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Environmental and management factors drive biological communities and ecosystem services in agroecosystems along an urban-natural gradient

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A R T I C L E I N F O

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A B S T R A C T

Biodiversity, ecosystem services and farming are inextricably linked. Peri-urban agricultural landscapes host wild species, provide essential services, and benefit citizens of nearby towns. We investigated the environmental and management factors that influence avian communities, pollinating insects and two key ecosystem services (pollination and nature-based recreation) along an urban-natural gradient dominated by agricultural areas (vineyards, apple orchards and grasslands) in northern Italy. Flower visiting-insects were mainly affected by management and environmental-climatic variables. The presence of flowers at the margins and within vineyard and apple orchard inter-rows best predicted the abundance of pollinators and flower-visiting insects in general. Different flower species exerted variable effects on different groups; a mix of flowering species should be recommended for supporting pollinators. Sward height and grassland cover promoted flower-visiting insect abundance, which was negatively affected by vineyards and apple orchards. Bird communities were mainly shaped by land-use/land-cover and management variables. Landscape heterogeneity and linear elements had a major positive effect on birds. Apple orchards negatively influenced species richness and the abundance of most avian species, while vineyards negatively impacted on overall bird abundance; hedgerows positively affected richness. Nature-based recreation was greater in areas with low or intermediate vineyard or urban cover. Apple orchards and intensively managed grasslands had negative, and waterways positive, effects on recreation. Peri-urban agricultural landscapes are important for biodiversity and ecosystem services, but apple orchards and large vineyards appear largely unsuitable. Maintaining heterogeneous landscapes and implementing biodiversity-friendly practices can further promote benefits for biodiversity and visitors and local populations. Synergic strategies that simultaneously promote the conservation of biodiversity and the supply of ecosystem services could be easily developed and implemented.

1. Introduction

Agriculture has been shaping landscapes for millennia, and farmed areas now cover approximately 40% of global and 50% of European lands (FAO, 2020). Biodiversity, ecosystem services (ES) and farming are therefore inextricably linked (Tommasi et al., 2021). Biodiversity underpins key functions, structures, and processes in agroecosystems, which are crucial for farming too. However, agriculture contributes by 70% to the loss of global terrestrial biodiversity (Convention on Biological Diversity, 2010), with fragmentation, habitat loss and changes in agricultural practices being among the main stressors.

Peri-urban agriculture plays an important role in a world characterized by an increasing urban population (United Nations, 2022), with consequent changes to landscape, environment and the supply of ecosystem services, by creating more complex landscapes that can i) host many wild species (Assandri et al., 2017a; Menon et al., 2016), ii) provide essential ES (Nicholls et al., 2020; Sanyé-Mengual et al., 2020), and iii) benefit citizens of nearby urban centres (Cortinovis and Geneletti, 2020; Torquati et al., 2020). Urban and peri-urban farmlands are generally distributed in small-scale areas and tend to be more

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sustainable as environmentally friendly practices (e.g., organic agriculture, polyculture farming) are adopted (Sanyé-Mengual et al., 2020). Furthermore, peri-urban agriculture sustains biodiversity at different levels by preserving open habitats which are important for many species, including some taxa of conservation concern (Assandri et al., 2017b).

With this study, we investigated the environmental and management factors that influence avian communities, pollinating insects and two key ES along an urban-natural gradient dominated by agricultural areas. We focussed on peri-urban farmlands, dominated by intensive vineyards and other permanent crops. Permanent crops are indeed among the farming systems that result in the highest environmental impacts (Martínez-Núñez et al., 2020; Martínez-Sastre et al., 2020; Muñoz-Sáez, 2017). Despite a too optimistic perception of permanent crops (Assandri et al., 2016; Pe'er et al., 2014), the expansion and intensification of such systems can have a great impact on the environment (e.g. Altieri and Nicholls, 2002), negatively affecting biodiversity and ES (Paiola et al., 2020). Within vineyards, which have shaped the landscape of many temperate regions from a cultural and ecological point of view, biodiversity and ES are strongly affected by several factors including soil management, landscape configuration and composition, structural elements, trellising systems, and management practices, which in turn are influenced by climate, irrigation, grape variety, and stakeholders' decisions (Paiola et al., 2020; Winter et al., 2018). Nevertheless, studies investigating the effect of vine crops on biodiversity and ES are still relatively scarce and limited to a few geographical areas and taxon, and more research is urgently needed to fill the main gaps.

We selected birds as a model group to evaluate the link between farming in peri-urban areas and biodiversity. Farmland birds have shrunk by 57% over the past 38 years globally (Havlíček et al., 2021), and by 32% since 2000 in Italy (Rete Rurale Nazionale et al., 2022), and much of this decline has been attributed to agricultural intensification (see Donald et al., 2006; Chamberlain et al., 2000; Morelli, 2013). Birds respond to multiple environmental and management variables (Paoletti, 1999), and are therefore powerful indicators of the quality of an agroecosystem and the general status of biodiversity (Gregory et al., 2003).

ES play an important role in human well-being by providing food, climate and disease regulation, fresh water, soil formation, primary production, aesthetic enjoyment, educational values, spiritual fulfilment, and other benefits (MA, 2005). Such services are essential to our life quality and social capital, but also to our survival, and the unsustainable use of most of these services is threatening our own welfare (MA, 2005). ES models are widely used by scientists and policy-makers as powerful tools to highlight the importance of preserving environmental quality within agroecosystems (La Notte et al., 2017). Here, we investigated cultural ecosystem services (CES) (i.e., nature-based recreational value of our study areas) and a regulating service (i.e., pollination) to obtain complementary information on factors driving ES supply in a peri-urban area. Synergic strategies that consider both biodiversity and ecosystem services allow the identification of management practices within agroecosystems that promote both nature conservation and more general human wellbeing (Assandri et al., 2018; Brambilla et al., 2017), and are especially needed considering the potentially weak spatial association between ES and relevant biodiversity traits (Morelli et al., 2017).

With this study, working along an urban-suburban-agricultural-seminatural-natural gradient we aim to understand how i) landscape composition, landscape configuration, topography, and crop management influence avian communities; ii) how environmental and management variables influence pollinating insects and hence a key ecosystem service in farmed areas; iii) how landscape characteristics influence nature-based recreation, a cultural ecosystem service that encompasses all physical and intellectual interactions with biota, ecosystems and landscapes (Vallecillo et al., 2019). The latter provide opportunities for people to experience direct contact with "nature", otherwise completely lost, especially in highly populated areas (Zulian et al., 2021). By identifying drivers of biodiversity and ecosystem services in a peri-urban agricultural area, we aim at identifying which landscape, topographic and management factors can be particularly important for policies and planning in crucial contexts linking anthropic to natural and semi-natural environments. Such contexts are often subject to heavy pressures and transformations, which could dramatically reduce their potential support to biodiversity, ecosystem services and local populations (Malano et al., 2014). We put particular emphasis on vineyards: while they represent one of the most impacting crops, at the same time vineyards play a crucial role in local economy and cultural landscapes, and simple management measures could boost their potential to accommodate biodiversity needs (e.g., Brambilla and Gatti, 2022). Therefore, the results of our study can have important implications for the development of effective management practices at different scales, from landscape to single parcels.

2. Materials and methods

2.1. Study area

The study area is located in the Adige Valley, southern Alps, within the central-southern portion of the Trento province, encompassing the Trento town and the surrounding rural and semi-natural landscapes (northern Italy; Fig. 1). Within this largely mountainous area, urban areas and perennial crops mostly occur in valley bottoms and in lower, gently sloping mountainsides. Fourteen farms of different extent and located at varying distances from urban areas and natural or semi-natural landscapes were involved in the study (13 wine farms, and one apple orchard). Given that the study was carried out within the area hosting the "Biodistretto di Trento" (a local association of organic farms), most farms sampled by our study were managed under an organic regime.

2.2. Experimental design and data collection

We selected 44 independent sampling sites (points), scattered across different environments within the study area (Fig. 1) in order to i) approximately match the proportion between different land-use/land-cover (LULC) in peri-urban farmed or semi-natural landscapes, and ii) adequately represent the urban-suburban-agricultural-semi-natural-natural gradient. Sampling sites were located at an average distance of 375 m between each other (minimum distance between neighbouring points c. 220 m). 33 sampling sites were in areas dominated by vineyards (17 under *spalliera* arrangement, and 16 showing the traditional *pergola* trellising system, characteristic of the Trento province), nine by apple orchards, one by forest, and one was within an urban park (Parco di Gocciadoro). In general, the network of sampling sites represents all the main environmental conditions found in the study area, in terms of topographical contexts and most relevant land-cover/habitat types surrounding farms.

2.2.1. Pollinators data

Pollinator abundances and their interactions with flowers are key components of the pollination ES (Biella et al., 2022; Liss et al., 2013). To estimate the potential for pollination service, we counted all the insects found on flowers considering broad groups as bees, bumblebees, wasps and ants, flies (Diptera), butterflies, bugs (Rhynchota), beetles (Coleoptera), grasshoppers (Orthoptera). The first five groups include key pollinators, while species belonging to the other three groups likely provide a marginal contribution to pollination within the study system. As pollinators abundance and community can vary over very fine spatial scales, our focus on flower-visiting insects was at a very fine grain. To cover most of the phenological season, we performed four subsequent surveys in 2021 and collected data from 28th to 31st May, 21st to 23rd June, 17th to 19th July, and from 22nd to 24th September. For each sampling site, at each sampling session we randomly selected three plots

