Spontaneous renaturalization of open ecosystems in the hills of Brescia seen through the bird community

Rocco Leo[1]*, Gabriele Romanenghi[2], Diego Franchini[3], Marco Gobbini[4]

Abstract - The sun-exposed open areas of the Brescia hills overlooking the Po Valley (*Avanalpica region*) were created by man starting from the 11th century. After the Second World War, following agro-pastoral abandonment, these areas have significantly shrunk. The evolution underway is towards the deciduous forest although in some areas the strong presence of quarries is blocking the vegetational succession or delaying it. Local birds are now largely associated with woodland coenosis and more scarcely with open areas, shrublands and wood edges. Seven open areas species have become extinct over the past 30 years: Woodchat Shrike, Barred Warbler, Rufous-tailed Rock-Thrush, Eastern Black-eared Wheatear, Tawny Pipit, Corn Bunting and Ortolan Bunting. Others, like Red-backed Shrike, Common Whitethroat, Cirl Bunting and Wood Lark have declined. Only the generalist Sardinian Warbler and Blue Rock-Thrush, typical of rocky areas with grassy spaces, are still relatively widespread although slightly decreasing. The Cirl Bunting, a species linked to traditional vineyards and orchards, is not expanding in the new intensively cultivated lands. The Eastern Subalpine Warbler is on the rise even though, due to its very low presence and lack of specific surveys, it may not have been detected in the past. The factors determining the presence of these species, i.e. traditional crops, flat open areas, soils with low grass and often with outcropping and/or rocky substrate, are in sharp decline. We can state that this bird community is negatively influenced by the percentage of tree cover and positively influenced by the presence of quarries which, however, represent an ephemeral and strongly impacting environment. In the absence of fires and/or natural disasters as well as human interventions, which are not likely to occur due to their poor economic sustainability, the prognosis for these birds is to be considered poor and a reduction in both bird and general biodiversity is to be expected.

Key words: Avanalpica region, farmland birds, quarries, hills, open areas, secondary succession, spontaneous renaturalization.

Riassunto - La rinaturalizzazione spontanea di ecosistemi aperti nelle colline bresciane vista attraverso la comunità ornitologica.

Le aree aperte ed esposte a solatio delle colline bresciane prospicienti la Pianura Padana (fascia "Avanalpica") sono state create dall'uomo a partire dall'anno mille ma, dal secondo dopoguerra in seguito all'abbandono agropastorale, sono in forte contrazione. L'evoluzione in corso è verso il bosco di latifoglie ma in alcune aree la forte presenza di cave blocca la successione secondaria o la rende molto più lenta. Gli uccelli presenti sono oramai in gran parte associabili alle cenosi boschive e più scarsamente a quelle arbustive e di mantello del bosco. Ben sette specie si sono estinte nel corso degli ultimi 30 anni: averla capirossa, bigia padovana, codirossone, monachella orientale, calandro, strillozzo e ortolano. Altre come l'averla piccola, la sterpazzola, lo zigolo nero e la tottavilla si sono fortemente ridotte. Solo il più generalista occhiocotto e il passero solitario, tipico di aree rocciose con spazi erbosi, sono ancora relativamente diffusi sebbene in leggero calo. Lo zigolo nero, specie legata ai vigneti e frutteti tradizionali, non si espande nelle nuove coltivazioni intensive. La sterpazzolina risulta in aumento anche se, per la sua scarsissima presenza e mancanza di ricerche specifiche, potrebbe non essere stata rilevata nel passato. I fattori determinanti la presenza di queste specie come i coltivi tradizionali, le aree aperte pianeggianti, i terreni con erba bassa e spesso con substrato affiorante e/o roccioso sono in forte riduzione. Sinteticamente possiamo affermare che la comunità di questi uccelli è negativamente influenzata dalla percentuale di copertura arborea e positivamente dalla presenza di cave, quest'ultimo è però un ambiente effimero e molto impattante dal punto di vista ambientale. In assenza di interventi umani, non ragionevolmente ipotizzabili per la scarsa sostenibilità economica, di incendi e/o catastrofi naturali la prognosi per questi uccelli è da ritenersi in genere infausta con una forte riduzione della biodiversità avifaunistica come anche di quella generale.

Parole chiave: Regione Avanalpica, avifauna delle aree agricole, cave, colline, aree aperte, successione secondaria, rinaturalizzazione spontanea.

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INTRODUCTION

The transformation of the Brescia hilly landscape began during the first deforestation in the Bronze Age, (Perego *et al.*, 2011). The archives of the monasteries of Santa Giulia (Brescia) and San Pietro (Serle) show that in the 10th century our study area was still mostly wooded but already interspersed with isolated pastures, fields and cultivated terraces (Menant, 1993). Both local sheep flocks and massive transhumant contingents were foraging here, contributing to the maintenance of pseudo-steppe areas (Menant, 1993). Towards the end of the 13th century, the deforestation (ancient *roncare*) of attractive areas was almost completed and several sun-exposed hillsides were exploited by man. After that century, the extension of open areas fluctuated following the demographic trend

while the extension of vineyards increased constantly (Menant, 1993; Archetti, 1998; Capra, 2008). The lowest forest coverage and maximum agricultural and pastoral extension were reached around the 1950s (Capretti, unpublished; Belfanti & Taccolini, 2008). In those years viticulture, fruit growing and horticulture were dominant, with the steepest and non-terraced areas managed as meadows-pastures with sparse shrubs. Sun-facing woods were very limited and grown in coppice (DUSAF, Classification of Agricultural and Forest Lands use, 1954; Capretti, unpublished). Since then, there has been a rapid decline in agro-pastoral use, while a spontaneous renaturalization of abandoned areas began followed by a rapid growth of shrubbed, and later wooded, topsoil. (Andreis, 1991; Capretti, unpublished; Benayas *et al.*, 2008). When the human activities ceased, forests started covering every previously open zone except for areas of rock formations and rare primitive grasslands. Strong karst phenomena only delayed the succession of the related conenoses (Svenning, 2002). In our study area, a specific case is represented by the massive presence of quarries, which creates a characteristic environment (Gilardelli *et al.,* 2016). The consequences on birds of the abandonment of rural areas have been extensively studied in Mediterranean contexts – which only bear a partial resemblance to the study area in question – (Preiss *et al.*, 1997; Coreau & Martin, 2007; Moreira & Russo, 2007; Sirami *et al.*, 2007, 2008; Prodon, 2020) and, in Italy, especially by M. Brambilla (see a partial reference in the bibliography). However, the number of studies in this regard cannot yet be defined as adequate (see summary in Rodríguez-Soler *et al.*, 2020) and those referring to the *Regione Avanalpica* (i.e.: pre-Alps Region bordering the Po Valley) or similar environments are very few (Farina, 1997; Laiolo, 2005). Therefore, the aim of this contribution is to analyze the environmental situation of the residual ecosystems of this region, notably those still open and sun-exposed, by analyzing the presence of typical Passeriformes with respect to the structure of the landscape and environmental variables. As highlighted by Brambilla *et al.* (2009b) these bird species are good indicators of local environmental quality. Although the survey is limited to the central portion of the Brescia province (Fig. 1), it can be also useful in the analysis of similar situations present in hilly areas overlooking the northern edges of the Po Valley. The purposes of this survey can be summarized as follows:

1. Scrutinize the state of the remaining open or semi-open areas.
2. Summarize the conservation status of the investigated species at various geographical scales.
3. Where there exist previous local data, highlight the species trend.
4. Find the environmental variables determining the species presence through fine-scale surveys also carried out on site (Brambilla *et al.*, 2009a).
5. In light of the results, hypothesize the evolution of the landscape and its avifauna component.

Before this contribution, the avifauna in the study area had been investigated limited to diurnal breeding birds of prey (Leo & Gobbini, 2013), to the Eagle Owl *Bubo bubo* (Leo & Capelli, 2007), to the Eastern Black-eared Wheatear *Oenanthe melanoleuca* (Gobbini, 2007), to the Red-backed Shrikes *Lanius collurio* (Brambilla *et al*., 2009a) and to the Wood Lark *Lullula arborea* (Maestri & Voltolini, 2013). In addition to the above, so far only two areas have been investigated extensively at the bird community level: the municipality of Paitone (Gobbini, 2010) and the plateau of Cariadeghe (Brichetti, 1993; AA.VV., 2015).

STUDY AREA

The investigated area includes the hills of Brescia that extend longitudinally for 152 km^2 from Monte Orfano to the W, as far as where the Valle Sabbia begins to the E (Fig. 1) and is located in the rectangle having the coordinates 45.62 N 9.92 E and 45.51 N 10.43 E. Some parts are included in the PLIS (Supra-municipal Park of Local Interest) "Parco delle Colline di Brescia", while others are part of the SIC (Site of Community Importance) "Altopiano di Cariadeghe" (IT2070018) and the Regional Natural Monument "Buco del Frate". The elevation of the sampled sites ranges from 130 to 730 m asl. For a detailed description of the area, see also Leo & Gobbini (2013). We sampled only locations with S, SE and SW exposure, with a vegetation structure from "open" to "almost completely closed", and of different origins and management. These sites are mainly cultivated fields, shrubby semi-natural habitats, primitive grasslands, evolving shrubs and active or disused quarries. All environments have some degree of xericity.

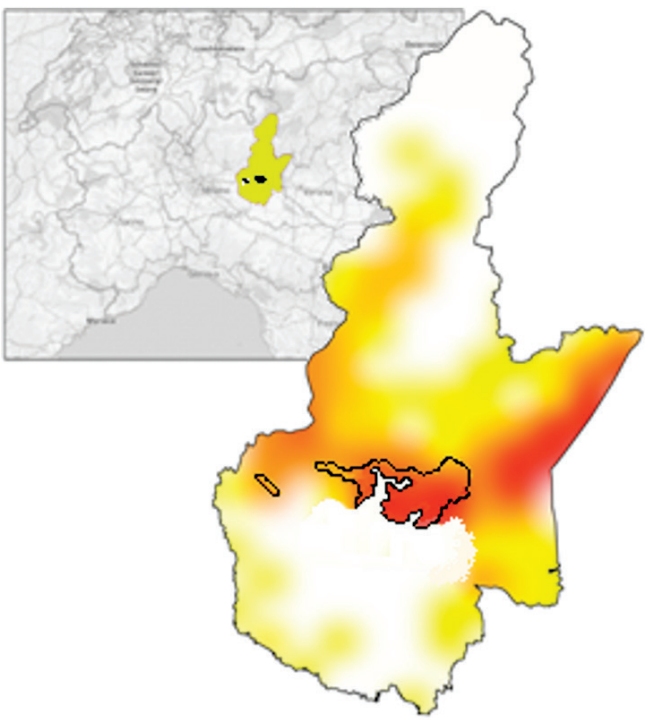

Fig. 1 - Location and extension of the study area. The map shows Steno-Mediterranean chorotypes present in the vegetation of the province of Brescia (red = maximum presence, revised from Martini *et al.*, 2012). / Localizzazione dell'area di studio. Corotipi stenomediterranei presenti nella vegetazione della provincia di Brescia (rosso = massima presenza, ridisegnato da Martini *et al.*, 2012).

Geology. The substrate is mainly constituted by carbonate rocks, present with various lithotypes, except for Monte Orfano, which is formed by conglomerate (Boni *et al.*, 1968, 1970). In the central and eastern area we can find karrens, sinkholes and caves (Schirolli, 1998) along with numerous and extensive quarries. In the quarries there often are imposing cliffs facing large flat areas (Vailati, 2003) and the soil is often endopercolative tending to become highly xeric.

Climate. The climate in the area is temperate with Atlantic influence (suboceanic) without drought periods and falls within the Cfa type (Martini *et al.*, 2012). The different indices of De Martonne, Lang and Emberger confirm the presence of a substantially humid climate (Capelli & Stefani, 1984). Therefore, the potential vegetation of the area is the broadleaf deciduous forest (Armiraglio, 2020). However, through the analysis of evapotranspiration, a summer water deficit has been identified in certain parts of the study area as a result of the coexistence of high sun exposure, steepness and endopercolative soil (Capelli & Stefani, 1984; Martini *et al.*, 2012).

Vegetation. The suprasoil consists mainly of thickets, coppices, woods and few forests of mixed broadleaf trees. The subdivision in the various environmental categories is summarized in Table 1. Thermo-xerophilous associations dominated by *Quercus pubescens*, *Ostrya carpinifolia* and *Fraxinus ornus* prevail. Conifers are limited to a few reforestations with *Cupressum sempervirens*, *Pinus picea, Pinus nigra* and *Pinus sylvestris* carried out after the Second World War. Of great naturalistic interest is the presence of euro-Mediterranean and steno-Mediterranean species (Fig. 1), such as *Phillyrea latifolia, Cercis siliquastrum, Erica arborea and Pistacia terebinthus,* in the most xeric areas (Andreis, 1991; Piseri & Vitale, 2002; Martini *et al.* 2012). This sub-Mediterranean vegetation was greatly favored by deforestations carried out in the past (Andreis, 1991; Capretti, unpublished). The small grassy areas are attributable to Xerobrometum and Brachypodietum communities dominated by *Bromopsis erecta, Chrysopogon gryllus, Bromopsis condensata, Melica ciliata, Stipa eriocaulis* and *Artemisia alba*. Among the crops, the grapevine *Vitis vinifera* prevails, followed by the olive tree *Olea europaea*. According to Habitat Directive 92/43/EEC, the investigated areas often fall within or are similar to the following environments (Brusa *et al.*, 2017; Armiraglio, 2020):

- 6210 - Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*), often evolving towards 91H0: Pannonian woods with *Quercus pubescens*.
- 6510 - Low altitude hay meadows (*Arrhenatherion elatioris*), limited to the "C" type elementary habitat, the most xeric.
- 8130 - Western Mediterranean and thermophilous screes (*Stipion calamagrostis*).

Land use over the years is summarized in Table 1, starting from the 1954 GAI flight to the most recent DUSAF system. The GIS values have been manually validated as the available data are sometimes inaccurate, especially those referring to open areas. The difference between sparse woods and bushes and between the latter and vineyards is not always clear on maps; therefore, the data on bushes and their evolution must be interpreted with caution. The continuous increase in woods, urbanized areas and quarries is evident. The widespread shrubs present in 1954 have all evolved into woods and almost all the meadows of that year are now shrublands.

METHODS

Given the small size and mosaic structure of the suitable areas, it was decided to survey them through the use of sampling points, located in the center of the open areas, with unlimited distance (Bibby *et al.*, 2000). The 105 sampled points (Fig. 2) were selected randomly among those deemed more suitable after a research on orthophotos and with a minimum distance of at least 250 meters between them, to ensure the independence of the samples. In order to verify the local status of some species of high conservation interest present in the past and now given as extinct (Eastern Black-eared Wheatear, Ortolan Bunting *Emberiza hortulana*, Woodchat Shrike *Lanius senator senator* and Tawny Pipit *Anthus campestris*), some additional points were checked. This, as well as the temporal evolution of some species, was possible because the authors already had good knowledge of the territory thanks to the constant monitoring of the populations of the most significant taxa present in the area (Gobbini, 2007, 2010; Leo & Gobbini, unpublished data). During the three-year survey, each of the 105 points was censused at least twice in the months of May and June. The samples per every site were carried out in different years and months, for a total of 260

Tab. 1 - Land use in the study area. / Uso del territorio nell'area studiata.

