effects of each environmental variables belonging to the above-mentioned groups. The ultimate goal of this study was to identify some potential measures for bird conservation at both landscape and field scale level, in respect to bird requirements during breeding and wintering seasons. Such findings could be then used to advice policymakers and future agri-environmental schemes both an national (i.e.) and international level (i.e. CAP).

2. Materials and Methods

2.1 Study area and experimental design

The study took place in Trento Province (South-eastern Alps, Italy) which is characterized by intensively cultivated and partly urbanized valley bottoms, mountainsides covered by woodlands (), interspersed by pastures (), apple orchards and vineyards and with anthropogenic grasslands (750 – 2,000 m). The highest grounds (>2,000 m) are covered by alpine meadows, localised scrub, rocks and seasonal snow. Mean human density is relatively low (86 inhabitants/km^2), especially in mountain areas (Servizio Statistica. Provincia Autonoma di Trento, 2013).

Vineyards primarily occur in the valley bottoms and hilly sides of the two main North-South oriented valleys (Adige and Sarca),between 65 m a.s.l. and 750 m a.s.l. Vineyards cover about 10,300 ha, corresponding to 2% of the total Trento Province, but to nearly 20% of all the farmable land (i.e. under 500 m a.s.l.).

2.(x)

To consistently survey birds across vineyards, we scattered 47 200-m long linear transect across the entire area (how big is the area?) (Fig.1). Each transect had a 100-m buffer area within which bird counts were performed and thus each census plot (how many plots?) covered 7.15 ha. Half of the transects were on the valley bottom and half on the sloping valley sides. To avoid double counting the same individuals we set the minimum distance among neighbouring transects to be of 300 m.

2.2. Bird data, avian community indexes and environmental variables

We censured birds at each plot (n=) three times during the breeding season (hereinafter: spring) (visit 1: 10th-18th April; visit 2: 13rd-22nd May; visit 3: 12nd-22nd June 2014) and twice in winter (visit 1: 14th–22nd December 2014; visit 2: 12nd–21st January 2015). Five to six transects per day were censured from dawn up to a maximum of five hours after it (5.30-10.30 a.m. in spring; 8:15-12.15 a.m. in winter). Surveys were conducted by the same observer avoiding precipitation and strong winds (above Beaufort scale four). To avoid problems in bird detectability depending on the time of the day (add reference), times of survey between visits were inverted. All bird contacts inside the 100-m buffer were mapped on aerial photographs (scale 1:2500 m) using standardise species and behavioural codes. All contacts were recorded as precise as possible, invariably at least at the habitat patch scale, where patch is a defined as a recognisable portion of the same habitat inside the plot or, in the case of vineyards, a parcel with a defined spatial arrangement or homogenous management. Two vineyards with the same spatial arrangement and homogeneous management could be owned by two different farmers; in such cases we counted them as a single patch. Such a census method is more time-consuming than the simple counts of individuals along the transect, but it allows the observer to obtain precise counts of each species, by paying attention to the exact location of all individuals, thus avoiding double counts and reducing biases due to imprecise mapping of the birds.

On the basis of the census results for all plots and for each season (spring and winter), we calculated four community indexes: species richness (hereinafter: richness), abundance, Pielou's evenness (evenness) and conservation index. We only considered birds standing in the plot (not overflying) and for spring survey, only breeding species in Trentino, based on our knowledge and available literature (Pedrini et al., 2003). We preferred to focus on breeding species because the environmental variables we measured are much more likely to be important for the pool of 'local' species than for migrant ones. The first three indexes were calculated in R (R Core Team, 2015) using the package vegan (Oksanen et al., 2015).

Richness was calculated cumulatively over the two (winter) or three (spring) censuses, whereas abundance (define) and evenness (define) were calculated as the mean value over the two/three censuses, respectively. Conservation index was a sum of scores attributed to each plot on the basis of the species occurring in it. Each species had a specific score ranging from 0 to 6 and calculated on the basis of: i) two European commonly recognised indicators: Annex I of the 'Birds' Directive 2009/147/EC (1 point for species listed in the Annex I) and on BirdLife (2004) assessment (3 points for SPEC 3; 2 points for SPEC 2, 1 point for SPEC 3); ii) two Italian bird conservation assessments: the Red List (Peronace et al. 2012: 4 points for critically endangered species, 3 point for endangered, 2 points for vulnerable, 1 point for near-threatened) and the Italian bird species' conservation status (Brambilla et al., 2013; Gustin et al., 2010) (bad: 2 points, inadequate: 1 point). Other authors (e.g. Ponce et al., 2014) adopted similar approaches using only SPEC scores. Our approach integrated up-to-date conservation priorities for the study area.

We measured directly in the field or in GIS several landscape, management and topographic-climatic variables. Land cover variables were measured based on an accurate photointerpretation of aerial photographs, updated and validated with field surveys at the patch scale. We defined eight habitat categories: woodlands, herbaceous croplands, marginal habitats, traditional orchards and olive groves, intensive apple orchards, meadows, urban areas, vineyards. Vineyards were the dominant typology, covering between 13.4% and 96.7% of plots (mean: 64 ± 2.7 SE %).

Based on these variables we also calculated the H' Shannon diversity index of land cover, the total number of habitat patches and the number of vineyard patches totally or partially overlapping with the plot.