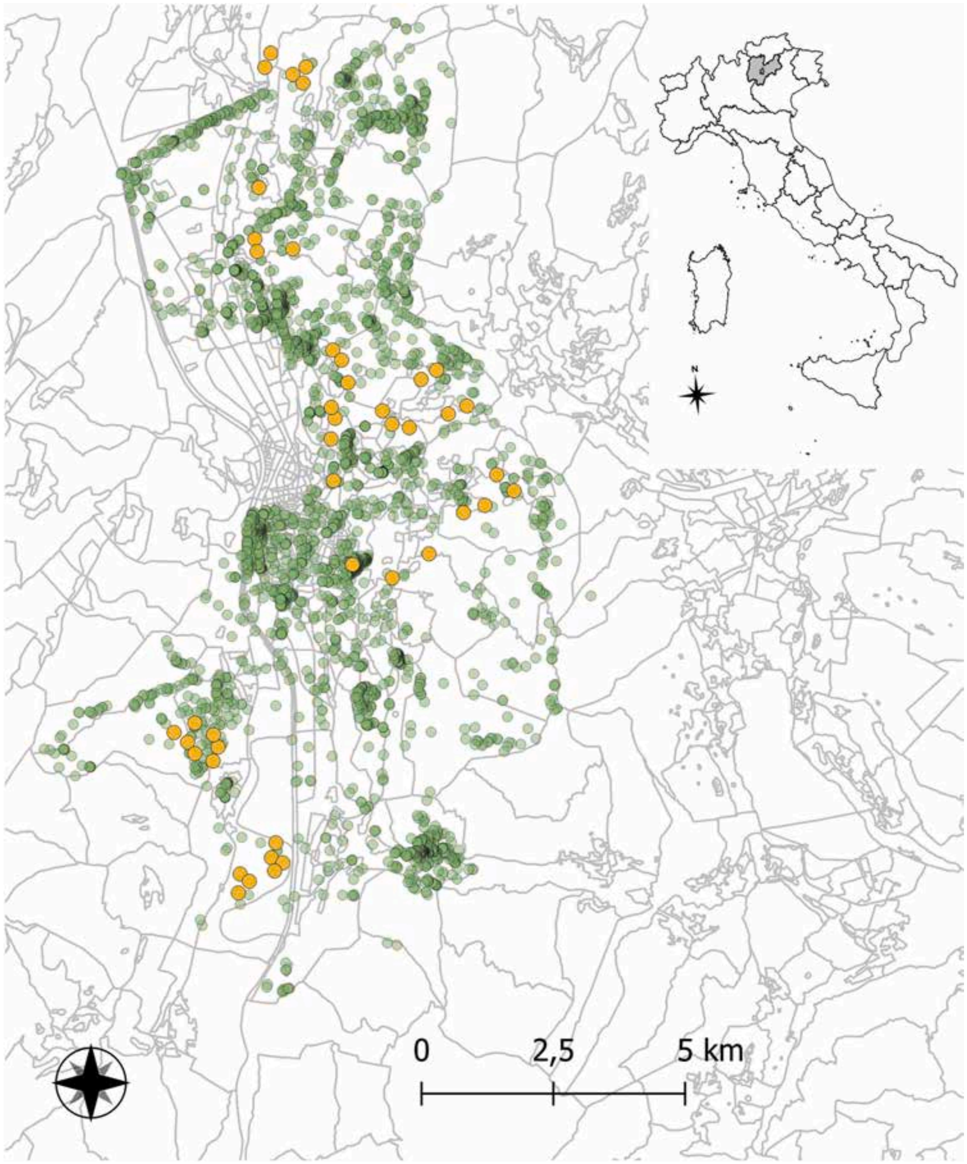

Fig. 1. Distribution of the 44 sampling sites (orange dots) in Trento and of iNaturalist data published in the "Terra-Aria-Acqua" project during 2014–2021 (smaller green dots); the grid used for the analysis of cultural ecosystem services is also displayed. The upper right inset shows the location of the Trento province (grey) and the municipality of Trento (pink) in Italy. Source of background map: https://www.istat.it/it/archivio/222527.

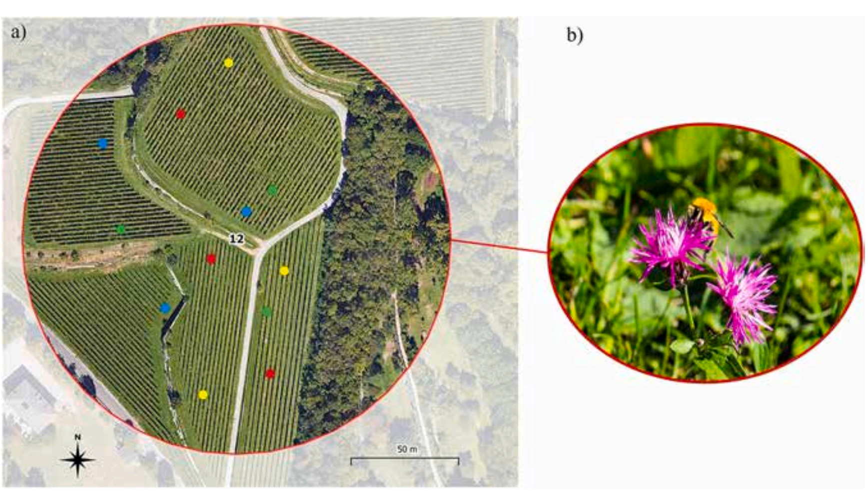

Fig. 2. Sampling design of pollinator survey within a sampling site. a) within each site, we chose at random 3 plots each census, distanced at least 50 m from each other, but within a 100-m buffer around the site. Each plot is represented with different colours based on the month in which data were collected. Green dots: May; blue dots: June; red dots: July; yellow dots: September; landscape of the sampling site is according to Google satellite (MA data ©2015 Google); b) A bumblebee foraging on a *Centaurea sp.* Flower.

of a 2.5 m of radius, located within the 100 m-buffer around the sampling site and separated by at least 50 m from each other (see Figs. 2 and 3), to minimise the risk of double counting the same individuals. At each plot, we counted all the insects observed on flowers for 5 min, including also bugs and grasshoppers which, although not actively involved in pollination, move frequently on flowers. Surveys were conducted from late morning to late afternoon, in days with no or weak wind, and without rain, to select days with maximum pollinator abundance (Eeraerts et al., 2021).

2.2.2. Bird data

Bird surveys focused on the breeding season and communities, considering their preeminent importance in the context of vineyards in the Trento province (Assandri et al., 2016). Bird census included three consecutive visits to each one of the 44 sampling sites, and spanned all over the breeding season to adequately sample the breeding periods of most species, considering the phenology of the different species potentially occurring within the study area. The first survey was carried out from 3rd May 2021–7 th May 2021, the second from 20th to 31st May 2021, and the third one from 8th to 11th June 2021. Data collection was based on 10-minutes point counts; each sampling site was used as a point count for bird surveys, and all contacts with birds within the 100 m-buffer were recorded. Point counts are among the methods most frequently used to collect standardized information on the abundance and density of breeding species, especially over relatively large study areas, and are particularly suited for passerines and other vocal species. Counts started at sunrise and, depending on the weather conditions, continued for a few hours (but no later than 11:00), to limit surveys to the time of maximum vocal activity of birds. Days with moderate or strong wind, or rain, were avoided.

2.2.3. Environmental drivers of birds and pollinators

Environmental data were collected to identify the main drivers of birds and pollinators, with a particular emphasis on landscape composition and configuration, and on fine-scale variables describing crop management and field characteristics, which are particularly relevant for the development of effective biodiversity-friendly management practices. Environmental data were obtained either i) using a GIS platform (using a 10-m resolution Digital Terrain Model (DTM) for topographical variables and a detailed LULC map, created by integrating different sources freely available for the province extent and by manually adjusting potential misclassified patches), or ii) directly measuring variables in the field. We quantified, within a 100-m buffer around the 44 sampling sites, LULC (%), main topographical indices (slope, elevation, solar radiation), the number of trees, the length of hedges, rows and ditches, the average size of the cultivated parcels, the crop management methods, the form of vine cultivation, soil treatments, the regime (conventional/organic), the height of the grassland sward (tall, low or no grass), the inter-row distance, the distance between plants in a row, signs of previous soil tillage (as tillage in the study area is usually performed before the period of our surveys), and the main flower species. In addition, to consider the potential confounding effect of weather on pollinators' abundance, for each plot sampling event we also recorded temperature (in °C), cloud coverage (as a percentage), and wind intensity. All the recorded variables are reported and described in Table 1.

2.2.4. Cultural Ecosystem Services data

To estimate CES, we focused on nature-based recreation, one of the key CES supplied by high-quality farmed landscapes (Brambilla and Ronchi, 2020; Zasada, 2011). We evaluated nature-based recreation using data collected by citizen scientists using the platform iNaturalist (https://www.inaturalist.org/), one of the most employed ones for biodiversity data collection. Big data and social media can indeed be successfully used to model CES (Fox et al., 2020; Havinga et al., 2020). To better assess the value of our study area for nature-based recreation, we used data collected from 2014–01–02 to 2021–10–15 and uploaded in iNaturalist for the portion of the Trento province encompassing our study area (see Fig. 1) and associated with the "Terra Aria Acqua" project (that included citizen-science data collection; iNaturalist, 2022). To avoid any bias related to dedicated research efforts in our data (see Brambilla and Ronchi, 2020), we have eliminated those observations uploaded by MUSE employees, resulting in a dataset of 5473 data. By knowing the exact geographical position of these observations, it is possible to perform a spatially explicit assessment of nature-based recreation specifically targeted at species observation, made possible by the occurrence of species and ecosystems of potential interest for citizen

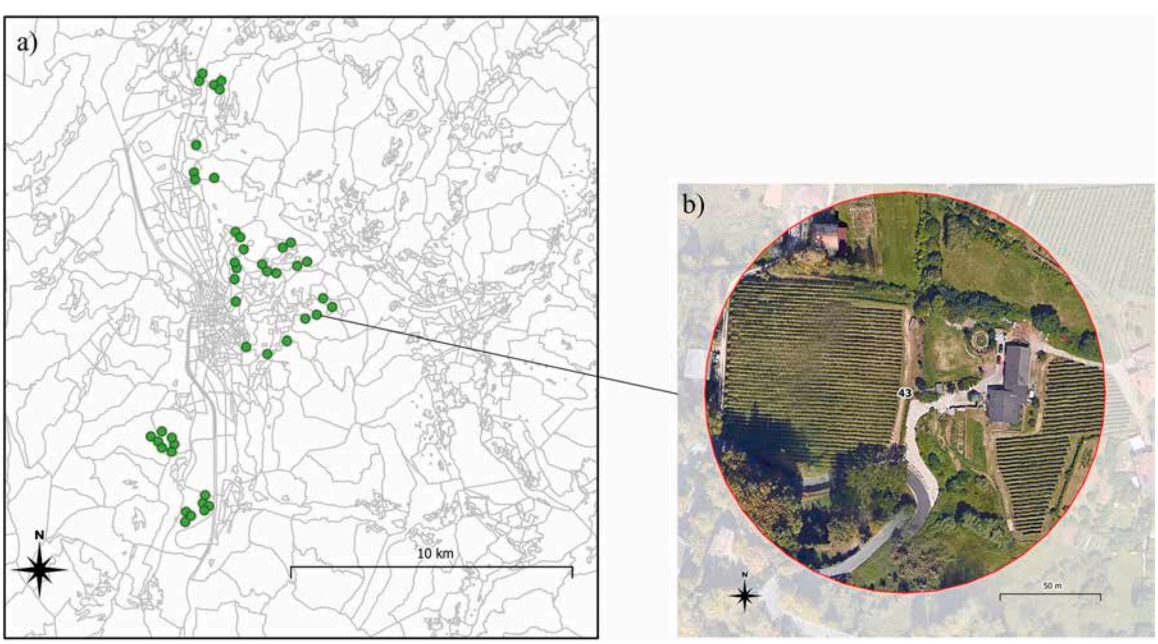

Fig. 3. a) Distribution of the 44 sampling sites (green dots) within the Municipality of Trento;
Source: https://www.istat.it/it/archivio/222527; b) a detailed map showing landscape characteristics of the sampling site 43 within the 100-m buffer in which the bird counts were carried out (MA data ©2015 Google).