Land use	GAI flight1954	DUSAF 1980	DUSAF 1999	DUSAF 2018	Change 1954-2018
Woodlands and fore-sts	52.1%	59.7%	65.6%	68.8%	16.7%
Meadows	17.2%	20.4%	12.8%	10.4%	-6.8%
Shrublands	17.1%	7.2%	6.3%	4.7%	-12.4%
Vineyards, orchards and olive groves	10.4%	5.9%	4.4%	5.1%	-5.4%
Urbanized areas	2.3%	4.5%	6.5%	7.5%	5.2%
Quarries	0.5%	0.9%	2.9%	3.4%	2.9%
Others areas	0.3%	1.4%	1.5%	0.2%	-0.1%

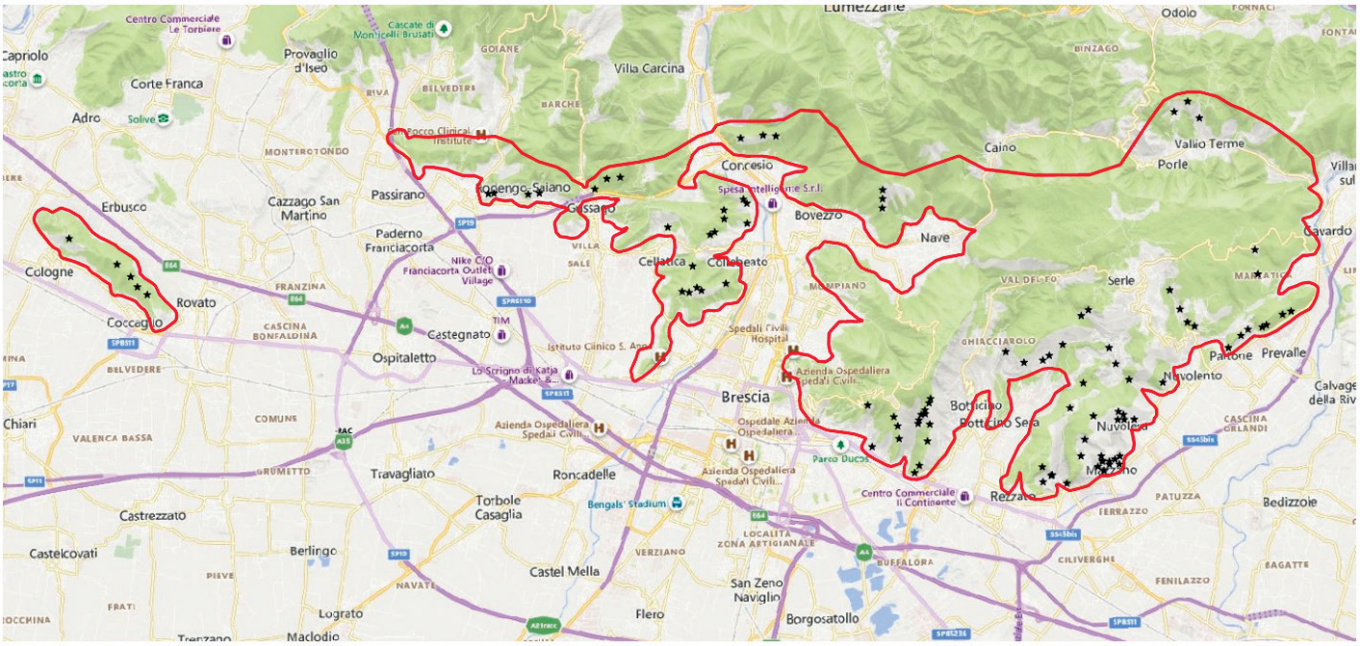

Fig. 2 - Location of the sampling points (dark dots) in the study area (in red). / Localizzazione dei siti campionati (punti) ed estensione dell'area di studio (in rosso).

visits. In addition to contacts with birds, a series of environmental variables were recorded within a radius of 100 m from the sampling points and the list is shown in Table 2. The variables describing habitat fragmentation around each survey point were evaluated using an ordinal reference 6-level grid (0: absent element, 1: isolated and single element, 2: element aggregated in small patches, 3: element aggregated in medium patches, 4: element grouped in one large patch, 5: linear structures). Conversely, the variables describing the herbaceous cover were measured on four orthogonal points located 50 meters from each sampling point. Grass density was measured interpolating a reference table. All the elements concerning the soil and the vegetation were collected directly at the sampling sites as they are often impossible to extract correctly using GIS only. These field data are often indispensable to describe

Tab. 2 - Environmental variables collected in the survey area. / Elenco delle variabili ambientali misurate nei siti campionati.

Type	**Measured variables**
Slope	Calculated between the highest and lowest altitude within a radius of 100 m around the sampling point.
Exposure	Absolute solar azimuth angle from south, in degrees (facing south= 0°).
Elevation	Height above sea level (at sampling point).
Terrace	Presence of terraces, dry stone walls or embankments. Binomial.
Grass: average height	Grass average height in cm.
Grass: density	Grass average density, from 0 to 3.
Grass: litter	Presence of dry grass on the ground. Binomial.
Shrub: structure	Spatial aggregation of shrub. Ordinal.
Shrub: average height	Shrub average height in cm.
Percent shrub cover	Percentage of the site area covered by shrubs.
Tree: structure	Spatial aggregation of trees. Ordinal
Percent tree cover	Percentage of the site area covered by trees.
Rock: structure	Spatial aggregation of rocks. Ordinal
Percent rock cover	Percentage of rock coverage on the ground.
Bare soil: structure	Spatial aggregation of bare area. Ordinal
Percent bare soil	Percentage of bare ground in the site (gravel, bare earth, dirty roads, etc.)
Quarry	Presence of a quarry, in use or not, within a 100 m radius. Binomial.
Quarry: active	Specifies whether the quarry is in use or abandoned. Binomial.
Cliff: height	Height of the cliff. If quarry with benches, it is the faces sum.
Principal plants	List of shrubs and trees covering >10% of the site. Binomial.

the relationship between habitat and fauna (Brambilla *et al.*, 2009a). The surveys took place between May 15th and July 1st of the years 2018, 2019 and, very limitedly, 2020. Each survey lasted 20 minutes and was carried out in the first four hours after dawn and, only in 10% of the cases, in the two hours before sunset. The starting date was chosen so as to avoid taking a census of late migrants, as some species may still be in transit at the end of May (Spina & Volponi, 2008; Brichetti & Fracasso, 2007-2015; authors' pers. obs.). Five-minute emission playback was used when searching for the Eastern Subalpine Warbler *Curruca cantillans* as well as for the species thought to be extinct. In total, 150 hours of sampling were carried out and 267 contacts with open-area birds were collected. Additional checks were carried out, including the use of mist-nets, only for the Eastern Subalpine Warbler, when contacted, to ascertain its possible breeding. Finally, the two subspecies of *C. cantillans* were determined, whenever possible, through the call or the male plumage. (Shirihai *et al.*, 2001; Brambilla & Guidali, 2005).

DATA ANALYSIS

For each of 105 sites, the environmental data collected in the various samples were averaged, while the number of recorded contacts was reduced to presence/absence (absence = no contact in two years, presence = at least one contact in two years). The species density was analyzed only for the Sardinian Warbler *Curruca melanocephala* because of the abundance of contacts per site and after making sure no double counting was occurring. The data were analyzed using R (R Core Team, 2013) with the aim of examining the factors determining the species presence. At first, a graphic exploration, species-by-species, of the variables was carried out. The variables were related to one another and to the presence/absence of the taxa. Data were checked in order to rule out outliers, multicollinearity (VIF <5) and concurvity (<0.5). The "linear structures" have been merged with those of the "medium patches" class.

Presence/absence was modeled using the *glm2* package (Marschner, 2011) as per Zuur *et al.* (2009, 2010). For the Blue Rock-Thrush *Monticola solitarius* and Cirl Bunting *Emberiza cirlus* the analysis was carried out with the *brglmFit* method of the *brglm2* package (Kosmidis, 2021) since the data exhibited a quasi-complete separation. The full model was then simplified using the *dredge* function of the *MuMIn* package (Barton, 2022) by choosing the most parsimonious among the suggested models, that is the one with the lowest AICc index (Akaike's information criterion corrected for small sample size). Uninformative parameters were eliminated following Leroux (2019). To verify the goodness of fit of each model, McFadden's R^2 and AUC were calculated. The two indexes oscillate between 0 and 1, exceeding 0.20 for McFadden's R^2 and 0.7 for the AUC, therefore the model is to be considered at least sufficient. A further check was performed by employing the Hosmer and Lemeshow test, with models only being reported when significant (i.e. test results = ns). The distribution (family) used in the models was binomial with *cloglog* link, which was deemed more suitable for an imbalanced dataset, except for the Sardinian Warbler and the Blue Rock-Trush, for which the link *logit* was utilized. For the Sardinian Warbler alone, the *mgcv* package (Wood, 2021) with Poisson distribution was used to analyze its density via GAM following an overdispersion check. Despite the presence of a relatively high number of "zeros" (that is, "species not present") in the response variable, zero-inflation was considered "a priori" acceptable because these are "true zeros" indicating "true absence" (Gonzalo-Turpin *et al*., 2008). After that, all models were verified using the *DHARMa* package (Hartig, 2022) for dispersion, zero-inflation and residuals distribution. In the models, the ratio between the number of sites with presence and the explanatory variables has always been kept between five and 10. Although a relatively low ratio can sometimes lead to poorly robust models (Vittinghoff & McCulloch, 2007), the authors did not want to employ grouping techniques for the explanatory variables (e.g.: PCA) so as to obtain more easily interpretable models. To highlight the environmental similarities of the different survey sites the *factoextra* package (Kassambara & Mundt, 2020) was used. The obtained grouping was considered acceptable when the clusters did not show any overlaps. The analyzed species for which the sample was deemed sufficient (n ≥14) are: Melodious Warbler, *Hippolais polyglotta*, Black Redstart *Phoenicurus ochruros*, Sardinian Warbler, Blue Rock-Thrush, Common Whitethroat *Curruca communis* and Cirl Bunting. Concerning the remaining species, no statistical models were made owing to an excessively small numerical sample (n≤ 7). For each analyzed species, the significant explanatory variables are reported in a dedicated table in decreasing order of importance. The transformation and subsequent ranking were obtained using the *caret* package (Fox & Weisberg, 2019). Finally, as far as correlation analyses between two variables are concerned, non-parametric statistics were used in order to avoid assumptions about the data normality.

RESULTS

Environment

The salient features of the 105 sampled sites are summarized in Table 3.

Many of the surveyed sites were quite steep, with an average slope of 34%. There were few relatively flat sites: only 23% were below 20% slope (Fig. 3). The detailed sun exposure of the sites is highlighted in Fig. 4 and is included almost symmetrically in an angle of ± 60° from south (48% more eastward, 35% more westward and 17% southward). Of the censused points, 23% fall into quarries, of which 71% were active and 14% presented some form of terracing, while 60% of the cliffs (maximum height 120 m) were located in quarries. When compared to other areas, both the presence and height of the cliffs were significantly higher in the quarries (for cliff presence: Fisher exact test, $p < 0.001$; for cliff height: Wilcoxon rank sum test, $W = 58$, $p < 0.001$). The sites, grouped through cluster analysis and using all environmental variables except *Principal plants*, are shown in Fig. 5 (Kme-

ans clustering with PCA). Cluster number 1 includes sites containing rocks, bare soil, cliffs and reduced vegetation (i.e. quarries) while the other classes are relatively more similar to each other: cluster number 2 has more trees and grass while cluster 3 is more shrubby and closed. The sites where the area covered by shrubs and trees is inferior to 10% were only 4%. Moreover, the open areas highlighted in Fig. 6, were almost always fragmented by the widespread presence of trees and shrubs; the sites where these are entirely absent were only 2% (Fig. 7). However, the association between trees and shrubs in Fig. 7 was not significant (Kendall's rank correlation, $p > 0.94$). The majority of the sites displayed a spatial structure of shrubs and trees scattered in small patches with few linear elements (Fig. 8). The more open sites, showing a less pronounced succession, were often located in or near quarries (Wilcoxon rank sum test, $W = 412$, $p < 0.001$). The height of the grass was positively correlated with its density and,

Tab. 3 - Summary of the environmental parameters measured. / Sintesi delle variabili ambientali dei siti.

Parameter	Mean ± s.d.	Min.	Max.
Solar azimuth angle	3±27	-60	60
Slope	34±18	0	78
Elevation	360±134	150	730
Grass average height	34±19	0	100
Shrub average height	134±73	0	288
Cliff height	9±19	0	120
Rock cover percentage	14±20	0	90
Tree cover percentage	17±14	0	70
Bare soil cover percentage	11±16	0	60
Shrub cover percentage	22±18	0	90

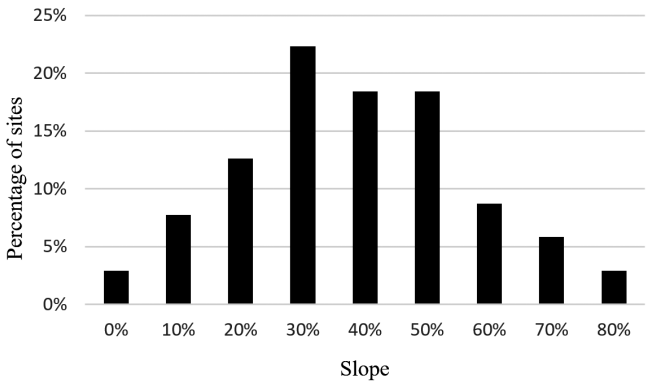

Fig. 3 - Distribution of sites according to slope. / Distribuzione dei siti in base alla loro pendenza.

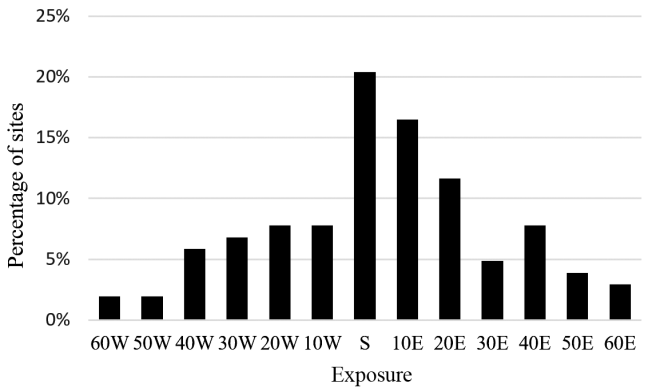

Fig. 4 - Distribution of sites exposure (i.e. 10E=10° from south, towards E). / Distribuzione dell'esposizione dei siti (es.: 10 E = 10° da sud, verso est).

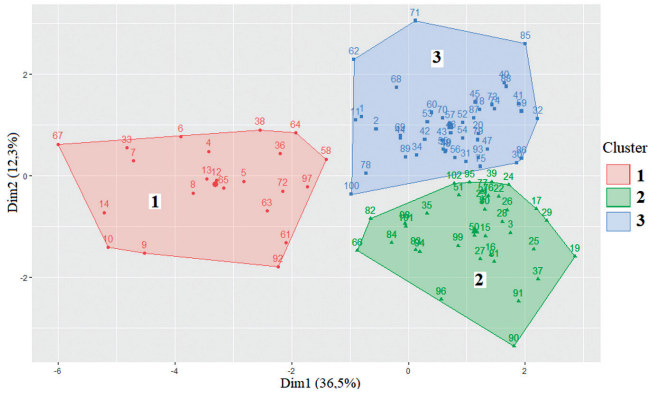

Fig. 5 - Site clustering according to environmental variables (Kmeans clustering with PCA). Cluster 1: more rocky areas, cluster 2: wooded and grassy areas and cluster 3: shrubby and closed areas. / Raggruppamento dei siti (Kmeans clustering con PCA) secondo le variabili ambientali. Il cluster 1 è caratterizzato da ampia presenza di rocce, il 2 da alberi ed erba mentre il 3 da cespugli fitti.

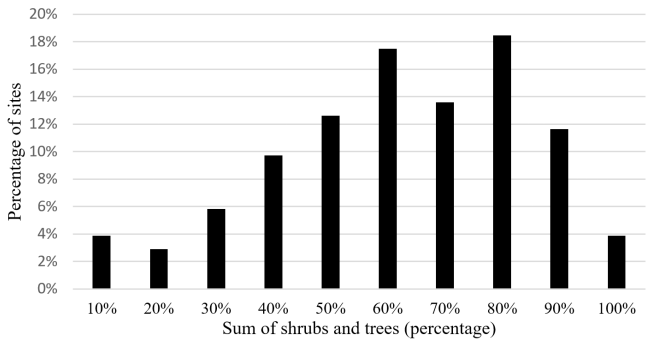

Fig. 6 - Percentage of sites according to the coverage sum of trees and shrubs. / Distribuzione dei siti in funzione della copertura di alberi e cespugli sommati tra loro.

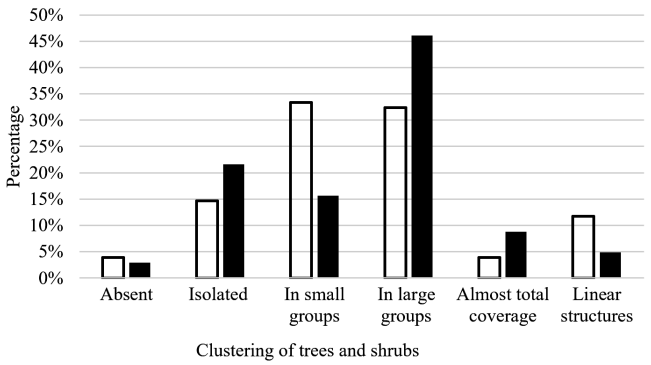

Fig. 7 – Percentage of sites according to spatial structure of trees (black bars) and shrubs (blank bars). / Struttura spaziale dei siti secondo il raggruppamento di alberi (barre nere) e cespugli (barre vuote).