We also measured via aerial photographs the length of hedgerows and tree rows within the plot, as well as the number of isolated tree and the number of isolated rural buildings (defined as small, traditional, uninhabited building used for agricultural purposes, typical and widespread in the study area). The definition of 'hedgerows' is complex because in real landscapes all possible transitional states between hedgerows and woodlands occur. We considered as hedgerows and three rows all the linear clusters of shrubs and/or trees, which were less than 15-m wide, isolated into the farmed landscape or originating from woodlands remains but clearly isolated from the main woodland area. Also in this case we carried out a specific field validation of the values derived via GIS.

Although viticulture is quite intensive in the valley bottoms, the very small mean vineyard farm size (less than 1 ha, F. Ghidoni (*pers. com*)) found in Trentino leads to a certain degree of agricultural heterogeneity, which we tried to describe by measuring some management variables at the scale of the individual vineyard patch. Despite this, vineyard features at ground level generally are very homogeneous (except at vine base, where herbicides or mowing are applied), because vineyard ground is covered by grass vegetation as a standard practice since ‘70s (Bertamini et al., 1999). Grass is usually mown three times per years (once during the spring period). Also phytosanitary treatments are uniform over all the vineyards in the province, because they are carried out according to the recommendations made by a central agricultural institute. The only major difference is between organic and conventional patches, so we quantified the amount of vineyards under the two different managements within each plot. We considered as "organic" only the farms officially certified by the Agricultural service of the Province. Organic and conventional viticulture differ mainly in the use of synthetic fungicides, insecticides, fertilizers and herbicides (not allowed in the former, see Table S1 in supplementary materials for further details). Organic viticulture in our study area is a marginal management form, accounting for less than 3% of the entire vineyard surface, consequently we were able to include some organic vineyards in one third of our sampling plots (mean ± sd 13.9 ± 26.7 %, range: 0-100 %).

We further distinguished between the two types of vineyard structure occurring in our study area: *pergola*, which is the traditional and predominant one (80% of vineyards in Trentino; Chemolli et al., 2007), and *spalliera*. The former consists of quite tall vines (up to more than 2m considering the secondary branches, growing in a dense canopy), supported by a robust structure of poles and beams. Spalliera is the most widespread vineyard arrangement, in which low vines are supported by wires bent among poles. *Pergola* implies a greater distance among vines rows (up to 5 m) than *spalliera* arrangement (generally less than 2 m) (See Fig. S1 in supplementary materials). In *pergola* vineyards, some typologies of mechanical activities (e.g. mechanical harvesting and pruning) are not possible, but apart from this the two types do not differ a lot in term of general management.

We also recorded if a vineyard patch had stone walls along at least one of its sides.

Topographic variables (i.e. elevation, aspect and slope) were derived from a 10-m resolution digital terrain model (made by the provincial authorities and publicly available). We also derived bioclimatic variables (BIO1-annual mean temperature; BIO12-annual precipitation) from WorldClim (www.worldclim.org, Hijmans, et al., 2005) at a 30 arc-seconds resolution.

2.3 Statistical analyses

We grouped all the environmental variables into three different categories of predictors: landscape, management and topographic-climatic variables (Table 1).

Although the percentage cover of vineyard is a land cover variable, we placed it with the management predictors, to correct for the cover of vineyard in the plot when evaluating the effect of the management variables, as well as to reduce collinearity amongst predictors in the landscape group. We placed hedgerows length and tree rows into the management group because in our study area their occurrence is determined by farmers' individual decisions. The same applies to the number of isolated trees and isolated rural buildings, which we combined into a single variable (index of traditional element). Their frequency in a plot depends on the level of agricultural intensification in the farmland, with extensive ones hosting much more traditional elements than the intensive ones. In order to have the same scale for both measurements, we log+1 transformed isolated trees before summing.

We initially applied the protocol for data exploration proposed by Zuur, Ieno, & Elphick (2010) for each group of predictors in order to avoid common statistical problems. This led us to apply log+1 transformation to woods, traditional orchards and apple, to reduce the weight of the outliers. H' Shannon diversity index of land cover was highly collinear (VIF = 11.4) with most land cover variables, so it was discarded from analyses. Also topographic-climatic variables were highly collinear among each other. We firstly removed elevation (as it was the variable most correlated with all the others, and in particular with BIO1-annual mean temperature, r = -0.8). Then, we also discardeBIO12-annual precipitation, because it was strongly correlated with BIO1 (r= 0.8).

In the case of dichotomous variables (i.e.. organic-conventional, *spalliera-pergola*, wall occurrence-wall absence), we used only one of the two values (the less represented of the two), because they are of course intrinsically collinear.

We ended up with 18 environmental variables (see Table 1) subdivided into the three groups that we analysed separately for each of the four response variables, for both spring and winter (N=47 plots, in all cases).

Our data present a strong spatial structure, and spatial autocorrelation is known to severely affect the results of regression analyses (Beale et al., 2010), so we used GLS models, which allow us to incorporate spatial structure (i.e. geographic coordinates of the plot centroids) into a linear model to correct for this violation of independence (Brambilla & Ficetola, 2012; Dormann et al., 2007). We fitted models by maximum likelihood and with a Gaussian spatial correlation structure; other structures of the spatial error gave identical results. When graphical analyses of relationships suggested potential quadratic effects, we included the corresponding quadratic term in the analysis. We fitted models using the R package 'nlme' (Pinheiro et al., 2015). Three response variables (richness, abundance and conservation index) were counts, so they should have been fitted using Poisson or negative binomial distributions, which is not possible with GLSs. We then tested for the normality of the residuals of the respective models using Kolmogorov-Smirnov test and given that they resulted to be normally distributed, we opted to use the GLS approach also for those variables to appropriately deal with spatial autocorrelation (output of normality tests are given in Table S2 in supplementary materials).

