Habitat, climate, topography and management differently affect occurrence in declining avian species: implications for conservation in changing environments

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Abstract

Climate and land-use change are the most severe threats to biodiversity; their effects are often intermingled, also with those of landscape/habitat management. Birds of mountain grassland are threatened and declining throughout Europe. Disentangling climate effects from those of land-cover and management on species occurrence is essential to identify distribution drivers, potential impacts of climate/land-use changes, and effective conservation strategies. We investigated occurrence drivers in skylark, water pipit and red-backed shrike in Central Apennines, Italy (750-2130 m asl). Topographic/climatic, land-cover and management fine-scale variables were considered as potential occurrence predictors. For all species, combining different types of predictors led to the most accurate models, but the relative importance of single-group varied: land cover was the most important for skylark, climate/topography for water pipit, all three groups had similar support for red-backed shrike. Skylark was positively affected by solar radiation and grassland cover, and negatively by bare ground, hedgerows, rocks, shrubland, and by ski-pistes and buildings, confirming sensitivity to anthropic alteration of semi-natural grassland. Water pipit was favoured by grazing and negatively impacted by shrubland and average temperature (most important predictor). Red-backed shrike was affected negatively by broadleaved forest and grazing occurrence, quadratically by isolated shrubs and positively by shrubland and grassland cover. Climate was a fundamental determinant of occurrence for water pipit, but not for the other species. Land-cover was important for all species and also management factors were invariably included in models. Climate, habitat and management traits differently contributed to occurrence patterns in these declining species. Conservation strategies need to embrace landscape planning to preserve grassland extents/mosaics, identify climate *refugia* for water pipit and implement dedicated management (preventing new ski-pistes over areas suitable for birds and carefully planning grazing). In the Apennines it should be possible to combine local, sustainable economies with biodiversity conservation by means of informed landscape planning.

Keywords

Apennines; climate; conservation; habitat preferences; land-cover; Passeriformes

Introduction

Climate and land-use change are two of the most severe threats to biodiversity and ecosystems nowadays and will continue to impact on Earth's environments in the next decades (Sala et al., 2000). Several studies in the recent literature evaluated and predicted the impacts of climate change (e.g. Selwood et al., 2015; Scridel et al., 2017) or the impact of land-use changes (e.g. Brambilla et al., 2017a) on bird species or communities. Although the importance of studies integrating both such drivers of biodiversity loss have been highlighted (Barbet-Massin et al., 2012; Sirami et al., 2017; Thuiller et al., 2008; Titeux et al., 2016), only a relatively few studies have simultaneously evaluated the effects of both (de Chazal and Rounsevell, 2009; Eglington and Pearce-Higgins, 2012; Pearce-Higgins et al., 2015). In addition to the importance of both climate and land-cover change *per se*, their effects are often almost inextricable, because they can frequently co-occur in the same areas and impact over the same systems, sometimes displaying synergistic effects (Mantyka-Pringle et al., 2012). Management for productive or conservation purposes may also interact with these drivers (e.g. Doley, 2010).

Mountain species are among the most threatened ones (Dirnböck et al., 2011), and in particular mountain birds are highly threatened because of both climate change (Brambilla et al., 2018b; Imperio et al., 2013; Lehikoinen et al., 2019; Revermann et al., 2012; Scridel et al., 2018; Sekercioglu et al., 2008) and land-cover change (Chamberlain et al., 2016), and the species inhabiting mountain grassland are particularly at risk (Brambilla et al., 2010; Chamberlain et al., 2013; Korner et al., 2018). The effects of climate and land-cover characteristics, and the impact of the relative changes, often come in the form of intermixed, overlapping effects, with interactions often hard to disentangle (de Chazal and Rounsevell, 2009). This difficult discrimination between the importance of climate and land-cover is very relevant for natural and semi-natural grassland and for the birds inhabiting them (e.g. Brambilla et al., 2018a). In fact, in a large part of Europe, semi-natural grasslands underwent a dramatic decline in recent decades (Pe'er et al., 2014) and, especially in the southern part of the continent, they are often confined to mountain regions (Korner et al., 2018), thus in climates colder than in the adjacent regions. Several species tied to this habitat are now largely restricted to mountains (Assandri et al., 2019a), but this could be linked either to habitat tracking or climate tracking under a changing temperature in these regions. Therefore, even if it could be hard to disentangle the effects of climate from those of land-cover on species occurrence in this context, this is essential for a correct evaluation of the identification of distribution drivers and hence of the potential impact of climate and land-use changes (Brambilla et al., 2019). Understanding such patterns in an artificially maintained habitat like grassland is further complicated by grassland management, which dramatically affect habitat structure and type with important consequences on breeding birds (Assandri et al., 2019b), and by other human interference (disturbance, habitat alteration) that may further complicate patterns (e.g. Laiolo et al., 2004; Thiel et al., 2007; Caprio et al., 2011).