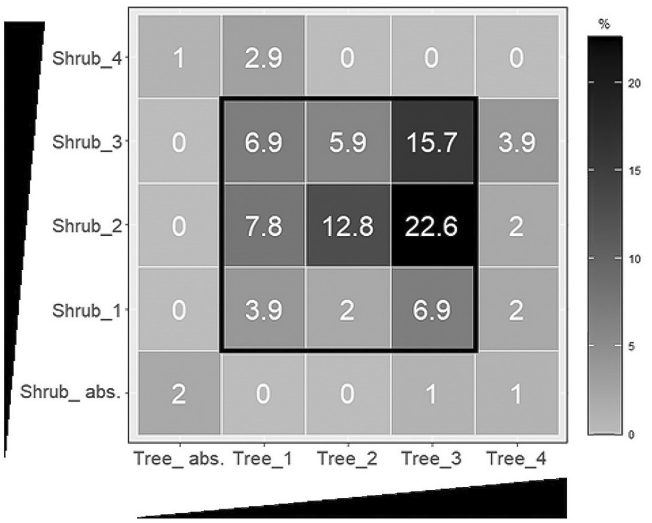

Fig. 8 - Percentage distribution of sites according to tree and shrub aggregation, from Abs.: absent elements to 4: maximum aggregation (see Methods). The central square highlights the sites where shrubs and trees tend to fragment the open areas the most. The sum of the sites in the central square is 84% of the total sites. / Distribuzione percentuale dei siti secondo l'aggregazione di alberi e cespugli (Abs.: elementi assenti, 4: massima aggregazione, vedi Metodi). Il quadrato centrale racchiude le aree più frammentate da cespugli e alberi. La somma delle aree nel quadrato costituisce l'84% del totale.

more weakly, with the quantity of litter (Kendall's rank correlation: z = 6.9 and z = 5.6, both p <0.001). None of the vegetation parameters was correlated significantly with exposure, elevation or slope (various Kendall rank correlations: all p> 0.2).

Avifauna

We analyze the presence of the main species connected to open environments; the 17 passerines of specific interest are summarized below with an additional analysis of the recorded bird community of the study area. In addition to the results, specific considerations are added for each recorded passerine and for the bird community analysis. The general considerations are reported in the Discussion paragraph. The European and Italian populations and their trends are summarized in Table 4.

Red-backed Shrike *Lanius collurio*

The species presence in Lombardy during the breeding season has been studied by Brambilla *et al.* (2009a; 2010) in various contexts, some even similar to our study area. The species displays a preference for mosaic habitats consisting mostly of meadows and pastures interspersed with uncultivated areas and with 15-35% hedges

Tab. 4 - European and Italian population and trend of treated species (from Brichetti & Fracasso, 2007-2015; Brichetti & Grattini, 2010; Nardelli *et al*., 2015; Jiguet *et al*., 2016; Staneva & Burfield, 2017; Brichetti & Grattini, 2018; Keller *et al*., 2020). / Popolazione e tendenza in Europa e in Italia delle specie descritte (da Brichetti & Fracasso, 2007-2015; Brichetti & Grattini, 2010; Nardelli *et al*., 2015; Jiguet *et al*., 2016; Staneva & Burfield, 2017; Brichetti & Grattini, 2018; Keller *et al*., 2020).

Species	European pairs	Italian pairs
Lanius collurio	7.4-14.3 million; stable.	20,000-60,000; 35-60% decrease (1990-2012).
Lanius senator	0.5-1.2 million; 36% decline (1998-2016).	4,000; 75-85% decrease (1990-2012).
Lullula arborea	2-4 million; slight expansion.	20,000-40,000; 45-55% increase, declining N of the Po River (1990-2012).
Hippolais polyglotta	2.3-3.8 million; expanding towards NE.	50,000-150,000; 55-65% increase (1990-2012).
Curruca nisoria	0.5-1 million; increasing in some areas.	90-100; 90-95% decrease (1980-2012).
Curruca melanocephala	7.6-16.1 million; slight northward expansion.	0.5-1.5 million; stable.
Curruca cantillans	3.3-5.2 million; slight northward expansion.	50,000-200,000 (with C. subalpina); unknown trend.
Curruca communis	17.3-27.8 million; stable.	50,000-250,000; 20-30% decrease (1990-2012).
Phoenicurus ochruros	5.7-10 million; increasing.	200,000-400,000; 15-25% increase (1990-2012).
Monticola saxatilis	89,000-283,000; slight decrease in less suitable areas.	5,000-10,000; unknown decrease.
Monticola solitarius	110,000-237,000; marked decrease.	10,000-20,000; unknown trend.
Oenanthe melanoleuca (with *O. hispanica*)	1.3-3.7 million; 40% decrease (1998-2016).	1,000-2,000; 60% decrease (2000-2011).
Anthus campestris	0.9-1.7 million; decreased in the NW.	15,000-40,000; 10-30% decrease (1990-2012).
Emberiza calandra	8.3-31.3 million; markedly decreasing in central range.	150,000-300,000; declining in N.
Emberiza cia	2-4 million; increasing.	30,000-60,000; negative trend.
Emberiza cirlus	2.5-4.5 million; stable.	0.5-1 million, in expansion.
Emberiza hortulana	3.3-7.1 million; 88% decrease (1980-2009).	500-1,500; strong decrease.

and shrubs. Good exposure, low slope and dry soil, not necessarily xeric, are other cofactors for the species presence. The optimal habitat is usually created and maintained by extensive agricultural use (Brambilla *et al.*, 2007b, 2009a, 2010; Keller *et al.*, 2020). In Lombardy, a population estimated at 7,100 pairs in 2016 with an average yearly decrease of 3.7% has been reported between 1992-2017 (Bani *et al.*, 2016). In the recent past, the species was widespread in the agroecosystem of the study area, making it one of the best known birds by the people living in the area. In the municipality of Paitone, in an area of 7.8 km^2, 30 pairs were surveyed in 1987, 29 in 1998, 23 in 2008, 12 in 2011, eight in 2013, seven in 2014 and five in 2015 (Gobbini, 2010; Gobbini, pers. obs.). On the Cariadeghe plateau (524 ha), 20 territories were surveyed in 1987, 23 in 2008, 29 in 2012 and 20 in 2015 (Brichetti, 1993; Casale & Brambilla, 2009; AA.VV., 2015). In 1986 on Monte Camprelle (municipality of Nuvolera), in 45 ha of unsuitable area due to the presence of many rocks and bare soil, four territories were recorded (Micheli & Cambi, unpublished data). In the hilly area of Collebeato, out of 65 ha of favorable habitat, 12 pairs were surveyed in 1987, eight in 1998, five in 2008, three in 2012 and 2014 and two in 2015 (Leo, pers. obs.). Fig. 9 illustrates the relative population trend in three different sub-areas. The current grassy surface is much less suitable for finding preys due to greater stems density and height of the grass together with the presence of straw litter, factors enhanced by grazing and haymaking abandonment (Tsiakiris, 2009). The rapid decline which has occurred in the Collebeato area is attributable to the fast local secondary succession with relative coverage of tall grasses, a rapid phenomenon due to greater soil fertility (see also Brambilla *et al.*, 2010). In the area of Paitone, which tends to be more karstic and rocky, this change of habitat causing the species decline has been delayed of a few decades. The species resistance on the Cariadeghe plateau is attributable to the still widespread presence of traditional forms of agriculture and cattle breeding, which have ceased or have been drastically reduced in the other sites of our study. The population dynamics on the plateau show that the species is still capable of remaining stable or even of increasing in optimal situations, as happened in Cariadeghe following specific interventions (Casale & Brambilla, 2009; Brichetti & Fracasso, 2020). In the present study, the Red-backed Shrike was found in one point only. Compared to previous data (see Fig. 9), the species has drastically declined in the study area and breeds only and irregularly in certain locations (Gobbini & Leo, pers. obs.).

Woodchat Shrike *Lanius senator*

The Woodchat Shrike breeds in mosaic environments with sparse herbaceous cover of various heights, scattered shrubs and a few trees. It is therefore found in open, relatively arid areas, located in abandoned or traditional fields or in pastures. The presence of anthropic or wooded areas appears to be limiting factors in breeding (Brambilla *et al.*, 2010; Chiatante *et al.*, 2014; Brambilla *et al.*, 2017a; Brichetti & Fracasso, 2020). In the 1980s, it was assumed that the population in Lombardy consisted of a few dozen pairs, mostly concentrated in the province of Brescia (Brichetti & Grattini, 2017). For details on the Italian decline see the summaries in Brichetti & Grattini (2017) and Brichetti & Fracasso (2020). At the end of the 1980s, in a district of 250 ha suitable for the species within the study area, there were still seven confirmed breeding pairs (0.28 pairs/10ha) which gradually became extinct by the year 2004 (see Fig. 10). The surveys carried out in this previously-breeding area have shown that a) the tree cover has risen from 20% to over 60% b) the traditional vineyards, sometimes making up the species core areas, have been abandoned c) the last pair bred where the original habitat had been kept intact. In 1986 two pairs were recorded in 45 ha on Monte Camprelle (Micheli & Cambi, unpublished data). The gradual transformation and disappearance of suitable habitats, adverse weather conditions during the late spring period as well as climatic-environmental problems in the African migrating and wintering areas have probably led to the extinction of the Woodchat Shrike as a breeding species (Brambilla *et al.*, 2017a; Brichetti & Grattini, 2017; Keller *et al.*, 2020).

Wood Lark *Lullula arborea*

During the breeding period the species is found in moderately wooded and bushy areas, often transitory in nature and located on poor soils where completely bare surfaces alternate with grassy stretches (Sirami *et al.*, 2011; Brichetti & Fracasso, 2020; Keller *et al.*, 2020). In Lombardy, a total of 1,000 pairs are estimated to breed in

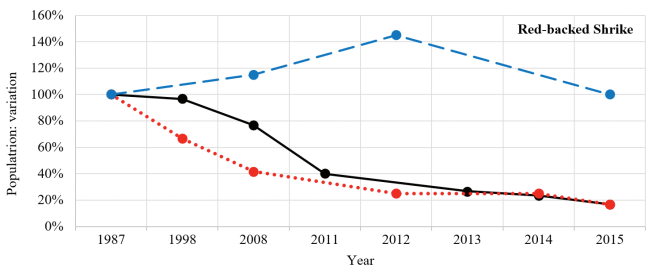

Fig. 9 - Percentage trend of the Red-backed Shrike population: Paitone (black line), Collebeato (red dots) and Cariadeghe (blue dash). / Andamento percentuale della popolazione di averla piccola: Paitone (linea continua nera), Collebeato (punteggiata rossa) e Cariadeghe (tratteggiata blu).

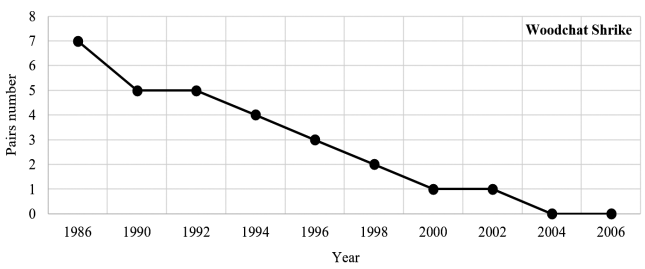

Fig. 10 - Trend of the Woodchat Shrike population (pairs) in a favorable part of the study area (250ha). / Andamento della popolazione di averla capirossa (coppie) in una parte favorevole dell'area di studio (250ha).

the Pavese Apennines as well as in very localized areas in the Alps and pre-Alps at elevations between 300 and 1,500 m asl (Vigorita & Cucè, 2008). In the province of Brescia the breeding of 13-14 pairs located only in the pre-Alps was ascertained between 2002 and 2005, at an elevation of 600-1300 m asl (Bertoli, 2010; Maestri & Voltolini, 2013), with the majority of pairs situated in thermophilic contexts between 600 and 800 m asl. In our area in 2002-2004 it nested at 600 m asl with 7-8 pairs in the municipality of Vallio (Maestri & Voltolini, 2013) and in 2004-2008 one pair nested at the edge of a quarry at an elevation of 400 m asl (Gobbini, 2007; Gobbini, pers. obs.). In the present research, a singing bird was contacted every year in a single site in the "A" area of the Maestri & Voltolini study (2013) where these authors had recorded between one and three pairs. The site is adjacent to a traditionally managed grassy vineyard located on the edges of a wood, an optimal habitat for the species, as highlighted by Bosco *et al.* (2019) and in the meta-analysis by Paiola *et al.* (2020). In our contexts, croplands and pastures and related ecotones at the edge of a wood constitute the preferred environment for the Wood Lark (Hawkes, 2019) even when these habitats are no longer exploited. The species, which has never been abundant in our study area, has therefore been further reduced due to the contraction of open areas and the now tall and dense grass that has followed the abandonment of grazing and of slash-and-burn of pastures (Sirami *et al.*, 2011). The Wood Lark is well suited to colonizing various environments even at high elevation and, therefore, the evolution of mountain pastures and prairies can favor its often transitory presence as evidenced, for example, in a prairie on Monte Guglielmo (Bertoli & Leo, pers. obs.).

Melodious Warbler *Hippolais polyglotta*

In our study area, the Melodious Warbler breeds in semi-open, sunny and generally dry environments with several shrubs and some tree cover (Brichetti & Fracasso, 2020). It tends to abandon environments where the vegetation evolves towards a very closed structure or where the presence of shrubs and trees is excessively scarce, and generally prefers plains and low elevations. Furthermore, the species can accept relatively wetter conditions even though, in our study area, these contexts are now completely wooded (Keller *et al.*, 2020). In Lombardy, approximately 4,000 pairs were estimated in 2016, over 70% of which are distributed in the plain, experiencing a growing population trend (Bani *et al.*, 2016). The province of Brescia hosts a population of 100-1,000 pairs (Brichetti, 1994) with a maximum density of 10-12 territories/10 ha in optimal habitats of karst hills (Brichetti & Cambi, 1985). The species is most widespread up to 600 m asl, with localized presences up to 1,000 m asl. In 1986, 38 pairs were detected in a grazed, rocky and strongly coppiced site of 45 ha in our study area, for a total density of 8.4 pairs/10 ha. (Micheli & Cambi, unpublished data). In the optimal environments of the municipality of Paitone, 1.7 pairs/10 ha were reported in 1995-1998, a figure which dropped to 1.2 in 2005-2008 and further reduced to 0.6 in 2021 (Gobbini, 2010; Gobbini pers. obs.). In the municipality of Mazzano in 2021, in a very favorable location characterized by an almost blocked succession due to widespread lithosol, a density of 8.3 pairs/10 ha (Gobbini pers. obs.) was recorded. In the survey, the Melodious Warbler was found in 28% of the sites, representing the second most common species. Among the sites, those less exposed to the south, with few trees and the least litter are preferred (Table 5). When tree coverage of 30% is reached, the species disappears. Its diffusion is maximum at low elevations, with the species also present in the "Parco delle Cave di San Polo", a flat area of 200 ha neighboring the study area. Here, the species has a density between 0.6 and 2.6 pairs/10 ha and is present in meadows where the presence of surface gravel has slowed down the secondary succession (Romanenghi, pers. obs.). Within the predictor range, at our latitude and within the slope range, the observed preference for more southerly exposures entails a maximum average variation of ± 10% of annual sunshine (Bartorelli, 1967) and of approximately ± 1.5°C of the annual temperature (Capelli & Stefani, 1984). Compared to the last decades of the 20th century, the Melodious Warbler has reduced its presence in our study area or has abandoned various sites due to an increase in litter, shrubs and tree encroachment, a phenomenon that started in the middle of the previous century and which is now almost completed. The excellent density detected in Mazzano in 2021, similar to Monte Camprelle in the 1980s, shows that the breeding population can still be large if suitable local conditions are present.

Barred Warbler *Curruca nisoria*

In Italy, in hilly contexts like ours, it bred on the edge of hedges and groves located in traditionally cultivated lands, shrublands and open areas. In the breeding area, the shrubby cover must be discontinuous and with scattered trees so as to form a mosaic environment (Cambi, 1979; Brichetti & Grattini, 2010; Ceresa *et al.*, 2020; authors' pers. obs.). However, the species is not strictly thermophilic as it also breeds near humid areas within its main range (Cambi, 1979; Keller *et al.*, 2020). Between 4-6 pairs were present on the Cariadeghe plateau in 1987 (Brichetti, 1993), although the species has not been observed since 2012 and is now considered extinct in that area (A.A.V.V., 2015). In 2005-2008, two pairs nested in the municipality of Paitone (Gobbini, 2010), but were no longer observed

Tab. 5 - GLM results of Melodious Warbler. / Risultanze dell'analisi GLM sul canapino.

Melodious Warbler	Estimate	Std. Error	Zvalue	Pr(>|z|)
Intercept	1.18	0.65	1.8	0.07
Percent tree cover	-0.074	0.025	-3.0	0.003
Elevation	-0.0044	0.0018	-2.4	0.02
Exposure, angle from S.	0.021	0.011	1.8	0.07
Grass litter: high amount	-0.71	0.41	-1.7	0.08
AUC: Area under the curve: 0.82; McFadden: 0.24				

in the following years (Gobbini, pers. obs.). In addition to the aforementioned sites, in the Garza valley, four pairs were present in the 1990s but became extinct in the early 2000s. In the context of this research the species was not contacted, therefore it may be considered extinct in the area, confirming what has already emerged for our province (Brichetti & Gargioni, 2016). The extinction of our population shown in Fig. 11 began in the late 1990s, similarly to what happened in South Tyrol (Ceresa, 2020). We can hypothesize that, at least in the study area, this extinction is not attributable to the use of pesticides, which are in fact totally absent, but to the change in landscape structure and especially to the general decline of a population located at the western limits of the species range. Historically, in Italy the species had a fluctuating trend with a peak in the 1980s-90s but since then has drastically decreased (Brichetti & Grattini, 2010).