We worked within an information-theoretic approach (Burnham and Anderson, 2002) and built all possible models for each response variables using each of the three predictor groups for both seasons. For this purpose, we used the dredge function in the R package 'MuMIn' (Barton, 2015).

We then averaged across all models with AICc<2 within each group, obtaining model-averaged coefficients and confidence intervals (Johnson and Omland, 2004).

Finally, we built four 'final' models per season (one per each response variables), selecting from the individual groups the predictors which had confidence intervals (as calculated in the previous step) not encompassing zero with $p<0.05$ and after checking again for collinearity, we built such multi-level models using all the selected predictors, adopting the same AICc-based ranking (Koleček et al., 2014).

In one case (winter evenness), we decided to include also the predictors whose confidence intervals did not encompass zero with $p<0.1$, because a lot of potentially relevant variables did not reach the more stringent threshold.

To define thresholds useful to derive concrete targets for conservation, we plotted the 'final' model predictions against some selected habitat predictors. We chose among the most important variables (according to the final models) the ones that were more severely affected by agricultural intensification: cover of marginal habitat, number of patches and length of hedgerows, which are all reduced by intensification.

3. Results

The four community indexes were calculated considering 59 bird species for spring and 51 for winter (for the full list of the species see Table S2 in supplementary materials*)*.

Richness, evenness and conservation index were significantly higher in spring than in winter, whereas abundance showed the opposite pattern (Table 2*)*.

On the basis of the AICc values (Table 3), models based on landscape predictors were generally better ranked than those based on management or topography-climate variables for all the community indexes, except for winter evenness, for which management models performed better than others.

Models based only on topographic-climatic features were always worse than the other two sets of models, except for winter evenness again, for which landscape model was the worst and topographic-climatic model stood between this and the most supported management one (yet all the models were comprised in a fairly small ΔAICc=4.12). Final models for richness, evenness (winter) and conservation index ranked better than the best models from individual group. This suggested that the combination of the three sets of predictors better explained variation in community indexes, which are thus likely affected by factors of different types (i.e. belonging to different groups), although for richness and winter evenness the difference was small (ΔAICc<2). For abundance (both spring and winter) and spring evenness the final model was the same of the best single-set-of-variables model.

3.1. *Effects of landscape, management and topographic-climatic variables on community indexes*

Our analysis was designed to end up with four averaged models combining each community response variable with the most relevant predictors (potentially belonging to different variable groups) identified in the previous step. Full results of the first step are summarized in the supplementary material (table S4 and S5). In short, amongst all landscape variables, the ones which were most frequently selected in the most supported models were: wood cover in spring (positive effect on richness and evenness, negative on abundance and conservation index), urban cover (quadratic unimodal effect on richness and conservation index, positive on abundance and negative on evenness). Considering management variables, hedgerow length had linear positive effects on all the community indexes in both seasons, except for winter abundance, when the effect was negative. In winter, the percentage of *spalliera* vineyard had negative effect on all the indexes, except for evenness (positive effect, but the standard error was very large), whereas stone walls had a positive effect on richness and abundance, and negative on evenness and conservation index.

Finally, the only topographic-climatic variable which had detectable effect on all four indexes (in spring) was slope, (positive effect on richness and evenness, negative on abundance and conservation index).

3.2. *Final models for the community indexes*

Outputs of the final model averaging for the four response variables are reported in Tables 4 (spring) and 5 (winter). The effects (linear positive or negative and quadratic) of predictors on response variables were the same as in the first step of the analysis (see table S4 and S5), but some of these variables were not selected (or had lesser relative importance) in the best models in this multi-level framework.

Richness in spring was affected by urban (quadratic unimodal effect) and vineyard cover (negative effect), and by vineyards with stone walls (positive effect); also wood cover was included (positive effect), but its confidence intervals encompassed zero. Slope was excluded from this model, because of its collinearity (VIF=3.73) with other variables. In winter, all the variables selected in the previous step (*i.e.* urban, marginal and crop covers, all with positive effects) were included in the best models, as well as hedgerow length (positive effect) and percentage of *spalliera* vineyard (negative effect), but the latter two variables showed confidence intervals including zero.

Abundance in spring was affected only by urban cover (positive effect) and by the number of patches (quadratic unimodal effect). In winter, all the variables previously selected (wood, apple orchard, *spalliera* with negative effect and number of patches with positive) were included also in the best final models, although all of them had confidence intervals encompassing zero.

For evenness in spring, all the variables selected at the previous step (i.e. wood, crop, *spalliera* cover and number of vineyard patches with positive effects; marginal habitat with quadratic unimodal effect; apple orchard, meadows and urban with negative effect) were included in the best models, although meadows and *spalliera* had confidence intervals including zero. In winter hedgerow length, and aspect (positive effect) and number of vineyard patches (negative effect) were included; however, only hedgerow length had confidence intervals not encompassing zero. The number of patches was excluded due to its high collinearity. For conservation index (in both seasons), all the variables selected by the previous step were included in the best models: in spring, aspect (positive effect), marginal habitats, urban cover, index of traditional elements (quadratic unimodal effect) and wood (negative effect); in winter: urban and hedgerow length (positive effect); marginal habitats cover (quadratic unimodal effect) and vineyard with stone walls and *spalliera* (negative effect).