Table 1
List of variables used in the analyses and their mean value ± standard deviation in sampling sites. Variables were either measured in a GIS environment (and then checked/validated in the field) or recorded directly in the field.

Acronym	Description	Mean±SD
Environmental-Climatic variables		
Month	May/June/July/September	
Date		
Temperature	Temperature (°C)	23.67 ± 4.43
Wind	0 = calm;1 = weak; 2 = moderate; 3 = strong wind	
Cloud coverage	% Of cloud cover	45.14 ± 37.76
Topographic variables for pollinators		
Slope	Mean slope (m)	10.36 ± 8.10
Solar radiation	Mean solar radiation (W/m2)	8669.11 ± 365.92
Elevation	Mean elevation (m)	406.78 ± 138.15
Topographic variables for birds		
Slope	Mean slope (m) / slope range (m)	13.81 ± 8.84 / 30.01 ± 16.54
Solar radiation	Mean solar radiation (W/m2)	8589.29 ± 342.76
Elevation	Mean/Minimum/Maximum elevation (m)	408.64 ± 138.18 / 386.86 ± 134.41 / 428.00 ± 144.80
Management variables		
Flowers	Presence/absence of flowers (yes/no)	
Sward height	Tall/low/no grassland sward	
Training system	*Pergola* vineyards, *spalliera* vineyards, apple orchards, grasslands	
Nets	Presence/Absence of nets covering vineyards/orchards (yes/no)	
Mowing regime	0 =mown; 1 =partially mown (e.g., mown except interrow); 2 =unmown	
Convolvulus flowers	Presence/absence of *Convolvulus spp.* (yes/no)	
White clover flowers	Presence/absence of *Trifolium repens* (yes/no)	
Red clover flowers	Presence/absence of Trifolium pratense (yes/no)	
Previous soil tillage	Whether previous soil tillage signs were present during sampling. 2 =tillage; 1 =partial tillage; 0 =no tillage	
Inter-row distance	Distance between rows (m)	2.72 ± 0.74
Distance between plants	Distance between plants in a row (m)	0.84 ± 0.39
LULC variables		
Vineyards	% Cover of vineyard	39.72 ± 28.93
Apple Orchards	% Cover of apple orchards	16.85 ± 31.21
Orchards	% Cover of orchards	0.05 ± 0.27
Crops	% Cover of herbaceous croplands	0.91 ± 3.32
Rocks and bare soils	% Cover of rocks and bare soils	1.13 ± 3.21
Roads and railways	% Cover of roads and railways	4.99 ± 2.88
Deciduous forests	% Cover of deciduous forests	20.73 ± 22.27
Urban areas and infrastructures	% Cover of urbanized areas and infrastructures	2.51 ± 3.68
Coniferous forests	% Cover of coniferous forests	2.43 ± 7.74
Urban green spaces	% Cover of urban green spaces	1.09 ± 5.86
Waterways	% Cover of waterways	0.33 ± 1.30
Number of puddles*	Number of puddles	0.05 ± 0.21
Ditches and canals	Ditches and canals (m)	24.17 ± 59.66
Grasslands, and herbaceous crops	% Cover of grasslands and herbaceous crops	9.35 ± 12.10
Bushes*	Number of bushes	0.07 ± 0.45
Tree rows	Length (m) of tree rows	98.87 ± 107.42
Hedgerows	Length (m) of hedgerows	98.41 ± 106.94
Trees	Number of isolated trees	6.30 ± 6.67

* Measured variables that were left out because they were scarcely represented.

scientists in and around Trento city. Notably, access to different areas and environments is usually free, except for buildings and private gardens.

2.3. Statistical analysis

2.3.1. Pollinators

For pollinators and flower-visiting insects in general, we have grouped the variables into four categories of predictors: topographic variables, environmental-climatic variables, management variables and LULC variables. Since we cannot exclude the non-independence of data collected around the same sampling site, we ran Poisson Generalized Linear Mixed Models (GLMMs) with the function “glmm” of the R package “glmmADMB”, with sampling site identity as a grouping (random) effect, to take into account the possible non-independence of the data collected within the buffer of the same sampling site. We built all possible models for each “group” of insects (bees, bumblebees, wasps and ants, flies, butterflies, bugs, beetles, grasshoppers, other insects) and for “all flower-visiting insects” (resulting from the sum of all insects detected on flowers). As date and temperature can exert a joint effect on pollinator abundance, we also considered their interaction. For each group of predictors, we tested the collinearity of the variables with the “vif” function of the R package “car” and discarded the variables with a GVIF (1 / (2 × Df)) greater than 5 (Fox and Monette, 1992), to avoid multicollinearity issues. To evaluate if the Poisson distribution was right for our data, we performed a statistical dispersion test on the residuals with the “DHARMa” function in the R package “DHARMa” (Hartig, 2020). In case of overdispersion ($P < 0.05$) we switched to a negative binomial distribution (Hilbe et al., 2013), which did not show over-dispersion, by using the “glmer.nb” command implemented in the R package “lme4” (Bates et al., 2015). Furthermore, we tested residuals’ uniformity, outlier occurrence, simulated vs. observed dispersion, and the possible presence of zero-inflation using the package “DHARMa”. All models were statistically validated according to these tests. We used the AICc (Akaike’s information criterion corrected for small sample size) for model building and comparison, which is founded on the information-theoretic approach (Burnham and Anderson, 2002). To compare the AICc of all possible models for each group of predictors, we used the “dredge” command of the R package “MuMIn” (Bartoń, 2020). Consequently, we compared the AICc value of the most supported model (after removing uninformative variable *sensu* Arnold, 2010) to evaluate the support of each group in predicting pollinators abundance. Then we built a synthetic model by including the variables of the most supported ones among the single-group models (Brambilla et al., 2021). Finally, the most supported models (ΔAICc < 2) were full averaged by using the “model.avg” function in the “MuMin” package. Model averaging is an alternative method to model selection which deals with model uncertainty and even out the overestimation and underestimation (Steel, 2020). For model validation, we built a model including all variables selected in the average model and used the package “DHARMa”. All models were then tested for spatial autocorrelation by running a Moran’s test with the “Moran.I” function in the “ape” package. To evaluate the potential spatial autocorrelation and to calculate a model R^2, we used a model including all and only the variables included in the averaged model.

2.3.2. Birds

We modelled the species richness and the total abundance of all bird species, and the abundance of the commonest single species, considering three groups of predictors: topographic variables, management variables, and LULC variables. Some species were excluded from the community analysis as they were either i) migratory species, ii) species that move over large surfaces and frequent the sampling site for trophic purposes but do not nest there, iii) species that have a very large home range or large territory, so their presence at the listening point is not representative of the local community (see supplementary material for excluded species).

For the bird community, we built two models, one considering as a dependent variable the overall abundance of bird assemblages (maximum number of individuals per species detected per point count during the sampling period), and one considering the species richness (number of species detected per point counts during the entire sampling period). The statistical procedure used is the same as that described for pollinator, but a GLM was used instead of a GLMM.

Only those species recorded in more than 20 out of 44 sampling sites were included in the species-specific analyses: blackcap (*Sylvia atricapilla*), European goldfinch (*Carduelis carduelis*), great tit (*Parus major*), common redstart (*Phoenicurus phoenicurus*), common chaffinch (*Fringilla coelebs*), blackbird (*Turdus merula*), song thrush (*Turdus philomelos*), and European serin (*Serinus serinus*). For blackcap, common chaffinch, and blackbird, all models – both with a Poisson distribution and a negative binomial– resulted overdispersed and were therefore discarded.

2.3.3. *Cultural ecosystem services assessment*

CES were analysed on a larger scale that includes the entire "Biodistretto di Trento". We created a 1 km x 1 km grid in a GIS environment, including a total of 209 cells, and calculated the number of iNaturalist photos published within each cell with the "point counts in polygon" command in QGIS. We used two groups of predictors for our data: topographic variables and LULC variables, which we obtained directly from the GIS environment by using the global solar radiation, slope, elevation, and LULC (percentage cover of selected categories; see Table 2 for a complete list and description of the considered variables). For the analysis, we run a generalised least squares (GLS) model with the function "gls" in the "nlme" package (Pinheiro et al., 2023), with a Gaussian spatial correlation structure, as a GLM was found to be spatially autocorrelated according to the Moran's I value. Then, we followed the same procedure described above for pollinators and bird data.

Table 2
List of variables used in the analysis of CES' data and their mean value ± standard deviation. Variables were measured in a GIS environment over each grid cell.