Sardinian Warbler *Curruca melanocephala*

It is the most generalist among the analyzed species as it is present in various low-elevation thermophilic contexts, ranging from sparse woods to grasslands with scattered shrubs. Warm areas with mosaic vegetation and widespread presence of shrubs, even though located in disturbed contexts such as urbanized areas, are generally positively selected (Guillaumet & Prodon, 2011; Keller *et al.*, 2020). In Lombardy, between 500 and 1,000 pairs were estimated in 2012, of which 100-200 in our province (Brichetti, 1994; Vigorita & Cucè, 2008). The species, very rare until the 1970s, progressively colonized all suitable provincial areas within two decades starting from the Lake Garda area (Brichetti & Cambi, 1979; Brichetti & Fracasso, 2007-2015). In 1986, 12 pairs were recorded in 45 ha on Monte Camprelle, with a density of 2.7 pairs/10 ha. (Micheli & Cambi, unpublished data). In the municipality of Paitone, 15 pairs were surveyed in 1998, 18 in 2008 and 30 in 2021, with a maximum density of 1.9 pairs/10 ha being detected in 50 ha of scrubland (Gobbini, 2010; Gobbini, pers. obs.). The increase of the species presence in the quarry area, compared to the rest of the study area (see Fig. 12), may depend on the different stage of the secondary succession. Due to karst soil in the Paitone quarry area, the succession is currently in the shrub encroachment phase, the most favorable to the species, while in Collebeato it has already reached the sparse wood stage. In various areas, the greater soil fertility, due to frequent agricultural origin, has accelerated the transition to woods that have become increasingly closed and humid with significant *Rubus ssp*. undergrowth. In these contexts, the Blackcap *Sylvia atricapilla* prevails over the Sardinian Warbler (Schaefer & Barkow, 2004). The species was found in 49% of the sampled sites, thus confirming its position as the most ubiquitous species. The factors determining the presence of the Sardinian Warbler are summarized in Table 6, while those determining its density are shown Fig. 13. Its presence is favored by shrubs with an optimum coverage of 45 to 75% and this species rapidly disappears as the coverage increases. Another favorable factor is the presence of dense grass. The probability of its occurrence is reduced with an increase in elevation and tree presence, with total absence when the tree coverage is over 60%. GAM confirms what appeared from GLM. Contrary to the usual preference for intermediate situations (see Cramp & Perrins, 1994; Shirihai *et al.*, 2001), in our study the Sardinian Warbler

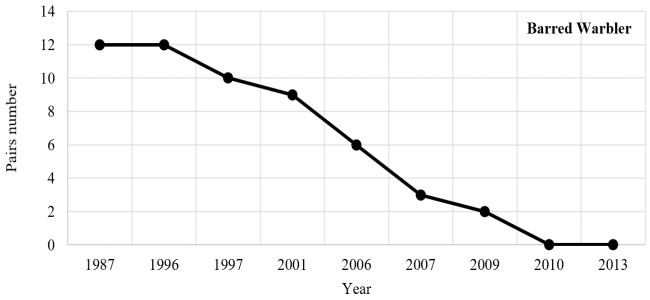

Fig. 11 - Trend of the population (pairs) of Barred Warbler in the study area. / Andamento della popolazione (coppie) di bigia padovana nell'area di studio.

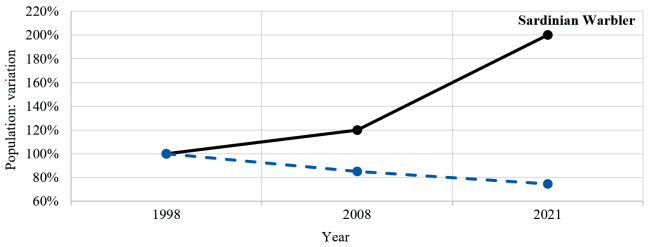

Fig. 12 - Percentage trend of the Sardinian Warbler population: Paitone (black, widespread presence of quarries) and Collebeato (blue, very limited presence of quarries). / Andamento percentuale della popolazione di occhiocotto: Paitone (linea nera, presenza diffusa di cave) e Collebeato (blu, presenza molto limitata di cave).

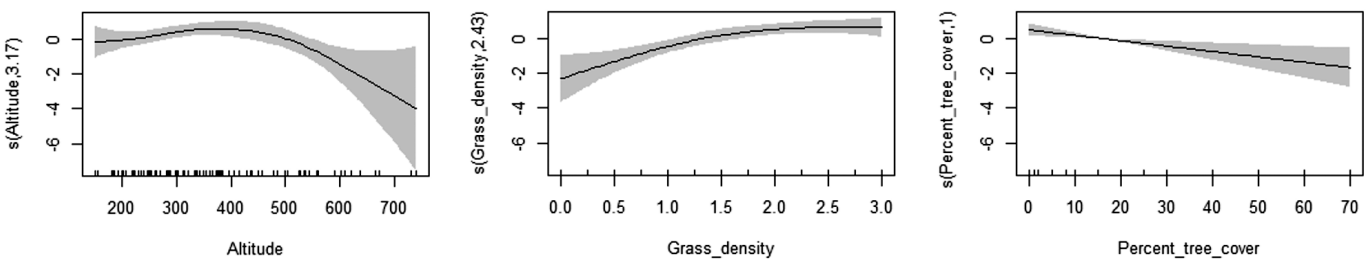

Fig. 13 - Correlation of the factors determining the Sardinian Warbler density (Elevation p <0.01, Grass density p <0.0002, Percent tree cover p <0.003). / Correlazione dei fattori che determinano la densità dell'occhiocotto (Altitudine: p <0.01, Densità dell'erba: p <0.0002 e Percentuale copertura arborea: p <0.003).

Tab. 6 - GLM results of Sardinian Warbler. / Risultanze dell'analisi GLM sull'occhiocotto.

Sardinian Warbler	Estimate	Std. Error	Zvalue	Pr(>|z|)
Intercept	-0,28	0,95	-0,3	0,77
Grass: density	1,5	0,4	3,8	0,001
Elevation	-0,0066	0,002	-3,1	0,002
Percent bush cover	0,041	0,015	2,7	0,007
Percent tree cover	-0,053	0,021	-2,5	0,012
AUC: 0.856; McFadden: 0.324				

does not select sites with shrubs of specific height. We have no grounded explanations for the species' preference for dense grass environments, but it appears to be the most important explanatory variable. We can hypothesize that in our thermophilic areas the widespread diffusion and the large ecological niche the species occupies is due to the substantial lack of competing species, as also reported by Martin & Thibault (1996) and Guillaumet & Prodon (2011).

Eastern Subalpine Warbler *Curruca cantillans*

The species is typical of environments characterized by dense and high shrubland interspersed with small and frequent grassy areas. It also requires the presence of scattered trees and/or wooded edges used as perching for song flights to mark the territory. The available studies often refer to *C. subalpina* (Brambilla *et al.*, 2007a; Coreau & Martin, 2007) and until now the differences between the reproductive habitats of *C. subalpina* and *C. cantillans cantillans* are not clearly defined yet, thus more specific studies are necessary (see Brambilla, 2007a vs. Morelli, 2013; Keller *et al.*, 2020). Among the analyzed species, it is the most linked to the advanced phase of the vegetational succession, when the presence of trees is close to constitute a homogeneous stand, with tall bushes forming the wood mantle (Shirihai *et al.*, 2001; Zbinden & Blondel, 1981). North of the Po River it is extremely localized, with only occasional breeding in pre-Alpine "xerothermic sites" (Brichetti & Fracasso, 2007-2015). In spring, our area is affected by the regular migration of the species, although in very small numbers. The median date of migration in the Brescia pre-Alpine area is May 3rd, which is the result of 30 previous opportunistic observations of almost all singing male individuals (Ornitho. it data plus authors' pers. obs.). This is a late date given the fact that the bulk of the migration occurs in mid-April (Brichetti & Fracasso, 2007-2015); in Veneto, similarly to our study area, the median date is April 25th. (Fracasso *et al.*, 2011). Undoubtedly, our sample includes some migrants that stop over as late as the end of June and also a large portion of the subsp. *cantillans* that has a delayed migratory flow (Brichetti & Fracasso, 2007-2015). Additionally, our previous data show that 58% of the population of Eastern Subalpine Warbler (n = 12) migrating through our area was made up by the subsp. *cantillans* and 42% by the subsp. *albistriata*, while the *C. subalpina* was never contacted. In neighboring Veneto (Fracasso *et al.*, 2011) the proportion between the two subspp. is inverted compared to our sample (*cantillans* 25%), even if the difference is not significant perhaps due to the limited number of samples (Fisher exact test, p> 0.19). Our data confirm what is already known (Lozano & Robson, 2011; Brambilla *et al.*, 2012;) on subsp. *albistriata* which, to reach its breeding sites east of the Friuli Region, can be seen during the spring migration flying in small numbers over the central and western Mediterranean Sea and has been recorded in southern France and along the Spanish coast (Lozano & Robson, 2011; Brambilla *et al*., 2012). The presence of subsp. *cantillans*, which typically breeds in southern and central Italy, could be due to some overshooting individuals (Brichetti & Fracasso, 2007-2015). At the listening points, the species was found in only five sites, all characterized by the presence of dense shrubs more than 1.8 meters high, with small clearings and few scattered trees. In subsequent specific rechecks, the species was no longer recontacted after June 20th except at one site. In this case, a female and two male singers of the subsp. *cantillans* were contacted throughout June, a situation classifiable as "possible breeding", which would be the fourth possible breeding known in our province (Brichetti & Gargioni, 2016). In Switzerland, all Eastern Subalpine Warbler subspp. are present, but the breeding ascertained concerns only the subsp. *albistriata* and the Western Subalpine Warbler *Curruca iberiae* (Marques & Jacquier, 2020). Our research also highlights that, in the absence of additional evidence, the repeated observations of territorial males present up to the end of June do not constitute proof of "possible breeding". In recent years, the breeding of the Eastern Subalpine Warbler appears increasingly frequent in the areas north of its usual range, as reported, for example, in Switzerland (Knaus *et al.*, 2018). However, the absence of systematic studies in our province does not allow us to confirm this trend with certainty.

Common Whitethroat *Curruca communis*

C. communis breeds in grassy environments with scattered low height shrubs (< 2 m) and few trees, although in the constant presence of extensive ecotonal margins (Tsiakiris, 2009). It does not require significant dry conditions, therefore edges between woods, shrubs and open areas in a temperate climate represent the optimum habitat for the species (Keller, 2020; Pollo, 2020). The estimated Lombardy population is 1,500-3,000 pairs (Vigorita & Cucè, 2008), while the province of Brescia hosts 200-300 pairs but in regression. In our province it is particularly widespread up to 700 m asl and there has been evidence of breeding at a maximum elevation of 1,600 m (Brichetti, 1994; Bertoli, 2010).

In 1986, nine pairs in 45 ha were surveyed in our study area on Monte Camprelle (Micheli & Cambi, unpublished data). In the municipality of Paitone, the 15 pairs surveyed in 1995-1998 decreased to four in 2005-2008 and to three in 2020 (Gobbini, 2010; Gobbini pers. obs.). On the Cariadeghe plateau, 11 pairs were breeding in

1987, but were no longer detected in 2012-2015 (Brichetti, 1993; AA.VV., 2015). In the present study, the Common Whitethroat was found in 25% of the sampled sites. The analysis shown in Table 7 highlights the species preference for high-elevation stations, with lack of terraces and few trees. It disappears where the tree cover exceeds 50%. Environments marked by extensive patches of bare soil and jagged contours are very favorable, particularly when characterized by long and wide ecotones between open areas and bushes. Among the various tested models showing similar significance (Δ AICc< 2), the *Patches of Bare Soil* variable can be replaced by *Rock Percentage, Bush Height* or *Quarry.* All these predictors have positive effects on the species presence with only a small loss of overall goodness of fit. The drastic decline of the Common Whitethroat in our areas can be explained by the encroachment of woods and shrubs followed by a reduction of long ecotones. The negative situation in the wintering areas undoubtedly constitutes a limit even though currently the conditions in Africa appear to be improving (see Tsiakiris, 2009).

Black Redstart *Phoenicurus ochruros*

In natural areas, it breeds in habitats with the simultaneous presence of rocky walls and/or large scattered boulders, useful for nest-building, and open areas where it searches for food. Stations with woods, dense shrubs and tall grasses are avoided (Sedláček *et al.*, 2004; Salgueiro *et al.*, 2020a). It always requires dry contexts, but not particularly xeric. It also breeds in synanthropic situations of various types, from urban centers to isolated ruins (Sedláček *et al.*, 2004; Keller *et al.*, 2020). It is a typically mountain species, although in recent times its range has expanded towards lower elevations, even reaching the plain (Brichetti & Fracasso, 2007-2015; Keller *et al.*, 2020). In Lombardy 11,000 pairs were estimated in 2016, with an annual increase of 3.5% from 1992 to 2016 (Bani *et al.*, 2016). Brichetti (1994) estimated a number of pairs exceeding 1,000 in the province of Brescia. Similarly, to what happened in the rest of Lombardy, the species spread progressively in the study area in the 1980s, then stabilized after 2000 (Bani *et al.*, 2016; authors' pers. obs.) and has now become widespread in all suitable contexts. In 2004-2005, 20 pairs were present in 30 surveyed quarries (Gobbini, 2007); in the municipality of Paitone, three pairs were present in active and disused quarries in 1995-1998 and two in 2005-2008 (Gobbini, 2010). The significant positive variables for the species presence, shown in Table 8, are as follows: the percentage of rocks, the presence of active quarries and, negatively, the tree cover. During the study, the species was contacted in 20 sites, 80% of which were located in quarries. Among the quarry sites, 19% were abandoned quarries. The model confirms the species dependence on rocky areas with low tree vegetation coverage; the lack of correlation with rock walls suggests the species tolerance for nesting close to the ground. The most advanced secondary succession stages were found to be less favorable due to the high presence of bushy and woody suprasoil, not suitable for the species trophic needs (Salgueiro *et al.*, 2020a).

Tab. 7 - GLM results of Common Whitethroat. / Risultanze dell'analisi GLM sulla sterpazzola.

Common Whitethroat	Estimate	Std. Error	Z value	Pr (>|z|)
Intercept	-4.1	0.95	-4.3	0.001
Elevation	0.0073	0.0018	4.0	0.001
Bare soil: one and big patch (score 4)	1.26	1.24	1.0	0.31 (n.s.)
Bare soil: medium and jagged patches (score 3)	1.71	0.65	2.7	0.009
Bare soil: many and little patches (score 2)	0.58	0.71	0.8	0.41 (n.s.)
Bare soil: few and little patches (score 1)	-0.78	0.97	-0.8	0.42 (n.s.)
Terraces: presence	-1.6	0.7	-2.2	0.03
Percent tree cover	-0.038	0.019	-1.9	0.05
AUC: Area under the curve: 0.87; McFadden: 0.316				

Rufous-tailed Rock-Thrush *Monticola saxatilis*

The species breeds in open and sunny rocky areas, rich in stony outcrops and always featuring large grassy patches. It therefore occupies a wide altitudinal range, from high-elevation grasslands to the edges of plains, with a maximum density between 1,000 and 2,000 m asl, while it is rare at low elevations (Brichetti & Fracasso, 2007-2015; Keller *et al.*, 2020). In Lombardy, 500-1,000 pairs were estimated at the end of the 1990s (Brichetti & Fracasso, 2007-2015), of which a few hundred in the province of Brescia (Brichetti & Cambi, 1985). A maximum density of 0.3 pairs/10 ha was also detected in two pre-Alpine areas of our province situated between 1,200 and 1,700 m asl, in xeric and endopercolative contexts similar to our study area (Cambi & Micheli, 1986; Bertoli, 2010).

The species has always been rare in the study area, often breeding occasionally. In the first decade of this century, only three pairs located in disused quarries were known, two of which were breeding at an elevation of 250 and 500 m asl (Gobbini, 2007) and one at 150 m (Leo in Brichetti & Fracasso, 2007-2015). Previously, a pair had reproduced until 1999 (nests at 320 and 460 m asl). Outside the extraction area, two additional pairs were known: one located in a stabilized rockslide surrounded by scat-

Tab. 8 - GLM results of Black Redstart. / Risultanze dell'analisi GLM sul codirosso spazzacamino.