Figure 2 shows a graphical representation of the effect of some relevant predictors according to the 'final' model predictions. In line with those relationship, when marginal habitat cover was between 15-20%, all the community indexes here considered displayed values above the respective. Similarly, about 30-50 habitat patches per plot (corresponding to 4-7 patches/ha) should be preserved to harbour bird communities richer and more abundant than the average ones.

Considering length of hedgerows and tree rows, about 200-400 m per plot (corresponding to 28-56 m/ha) in winter is needed to guarantee richer and more even communities than average. In addition, the more hedgerows are provided, the highest is the conservation index of the bird community.

4. Discussion

Farmland biotic communities are shaped by both landscape structure and agricultural management, with multi-level interactions often difficult to disentangle (Batáry et al., 2011). Generally, the landscape structure plays a key role, but also management may affect communities (Fuentes-Montemayor et al., 2011; Purtauf et al., 2005; Schmidt et al., 2005; Weibull et al., 2003). The landscape level was the most important one for the majority of the community indexes considered in our study system, but some features describing agricultural management also had an effect on communities for some combinations of indexes and seasons, the likely similar importance of the two groups of variables was suggested by the limited difference in AICc (<4) between landscape and management models. On the other side, over the geographically restricted area covered by our study, topographic and climatic variables had lower importance.

Models considering together landscape, management and topographic features were generally better than the ones considering only one level of environmental features. This suggests that avian communities in vineyards are affected by a plurality of factors and not only by a single type of environmental traits. Importantly, the effect of several factors was different on different indexes, and also varied with season: in the final models, there is no variable having a consistently positive or negative effect for all indices or in both seasons.

In this vineyard-dominated agroecosystem, the amount of vineyard cover had a negative effect on the species richness. On the opposite, the amount of other landcovers broadly resulted in a positive effect on most community indexes. The positive effect of heterogeneity on biodiversity in agricultural systems is widely recognised and this is likely one of the main reasons why intensification, which causes a marked reduction of heterogeneity, has so detrimental effects on biodiversity (Benton, Vickery, & Wilson, 2003). Studies on the effect of heterogeneity in permanent crops are scarce, but in Spanish olive groves Castro-Caro et al. (2014a) found no effect of landscape heterogeneity on abundance and richness of songbirds, although hedgerows, that generally characterized extensive and heterogeneous agricultural systems, had positive effect on those two community parameters (Castro-Caro et al., 2015). In our study system habitat heterogeneity is clearly important: the number of habitat patches (a measure of it) had indeed a positive linear effect on richness and abundance in winter and a quadratic unimodal effect on spring abundance. Consistently the number of vineyard patches, which is an indirect measure of the probability of having different management systems and overall of agricultural heterogeneity, had largely similar effects on community indexes.

Several habitat traits had different effects on the different community indexes. Woodlands (in spring) were associated to richer and even communities, but had negative effect on species of conservation concern, that in our study area (as over most of

Europe) are mainly tied to agricultural and open habitats. In addition, residual woodlots in the vineyard matrix are often small and disturbed, thus unlikely suitable for forest species of conservation concern, which generally show more specialized ecological requirements. Arable crops (mainly small family-ran vegetables fields interspersed among vineyards) showed positive effect on richness (spring) and evenness (winter).

The effect of marginal habitats on community indexes in spring were generally better modelled through a quadratic unimodal relationship. Given that we included in this category not only fallow lands, hedgerows and three rows, but also elements marginal to vineyard like roads and field margins, it is possible that above a certain amount, road occurrence could result in a considerable disturbance. In winter, vineyards are very poor habitat (only used by flocks of finches and thrushes), and most birds are thus forced to exploit all kinds of marginal habitats, including roads and field margins, where some tall grasses were left, this potentially explaining the positive linear relationship in this season.

The key importance of marginal elements (in particular hedgerows and tree rows) was confirmed by the management models. These elements are mostly tied to a traditional and extensive farming, as are isolated trees and rural buildings. Trees and buildings are probably less important than hedgerows at the scale we worked, but still had positive effects, in particular on the species of conservation concern, providing potential nest sites in the monotonous vineyard matrix.

The importance of patches of different habitats within the vineyard matrix was also confirmed by the amount of urban cover in the plot. Urban cover promoted bird assemblages that were abundant but scarcely even, and this is consistent with the effects of urbanization worldwide (Chace and Walsh, 2006). Urban cover had also a positive effect on richness and conservation index until a certain threshold, then the quadratic unimodal relationship suggested an opposite effect. These overall positive or quadratic effects were likely due to additional habitats potentially suitable for different species hosted by sparse and small urban areas occurring in the study plots. Gardens with big trees, vegetable gardens and buildings offer a variety of possible nest sites. In winter the positive effect of urban areas was even stronger, probably because towns in winter are warmer and provide greater feeding opportunities for birds than surrounding areas. During the breeding season, apple orchards interspersed within the vineyard matrix had a negative effect on deplete community evenness, probably because such crops host a few but widespread species, which could be very abundant in apple orchards (e.g. blackbird *Turdus merula* and song thrush *Turdus philomelos*; see also Brambilla et al. (2015)). The opposite was found in winter, when probably the few species feeding on ground grass preferred more open crops.