Acronym	Description	Mean ± SD
Topographic variables		
Slope	Mean slope (m) measured	18.69 ± 0.22
Solar radiation	Mean solar radiation (W/m2) measured	8168.02 ± 547.63
Elevation	Mean elevation (m) measured	611.20 ± 330.89
LULC		
Waterways	% Cover of waterways	1.35 ± 2.77
Wetlands	% Cover of peat bogs + % cover of wetland	0.07 ± 0.37
Arboriculture	% Cover of land dedicated to arboriculture	0.04 ± 0.21
Deciduous forests	% Cover of deciduous forests	29.18 ± 24.31
Mixed forests	% Cover of mixed forests	9.12 ± 13.86
Coniferous forests	% Cover of coniferous forests	20.15 ± 24.32
Intensive grasslands	% Cover of grassland subject to intensive management	4.79 ± 6.26
Uncultivated and marginal areas	% Cover of uncultivated and marginal areas	0.60 ± 1.32
Grasslands	% Cover of grasslands	0.07 ± 0.64
Subalpine shrubland	% Cover of bushes of the subalpine plain	0.93 ± 3.68
Continuous urban areas	% Cover of continuous urban areas	10.22 ± 16.23
Discontinuous urban areas	% Cover of discontinuous urban areas	2.02 ± 3.55
Urban green spaces	% Cover of urban green spaces	0.29 ± 1.46
Roads and railways	% Cover of roads and railways	1.44 ± 1.66
Infrastructures	% Cover of other infrastructures	1.28 ± 3.25
Quarries	% Cover of quarries	0.81 ± 4.29
Heterogeneous agricultural crops	% Cover of heterogeneous agricultural crops	0.94 ± 2.79
Other crops	% Cover of other crops	0.10 ± 0.23
Orchards	% Cover of orchards	0.89 ± 2.54
Vineyards	% Cover of vineyards	10.01 ± 12.84
Apple orchards	% Cover of apple orchards	4.12 ± 10.86
Small orchards	% Cover of small orchards	0.12 ± 0.41
Rocks	% Cover of rocks	0.71 ± 2.62
Rocks and bare soils	% Cover of rocks and bare soils	0.04 ± 0.41
Transitional vegetation	% Cover of developing woodland/ shrubs and scattered vegetation	0.04 ± 0.31
Alpine grassland	% Cover of grasslands of the alpine horizon	0.34 ± 1.87
Extensive grasslands	% Cover of extensive managed grasslands	0.11 ± 0.48
Tree-lined grassland	% Cover of tree-lined grasslands	0.33 ± 1.77

3. Results

3.1. *Environmental and management drivers of the abundances of flower-visiting insects*

The most abundant groups in the whole sampling period were bees (1150 total individuals), followed by flies (mostly hoverflies, 645 individuals). All final models are reported in Table 3. Overall, the most relevant variables for the majority of flower visiting insects were temperature and sampling period: the abundance of insects tended to decrease over the months, with a decrease from May to September (Table 3, Fig. 4), except for "other insects", whose abundance is predicted to increase over the sampling period. The number of flower visitors slightly increased with temperature (Table 3, Fig. 5b), except for bees, for which a slight decrease was found (see supplementary material).

Flower occurrence predicted the abundance of all groups of flower-visiting insects, except for bugs and other insects. Specifically, the presence of *Convolvulus* flowers had a positive influence on the predicted abundance of wasps and ants, but negative on bumblebees; white clover flowers exerted a negative effect both on bumblebees and butterflies, while the presence of red clover flowers showed a positive effect on the predicted abundance of bumblebees and beetles.

The height of the grass sward was also an important predictor for most pollinators, which were positively associated with a tall sward (Table 3; Fig. 5a). The influence of training system was only relevant for the model including all flower-visiting insects, whose abundance was highest in grassland (Table 3; Fig. 6d), and lowest in woodlands (Fig. 6d), while there was no substantial difference between apple orchards (Table 3; Fig. 6a), *pergola* vineyards (Table 3; Fig. 6b) and *spalliera* vineyards (Table 3; Fig. 6c). The percentage cover of roads and railways positively affected the abundance of the majority of pollinators (see Table 3), but their cover was almost invariably low, and most of the observations appeared concentrated around a coverage of 5%. Urban areas and infrastructures also exerted a positive effect both on the predicted abundance of flower-visiting insects (Table 3; Fig. 7), and on the predicted abundance of other insects (Table 3); also in this case, the percentage cover was in general low. Apple orchards had a negative influence on bees, butterflies, and beetles, but a positive influence on flies (Table 3). Vineyards had a negative effect on wasps and ants, and beetles (Table 3). For all the other effects, see Table 3.

3.2. *Environmental and management variables that influence the bird community*

Overall, 69 bird species were recorded, of which 51 were breeding or potentially breeding species and were included in the community analysis (see supplementary material). Of these, only 8 were found to be very common as they were recorded in more than half of the sampling sites.

Table 3
Estimate, standard error and marginal and conditional R^2 of the final model for all flower-visiting insects, bees, bumblebees, wasps and ants, flies, butterflies, bugs, beetles, grasshoppers, and other insects. The effects for which the estimate ± 95% confidence interval does not encompass zero are shown in bold.

	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE
	All flower visiting insects	*Bees*	*Bumblebees*	*Wasps and ants*	*Flies*	*Butterflies*	*Bugs*	*Beetles*	*Grasshoppers*	*Other insects*
Data	**-0.82 ± 0.11**	**-1.04 ± 0.17**	-0.54 ± 0.36	**-0.98 ± 0.13**				**-0.63 ± 0.21**		0.37 ± 0.46
Temperature	0.07 ± 0.06	-0.01 ± 0.08	0.22 ± 0.29	0.48 ± 0.09		**0.32 ± 0.10**		**0.57 ± 0.23**		0.20 ± 0.29
Data:Temperature	0.09 ± 0.10	0.15 ± 0.16	0.29 ± 0.38					**0.77 ± 0.32**		0.29 ± 0.41
Sward height (tall)	**0.56 ± 0.15**	**0.82 ± 0.24**	**1.61 ± 0.57**		0.21 ± 0.19	0.49 ± 0.31			**1.25 ± 0.42**	
Sward height (low)	-0.09 ± 0.15	-0.14 ± 0.25	0.28 ± 0.57		**-0.43 ± 0.19**	-0.45 ± 0.32			-0.62 ± 0.46	
Flowers (yes)	**2.75 ± 0.29**	**2.22 ± 0.46**	**2.14 ± 1.08**	**3.25 ± 0.75**	**2.60 ± 0.47**	**3.16 ± 1.02**		**2.87 ± 1.05**	0.69 ± 1.00	
Training system (apple orchards)	0.47 ± 0.51									
Training system (pergola)	0.69 ± 0.49									
Training system (grasslands)	**1.55 ± 0.55**									
Training system (spalliera)	0.73 ± 0.49									
Nets (no)	-0.21 ± 0.59	-1.28 ± 0.80								
Nets (yes)	**1.63 ± 0.63**	0.09 ± 0.96								
Urban areas and infrastructures	0.14 ± 0.06									0.31 ± 0.23
Roads and railways	**0.16 ± 0.06**	**0.26 ± 0.12**		0.10 ± 0.12	0.09 ± 0.10	0.04 ± 0.10		0.03 ± 0.10		
Apple orchards		**-0.59 ± 0.14**			0.13 ± 0.11	-0.11 ± 0.16		-0.13 ± 0.23		
Convolvulus flowers (yes)			**-1.23 ± 0.38**	**0.52 ± 0.21**						
White clover flowers (yes)			**-0.81 ± 0.32**			-0.07 ± 0.16				
Red-clover flowers (yes)			**1.05 ± 0.42**					0.55 ± 0.33		
Previous soil tillage (1)			**-2.82 ± 0.70**	0.86 ± 0.88						
Previous soil tillage (2)			**-2.45 ± 0.73**	0.83 ± 0.86						
Puddles and ditches			-0.09 ± 0.19							
Coniferous forest			-0.08 ± 0.30					0.17 ± 0.19	0.41 ± 0.15	
Vineyard				**-0.30 ± 0.12**				-0.11 ± 0.21		
Wind (1)					-0.12 ± 0.15					
Wind (2)					**-0.76 ± 0.25**					
Elevation					**-0.54 ± 0.09**	**-0.45 ± 0.14**			**-1.29 ± 0.22**	0.12 ± 0.22
Ditches and canals (m)					0.15 ± 0.11					
Deciduos forests						0.04 ± 0.11				
Urban green spaces						0.04 ± 0.09				0.11 ± 0.15
Slope							**0.75 ± 0.34**		**0.47 ± 0.19**	**0.70 ± 0.21**
Trees							0.62 ± 0.55			
Tree rows								0.12 ± 0.17		
Solar radiance									**0.64 ± 0.20**	
Marginal/ Conditional R^2	**0.66/0.68**	**0.49/0.58**	**0.17/0.17**	**0.53/0.55**	**0.44/0.48**	**0.33/0.38**	**< 0.01/ 0.03**	**0.33/0.38**	**0.28/0.30**	**0.03/0.03**

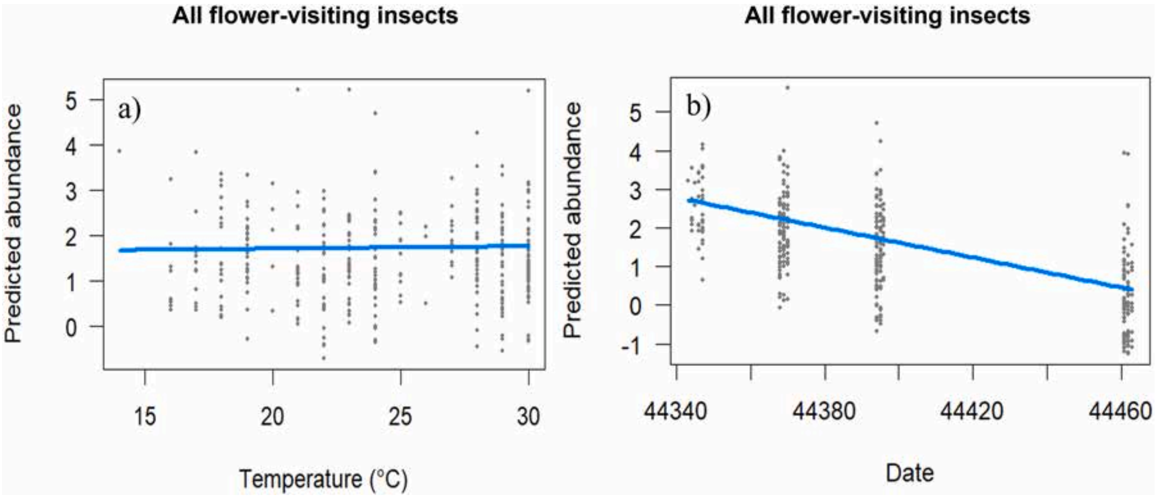

Fig. 4. Model-based predicted abundance of all flower-visiting insects in relation to a) temperature and b) date.