Black Redstart	Estimate	Std. Error	Z value	Pr (>|z|)
Intercept	-2.85	0.95	-3.0	0.003
Percent rock cover	0.09	0.03	3.4	0.005
Quarry active	2.64	0.94	2.8	0.005
Percent tree cover	-0.10	0.03	-1.7	0.08
AUC: Area under the curve: 0.96; McFadden: 0.59				

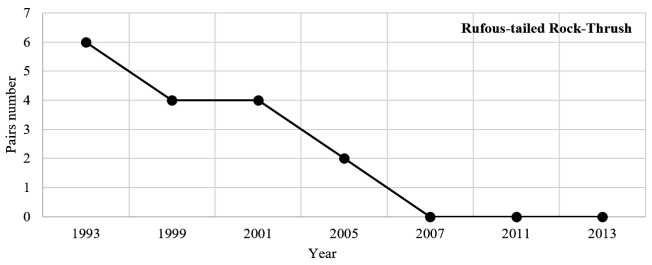

Fig. 14 - Trend of the Rufous-tailed Rock-Thrush population (pairs) in the study area. / Andamento della popolazione (coppie) del Codirossone nell'area di studio.

Table 9 - GLM results of Blue Rock-Thrush. / Risultanze dell'analisi GLM sul passero solitario.

Blue Rock-Thrush	Estimate	Std. Error	Z value	Pr (>|z|)
Intercept	-6.8	1.7	-4.1	0.001
Percent rock cover	0.04	0.01	2.7	0.007
Quarry active	3.14	1.19	2.6	0.008
Percent bare soil	0.054	0.023	2.4	0.02
Slope	5.7	2.4	2.3	0.02
AUC: Area under the curve: 0.99; McFadden: 0.803				

tered shrubs at 410 m asl and the other in a prairie with outcropping stones at 670 m asl. Both pairs became extinct in the mid-1990s (Leo, pers. obs.). Since the species has never been observed in the investigated areas during the present research, we consider it extinct. Its local extinction (Fig. 14) is similar to that documented by Basso & Piva (2019) for the Colli Euganei (northern Italy), which was possibly triggered off by habitat changes and, as also reported by Saporetti (2012) for Lombardy, occurred first in pairs breeding at low elevations. The quarries, an environment with lots of rocks and walls available, do not provide the extensive grassy meadows that the species requires to feed. The presence of neighboring populations located on the pre-Alps could contribute to a fast re-colonization if satisfactory environmental conditions returned (see Rey & Jacot, 2018).

Blue Rock-Thrush *Monticola solitarius*

It typically breeds in steep environments at low elevation, with a strong presence of rocks, as well as in sunny and arid conditions, characterized by low soil cover: an environment sometimes also shared with the Eastern Black-eared Wheatear. The species occurs mainly in natural rocky areas and more rarely in synanthropic situations where ruins or monuments are present (Keller *et al.*, 2020; Açaí Bracho Estévanez, 2021). Its range spreads up to 700 m asl, locally up to 1,100 m. Above this altitude it is replaced by the Rufous-tailed Rock-Thrush. In Lombardy, 50 pairs are estimated, of which 20-40 in the province of Brescia, mainly distributed along the coastal cliffs of the Garda and Iseo lakes and in thermophilic hills (Brichetti & Fracasso, 2007-2015). Of note is the species rare breeding at high elevations, up to 1,800 m asl, and in urban contexts (summary in Bertoli, 2010). In the study area, the Blue Rock-Thrush has been observed mainly in active and disused marble quarries. In 2004-2005, 28 pairs were recorded in 30 quarries between 200 and 700 m asl. In the municipality of Paitone, six pairs, recorded in 1995-1998, rose to eight in 2005-2008 and reduced to four in 2020 and to three in 2021 (Gobbini, 2007, 2010; Gobbini, pers. obs.). Outside the quarry area, seven pairs are known (Leo, pers. obs.). In the study, the species was found in 18.6% of the sampled locations. Our analysis highlights the species preference for territories located in active quarries, particularly in rather steep contexts characterized by bare soil and rocks (see Table 9). The model obtained has proven especially effective in explaining the presence of the species. The vast majority of the active quarries sampled was found to be occupied (94%) while the abandoned ones recorded a significant lower presence (29%), thus indicating non-random difference (Fisher Exact Test, p=0.003). The species slowly tends to disappear following the abandonment of mining activities, as it happened in two quarries in the study area where the Blue Rock-Thrush disappeared within 40-50 years after the end of mining activities. According to Gilardelli *et al.* (2016), the bare soil in abandoned quarries evolves into grassland within 7-21 years and into scrubland in 42-58 years. The vertical walls that have remained unchanged can still provide useful opportunities for the species nesting and singing, but an abandoned quarry can no longer be a suitable site for the Blue Rock-Thrush due to the absence of the trophic niche made up of grasslands. These results have also been observed in Spain (see Castillo *et al.*, 2008). In the light of the authors' knowledge and *contra* previous estimations, at least 40 pairs are currently present in the study area alone. It can therefore be assumed that the species population in Lombardy is higher than estimated in previous studies.

Eastern Black-eared Wheatear *Oenanthe melanoleuca*

In Italy, the species is present in habitats characterized by bare soil and large rocky areas located in contexts with poor tree cover and sparse vegetation, all of which situated in highly xeric and sometimes steep habitats (see Guerrieri *et al.*, 2001 for central Italy; Micheli, 2005 for Trentino; Brambilla *et al.*, 2013 for southern Italy). Brambilla's study (2013) shows that the presence of the species is influenced by three environmental variables: bare soil, pastured meadows and SE exposure. In Micheli's study (2005) the species was present on moraines and rock falls with scarce vegetation cover. In our province, the species was detected only in quarries, especially if active, because they are the most common rocky locations with extreme xeric conditions and low vegetation. There, the species was observed in association with the Blue Rock-Thrush (Gobbini, 2007) as it occurs in other regions (Açaí Bracho Estévanez, 2021). The Italian pairs were mostly located in the southern regions, with only small and disjointed nuclei on the verge of extinction in northern Italy (Parodi, 2006; Speranza, 2020). These nuclei constitute the northern limit of the European area (Keller *et al.*,

2020). As mentioned, the only known breeding sites in our province, observed since the 1960s, were all located in quarries falling within our study area. The size of the population in the 1980s, already declining at that time, was estimated at 3-10 pairs (Brichetti & Cambi, 1985). In 2003, a census carried out in 30 quarries found four pairs, which decreased to two in 2004-2005 (Gobbini, 2007). In 2007, three males and one female were observed (Micheli & Rizzardini, pers. obs.). The last two observations, both of a single singing bird, date back in May 2011 and June 2013 and were not followed by actual nesting (Gobbini & Leo, pers. obs.). Extinction is shown in Fig. 15. All observations refer to *O. melanoleuca* in the *stapazina* (which is the majority) and *aurita* morphs. In addition to the survey points, during the present investigation the species was actively sought, but without success in locations previously occupied. Since some of these quarries are not fully accessible, the authors cannot totally exclude the possible episodic presence of the species in these sites. The causes of the extinction should mainly be attributed to the weakness of a subpopulation located at the northern range limit during a negative trend of the species general dynamics rather than to specific habitat problems. In our study area, unlike other contexts in northern Italy, suitable habitats are still present as, although the abandoned quarries are becoming increasingly grassed, active and suitable quarries remain widespread.

Tawny Pipit *Anthus campestris*

It breeds in arid, steppe-like open environments, characterized by a sparse herbaceous cover and by the limited but necessary presence of scattered bushes and/or boulders which the species utilizes as perches for territorial singing (Keller *et al.*, 2020). In the Trebbia valley (northern Apennines, Lombardy) the presence of the species is positively associated with grasslands and negatively associated with wooded and bushy environments (Brambilla & Rubolini, 2005). The species is undergoing a negative trend presumably caused by an increase in soil plant cover, which led to the transition to more fertile substrates and therefore to fewer bare areas and a consequent change of the entomofauna (van Turnhout, 2005). In Lombardy, the species breeds extensively in the open and arid environments of the Oltrepò Pavese while it is mainly localized in the pre-Alps. In the mid-1980s, Brichetti & Fasola (1990) estimated fewer than 100 pairs, 10-20 of which in the province of Brescia. Currently, it is regularly present

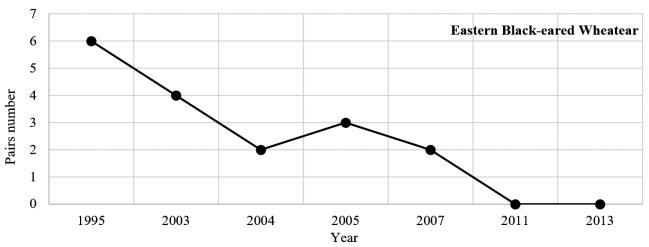

Fig. 15 - Trend of the Eastern Black-eared Wheatear population (pairs) in the study area. / Andamento della popolazione (coppie) di Monachella orientale nell'area di studio.

in the Brescia plain with 1-2 individuals only at the civil airport of Montichiari (authors' pers. obs.). Occasional reports come from the foothills: in the 1980s, 1-2 pairs were detected in the Valle Sabbia at 1,300 m asl on grassy and stony steep slopes (Cambi & Micheli, unpublished data), while in June 2014-2015 one individual was observed in a meadow at 1,730 m asl in Collio and one was detected on 1 ha stony plateau devoid of vegetation at 1,850 m asl (Bertoli, pers. obs.). In the municipalities of Nuvolento e Mazzano, in the 1980s few pairs were breeding on the arid platforms of active quarries, a habitat with sparse and low herbaceous vegetation (Brichetti & Cambi, 1985). In the period 2004-2005, the nesting of two pairs in disused quarries in Mazzano and Botticino was ascertained (Gobbini, 2007), and their presence was established until 2007 (Gobbini, pers. obs.). The irregular breeding of a pair, which continued until 2007, was discovered on Colle S. Eusebio (Leo, pers. obs.), in a badland-like area. The fact that the species was not contacted during our research is further evidence of the extinction of the species in the study area. While suitable environmental conditions are still present in certain areas of the quarries, the remaining low slopes have proved unsuitable for the species as they currently lack any bare soil.

Corn Bunting *Emberiza calandra*

It breeds in flat open environments of various types, such as pastures, steppes and arable land, characterized by the absence of wooded areas but with a few shrubs at most. A moderately xeric environment favors the species due to the greater presence of grass. (Donald & Aebischer, 1997; Tsiakiris, 2009). Studies carried out in Lombardy by Brambilla *et al.* (2009b) have shown that the preferred breeding environment consists of arable land featuring rocks and isolated hedges. In the 1980s, its distribution in Lombardy was concentrated in the Oltrepò Pavese, in the central-eastern sectors of the plain as well as in the pre-Alpine hills (Brichetti & Fasola, 1990). In 2008 Vigorita & Cucè (2008) estimated 1,500-3,000 pairs but suffering a moderate decline. In the province of Brescia, 100-300 pairs were estimated (Brichetti, 1994), especially in the Garda morainic amphitheater, with a density of 3-4 pairs/10 ha. In recent years, it appears that the species is mainly confined to the Montichiari-Ghedi airport area (eight singing males, Gagliardi *et al.*, 2009) while it maintains a scattered presence in the Garda area and, more sporadically, in the plains. In the study area, the species was never abundant, as it lacked the ideal habitat of arable land or flat grasslands. It was only present at the edge of some quarries and in certain sub-flat meadows, exclusively during the breeding season. In the hills of Paitone, five pairs were surveyed in the period 1995-1998 but none in the period 2005-2008 (Gobbini, 2010), with the last breeding occurring in 2013 in the meadows of Marguzzo (municipality of Paitone) at 440 m asl. In 1986, two pairs were observed in a 45 ha area on Monte Camprelle, at an altitude of 530 m asl (Micheli & Cambi, unpublished data). The two pairs soon reduced to one, until extinction in 2000 (Gobbini, pers. obs.). On the hills of Campiani (municipality of Collebeato) the last breeding dates back

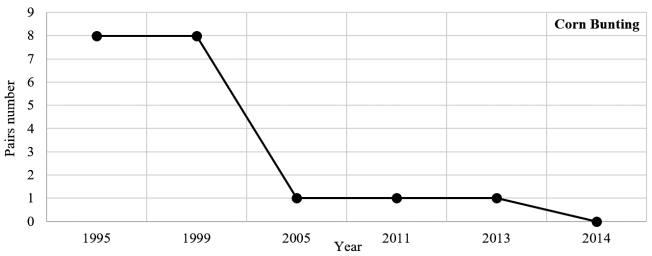

Fig. 16 - Trend of the Corn Bunting population (pairs) in the study area. / Andamento della popolazione di Strillozzo (coppie) in una parte dell'area di studio.

to 1998 (Leo, pers. obs.). The species was not contacted during the present investigation. The local extinction of the species (Fig. 16) is explained by the complete disappearance of already scarce suitable habitats as well as by a general regional decrease.

Rock Bunting *Emberiza cia*

At low altitudes and in our latitudes, the species always breeds on steep slopes facing south in semi-steppe environments characterized by the presence of rocky outcrops, shrubs and trees. This species can be usually found in areas that almost always feature furrowed fields, badlands or narrow streams (Sánchez *et al.*, 2009; authors' pers. obs.), an intermediate environment between the two cases classified by Sánchez *et al.* (2009): the Mediterranean and Central European. In Lombardy, 1,000-2,000 pairs were estimated, but the population trend was unknown (Vigorita & Cucè, 2008), while 200-500 pairs were present in the province of Brescia at the beginning of the 1990s, exhibiting a tendency towards stability or a slight decrease (Brichetti, 1994). In the study area, the species was widespread, although not abundant, in all suitable contexts. In the period 1995-2008, the species was present with two stable pairs in the municipality of Paitone (Gobbini, 2010), with additional occurrence at 250 m asl in Mazzano (Brichetti & Gargioni, 2009). The present study has identified seven active breeding sites, five of which located near quarries, a distribution further supported by authors' observations in unsampled sites of the study area. The presence of the species has been increasing in the quarries, although it has often decreased in the remaining environments where it tends to local extinctions. In the municipality of Caino, in the northern part of the area, in an 800 m transect three singers observed in 1995 and 2001 declined to only one in 2020. The different evolution of disused quarry areas, which have shifted from extreme edaphic and vegetational conditions towards a moderate herbaceous cover, compared to the other areas, which have changed from grassland to markedly shrubland, explains the different dynamics affecting these small populations. The decrease of open areas with bare soil and low herbaceous cover, also due to a reduction in prescribed fires, probably constitutes one of the causes of this negative trend (Pons & Clavero, 2010). As anecdotal evidence, the species has been reported to breed in a shrubby area a year following a fire.

Cirl Bunting *Emberiza cirlus*

It breeds in open, sunny and not excessively arid environments, characterized by low slopes and an extensive herbaceous cover, provided they feature shrubby patches and some elevated perches. In our province, these environments are located in hilly areas that have mainly been traditionally cultivated in the form of mosaic landscape (Maestri & Voltolini, 2013; authors' pers. obs.). Orchards, olive groves or other intensively farmed crops do not represent a favorable habitat due to the lack of a bushy layer and the scarcity of insects caused by the use of pesticides (Brambilla *et. al*., 2008).

In Lombardy, the species occurrence was scarce in the Alpine region throughout the 1980s, as it was widespread only in the Pavia Apennines (Brichetti & Fasola, 1990). The last regional estimate, dating back to 2007, reported 1,500-3,000 pairs in slight increase (Vigorita & Cucè, 2008).

In the province of Brescia the species seems to have expanded in number and range in recent decades, especially in the thermophilic hills, an evolution perhaps justified by the increased ornithological knowledge of the territory (Brichetti & Gargioni, 2009). However, it should be taken into account that some local elderly farmers interviewed by the authors have claimed that the species was one of the most widespread in cultivated areas in the years following the Second World War and suffered a drastic decline in the 1960s-1970s.

In the study area, one pair was initially present in the municipality of Paitone in the period 1995-1998, increasing to three in 2005-2008 (Gobbini, 2010). Additionally, a probable breeding was reported in 2015 on the Cariadeghe plateau (AA.VV., 2015). In the study, the species was found in 12.7% of the listening points. As shown in Table 10, the species favors vineyards, avoids steep habitats and prefers areas with less southern exposure. All the vineyards present in the study area are now intensively exploited and managed, in order to reduce foliage, with trellis systems based on various types of espalier (e.g.: Guyot) and undergo severe green pruning in spring. These practices are of particular concern for the avifauna (Paiola *et al*., 2020). However, these vineyards are often limited in extension, surrounded by shrubs and/or woods and are rarely weeded. Consequently they have become an intermediate habitat for this species with its grass inter-rows, suitable for feeding, as well as shrubs and trees, suitable for nesting and territorial singing (Brambilla *et. al*., 2008; Paiola *et al.*, 2020). For considerations on exposure, please refer to the Melodious Warbler.

Tab. 10 - GLM results for Cirl Bunting. / Risultanze dell'analisi GLM sullo zigolo nero.