To the best of our knowledge, this is the first time that the effect of organic versus conventional agriculture was evaluated in vineyard using bird assemblages as bioindicators. We found no effect of organic farming on our communities: this is quite surprising, given the reported positive effect of organic farms, hosting host richer, more diverse or more abundant communities of organism, including birds (Tuck et al., 2014), than conventional ones, mainly due to the sympathetic management of non-crop marginal habitats (Hole et al., 2005). This was also reported for birds in fruit orchard system (Genghini et al., 2006) and for invertebrates (Caprio et al., 2015; Isaia et al., 2006; Sabbatini Peverieri et al., 2009) or plants (Nascimbene et al., 2012) in vineyards, although no positive effect of organic farming was detected by Brugisser et al. (2010). At the landscape scale, the effect of organic farming was shown to be less influent than the structure of the surrounding landscape (e.g. Fuller et al., 2005). Organic farming is expected to be particularly important in intensive and non-permanent crops (Bengtsson et al., 2005), thus in agroecosystems quite different from ours. Moreover, in Trentino organic wine farming is mostly adopted in easy-to-mechanize fields, often resulting from the recent reclamation of natural and semi-natural areas and it is quite intensive. In organic fields phytosanitary treatments are generally more frequent than in conventional ones, although mostly copper, sulphur and pyrethrin are used instead of other synthetic chemicals. Nevertheless, these products are known to negatively affect arthropod communities in vineyards (Nash et al., 2010).

Additionally, organic farms are few and quite isolated in the matrix dominated by conventional vineyard. Therefore, also pesticide drift from other farms could potentially vanish the potential benefits of organic management. All those elements probably concur to explain why organic management had no effects in bird communities.

In short, even if we included in our experimental design much more organic vineyards than those averagely occurring in Trentino, organic vineyards sampled in our study were relatively few and embedded in a matrix dominated by conventional vineyards, and further investigation is needed to better understand the effect of organic farming on birds.

The effect of *spalliera* vineyards was complex and season-dependent. In spring the percentage of *spalliera* enhanced richness likely thanks to the heterogeneity it adds in the uniform matrix of *pergola* vineyard, and possibly because is often located on the steepest slopes, in rather well-preserved traditional agricultural areas, close to the altitudinal limit of vineyard, in species-rich landscape. Moreover, mowing is generally done every second row in *spalliera* vineyards, this creating an alternation of high and low sward, typical of the ‘kitchen-dining room’ system (Vickery and Arlettaz, 2012), which is particularly suitable for ground feeding birds. On the contrary, abundance is lowered by the relative amount of *spalliera* because the very simple structure (compared with *pergola*) reduces the availability of potential breeding sites. In winter, all the indexes were negatively affected by *spalliera* vineyards, maybe because the sloping and relatively high-elevation areas where they occur are less favorable for birds and because the positive ‘kitchen-dining room’ effect is irrelevant in winter, when the grass sward in the vineyards is used only by a few generalist species.

Stone walls probably had hardly any direct influence on bird communities at the landscape scale and the effects we found are likely more due to the level of local intensification, as stone walls are mainly found on the valley sides, where intensification is generally lower. Given this, the surprising negative effects of stone wall occurrence on the conservation index were due to the local distribution of wryneck *Jynx torquilla* and spotted flycatcher *Muscicapa striata*, which mostly occur in the valley bottoms where stone walls are scarcer; this is also consistent with the slope effects we found. Stone walls could be still important for birds (Woodhouse et al., 2005), but their effect should be better investigated at a finer spatial scale (e.g. individual home range).

In general, we acknowledge that the effect of some management variables (e.g. *spalliera* vineyards, stone walls) was difficult to disentangle from the confounding effect of other factors, in particular slope, which in our Alpine context creates strong gradients associated with different frequencies of *spalliera* and stone walls. Specifically designed studies (e.g. reducing altitudinal and slope range) are required for a full understanding of the effects of those variables.

Finally, winter bird assemblages significantly differ from the spring ones, with the latter being richer, more even and more relevant for conservation (but lower in biomass). This is partially consistent with a previous study (Laiolo, 2005) reporting a higher abundance in winter. However, she considered vineyards as a very poor habitat for breeding birds, this suggesting that local drivers, mainly dependent on management practices (e.g. the traditional *pergola* structure), could have a determinant role in shaping bird communities in vineyard landscapes.

5. Conclusions

In this work, using birds as indicators, we provided information on multi-season biodiversity drivers in vineyards, an economically relevant agroecosystem poorly considered in conservation biology. Understanding the effect of vinegrape cultivation on biodiversity is urgent required because this crop is expanding in temperate regions outside the Mediterranean basin and upwards in mountain areas. This phenomenon originates in response to climate change and fast economic and social development, especially of the ‘second world’ countries (Viers et al., 2013). However, this expansion is happening at the expense of natural habitats (Jedlicka et al., 2014).

In our study, birds showed clear responses according to landscape and management variables and they confirmed to be reliable indicators for biodiversity patterns also in this largely artificial habitat. This is particularly relevant because there are very few studies on this *taxon* carried out at the community level in different seasons of the year in vineyards or in similar intensive permanent crops (but see Castro-Caro et al., 2015, 2014a, 2014b for olive groves). Investigating bird assemblages also in winter allowed us to point out differences with breeding season in relation to some environmental variables, posing further challenges for conservation efforts.

Landscape heterogeneity is a key element also for the conservation of birds in vineyards. Conservation efforts should thus enhance it, especially by preserving (and maybe restoring) habitats different from the crop itself and in particular the marginal ones. Linear (hedgerows, tree rows) and punctual (isolated trees, rural buildings) marginal features all have major positive effects on community and on species of conservation concern, thus being particularly relevant.