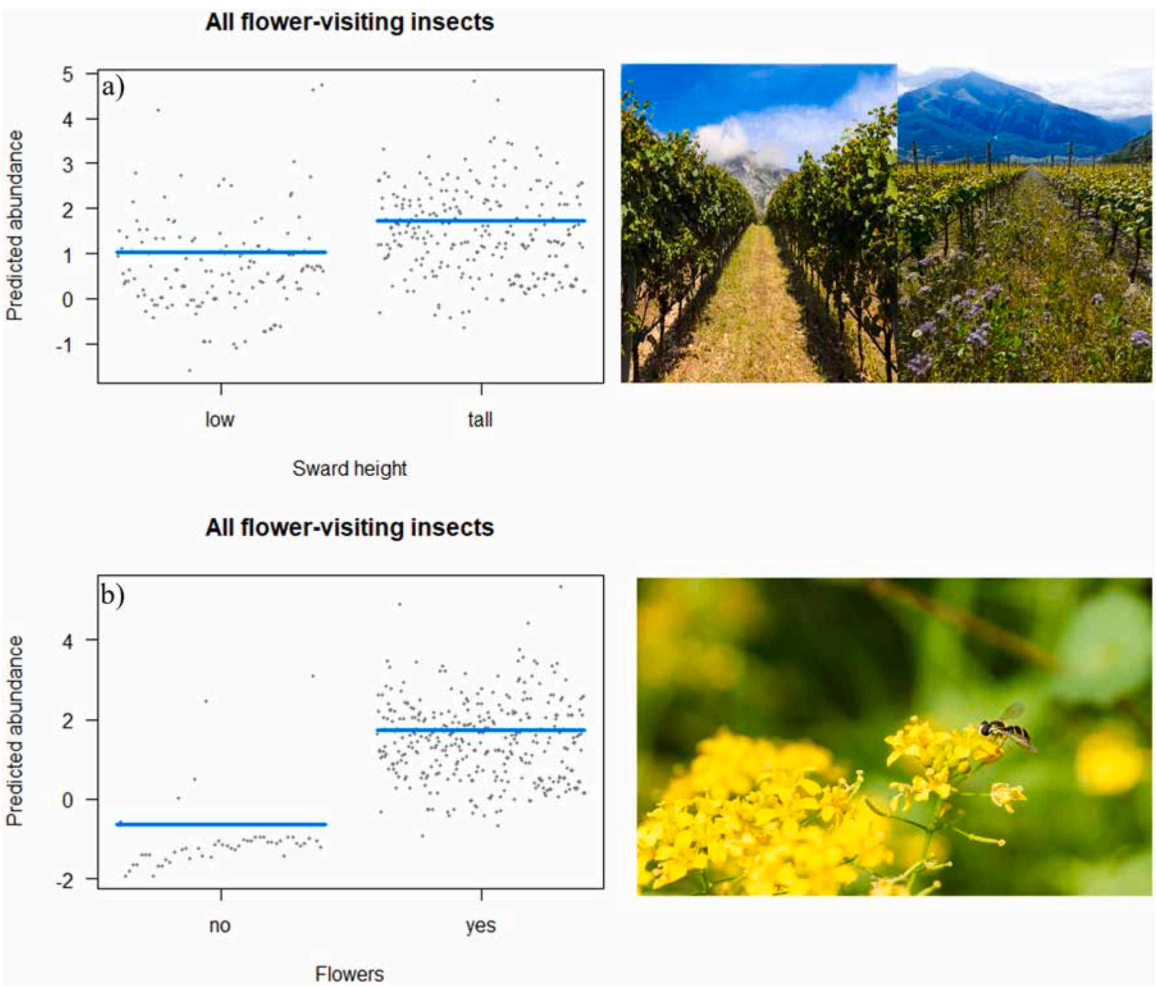

Fig. 5. Model-based predicted abundance of all flower-visiting insects in relation to the a) sward height and b) presence of flowers. Pictures from vineyards in Trentino (EG, 2021; left: September, right: May 2021).

In the community-level analyses (Table 4), the overall abundance of birds was mostly influenced by landscape variables. Specifically, deciduous forests (coefficient ± SE: 0.10 ± 0.03, Fig. 8a), and urban areas and infrastructures (coefficient ± SE: 0.11 ± 0.03, Fig. 8b) exerted a positive effect on bird abundance, as opposed to vineyards (coefficient ± SE: −0.04 ± 0.04) which exerted a negative impact (Fig. 8c). Apple orchards had a negative effect on bird species richness (coefficient ± SE: −0.23 ± 0.04, Fig. 9a). Conversely, bird species richness increased with cover of urban areas and infrastructures (coefficient ± SE: 2.72 ± 1.05, Fig. 9b), roads and railways (coefficient ± SE: 0.08 ± 0.03, Fig. 10a),

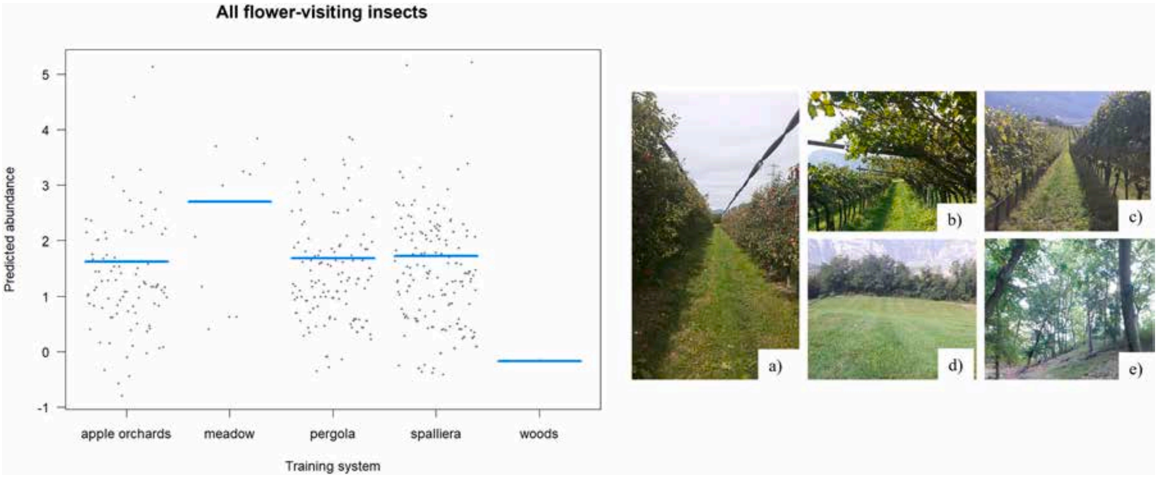

Fig. 6. Model-based predicted abundance of all flower-visiting insects in relation to the vineyard trellising system *pergola* (b) and *spalliera* (c), apple orchards (a), grassland (d) and woodlands (e) in sampling plots. Pictures: apple orchards (a), pergola vineyard (b), spalliera vineyard (c), grassland (d), and woodlands (e) in sampling areas, EG, 2021.

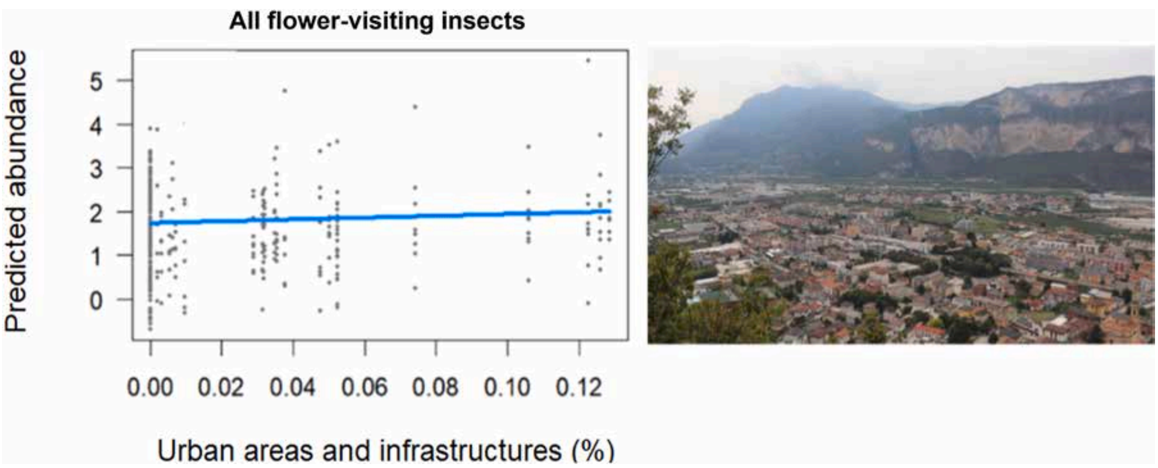

Fig. 7. Model-based predicted abundance of all flower-visiting insects in relation to the percentage cover of urban areas and infrastructures in sampling areas. Picture: Trento city, EG, 2021.

rocks and bare soils (coefficient ± SE: 0.03 ± 0.03, Fig. 10b), and with the length of hedgerows (coefficient ± SE: 0.09 ± 0.04, Fig. 11).

The response to different type of environmental variables varied among species according to their ecological requirements (Table 4). At a species-level analysis, birds with well-known anthropophilic habits – i. e., Italian sparrow (coefficient ± SE: 0.69 ± 0.19), common redstart (coefficient ± SE: 0.52 ± 0.13) and European serin (coefficient ± SE: 0.27 ± 0.13) – responded positively to the presence of urban areas and infrastructures. Linear and punctual elements –hedgerows and trees – exerted a positive effect on the predicted abundance of European serin (coefficient ± SE: 0.49 ± 0.19) and common redstart (coefficient ± SE: 0.25 ± 0.21), but not on that of song thrush (coefficient ± SE: −0.79 ± 0.26). Finally, the percentage cover of vineyard in our sample areas had a negative impact on song thrush (coefficient ± SE: −0.71 ± 0.18), and great tit (coefficient± SE: −0.62 ± 0.27).

3.3. Environmental and management variables that influence CES data

The number of observations published in iNaturalist per cell associated with the "Terra Aria Acqua" project was affected by elevation (coefficient ± SE: −0.07 ± 0.07). This is likely due to the effect of varying ease-of-access, as areas located at higher elevation are in general less easily reachable and therefore less exploited by visitors for nature-based recreation activities. Waterways (coefficient ± SE: 0.07 ± 0.04, Fig. 12b) exerted a positive effect on the number of observations, which were more abundant within cells with a higher percentage cover of rivers (e.g., Adige) and streams. Conversely, the percentage cover of apple orchards negatively affected nature-based recreation (coefficient ± SE: −0.05 ± 0.06, Fig. 13). Similarly, intensively managed grasslands (coefficient ± SE: −0.09 ± 0.05, Fig. 12a) had a negative effect on the number of observations. Finally, vineyards (coefficient ± SE: linear term: 0.09 ± 0.12; squared term: −0.04 ± 0.05, Fig. 14a) and continuous urban areas (coefficient ± SE: linear term: 0.29 ± 0.11; squared term: coefficient ± SE: −0.06 ± 0.04, Fig. 14b) had a quadratic effect on CES, meaning that the number of observations increased at low values, peaked at the intermediate cover, and then decreased with higher share.