Cirl Bunting	Estimate	Std. Error	Zvalue	Pr(>|z|)
Intercept	-2.04	0.7	-2.9	0.003
Principalplants: vineyards	2.1	0.6	3.8	0.001
Exposure, angle from S	0.025	0.015	1.7	0.09
Slope	-3,0	1.8	-1.6	0.1
AUC: Area under the curve: 0.78; McFadden: 0.24				

Ortolan Bunting *Emberiza hortulana*

The species usually breeds in open or semi-open habitats of various types while its presence in the southern part of the range is often associated with dry areas featuring sparse vegetation, scattered trees and bare soil (Menz & Arlettaz, 2012; Brambilla *et al.*, 2017b; Keller, 2020). Post-fire situations favor the species (Pons & Clavero, 2010; Menz & Arlettaz, 2012) which disappears as the vegetation succession progresses (Bogliani *et al.*, 2003; Sirami *et al.*, 2007).

In the Oltrepò Pavese, the density of the species is higher in the presence of a great shrub cover, hedges, alfalfa *Medicago sativa* coverage of around 50% as well as 5-20% bare soil, which represents a decisive factor (Brambilla *et al.*, 2016). As a general rule, bare soil or sparse grass areas are the preferred foraging habitat for the species (Menz & Arlettaz, 2012). In central Italy, a higher density was found at altitudes below 500 m asl characterized by a slope of less than 15% (Pruscini *et al.*, 2013). In the province of Brescia, 50-150 pairs were estimated in the period 1980-1984 (Brichetti & Cambi, 1985). Later published data give evidence of only three breeding sites: one in 1987 above Lumezzane at 1,000 m asl, one in 1989 in the plain near Travagliato (Brichetti, 1992) and one in 2003-2004 with 1-2 pairs in the eastern Brescia pre-Alps (Maestri & Voltolini, 2013). In recent times (2018-2020) the only observation published on Ornitho.it is of a single bird in late migration along the lowland stretch of the Oglio river. In the period 1994-1999, during the breeding census of the Brescia plain, no individual was contacted (Brichetti & Gargioni, 2005).

In the study area, the species was known to breed in five locations (for the trend in three of them see Fig. 17). The following data are based on the authors' observations, unless otherwise stated:

1. Mazzano, in a 15 ha disused quarry colonized by Black Poplar *Populus nigra* shrubs, at an elevation of 460 m asl. The area was visited uninterruptedly from 1999 to 2010, leading to the subsequent results: eight singers in 1999, three in 2000, three in 2001, three in 2002, three in 2003, five in 2004, five in 2005, five in 2006, four in 2007, two in 2008, one in 2009, one in 2010. The species was no longer observed after the year 2010.

2. Brescia, on the south side of Monte Maddalena in an eight ha meadow at 600 m asl, two singers were detected until 2005 and one in 2006.

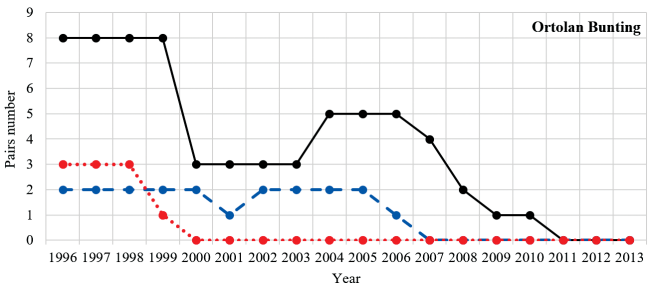

Fig. 17 - Extinction of Ortolan Bunting in three sub-areas of the study. Mazzano (continuous black line), Concesio (dotted red) and Brescia (dashed blue). / Estinzione dell'ortolano in tre sotto-aree dello studio. Mazzano (linea continua nera), Concesio (tratteggiata rossa) e Brescia (tratteggiata blu).

3. Concesio, three singers were identified in a 14 ha sunny meadow at 250 m asl until 1998, while a single singer reported in 1999 was no longer contacted in the following years.

4. Nuvolera, on the southern slope of Monte Camprelle, at an average elevation of 250 m asl, 11 inhabited territories spread over 45 ha were found in 1986 (Micheli & Cambi, unpublished data).

5. Vallio, where 1-2 pairs were present in 2003 and 2004 (Maestri & Voltolini, 2013).

During the present research, the species was not recorded in any of the 105 sites. The causes of its extinction have been hypothesized to be the dense afforestation and grassing after the abandonment of pastoral and agricultural activities as well as the general status of the Ortolan Bunting. The quarry environment in point 1), decidedly favorable for the species given its 5% slope, remained stable during the mining exploitation until the 1950s. The initially almost absent shrubby cover has currently risen to 50% and the original sparsely grassed and bare ground is now covered with dense grass. A similar phenomenon occurred in the other sites, too. At the habitat level, the favoring presence of bare areas located in slightly steep environments is currently only limited to active quarries where the rock or gravel substrate is nevertheless unsuitable for the species. Furthermore, the areas inhabited by the species in the past are now renaturalized and have changed into dense shrublands or have been converted to intensive vineyards, the latter constituting an unsuitable habitat (Brambilla *et al.*, 2017b). This dramatic situation is also shared by other suitable areas, such as the Pavese Apennines, where 75% of the habitat has been lost in the last 60 years (Brambilla *et al.*, 2017b). In conclusion, it should be added that the Ortolan Bunting presence in our province represents the northern limit of its Italian range and that the decline of the species in Europe has also greatly decreased the contingents observed during migration (Spina & Volponi, 2008; authors' pers. obs.).

Structure of the bird community

Excluding the species observed in flight as well as the more ubiquitous ones, the surveyed bird species were classified according to the reproductive habitats reported in Brichetti & Fracasso (2007-2015). The species related to woods or more microthermic contexts were found in 89% of the sites, while the average percentage of these species represented roughly 57% of the total taxa observed at each site. The sites located in quarries show a similar number of woodland species to those of the remaining areas, even though vegetational succession in the quarries is delayed (Wilcoxon rank sum test, $W = 1039$, $p > 0.71$). An "island" effect has been hypothesized because the quarries are inscribed in expanding wooded areas. On the other hand, the difference in the number of species associated to open habitats is evident (Wilcoxon rank sum test, $W = 482$, $p < 0.001$), in fact the quarries host at least one more species (2.9 vs. 1.6). An acceptable clustering of the surveyed sites using all the species detected or the aforementioned reproductive habitat classification is not feasible. This highlights the substantial uniformity of the taxa and classes present in the various sites (Kmeans clu-

stering with PCA, not shown). Therefore, the open areas surveyed are now surrounded and/or heavily penetrated by woods and their bird community, thus largely losing the original xerophilic or thermophilic character of its avifauna. The GAM analysis of the environmental variables determining the number of relevant species per site has ascertained the significance of two variables: the tree cover and the presence of quarries. Little tree cover allows the species to find various open environments, with different densities of shrubs and of the other measured factors. On the other hand, the presence of quarries increases the general richness of the avifauna adding taxa typical of rocky environments. In addition, quarries also help to slightly dampen the negative effects resulting from the presence of trees. These two factors are shown in Fig. 18.

DISCUSSION

Our study strongly indicates that the open or semi-open areas in our hills are experiencing a sharp decline, as they have halved in size in the last 60 years. Numerical estimates should be considered conservative due to the underestimated GIS classification of open and shrubby areas (Table 1). When assessed qualitatively, the situation appears even more dramatic; the few remaining open areas are largely steep and covered with shrubs and the trees are increasing quickly. Large, open, grassy and slightly bushy areas, as well as semi-flat environments with low height grass, are practically absent (Fig. 8). The few that have been found (remains of old *segàboi*) are all decidedly steep and of irrelevant extension, which makes them essentially unsuitable for the species of our research. In environments on more endopercolative soils, such as those located inside or close to quarries or in karst contexts (cluster 1, Fig. 5), the vegetational succession is at a more primitive phase (Fig. 19), and plant species undergo a slower recovery (Gilardelli *et al.*, 2016). This delay is also linked to the scarce pedogenesis of the large limestone outcrops of the "Corna" type, especially present in this area (Boni *et al.*, 1968). The most rare and typical species of steppe or sub-Mediterranean areas (sensu lato) are concentrated here, even though to a lesser extent than in the past. In the last 60 years, the ongoing global warming has resulted in an estimated increase of the average yearly temperature of 2.1-2.7 °C in the study area (Copernicus and ECMWF dataset, accessed via https://climatechange.europeandatajournalism.eu) with progressively more frequent hot-dry periods (Brunetti *et al.*, 2006). However, it has emerged that this increase in xerophilic conditions (Martini *et al.*, 2012) was not matched by a greater presence of Mediterranean or steppe chorological birds. Our situation is more akin to that found in the Spanish hills of Catalonia (Prodon, 2020) and different from what is happening in Switzerland (Knaus *et al.*, 2018). The most significant breeding in Switzerland occurred in Valais, a relatively xeric region characterized by primitive soils and a vegetational succession in its starting phase (Marques & Jacquier, 2020). So far, even in the presence of a decrease in spring and summer precipitations, the temperature increase in our area is not such as to prevent an evolution towards forests as the rain is more than sufficient to compensate for the increased evapotranspiration (Brunetti *et al.*, 2006). Moreover, in the year 2022, characterized by an outstanding and prolonged summer xericity, the majority of shrubs and trees in the most endopercolative areas (particularly rocky and steep environments) were severely damaged but turned green again in September (authors' pers. obs.). However, it is too early to determine the future impact on vegetation of these extreme weather conditions on vegetation. Therefore, as already pointed out by Blondel & Farrè (1988), secondary succession was found to lead to an increase in avifauna linked to woods as well as an increase in widely distributed species of no conservation concern (Preiss *et al.*, 1997; Sirami *et al.*, 2007). The Eurosiberian avifauna is increasing at the expense of its Mediterranean counterpart (Prodon, 2020), with the greatest decline affecting migratory species (Sirami *et al.*, 2008). This trend has been confirmed by the ubiquitous presence of avifauna associated to wood coenoses and to relatively microthermal shrubs (e.g.: *Rubus* ssp.). These species were absent or considerably less widespread in earlier times (e.g.: *Picidae* and *Certhiidae*). Today's landscape, especially on a medium and large scale, appears significantly more trivialized than in the past, as it is also happening in many other similar situations (Tscharntke *et al.*, 2005; review in Sirami *et al*., 2008). The value of open areas managed by traditional agriculture for the preservation of these birds, all of which remain in a difficult state of conservation, has been certified in environments partly similar to ours by Farina (1997), Laiolo (2005) and Brambilla *et al.* (2010). Last but not least, the loss of cultural heritage stemming from activities connected to open areas should not be underestimated (Moreira & Russo, 2007; Capra, 2008; Plieninger *et al.*, 2015; Crumley *et al.*, 2017). Nevertheless, the Sardinian Warbler has resisted and sometimes expanded thanks to its generalism, the Black Redstart has colonized the quarries district and the Melodious Warbler has survived where gravel lithosols have not become strongly grassed. The Blue Rock-Thrush has only moderately suffered from these changes, as it is mostly present in quarries where the succession is delayed or stopped (Fig. 20), even though hints of its

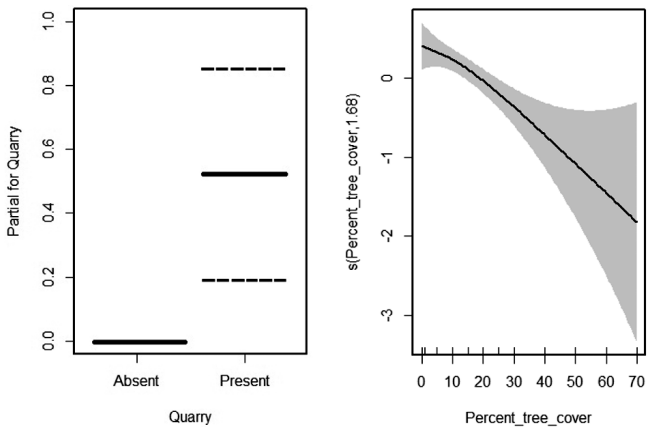

Fig. 18 - Trend of the factors determining species richness in open environments (in both factors p <0.002). / Andamento dei fattori che determinano la ricchezza di specie in ambienti aperti (in entrambi i fattori p<0.002).

Fig. 19 - Karren now colonized by bushes although still in the primitive succession stage. / Karren oramai colonizzati da cespugli sebbene ancora in fase di successione primitiva. (Photo: / Foto: G. Romanenghi).

Fig. 20 - Active quarry with overburden and benches, habitat of Blue Rock-Thrush and once of Eastern Black-eared Wheatear. / Cava attiva con riporti di terra e pareti, habitat preferenziale di passero solitario e un tempo di monachella orientale. (Photo: / Foto: M. Gobbini).

decline exist in case of exploitation abandonment. Some species, such as the Wood Lark and Tawny Pipit, now extinct in the study area, have tended to colonize higher altitudes where, due to the temperature increase, they can find more suitable meadows. This tendency has also been observed in other species in the province of Brescia, the most striking being the Short-toed Snake Eagle *Circaetus gallicus* (authors' pers. obs.) even if the evidence of these general ascents remains weak and debated (see review by Vitasse *et al.*, 2021).

The conditions of advanced succession, before total afforestation, could be favorable to the settlement of the Eastern Subalpine Warbler (Sirami *et al.*, 2007), the species that requires open areas and low vegetation the least, although further medium-long term studies in our area are needed to confirm this hypothesis.

Even though the present research has focused on the variation of breeding habitats, the extinction or decline of migratory species may, however, have other contributing causes such as specific conditions in the wintering areas. In the study area, hunting pressure and use of pesticides are not significantly relevant, but they may have a high impact in wintering areas (see summary and bibliography in Vickery *et al.*, 2014).

Concerning the Eastern Black-eared Wheatear, its highly probable disappearance is attributable to the general trend of the species rather than to local factors, as the study area currently hosts many sites suitable for its breeding.

Our study shows that the biodiversity of the area has lost seven of the analyzed species (Ortolan Bunting, Tawny Pipit, Red-backed Shrike, Corn Bunting, Eastern Black-eared Wheatear, Rufous-tailed Rock-Thrush and Barred Warbler) and has gained the presence of the Black Redstart and of many woodland species that were already widely spread in the neighboring territory. In accordance with the timing of the vegetational succession, as per Sirami *et al.* (2007), the decline of the species studied began in the 1980s, approximately 20-30 years after the abandonment of extensive agricultural practices and was almost completed by the beginning of the 21st century. These losses are all relevant at the provincial level, and only for the Eastern Black-eared Wheatear and Ortolan bunting, for all northern Italy. However, given the small size of the populations once present, their extinction constitutes more a biogeographical loss rather than a threat to all the breeding contingents.

The residual area, where open habitats are mostly widespread, is located north-east of Brescia. In this district, the presence of active or abandoned quarries is very high, constituting the so-called "Brescian Karst", i.e. the second largest marble extraction center in Italy with 135 censused active quarries (Gilardelli *et al.*, 2016). As highlighted for the Blue Rock-Thrush, the abandonment of mining exploitation has been reported to reduce medium-scale bird biodiversity. Therefore, any recovery effort should take this phenomenon into account. Nevertheless, a recurrent approach consists in covering the less vertical areas with landfill, sowings and plantings to favor the establishment of wooded topsoil and netting of walls (Boscutti *et al.*, 2017). As a consequence of this approach, the initial conditions of the succession are accelerated, leading to the loss of rare and localized species (Germano *et al.*, 2016; Salgueiro *et al.*, 2020b). Almost all the rocky walls in our area, which constitute the exclusive breeding habitat for the Eagle Owl, are located in quarries (Leo & Capelli, 2007; authors' pers. obs.). Under a bird conservationist approach, a slow or partial renaturalization of the quarries and their neighbouring areas should therefore be encouraged, as it also provides an even cheaper approach than that of an active recovery (Salgueiro *et al.*, 2020a, 2020b).

The survey and related analyses shown here present some limitations due to the small extension of the investigated area which excludes currently suitable habitats around the lakes of Garda and Iseo as well as a few "xerothermic sites" located in the Brescia valleys (see Fig. 1). Another limitation of our study lies in data imbalance, an intrinsic consequence when sampling a population often close to extinction. As a result, the dataset contains significantly more absences than presences, a factor resulting in a reduction of the number of predictors and in weak models which suggest a cautious interpretation of the outcomes. Finally, the models found can sometimes explain only a limited part of the variance, the one related to the "differences within sunny open areas", as the analysis is carried out inside suitable areas, thus excluding unsuitable habitats and their related strong negative predictors.