Vineyard management has a noticeable role in shaping avian communities too. As a consequence, farmers have a key role in enhancing (or depleting) biodiversity in vineyards by means of their choices. Policies targeted at maintaining the small farm mean size (e.g. favoring family-run farms) could enhance bird communities in the study region, by favoring small-scale heterogeneity in management and vineyards traits.

The recent trend in Trentino viticulture is facing a slow, but increasing, abandonment of the traditional *pergola* system, progressively replaced by the *spalliera* system. Results suggested that the latter has ambiguous (but mainly negative) effects on birds; thus a better assessment of the impact of this vineyard type is urgently needed, in particular at the upper sites, where quite rich communities still occur.

Based on our results, we recommend some general conservation measures aiming at favoring vineyard bird communities. In particular, we suggest that a mean of 4-7 different patches/ha should be preserved in the farmed landscape, including also patches different from vineyard. In particular, marginal habitats should represent the 15%-20% of the whole landscape and the density of hedgerow and tree rows should be at least 28-56 m/ha.

Our findings could be relevant in an applied EU policy framework, considering that vineyard was excluded from the 'greening' measures included in the last CAP reform, and then Member States and local governments are expected to define adequate measures to counteract the loss of biodiversity in this type of ecosystem.

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Figure captions

Fig. 1. Study area. A: Location of Trento Province in the Northern Italy. B: Vineyard cover in Trento Province (in violet). C: position of the 47 plots in Trento Province wine district.

Fig. 2. Graphical representation of the effect of marginal habitat cover, number of habitat patches and length of hedgerows and tree rows on the community indexes, as predicted by the final (multi-level) models. Other predictors included in the models are kept constant at their mean value. For habitat patches and hedgerow length, the predictor values refer to number and length over the plot (7.15 ha). Dashed lines represent the 95% confidence intervals of the mean. Horizontal dotted line show the mean values of raw data for each response variables.

Table captions

Table 1. List of variables used in the analysis.

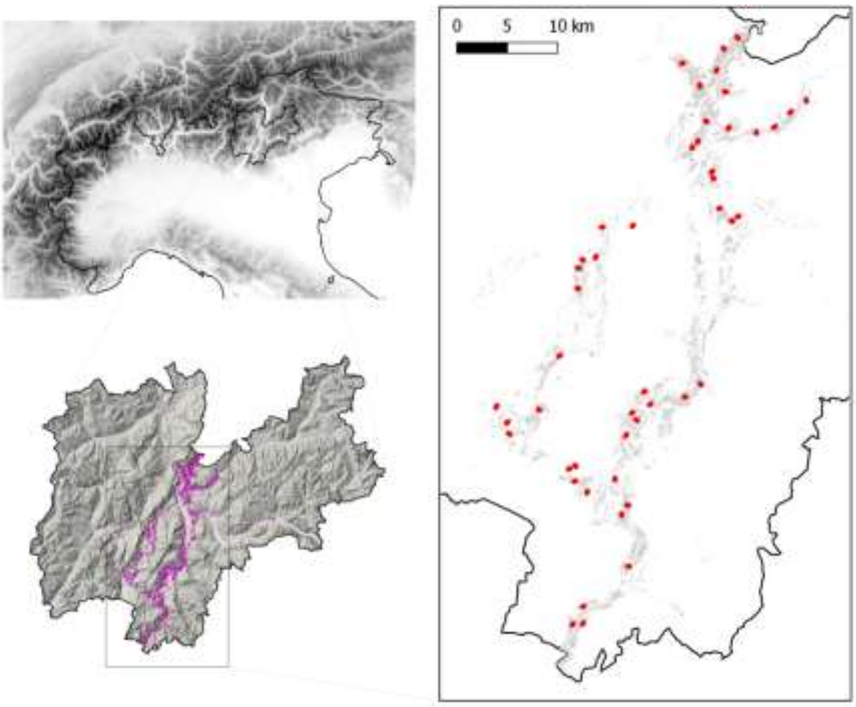
Table 2. Mean values (± standard errors) and results of t-test testing for differences in means of the 5 response variables for spring and winter (N=47). Levels of significance: *: <0.05; ***: <0.001.

Table 3. AICc of the best models for each of the three groups of predictors and for the final models. Models in bold are most supported ones among the three competing groups. Data are shown for all response variables and for both seasons.

Table 4. Model averaged parameter estimates, standard errors and relative variable importance (R.V.I) of models with ΔAICc < 2 for spring: final model. Variables in bold are those for which confidence intervals did not encompass zero. NS: variables used in the dredge (coming from the first step of the analysis) but not selected by the best models (ΔAICc < 2).

Table 5. Model averaged parameter estimates, standard errors and relative variable importance (R.V.I) of models with ΔAICc < 2 for winter: final model. Variables in bold are those for which confidence intervals did not encompass zero. NS: variables used in the dredge (coming from the first step of the analysis) but not selected by the best models (ΔAICc < 2).

Figure 1.