4. Discussion

Agricultural areas in anthropized landscapes play a critical role in providing ecosystem services for human well-being as well as biodiversity. They often provide irreplaceable ecosystem services, encompassing provisioning, regulating and cultural ones, and may harbour rich and diverse biological communities (Livesley et al., 2016; Wilhelm and Smith, 2018; Zasada, 2011). However, their effectiveness can be weakened by unfavourable landscape composition or configuration

Table 4
Estimate, standard error and marginal and conditional R^2 of the final model for bird community and for single species for which specific models were possible (N > 20, model convergence and validation achieved). The effects for which the estimate ± 95% confidence interval does not encompass zero are shown in bold.

	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE	Estimate ± SE
	Bird community – Predicted abundance	*Bird community – Species richness*	*European goldfinch*	*Great tit*	*Common redstart*	*Italian sparrow*	*Song thrush*	*European serin*
Urban areas and infrastructures	**0.11 ± 0.03**	**0.11 ± 0.03**			**0.52 ± 0.13**	**0.69 ± 0.19**		**0.29 ± 0.13**
Deciduos forests	**0.10 ± 0.03**						**-0.51 ± 0.27**	**-0.46 ± 0.20**
Hedgerows		**0.09 ± 0.03**			0.25 ± 0.21			
Apple orchards		**-0.23 ± 0.04**		**-0.62 ± 0.27**				
Rocks and bare soils		0.03 ± 0.03	0.12 ± 0.13					**0.35 ± 0.13**
Roads and railways		**0.08 ± 0.03**				**0.61 ± 0.25**		
Maximum elevation			-0.18 ± 0.18		**0.49 ± 0.18**			**-0.65 ± 0.17**
Coniferous forests						**-1.55 ± 0.57**	-0.11 ± 0.13	
Trees							**-0.79 ± 0.26**	**0.49 ± 0.19**
Vineyards	-0.04 ± 0.04						**-0.71 ± 0.18**	
Marginal/Conditional R2	**0.43/0.43**	**0.65/0.65**	**0.12/0.12**	**0.28/0.28**	**0.35/0.35**	**0.69/0.69**	**0.62/0.62**	**0.51/0.51**

(Anderle et al., 2022), or by unsustainable management practices, and particularly by intensive farming (Assandri et al., 2019; Hendershot et al., 2020; Rollin et al., 2013). With this study, we have identified the main LULC and management drivers of biological communities (using birds as a model group) and ecosystem services (focussing on pollination and nature-based recreation, two key services for peri-urban agricultural areas). The awareness about such key drivers can be used to develop and implement effective strategies encompassing both landscape planning and biodiversity-friendly management.

4.1. Pollinators

The abundance of main pollinators and of other flower-visiting insects on flowers, which is directly related to the pollination service in this vineyard-dominated landscape, is mainly influenced by farm management and environmental-climatic variables. The best model combined topographic, environmental-climatic, management and LULC variables together, suggesting that pollinators respond to multiple factors. Date and temperature, and in most cases also their interaction, were crucial in driving insect abundance on flowers, consistently with the well known marked seasonal patterns (Corbet, 1990; Gordo and Sanz, 2006; Huntley et al., 2008). Pollinators' abundance decreased along the season, after a maximum of individuals detected in May. This could be for phenological reasons of the life cycle of many insect species avoiding summer heat and/or the disturbance occurring in September, with the lowest number of pollinators when grape harvesting occurs.

Crop management is highly relevant in influencing pollination service (Tommasi et al., 2021) and our data confirmed this in our system. In particular, the presence of flowers within vineyard and apple orchard inter-rows best predicted the abundance of flower-visiting insects. In fact, wild flower growth and maintenance are mainly linked to management practices such as mowing, soil tillage and cover cropping techniques (Winter et al., 2018). Similarly, sward height promoted pollinators abundance, probably also by enhancing floral visual attraction to pollinators. Soil tillage was found to be less relevant for many pollinators, except for bumblebees, wasps and ants. In fact, partial-tillage and no-tillage were associated with greater flower resources in other vineyards (Brambilla and Gatti, 2022). The presence of grasslands in the landscape, where they mostly occur as uncultivated areas and/or resting vineyards, also exerted positive effects, likely thanks to limited management (with mowing occurring in such patches within the study area only in September). As expectable, tall grass with abundant growth of spontaneous flora host a high abundance of pollinating insects.

Considering the trellising system, there was no substantial difference between *pergola* and *spalliera*, probably because pollinators respond more to the previously mentioned factors, rather than to the vineyard structure. Overall, pollinators responded negatively to the percentage coverage of vineyards and apple orchards, suggesting that the intensive management of these crops makes them less suitable to support pollinators than semi-natural and less intensive areas. Furthermore, dwelling in these agroecosystems exposes pollinators to a wide range of agrochemicals when foraging, potentially causing both direct and indirect intoxication (Main et al., 2020). Unfortunately, we do not have information about pesticide use; however, within each crop type, pesticides are relatively uniformly used across farms as all adopt the same management protocols.

The positive effect of anthropized areas, at a low percentage cover, is likely due to the presence of green spaces in urban areas (Biella et al., 2022; Tommasi et al., 2022), where pollinators may prefer to forage and shelter.

4.2. Birds

Overall, bird communities resulted to be mainly shaped by LULC and management variables, but nevertheless they respond to a plurality of factors, often hard to disentangle. As other studies pointed out (Anderle et al., 2022, 2023; Benton et al., 2003), spatial heterogeneity had a positive effect on biodiversity in agricultural areas and can moreover mitigate the negative effect of vineyard expansion. In our study, the presence of marginal habitats, specifically deciduous forests, had a positive effect on the predicted abundance of avian communities. These areas can provide food supply, shelter from agricultural activities, and a higher availability of nest sites for many species. Moreover, urban cover promoted a higher species richness and abundance in the vineyard dominated landscape, in line with other research findings (Assandri et al., 2016). Public parks, domestic and community gardens, green roofs, and buildings offer more foraging opportunities and possible nest

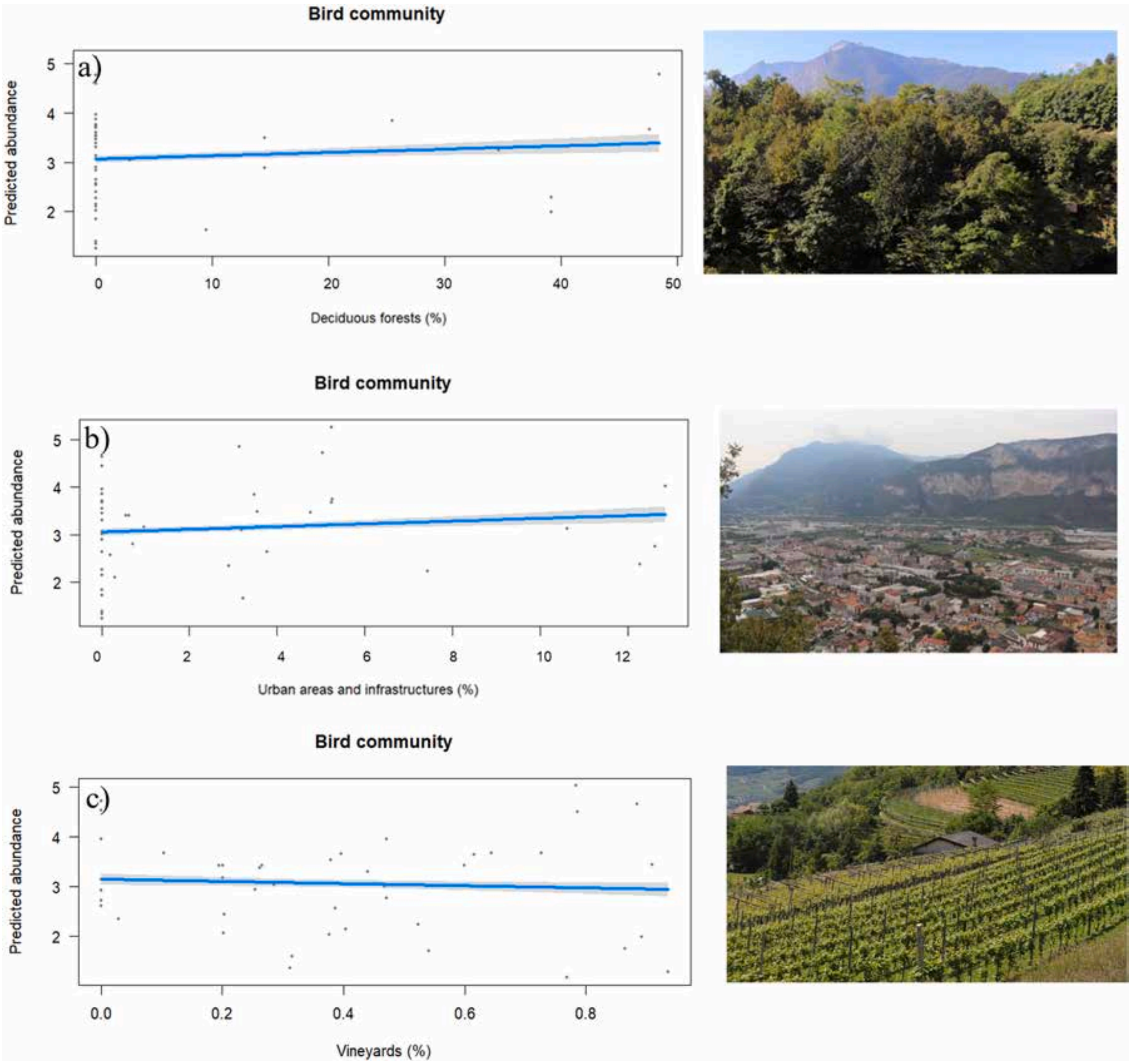

Fig. 8. Model-based predicted abundance (and 95% confidence interval) of bird community in relation to a) the percentage cover of the deciduous forests, to b) the percentage cover of the urban areas and infrastructures, and to c) the percentage cover of vineyards in sample areas. Pictures feature a) a deciduous forest at the vineyard margin b) Trento city, and c) a vineyard in Trentino (EG, 2021).

sites, especially at low cover of urbanized areas, as in our study system. As expected, vineyards exerted a negative impact on the overall bird abundance, while apple orchards had a negative influence on species richness and on the predicted abundance of most bird species. In our study area, permanent crops dominate the surrounding landscape, often resulting in a homogeneous landscape, which becomes largely unsuitable for biodiversity when permanent crops are very intensively managed. For instance, apple trees were frequently covered by nets during the breeding period, resulting in less chance of nesting for birds, as already found for some species in the same study region (Brambilla et al., 2015, 2013). Moreover, soil tillage or disturbance may reduce the abundance of entomofauna, thus inducing birds (both insectivorous and non-insectivorous species that require arthropods as nestling food) to forage elsewhere (Brambilla et al., 2013; Capinera, 2018).