CONCLUSIONS

In our Avanalpica region, as in many parts of the sunny hill belt of northern Italy, the creation of open areas in the absence of anthropic interventions can only occur due to forest fires and/or extreme weather events (e.g. the Vaia storm). In addition, the widespread and intense presence of large wild herbivores or particular edaphic conditions may enable the natural maintenance of these areas (Svenning, 2002; Navarro *et al.*, 2015). Currently, human interventions only involve the introduction of vineyards and olive groves of negligible naturalistic value. Other desirable agronomic interventions are no longer economically self-sufficient and need to be subsidized in order to be implemented and last over time (Brambilla *et al.*, 2010). The establishment in 1995 of the "Parco delle Colline di Brescia", which covers a large portion of the study area, has not yet reversed the aforementioned evolution. Probably, not even the increase in temperatures following global warming will help restore the previous situation, although it can help slow down the evolution. Nevertheless, given their economic payback, the survival of the active quarries and related areas can be expected. Even though they are ephemeral habitats creating a significant environmental and landscape impact, quarries are now inherent to the history of the local communities and their material culture.

In conclusion, it is easy to hypothesize that the territory studied will appear mostly forested in the future, leading to the near extinction of the ornithic community associated to open areas (Sirami *et al*., 2008). However, the current evolution must be considered as a complex,

albeit debated, process of renaturalization of the area back to its original conditions, thus favoring a situation of greater stability and resilience in the long term (Lasanta *et al.*, 2015). In particular, we can expect a reduction of ephemeral environments and a renewed potential for ungulates and large carnivores (Svenning, 2002; Navarro *et al.*, 2015). The processes described herein include other positive aspects, such as an increase in carbon fixation and greater soil stability in the long term. However, the biodiversity of the avifauna will undoubtedly be reduced at various scales, the landscape trivialized and its associated material culture lost (Pereira *et al.*, 2012; Navarro *et al.*, 2015; Lasanta *et al.*, 2015).

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REFERENCES

AA.VV., 2015 – Altopiano di Cariadeghe: conservazione di ambienti prativi di interesse comunitario e di habitat per l'avifauna nidificante e migratoria. *Fondazione Lombardia per l'Ambiente* e *Comune di Serle*.

Açaí Bracho Estévanez C., 2021 – A case of spatial coexistence among Black Wheatear *Oenanthe leucura*, Black-eared Wheatear *Oenanthe hispanica* and Blue Rock-Thrush *Monticola solitarius* in the Western Mediterranean. *Avocetta* 45 (1): 95-103. <https://doi.org/10.30456/AVO.2021102>

Andreis C., 1991 – Lineamenti vegetazionali pre-agricoli della pianura e della collina bresciana. In: Il paesaggio bresciano. Trasformazione e problemi. Atti del convegno di studi. AA.VV. *Ateneo di Brescia e Fondazione Banca Credito agrario bresciano*, Brescia: 53-72.

Archetti G., 1998 – Tempus vindemie: per la storia delle vigne e del vino nell'Europa medievale. *Fondazione civiltà bresciana*, Brescia.

Armiraglio S., 2020 – Biodiversità nel comune di Brescia. In: Relazione sullo stato dell'Ambiente del Comune di Brescia secondo il metodo DPSIR. AA.VV. *Comune di Brescia*.

Bani L., Luppi M. & Orioli V., 2016 – Monitoraggio dell'avifauna nidificante in Lombardia. *Dipartimento di Scienze dell'Ambiente e della Terra e Università degli Studi di Milano Bicocca*.

Barton K., 2022 – *MuMIn*: Multi-Model Inference. R package version 1.46.

Bartorelli U., 1967 – Tavole numeriche dell'assolazione annua. *Annuali dell'Accademia Italiana di Scienze Forestali*, 16: 61-83.

Basso M. & Piva L. (eds.), 2019 – Atlante degli uccelli nidificanti in provincia di Padova (2006-2010). *Associazione Faunisti Veneti*.

Belfanti M. & Taccolini M. (eds.), 2008 – La rivoluzione verde del XX secolo, in Storia dell'agricoltura bresciana. *Fondazione Civiltà Bresciana*, Brescia, III.

Benayas R. J. M., Bullock J. M. & Newton A. C., 2008 – Creating woodland islets to reconcile ecological restoration, conservation, and agricultural land use. *Frontiers in Ecology and the Environment*, 6 (6): 329-336.

Bertoli R., 2010 – Atlante degli uccelli nidificanti sul massiccio del Monte Guglielmo (Prealpi bresciane, Lombardia, Italia settentrionale). *Natura Bresciana*, 37: 65-128.

Bibby C. J., Burgess N. D., Hill D. A., Hillis D. M. & Mustoe S., 2000 – Bird census techniques. *Elsevier*.

Blondel J. & Farré H. 1988 – The convergent trajectories of bird communities along ecological successions in European forests. *Oecologia*, 75: 83-93.

Bogliani G., Cova C. & Polani F., 2003 – La natura tra Nure e Scrivia. Il territorio del Giardino di Pietra Corva. *Provincia di Pavia*, Pavia.

Boni A., Cassinis G., Cavallaro E., Cerro A., Fugazza F., Zezza F., Venzo S. & Medioli F., 1968 – Carta Geologica d'Italia alla scala 1:100.000, Fg. 47 Brescia. II edizione. *Poligrafica & Cartevalori*, Ercolano (Na).

Boni A., Cassinis G. & Venzo S., 1970 – Note illustrative della Carta geologica d'Italia alla scala 1:100.000. Fg. 47 Brescia. 1-93. *Poligrafica & Cartevalori*, Ercolano (Na).

Bosco L., Arlettaz R. & Jacot A., 2019 – Ground greening in vineyards promotes the Woodlark *Lullula arborea* and their invertebrate prey. *Journal of Ornithology*, 160 (3): 799-811. <https://doi.org/10.1007/s10336-019-01666-7>

Boscutti F., Vianello A., Bozzato F. & Casolo V., 2017 – Vegetation structure, species life span, and exotic status elucidate plant succession in a limestone quarry reclamation. *Restoration Ecology*, 25 (4): 595-604.

Brambilla M. & Guidali F., 2005 – Quando la voce è tutto: l'identificazione delle sottospecie di sterpazzolina *Sylvia cantillans*. In: Atti XIII Convegno Italiano di Ornitologia. *Avocetta*, 29 (Special Issue): 154.

Brambilla M. & Rubolini D., 2005 – Caratteristiche macroambientali dell'habitat riproduttivo del Calandro *Anthus campestris*. In: Atti XIII Convegno Italiano di Ornitologia. *Avocetta*, 29 (Special Issue): 105.

Brambilla M., Reginato F. & Guidali F., 2007a – Brief report Habitat use by Moltoni's Warbler *Sylvia cantillans moltonii* in Italy. *Ornis Fennica*, 84: 91-96.

Brambilla M., Rubolini D. & Guidali F., 2007b – Between land abandonment and agricultural intensification: Habitat preferences of Red-backed Shrikes *Lanius collurio* in low-intensity farming conditions. *Bird Study*, 54 (2): 160-167. <https://doi.org/10.1080/00063650709461471>

Brambilla M., Guidali F. & Negri I., 2008 – The importance of an agricultural mosaic for Cirl Buntings *Emberiza cirlus* in Italy. *Ibis*, 150: 628-632.

Brambilla M., Casale F., Bergero V., Crovetto G. M., Falco R., Negri I., Siccardi P. & Bogliani G., 2009a – GIS models work well but are not enough: Habitat preferences of *Lanius collurio* at multiple levels and conservation implications. *Biological Conservation*,

142 (10): 2033-2042. <https://doi.org/10.1016/j.biocon.2009.03.033>

Brambilla M., Guidali F.& Negri I., 2009b – Breeding-season habitat associations of the declining Corn Bunting *Emberiza calandra* - a potential indicator of the overall bunting richness. *Ornis Fennica*, 86: 41-50.

Brambilla M., Casale F., Bergero V., Bogliani G., Crovetto G. M., Falco R., Roati M. & Negri I., 2010 – Glorious past, uncertain present, bad future? Assessing effects of land-use changes on habitat suitability for a threatened farmland bird species. *Biological Conservation*, 143 (11): 2770-2778. <https://doi.org/10.1016/j.biocon.2010.07.025>

Brambilla M., Vitulano S., Ferri A., Spina F., Fabbri E. & Randi E., 2012 – An unexpected pattern of migration revealed in the Subalpine Warbler *Sylvia cantillans complex* by mitochondrial DNA analyses. *Ibis*, 154 (3): 616-620.

Brambilla M., Fulco E., Gustin M. & Celada C., 2013 – Habitat preferences of the threatened Black-eared Wheatear *Oenanthe hispanica* in southern Italy. *Bird Study*, 60 (3): 432-435. <https://doi.org/10.1080/00063657.2013.819831>

Brambilla M., Gustin M., Vitulano S., Negri I. & Celada C., 2016 – A territory scale analysis of habitat preferences of the declining Ortolan Bunting *Emberiza hortulana*. *Bird Study*, 63 (1): 52-57. <https://doi.org/10.1080/00063657.2015.1126219>

Brambilla M., Gustin M., Fulco E., Sorace A. & Celada C., 2017a – Coarse landscape features predict occurrence, but habitat selection is driven by specific habitat traits: Implications for the conservation of the threatened Woodchat Shrike *Lanius senator*. *Bird Conservation International*, 27 (1): 58-70. <https://doi.org/10.1017/S0959270916000034>

Brambilla M., Gustin M., Vitulano S., Falco R., Bergero V., Negri I., Bogliani G. & Celada C., 2017b – Sixty years of habitat decline: impact of land-cover changes in northern Italy on the decreasing Ortolan Bunting *Emberiza hortulana. Regional Environmental Change*, 17 (2): 323-333. <https://doi.org/10.1007/s10113-016-1019-y>

Brichetti P., 1992 – Atlante degli Uccelli Nidificanti in provincia di Brescia (Lombardia). Aggiunte 1985-1991. *Natura Bresciana*, 27: 201-221.

Brichetti P., 1993 – Situazione avifaunistica, aree di particolare interesse e proposte gestionali. In: Studi preliminari per la redazione del Piano della Riserva Naturale "Altopiano di Cariadeghe". AA.VV. *I.G.B.,* Brescia: 57-65, 168-203.

Brichetti P., 1994 – Situazione dell'avifauna della provincia di Brescia (Lombardia). Aggiornamento 1993. *Natura Bresciana*, 29: 221-249.

Brichetti P. & Cambi D., 1979 – L'Occhiocotto *Sylvia melanocephala* (Gmelin) nell'Italia settentrionale. *Uccelli d'Italia*, 4 (2): 68-78.

Brichetti P. & Cambi D., 1985 – Atlante degli uccelli nidificanti in Provincia di Brescia (Lombardia) 1980-1984. *Natura Bresciana*, Monografia 8.

Brichetti P. & Fasola M., 1990 – Atlante degli uccelli nidificanti in Lombardia. 1983-87. *Editoriale Ramperto*, Brescia.

Brichetti P. & Fracasso G., 2007-2015 – Ornitologia italiana. Volumi 4-9. *Alberto Perdisa Editore*, Bologna e *Edizioni Belvedere*, Latina.

Brichetti P. & Fracasso G., 2020 – The birds of Italy, vol. 2. Pteroclidae-Locustellidae. *Edizioni Belvedere*, Latina.

Brichetti P. & Gargioni A., 2005 – Atlante degli uccelli nidificanti nella "bassa" pianura lombarda (Italia settentrionale). *Natura Bresciana*, 34: 67-146.

Brichetti P. & Gargioni A., 2009 – Atlante degli uccelli nidificanti in provincia di Brescia (Lombardia). Aggiunte 1992-2006. *Natura Bresciana*, 36: 125-139.

Brichetti P. & Gargioni A., 2016 – Check-list degli uccelli della provincia di Brescia (Lombardia) aggiornata al dicembre 2016. *Natura Bresciana*, 40: 87-100.

Brichetti P. & Grattini N., 2010 – Distribuzione ed evoluzione delle popolazioni di Bigia padovana *Sylvia nisoria* nidificanti in Italia nel periodo 1970-2009. *Alula*, 17 (1-2): 13-22.

Brichetti P. & Grattini N., 2017 – Distribuzione e consistenza delle popolazioni di Averla capirossa *Lanius senator* nidificanti in Italia settentrionale nel periodo 1980-2016. *Alula*, 24 (1-2): 29-40.

Brichetti P. & Grattini N., 2018 – Distribuzione ed evoluzione delle popolazioni di Ortolano *Emberiza hortulana* nidificanti in Italia settentrionale nel periodo 1980-2017. *Alula*, 25 (1-2): 19-36.

Brunetti M., Maugeri M., Monti F. & Nanni T., 2006 – Temperature and precipitation variability in Italy in the last two centuries from homogenized instrumental time series. *International Journal of Climatology*, 26 (3): 345-381. <https://doi.org/10.1002/joc.1251>

Brusa G., Cerabolini B. E. L., Dalle Fratte M. & De Molli C., 2017 – Protocollo operativo per il monitoraggio regionale degli habitat di interesse comunitario in Lombardia. Versione 1.1. *Università degli Studi dell'Insubria, Fondazone Lombardia per l'Ambiente e Osservatorio Regionale per la Biodiversità di Regione Lombardia*.

Cambi D., 1979 – Contributo allo studio sulla biologia riproduttiva e sulla distribuzione di *Sylvia nisoria* (Bigia padovana) in Italia. *Rivista italiana di Ornitologia*, 49: 208-229.

Cambi D. & Micheli A., 1986 – L'avifauna nidificante della "Corna di Savallo" (Prealpi Bresciane, Lombardia): censimento ed ecologia. *Natura Bresciana*, 22: 103-178.

Capelli M. & Stefani A., 1984 – Caratteri ecologici di un ceduo del monte Maddalena (Brescia). *Natura Bresciana*, 21: 91-122.

Capra M., 2008 – Per seminare guardavamo la luna. Testimonianze di vita contadina e cultura materiale rurale nel Parco delle Colline di Brescia. *Grafo*, Brescia.

Capretti C., unpublished – Le trasformazioni del bosco bresciano dall'Ottocento ad oggi attraverso l'analisi dei catasti storici e lo studio della vegetazione attuale. Tesi di Laurea magistrale. Università degli Studi Milano. Anno accademico 2002-2003.

Casale F. & Brambilla M., 2009 – Averla piccola. Ecologia e conservazione. *Fondazione Lombardia per l'Ambiente e Regione Lombardia*, Milano.

Castillo I., Elorriaga J., Zuberogoitia I., Azkona A., Hidalgo S., Astorkia L., Iraeta A. & Ruiz F., 2008 – Importancia de las canteras sobre las aves rupícolas y problemas derivados de su gestión. *Ardeola*, 55 (1): 103-110.

Ceresa F., Anderle M., Hilpold L., Maistri R., Niederfriniger O., Sascor R. & Kranebitter P., 2020 – Current distribution and population size of the Barred Warbler *Sylvia nisoria* in South Tyrol (Italy). *Avocetta*, 44 (1): 29-31. <https://doi.org/10.30456/AVO.2020101>

Chiatante G., Brambilla M. & Bogliani G., 2014 – Spatially explicit conservation issues for threatened bird species in Mediterranean farmland landscapes. *Journal for Nature Conservation*, 22 (2): 103-112. <https://doi.org/10.1016/j.jnc.2013.09.006>

Coreau A. & Martin J. L., 2007 – Multi-scale study of bird species distribution and of their response to vegetation change: A Mediterranean example. *Landscape Ecology*, 22 (5): 747-764. <https://doi.org/10.1007/s10980-006-9074-2>

Cramp S. & Perrins C. M. (eds.), 1994 – The Birds of the Western Palearctic, Vol. 9. *Oxford University Press*, Oxford.

Crumley C. L., Kolen J. C. A., de Kleijn M. & van Manen N., 2017 – Studying long-term changes in cultural landscapes: outlines of a research framework and protocol. *Landscape Research*, 42 (8): 880-890. <https://doi.org/10.1080/01426397.2017.1386292>

Donald P. F. & Aebischer N. J. (eds.), 1997 – The ecology and conservation of Corn Bunting *Miliaria calandra*. Proceedings of a Conference Held at Fordingbridge, Hampshire, 2-3 March 1995. *UK Nature Conservation*, 13.

Farina A., 1997 – Landscape structure and breeding bird distribution in a sub-Mediterranean agro-ecosystem. *Landscape Ecology*, 12: 365-378. <https://doi.org/10.1023/A:1007934518160>

Fox J. & Weisberg S., 2019 – An R Companion to Applied Regression. Third Edition. *Sage*, London.

Fracasso G., Cerato E., Sattin L. & Bonato R., 2011 – La migrazione della Sterpazzolina comune, *Sylvia cantillans*, nel Veneto (Passeriformes, Sylviidae). In: Atti 6° Convegno Faunisti Veneti. Bon M., Mezzavilla F., Scarton F. (eds.). *Bollettino del Museo di Storia Naturale di Venezia*, suppl., 61: 250-258.

Gagliardi A., Bertoli R., Dinetti M. & Gargioni A., 2009 – Presenze avifaunistiche nell'aeroporto "Gabriele D'Annunzio" di Brescia-Montichiari. *Natura Bresciana*, 36: 63-77.