Colour in print is not required

Figure 2

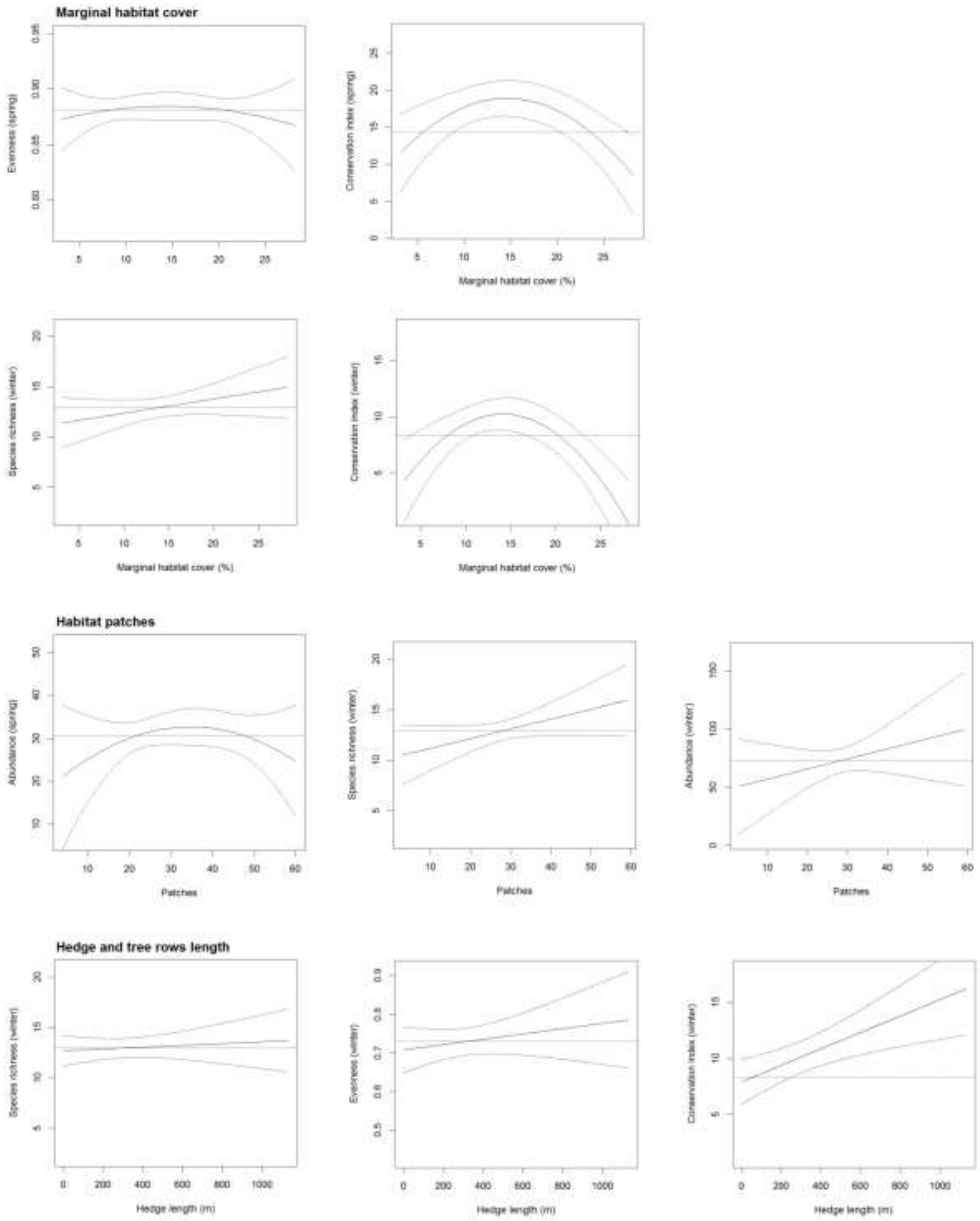

Marginal habitat cover
Evenness (spring)
0.80
0.85
0.90
0.95
5
10
15
20
25
Conservation index (spring)
0
5
10
15
20
25
Marginal habitat cover (%)
Species richness (winter)
Conservation index (winter)
Marginal habitat cover (%)
Marginal habitat cover (%)
Habitat patches
Abundance (spring)
10
20
30
40
50
60
Patches
Species richness (winter)
Patches
Abundance (winter)
0
50
100
150
Patches
Hedge and tree rows length
Species richness (winter)
0
200
400
600
800
1000
Hedge length (m)
Evenness (winter)
0.5
0.6
0.7
0.8
0.9
Hedge length (m)
Conservation index (winter)
Hedge length (m)

Table 1

Acronym	Description	Mean ± SD
Landscape variables		
Woods	% cover of woodlands (large majority of broadleaved woodlands)	6.2 ± 8.9 %
Crops	% cover of herbaceous croplands (mainly small family-ran fields; in winter contain also extirpated wood crops)	2.3 ± 5.7 %
Marginal	% cover of marginal habitats (field margins, hedges and tree rows, abandoned areas with scattered shrubs, roads)	14.2 ± 6.1 %
Traditional orchards	% cover of traditional orchards and olive groves	2 ± 4.4 %
Apple	% cover of intensive apple orchards	4.6 ± 9.4 %
Meadows	% cover of meadows	4 ± 7.7 %
Urban	% cover of urban areas	2.7 ± 4.3 %
Patches	Number of habitat patches into the plot	29 ± 11
Management variables		
Vineyards	% cover of vineyards	64 ± 18.7 %
Hedgerow	Hedgerows and tree rows length in the plot	318 ± 285.7 m
Index of traditional elements	Number of isolated trees (log+1 transformed) + number of isolated rural buildings	4.1 ± 2.4
Organic	% of organic vineyards into the plot	13.9 ± 26.7 %
Spalliera	% of *spalliera* vineyards into the plot	18.3 ± 29.7 %
Wall	% of vineyard into the plot with stone wall along at least one of their sides	46.9 ± 40.5 %
Vineyard patches	Number of vineyard patches into the plot	20 ± 9
Topographic-climatic variables		
Slope		8.9 ± 7.8°
Aspect	In degrees from South	56.6 ± 34.4 °
BIO1	Annual mean temperature derived from Hijmans et al., 2005	11.6 ± 1.5 °C