Hedgerows had a positive effect on species richness. They are a source of food, provide shelter opportunities, roost sites, singing perches, nesting sites and a safe cover that facilitates species movements (Hinsley and Bellamy, 2000). Moreover, they are important habitat for many species, such as for common redstart, whose abundance was positively influenced by hedges.

The topographic variables that best predicted bird abundance were elevation and slope. Overall, management factors (e.g., trellising system) in vineyard-dominated landscape did not seem to influence the predicted abundance of avian species. This is likely due to the overriding importance of landscape configuration and composition within and around cultivated areas (Assandri et al., 2016).

4.3. The different contribution of land-use categories to nature-based recreation

The number of observations recorded by nature recreationists was greater in those areas with low or intermediate vineyard cover. Vineyards are traditional elements of the landscape, often perceived as linked to traditional heritage and shaping cultural landscape. Thus, they are very appealing and often linked to specific form of natural and cultural tourism (Sparks, 2007). Moreover, they can host interesting species for birdwatchers (see e.g., Buehler et al., 2017; Brambilla and Ronchi, 2020). Nevertheless, at a higher cover, those areas can profoundly modify the landscape and exert a strong impact on biodiversity, resulting in a lower exploitation by nature recreationists (Brambilla and Ronchi, 2020). Similarly, continuous urban areas were more frequented at a low or intermediate cover for nature-based activities. In fact, while some potentially interesting species are more or less linked to urban ecosystems, we believe that such an effect is mostly related to easier

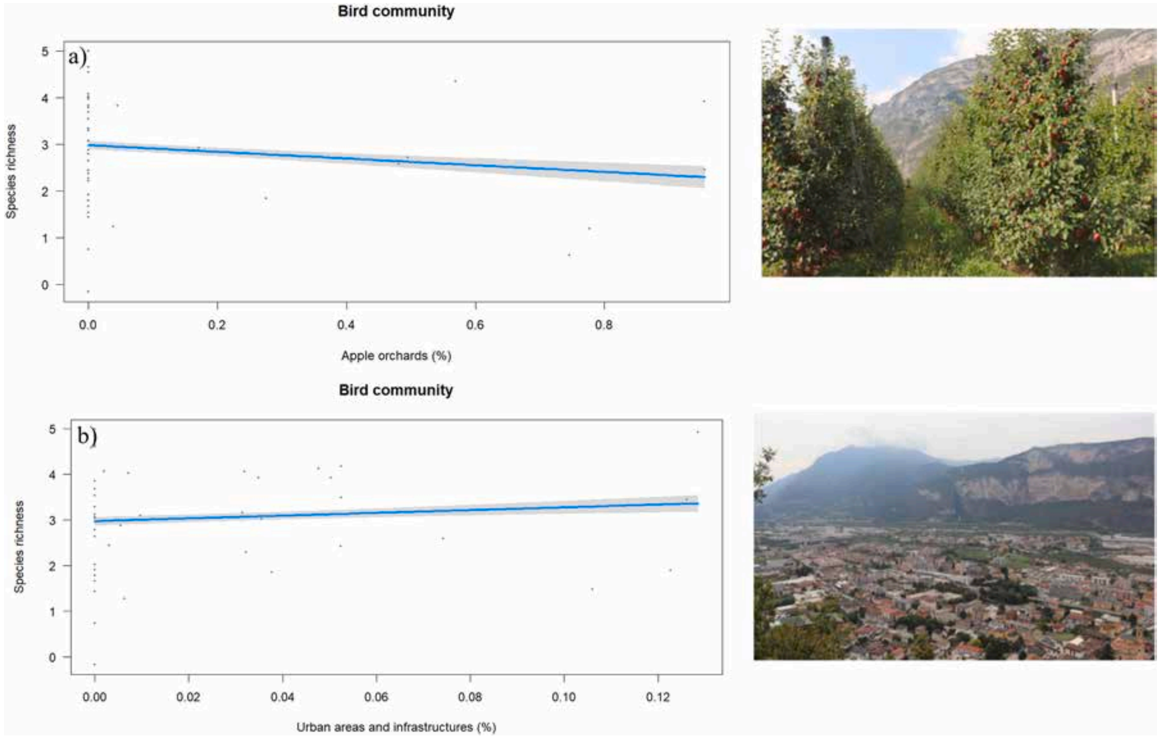

Fig. 9. Model-based predicted species richness (and 95% confidence interval) of bird community in relation to a) the percentage cover of apple orchards and b) the percentage cover of the urban areas and infrastructures in sample areas. Pictures of a) apple orchards and b) Trento city (EG, 2021).

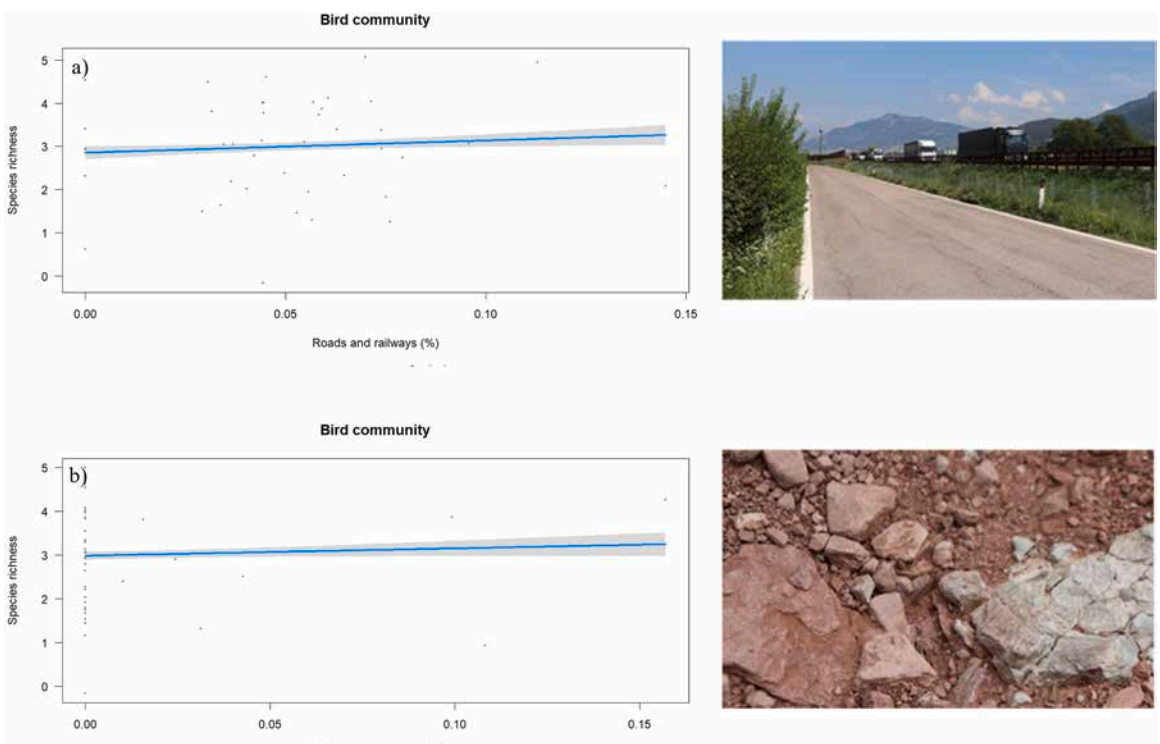

Fig. 10. Model-based predicted species richness (and 95% confidence interval) of bird community in relation to a) the percentage cover of roads and railways b) the percentage cover of rocks and bare soils. Both pictures were taken within the "Biodistretto di Trento" farms (EG, 2021).

accessibility and higher amount of time spent by people in cities and towns, irrespectively of their own values for nature observers. Furthermore, at a higher extent of urban cover, the number of observations decreased as large urban areas are mainly associated with low biodiversity levels.

Apple orchards had a negative effect on the number of observations collected by nature recreationists. Such intensive and highly mechanised crops are unlikely to be perceived as hosting a valuable biodiversity.

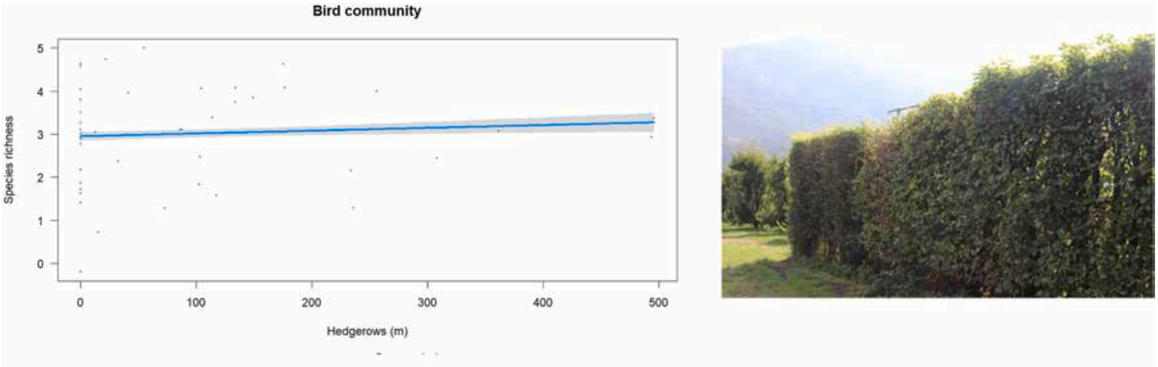

Fig. 11. Model-based predicted species richness (and 95% confidence interval) of bird community in relation to the length of hedgerows in sample areas. Picture: hedgerows in Trentino orchards (EG, 2022).