Germano D., Machado R., Godinho S. & Santos P., 2016 – The impact of abandoned/disused marble quarries on avifauna in the anticline of Estremoz, Portugal: does quarrying add to landscape biodiversity? *Landscape Research*, 41 (8): 880-891. <https://doi.org/10.1080/01426397.2016.1174772>

Gilardelli F., Sgorbati S., Armiraglio S., Citterio S. & Gentili R., 2016 – Assigning plant communities to a successional phase: Time trends in abandoned limestone quarries. *Plant Biosystems*, 150 (4): 799-808. <https://doi.org/10.1080/11263504.2015.1011722>

Gobbini M., 2007 – La Monachella *Oenanthe hispanica* nel Bresciano: primo censimento delle coppie nidificanti. *Picus*, 64: 131-134.

Gobbini M., 2010 – Avifauna nidificante del comune di Paitone (Lombardia). *Natura Bresciana*, 37: 127-134.

Gonzalo-Turpin H., Sirami C., Brotons L., Gonzalo L. & Martin J. L., 2008 – Teasing out biological effects and sampling artifacts when using occupancy rate in monitoring programs. *Journal of Field Ornithology*, 79 (2): 159-169. <https://doi.org/10.1111/j.1557-9263.2008.00158.x>

Guerrieri G., Santucci B. & Castaldi A., 2001 – Selezione di habitat e riproduzione della Monachella, *Oenanthe hispanica*, nell'Italia centrale. *Rivista italiana di Ornitologia*, 71 (1): 27-44.

Guillaumet A. & Prodon R., 2011 – Avian succession along ecological gradients: insight from species-poor and species-rich communities of Sylvia warblers. *Current Zoology*, 57 (3): 307-317. <https://academic.oup.com/cz/article/57/3/307/1815647>

Hartig F., 2022 – *DHARMa*: Residual Diagnostics for Hierarchical (Multi-Level/Mixed) Regression Models. R package version 0.4.5.

Hawkes R. W., Smart J., Brown A., Jones H. & Dolman P. M., 2019 – Experimental evidence that ground disturbance benefits Woodlark *Lullula arborea*. *Ibis*, 161 (2): 447-452.

Jiguet F., Arlettaz R., Bauer H. G., Belik V., Copete J. L., Couzi L., Czajkowski M. A., Dale S., Dombrovski V., Elts J., Ferrand Y., Hargues R., Kirwan G. M., Minkevicius S., Piha M., Selstam G., Skierczyñski M., Siblet J.-P. & Sokolov A., 2016 – An update of the European breeding population sizes and trends of the Ortolan Bunting (*Emberiza hortulana*). *Ornis Fennica*, 93 (3): 186-196.

Kassambara A. & Mundt F., 2020 – *Factoextra*: Extract and Visualize the Results of Multivariate Data Analyses. R package version 1.0.7.

Keller V., Herrando S., Voříšek P., Franch M., Kipson M., Milanesi P., Martí D., Anton M., Klvaňová A., Kalyakin M. V., Bauer H.-G. & Foppen R. P. B., 2020 – European Breeding Bird Atlas 2: Distribution, Abundance and Change. *European Bird Census Council & Lynx Edicions*, Barcelona.

Knaus P., Antoniazza S., Wechsler S., Guélat J., Kéry M., Strebel N. & Sattler T., 2018 – Atlante degli uccelli nidificanti in Svizzera 2013-2016. Distribuzione ed evoluzione degli effettivi degli uccelli in Svizzera e nel Liechtenstein. *Stazione ornitologica svizzera*, Sempach: 424-425.

Kosmidis I., 2021 – *Brglm2*: Bias Reduction in Generalized Linear Models. R package version 0.7.1.

Laiolo P., 2005 – Spatial and Seasonal Patterns of Bird Communities in Italian Agroecosystems. *Conservation Biology*, 19 (1): 275-277. <https://doi.org/10.1111/j.1523-1739.2005.00207.x>

Lasanta T., Nadal-Romero E. & Arnáez J., 2015 – Managing abandoned farmland to control the impact of re-vegetation on the environment. The state of the art in Europe. *Environmental Science & Policy*, 52: 99-109.

Leo R. & Capelli S., 2007 – Accertata nidificazione di Gufo reale (*Bubo bubo*) in una cava in comune di Rezzato. *Natura Bresciana*, 35: 185.

Leo R. & Gobbini M., 2013 – I rapaci (Falconiformes) nidificanti delle colline ad est di Brescia (Lombardia orientale). *Natura bresciana*, 38: 101-108.

Leroux S. J., 2019 – On the prevalence of uninformative parameters in statistical models applying model selection in applied ecology. *PLOS ONE*, 14 (2): e0206711. <https://doi.org/10.1371/journal.pone.0206711>

Lozano C. B. & Robson D., 2011 – Subalpine Warbler (*Sylvia cantillans*) and Moltoni's Warbler (*Sylvia moltonii*). *Monografies del Museu de Ciències Naturals*:182-189.

Maestri F. & Voltolini L., 2013 – Biologia riproduttiva della Tottavilla (*Lullula arborea*) sulle Prealpi bresciane e gardesane. *Natura Bresciana*, 38: 109-125.

Marques D. A. & Jacquier S., 2020 – Seltene Vogelarten und ungewöhnliche Vogelbeobachtungen in der Schweiz im Jahre 2012. *Der Ornithology Beobachter*, 117: 312-337.

Marschner I. C., 2011 – *Glm2*: Fitting generalized linear models with convergence problems. *The R Journal*, 3 (2): 12-15.

Martin J. L. & Thibault J. C. 1996 – Coexistence in Mediterranean warblers: Ecological differences or interspecific territoriality? *Journal of Biogeography*, 23 (2): 169-178. <https://doi.org/10.1111/j.1365-2699.1996.00028.x>

Martini F., Bona E., Federici G., Fenaroli F. & Perico G. (eds.), 2012 – Flora vascolare della Lombardia centro-orientale. Vol. I. Parte generale. *Lint Editoriale*, Trieste.

Menant F., 1993 – Campagnes lombardes du Moyen Âge. L'économie et la société rurales dans la région de Bergame, de Crémone et de Brescia du X^{e} au XIII^{e} siècle. *École française de Rome*, Roma, 281. <https://doi.org/10.3406/befar.1993.1232>

Menz M. H. M. &Arlettaz R., 2012 – The precipitous decline of the Ortolan Bunting *Emberiza hortulana*: time to build on scientific evidence to inform conservation management. *Oryx*, 46 (1): 122-129.

Micheli A., 2005 – Monachella. In: Atlante degli Uccelli nidificanti e svernanti in provincia di Trento. Pedrini P., Caldonazzi M. & Zanghellini S. (a cura di). *Museo tridentino di scienze naturali*, *Acta Biologica*, Trento, 80 (2003) suppl. 2: 411-412.

Moreira F. & Russo D., 2007 – Modelling the impact of agricultural abandonment and wildfires on vertebrate diversity in Mediterranean Europe. *Landscape Ecology*, 22 (10): 1461-1476.

Morelli F., 2013 – Relative importance of marginal vegetation (shrubs, hedgerows, isolated trees) surrogate of HNV farmland for bird species distribution in Central Italy. *Ecological Engineering*, 57: 261-266. <https://doi.org/10.1016/j.ecoleng.2013.04.043>

Nardelli R., Andreotti A., Bianchi E., Brambilla M., Brecciaroli B., Celada C., Dupré E., Gustin M., Longoni V., Pirrello S., Spina F., Volponi S. & Serra L., 2015 – Rapporto sull'applicazione della Direttiva 147/2009/CE in Italia: dimensione, distribuzione e trend delle popolazioni di uccelli (2008-2012). *ISPRA*, Rapporto 219/2015.

Navarro M. L., Proença V., Kaplan O. J. & Pereira M. H., 2015 – Maintaining disturbance-dependent habitats. In: Rewilding European landscapes. Pereira M. H. & Navarro M. L. (eds.). *Springer International Publishing*: 143-167. <https://doi.org/10.1007/978-3-319-12039-3_8>

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

Parodi R., 2006 – Check-list degli uccelli del Friuli-Venezia Giulia. *Gortania, Atti del Museo Friulano di Storia Naturale*, 28: 207-242.

Perego R., Badino F., Deaddis M., Ravazzi C., Vallè F. & Zanon M., 2011 – L'origine del paesaggio agricolo pastorale in nord Italia: espansione di *Orlaya grandiflora* (L.) Hoffm. nella civiltà palafitticola. *Notizie Archeologiche Bergomensi*, 19: 161-173.

Pereira H. M., Navarro L. M. & Martins I. S., 2012 – Global biodiversity change: the bad, the good, and the unknown. *Annual Review of Environment and Resources*, 37: 25-50.

Piseri A. & Vitale P., 2002 – Nuvolera: i paesaggi, l'ambiente. *Grafo edizioni*, Brescia.

Plieninger T., Kizos T., Bieling C., Dû-Blayo L., Budniok M. A., Bürgi M., Crumley C. L., Girod G., Howard P., Kolen J., Kuemmerle T., Milcinski G., Palang H., Trommler K., & Verburg P. H., 2015 – Exploring ecosystem-change and society through a landscape lens: Recent progress in European landscape research. *Ecology and Society*, 20 (2): 5. <https://doi.org/10.5751/ES-07443-200205>.

Pollo R., 2020 – Monitoring of a community of breeding birds in an agroecosystem with high environmental heterogeneity. *Avocetta*, 44 (2): 75-86. <https://doi.org/10.30456/AVO.2020207>

Pons P. & Clavero M., 2010 – Bird responses to fire severity and time since fire in managed mountain rangelands. *Animal Conservation*, 13 (3): 294-305.

Preiss E., Martin J. L. & Debussche M., 1997 – Rural depopulation and recent landscape changes in a Mediterranean region: consequences to the breeding avifauna. *Landscape Ecology* 12: 51-61.

Prodon R., 2020 – Focus consequences for avifauna of landscape encroachment by woody vegetation in northern Catalonia. *Revista Catalana d'Ornitologia*, 36: 1-9. <https://doi.org/10.2436/20.8100.01.15>

Pruscini F., Morelli P., Perna P., Felicetti N. & Santolini R., 2013 – L'Ortolano *Emberiza hortulana* nella Regione Marche: analisi della distribuzione e preferenze ambientali. *Avocetta*, 37 (1): 15-20.

R Core Team, 2013 – R: A language and environment for statistical computing. *R Foundation for Statistical Computing*, Vienna, Austria.

Rey L. & Jacot A., 2018 – Temporal changes of the breeding bird community in the burnt forest of Leuk. *Schweizerische Zeitschrift für Forstwesen*, 169 (5): 299-307. <https://doi.org/10.3188/szf.2018.0299>

Rodríguez-Soler R., Uribe-Toril J. & de Pablo Valenciano J. 2020 – Worldwide trends in the scientific production on rural depopulation, a bibliometric analysis using bibliometrix R-tool. *Land Use Policy*, 97: 104787. <https://doi.org/10.1016/j.landusepol.2020.104787>

Salgueiro P. A., Silva C., Silva A., Cátia S. & Mira A., 2020a – Can quarries provide novel conditions for a bird of rocky habitats? *Restoration Ecology*, 28 (4): 988-994. <https://doi.org/10.1111/rec.13080>

Salgueiro P. A., Prach K., Branquinho C. & Mira A., 2020b – Enhancing biodiversity and ecosystem services in quarry restoration – challenges, strategies, and practice. *Restoration Ecology*, 28 (3): 655-660. <https://doi.org/10.1111/rec.13160>

Sánchez S., Václav R. & Prokop P., 2009 – An inter-regional approach to intraspecific variation in habitat association: Rock Buntings *Emberiza cia* as a case study. *Ibis*, 151 (1): 88-98. <https://doi.org/10.1111/j.1474-919X.2008.00894.x>

Saporetti F., 2012 – I Passeriformi (Passeriformes) degli ambienti aperti come indicatori della successione ecologica nel SIC Val Veddasca (Lombardia, Italia). *Bollettino della Società Ticinese di Scienze Naturali*, 100: 79-88.

Schaefer T. & Barkow A., 2004 – Habitat and nest site preferences of *Sylvia atricapilla* and *S. melanocephala* in Majorca. *Ardeola*, 51 (2): 445-450.

Schirolli P., 1998 – Dietro il paesaggio. La vicenda geologica della "Terra dei marmi". In: La via del marmo. Storia, ambiente, territorio. Rocchi N. & Simoni C. (eds.). *Grafo edizioni*, Brescia: 7-21.

Sedláček O., Fuchs R. & Exnerová A., 2004 – Redstart *Phoenicurus phoenicurus* and black redstart *P. ochruros* in a mosaic urban environment: neighbours or rivals. *Journal of Avian Biology*, 35 (4): 336-343.

Shirihai H., Gargallo G. & Helbig A. J., 2001 – Sylvia Warblers: Identification, taxonomy and phylogeny of the genus *Sylvia*. *Helm*, London.

Sirami C., Brotons L. & Martin J. L., 2007 – Vegetation and songbird response to land abandonment: from landscape to census plot. *Diversity and Distribution*, 13 (1): 42-52.

Sirami C., Brotons L., Burfield I., Fonerflick J. & Martin, J. L., 2008 – Is land abandonment having impact on biodiversity? A meta-analytical approach to bird distribution changes in the north-western Mediterranean. *Biological Conservation*, 141 (2): 450-459.

Sirami C., Brotons L. & Martin J. L., 2011 – Woodlarks *Lullula arborea* and landscape heterogeneity created by land abandonment. *Bird Study*, 58 (1): 99-106. <https://doi.org/10.1080/00063657.2010.532861>

Speranza G., 2020 – Eastern Black-eared Wheatear *Oenanthe melanoleuca*. In: Bird news. Bazzi G. (eds.). *Avocetta*, 44: 49.

Spina F. & Volponi S., 2008 – Atlante della Migrazione degli Uccelli in Italia. Volume 2, Passeriformi. *ISPRA. Tipografia SCR*, Roma.

Staneva A. & Burfield I., 2017 – European birds of conservation concern. Populations, trends and national responsibilities. *BirdLife International*.

Svenning J. C., 2002 – A review of natural vegetation openness in north-western Europe. *Biological Conservation*, 104 (2): 133-148.

Tscharntke T., Klein A. M., Kruess A., Steffan-Dewenter I. & Thies C., 2005. – Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management. *Ecology Letters*, 8 (8): 857-874. <https://doi.org/10.1111/j.1461-0248.2005.00782.x>

Tsiakiris R., Stara K., Pantis J. & Sgardelis S., 2009 – Microhabitat selection by three common bird species of montane farmlands in northern Greece. *Environmental Management*, 44 (5): 874-887. <https://doi.org/10.1007/s00267-009-9359-8>

Vailati D., 2003 – Il "Carso bresciano" e il Buco del Frate. *Associazione Scientifica Studi Carsici "G.B. Cacciamali"*, Brescia.

van Turnhout C., 2005 – The disappearance of the Tawny Pipit *Anthus campestris* as a breeding bird from The Netherlands and Northwest-Europe. *Limosa*, 78: 1-14.

Vickery J. A., Ewing S. R., Smith K. W., Pain D. J., Bairlein F., Škorpilová J. & Gregory R. D., 2014 – The decline of Afro-Palaearctic migrants and an assessment of potential causes. *Ibis*, 156 (1): 1-22.

Vigorita V. & Cucè L., 2008 – La fauna selvatica in Lombardia. Rapporto 2008 su distribuzione, abbondanza e stato di conservazione di uccelli e mammiferi. *Regione Lombardia*, Milano.

Vitasse Y., Ursenbacher S., Klein G., Bohnenstengel T., Chittaro Y., Delestrade A., Monnerat C., Rebetez M., Rixen C., Strebel N., Schmidt B. R., Wipf S., Wohlgemuth T., Yoccoz N. G. & Lenoir J. 2021 – Phenological and elevational shifts of plants, animals and fungi under climate change in the European Alps. *Biological Reviews*, 96 (5): 1816-1835. <https://doi.org/10.1111/brv.12727>

Vittinghoff E. & McCulloch C. E., 2007 – Relaxing the rule of ten events per variable in logistic and Cox regression. *American Journal of Epidemiology*, 165 (6): 710-718.

Wood S., 2021 – *Mgcv*: Mixed GAM Computation Vehicle with Automatic Smoothness Estimation. R package version 1.8-38.

Zbinden N. & Blondel J., 1981 – Zu Raumnutzung, Territorialität und Legebeginn mediterraner Grasmücken in. (*Sylvia melanocephala, S. sarda, S. cantillans, S. hortensis*) in Südfrankreich. *Der Ornithology Beobachter*, 78: 217-231.

Zuur A. F., Ieno E. N., Walker N. J., Saveliev A. A. & Smith G. M., 2009 – Mixed Effect Models and Extensions in Ecology with R. *Springer*, Berlin.

Zuur A. F., Ieno E. N. & Elphick C. S., 2010 – A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution*, 1: 3-14.