Table 2

	Plot means				
	Spring	Winter	t	df	p
Species richness	14.32 ± 0.60	12.94 ± 0.57	1.66	92	*
Abundance	30.68 ± 1.81	72.68 ± 5.65	-7.11	55.27	***
Pielou's evenness	0.88 ± 0.01	0.73 ± 0.02	7.44	54.34	***
Conservation index	14.26 ± 1.02	8.36 ± 0.70	4.75	81.48	***

Table 3

	Species richness		***Abundance***		***Pielou's evenness***			
	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter
Landscape	**248.83**	**256.96**	**352.36**	**478.00**	**-184.60**	-50.12	**298.75**	**277.89**
Management	252.75	258.98	372.01	478.84	-170.64	**-54.24**	319.34	280.16
Topographic-climatic features	258.28	261.19	373.28	482.47	-163.38	-51.92	319.66	284.77
Final model	*246.04*	*256.46*	*352.36*	*478.00*	*-184.60*	*-55.32*	*295.40*	*265.61*


806
807

Table 4

	Species richness		*Abundance*		*Pielou's evenness*			
	Coef. ± st. er.	R.V.I.	Coef. ± st. er.	R.V.I.	Coef. ± st. er.	R.V.I.	Coef. ± st. er.	R.V.I.
Intercept	13.43 ± 2.73		13.33 ± 11.15		8.39 * 10^-1 ± 2.58 * 10^-2		1.71*10^-1 ± 3.72	
Woods	8.82*10^-1 ± 4.47*10^-1	0.32			**1.10 * 10^-2 ± 4.71 * 10^-3**	0.94	**-1.49 ± 5.88*10^-1**	1
Crops					**2.40*10^-3 ± 9.67*10^-4**	1		
Marginal	NS				**6.96*10^-3 ± 3.30*10^-3**	0.38	**1.65 ± 4.82*10^-1**	1
Marginal^2	NS				**-2.43*10^-2 ± 1.05*10^-4**	0.38	**-5.64*10^-2 ± 1.47*10^-2**	1
Traditional orchard								
Apple					**-8.25*10^-3 ± 3.82*10^-3**	0.87		
Meadows					-1.52*10^-3 ± 7.84*10^-4	0.66		
Urban	**9.98*10^-1 ± 2.73*10^-1**	1	**1.64 ± 3.19*10^-1**	1	**-3.92*10^-3 ± 1.12*10^-3**	1	**2.15 ± 4.60*10^-1**	1
Urban^2	**-5.24*10^-2 ± 1.71*10^-2**	1					**-1.14*10^-1 ± 2.77*10^-2**	1
Patches			**1.27 ± 4.60*10^-1**	0.67				
Patches^2			**-1.84*10^-2 ± 7.27 * 10^-3**	0.67				
Vineyards	**-5.80*10^-2 ± 2.50*10^-2**	0.68						
Hedgerow	NS		NS					
Index of traditional elements							1.90 ± 1.01	0.80
Index of traditional elemens^2							-1.51*10^-1*1.17*10^-1	0.80

Organic								
Spalliera	NS				3.75*10^-4 ± 1.86*10^-4	0.61		
Wall	**3.61*10^-2 ± 1.26*10^-2**	1						
Vineyard patches					**1.53*10^-3 ± 7.34*10^-4**	0.78		
Slope	NS							
Aspect							**5.02*10^-1 ± 2*10^-1**	1
BIO1								

Table 5

	Species richness		*Abundance*		*Pielou's evenness*			
	Coef. ± st. er.	R.V.I.	Coef. ± st. er.	R.V.I.	Coef. ± st. er.	R.V.I.	Coef. ± st. er.	R.V.I.
Intercept	6.81 ± 2.08				7.56*10^-1 ± 5.66*10^-1		3.26*10^-2 ± 2.71	
Woods			-10.28 ± 5.15	0.43				
Crops	**2.01*10^-1 ± 9.31*10^-2**	0.76						
Marginal	**1.86*10^-1 ± 8.19*10^-2**	0.76					**1.39 ± 3.77*10^-1**	-
Marginal^2							**-4.93*10^-2 ± 1.14*10^-2**	-
Traditional orchards								
Apple			-8.91 ± 4.69	0.73				
Meadows								
Urban	**3.30*10^-1 ± 1.29*10^-1**	1					**4.03*10^-1 ± 1.28*10^-1**	-
Urban^2								
Patches	**1.10*10^-1 ± 4.73*10^-2**	0.89	1.23 ± 6.70*10^-1	0.71				
Vineyards								
Hedgerow	3.74*10^-3 ± 1.92*10^-3	0.24			**1.22*10^-4 ± 6.60*10^-5**	0.61	**7.30*10^-3 ± 2.36*10^-3**	-
Index of traditional elements								
Organic								
Spalliera	-3.36*10^-2 ± 1.79*10^-2	0.53	-3.85*10^-1 ± 1.97*10^-1	0.74			**-5.90*10^-2 ± 1.77 * 10^-2**	-
Wall							**-4.82*10^-2 ± 1.68*10^-2**	-
Vineyard patches					-4.83*10^-3 ±	1		

					2.12*10^-3			
Slope								
Aspect					1.11*10^-3 ± 5.41*10^-4	0.77		
BIO1								