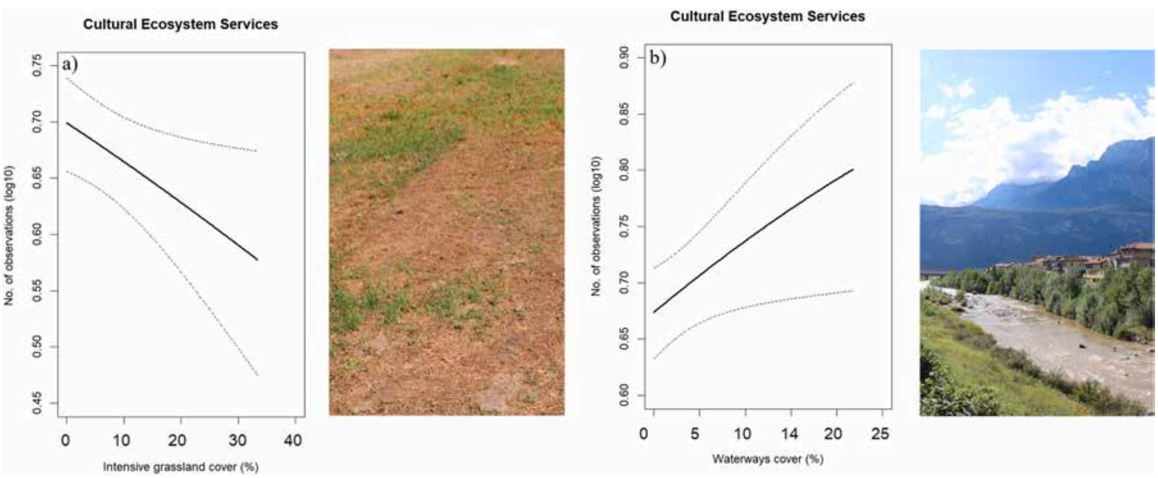

Fig. 12. Model-based predicted number of observations (log10) and 95% confidence interval within the study area in relation to the percentage cover of a) intensive grasslands and b) waterways. Pictures feature a) an intensive grassland in Trentino near an apple orchard, and the b) Avisio river (EG, 2022).

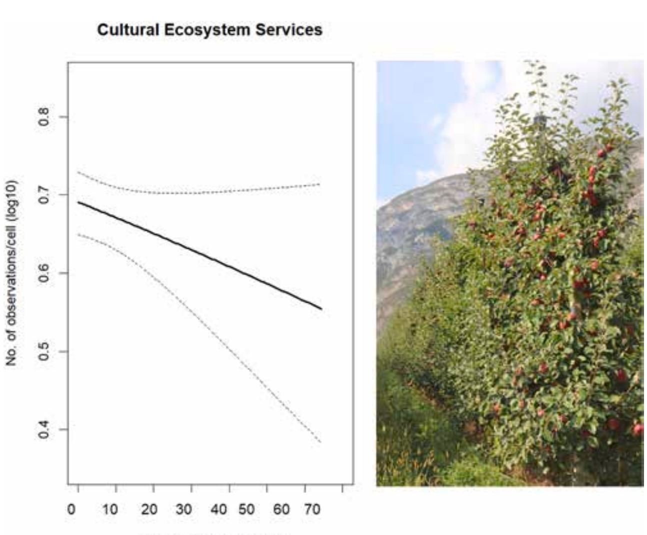

Fig. 13. Model-based predicted number of observations (log10) and 95% confidence interval within the study area in relation to the percentage cover of apple orchards (orchard picture EG, 2022).

Nevertheless, there are some forms of tourism linked to apple orchards in Trentino, but mainly concentrated outside the area, in Val di Non, where orchards strongly characterise the valley landscape.

The positive effect of waterways is most likely due to the Adige and Avisio rivers, which offer highly appreciated landscapes within the study area, as well as suitable habitats for multiple species. Finally, intensively managed grasslands had a negative effect on the number of observations published by nature observers. In fact, they have a poor ecological value and are often associated with low biodiversity (Plantureux et al., 2005) or impoverished biological communities (Assandri et al., 2019).

5. Conclusions

This work, by focusing on a farmed district with a high share of organic agriculture, located within and around the Trento Municipality, provides evidence of the potential importance of peri-urban agricultural landscapes for biodiversity and ecosystem services, but also sheds light on how vineyards and apple orchards could be largely unsuitable for biodiversity and related ecosystem services. Permanent crops were thought to be "green" by definition and were therefore excluded from any biodiversity-friendly measure furthered through the European Common Agricultural Policy (CAP) reform occurred in 2013. However, several works have highlighted their impact on many organisms, as well as on ecosystem services (e.g., Paiola et al., 2020). This is particularly concerning as these crops are undergoing a strong expansion, thus potentially leading to further impact on biodiversity and ecosystem services.

Landscape heterogeneity and the occurrence of linear elements had a major role in supporting bird abundance and species richness, both at

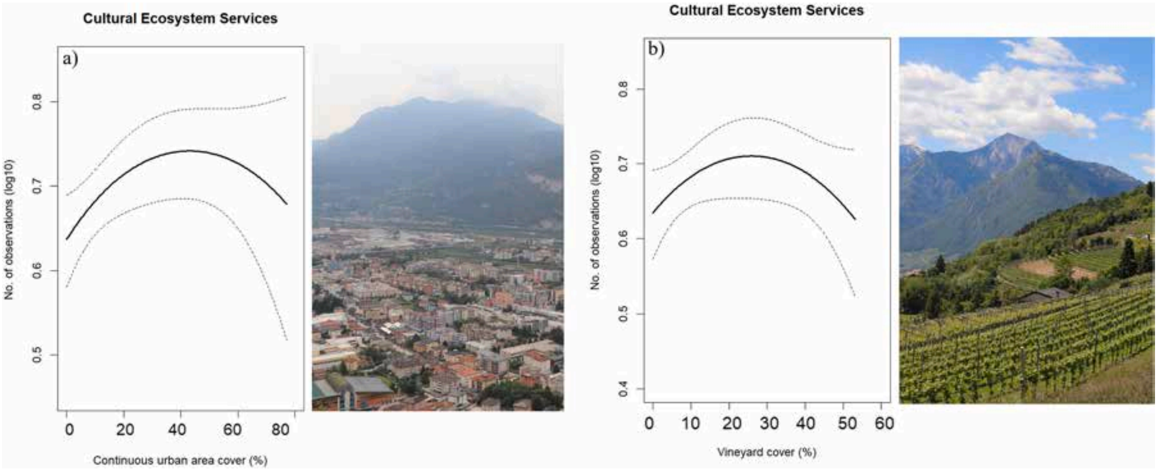

Fig. 14. Model-based predicted number of observations (log10) and 95% confidence interval within the study area in relation to the a) percentage cover of continuous urban areas and b) vineyard. Pictures feature a) Trento city and b) vineyard (EG, 2021).

community and species levels, consistently with other studies (Anderle et al., 2023; Assandri et al., 2016, 2017, 2017c; Princé and Jiguet, 2013). Conservation efforts should enhance landscape heterogeneity by preserving and restoring marginal habitats both at the landscape and field scale.

Pollination service was mainly driven by management factors reflecting the crucial role of farmers' decisions in enhancing or depleting pollinators abundance. To encourage the presence of pollinating insects within vineyards, winegrowers must ensure the availability of suitable environments for foraging and nesting (Haaland et al., 2011; Wersebeckmann et al., 2023). For instance, small-scale interventions can successfully restore pollinator communities by encouraging farmers to adopt low-effort conservation strategies, as Donkersley et al. (2023) suggested. In doing so, conservation efforts should promote pollinators-friendly practices and management strategies that increase floral resources (also within vineyards, see Griffiths-Lee et al., 2023), limit the frequency of vegetation management (see e.g., Maurer et al., 2020), and drastically reduce the input of agrochemicals (e.g., herbicides, pesticides). Some of these measures could become part of agri-environmental schemes targeting inter-row and ground vegetation management, which could contribute to biodiversity conservation and the supply of ecosystem services even if they belong to the very production area.

Landscape heterogeneity had a minor effect on flower visiting insects, but marginal habitats and ecological infrastructures can be important to buffer and mitigate the negative effect of permanent crops (see also Kratschmer et al., 2018, and Rosas-Ramos et al., 2019). Based on our results, we recommend i) preserving or recreating field margins; ii) planting wildflower strips in vineyards; iii) promoting the growth of inter-rows vegetation and spontaneous flowers; iv) or sowing suitable cover crops between rows. Furthermore, the implementation of these practices can also provide a potential spectrum of ecosystem services relevant for winegrowers, such as biological pest control (by hosting auxiliary insects or insectivorous birds, e.g. Brambilla and Gatti, 2022), soil erosion and soil loss mitigation (Brambilla et al. ,2017; Winter et al., 2018), and increased appeal for nature-based recreation (Brambilla and Ronchi, 2020). Moreover, tall sward can reduce the splashes of rain drops towards the vine which is a vehicle of downy mildew spores (Willocquet and Clerjeau, 1998).

Biodiversity conservation within peri-urban agricultural landscapes dominated by permanent crops is fundamental not only for the resilience of the agroecosystem, but also for cultural, aesthetic, and recreational/touristic aspects. For instance, vineyards were positively perceived by nature recreationists at low or intermediate cover, suggesting that the maintenance of surrounding landscapes and the implementation of biodiversity-friendly practices can further promote benefits for visitors and local populations (Bentley Brymer et al., 2020; Bratman et al., 2019, 2012). When intensively managed, permanent crops have a strong negative impact on ecosystems, by depleting habitats and eroding biodiversity. However, correct management practices and conservation measures can soothe these stressors as vineyards have the potential to support biodiversity (Paiola et al., 2020). Moreover, customers increasingly demand for biodiversity and environmental-friendly products, progressively shifting the market towards a more sustainable viticulture (Galati et al., 2019; Gary et al., 2009). Synergic strategies that simultaneously promote biodiversity conservation and the supply of ecosystem services may be more effective in influencing decision-makers and raising people's awareness as they provide a broader spectrum of benefits (Brambilla et al., 2017). Planning instruments can support the implementation of these strategies by integrating them into decision-making processes and guiding policy-makers to make choices towards biodiversity conservation and ecosystem services enhancement for human well-being. Such strategies could be implemented also within the "Biodistretto di Trento", in particular by promoting the maintenance (or creation) of flower areas and semi-natural environments at the margins, reducing and or/alternating cuts of ground vegetation, maintaining landscape heterogeneity, promoting the presence of linear (hedgerows, tree rows) and punctual elements (trees).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All data have been uploaded on the public repository of Milan University at the following link https://doi.org/10.13130/RD_UNIMI/010WT5.

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Supplementary material

Models' ranking, list of excluded bird species and graphical visualization of all models' effects.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2023.108693.

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