With this study, we focus on an ideal model to investigate the effects of climate and land-cover on species occurrence, by investigating grassland bird occurrence in central Apennines, Italy. In this area, traditional land-use has resulted in large extents of grassland along elevation gradients, from low areas (< 1000 m asl), where this habitat would never predominate, to higher elevation (> 1800 m), where grassland is the climax vegetation because of climatic constraints. Such gradients of grassland habitats, which have disappeared from large parts of Europe following intensification or abandonment, are still relatively common within the area. By evaluating the relative importance of topographical, climatic, land-cover and management-related factors on the occurrence of breeding grassland birds, we provide essential information to understand the distribution drivers for three declining avian species. Exploring occurrence determinants can help evaluate the relative importance of physical, biological and human attributes of the environment, and is needed to assess the potential impact of land-cover and climate changes.

As target species, we selected breeding passerine birds likely to be differently affected by climate, land-cover and management: skylark *Alauda arvensis*, water pipit *Anthus spinoletta* and red-backed shrike *Lanius collurio*. Skylark is a typical grassland species, occurring over an extremely large range and over a wide elevation gradient in Italy (from the sea level, to above 2500 m), and mostly behaving as a short-range migrant; it is particularly sensitive to agricultural practices (Topping et al., 2013). Water pipit is a species restricted to open habitats in the main mountain areas of central and southern Europe and western Asia, breeding only at relatively high elevation, often performing elevational movements in winter or short migration; it has been reported as one of the species threatened by climate change on European mountains (Brambilla et al., 2017a; Chamberlain et al., 2013), including the study area (Brambilla et al., 2019). Red-backed shrike is tied to semi-open habitats with a mosaic of grassland or grassland-like and shrub patches (Brambilla et al., 2009; Ceresa et al., 2012), occurring over a large area and within broad elevational gradients, and performing long-distance migrations to and from its winter quarters in Subsaharian Africa; this species is particularly sensitive to landscape-level changes and in particular to both agricultural intensification and land abandonment (Brambilla et al., 2010, 2007). Therefore, we expected a strong importance of climate for water pipit, but not for skylark and red-backed shrike, as the latter two species inhabit broad latitudinal and elevational gradients, encompassing nearly all the climatic conditions found in the study area. We also expected an important effect of management factors for skylark and of habitat characteristics (land-cover) for red-backed shrike. Importantly, all these three species are declining in Europe and/or Italy (BirdLife International, 2015; Gustin et al., 2016), thus defining their habitat association and the potential effects of land-cover and climate change is particularly urgent for their conservation.

Methods

Study area

Central Apennines (central-southern Italy) include some of the highest mountains of southern Europe and qualify as an ideal study system to investigate the effects of climate and land-cover on species occurrence. Within this area, long-term forest clearing for pasture creation has resulted in large extents of grassland, occurring along broad elevation gradients, and used as seasonal pastures. Forest limit within the study area occurs naturally around 1400-1600m (Piermattei et al., 2016), with the treeline mostly located between 1700 and 1800m (maximum elevation reached by beech *Fagus sylvatica*, cf. Magnani, 2007; Pezzi et al., 2007); above 1800m, low shrubland and grassland occur as climax vegetation.

We carried out the study in six areas, overlapping with different mountain systems (and parks): Sibillini (Sibillini National Park), Laga (Gran Sasso – Monti della Laga National Park), Gran Sasso (Gran Sasso – Monti della Laga National Park), Velino-Sirente (Natural Park), Marsica (Abruzzo, Lazio e Molise National Park), Majella (Majella National Park; Fig. 1). All study areas occur within the broad-scale range of all target species (Nardelli et al., 2015).

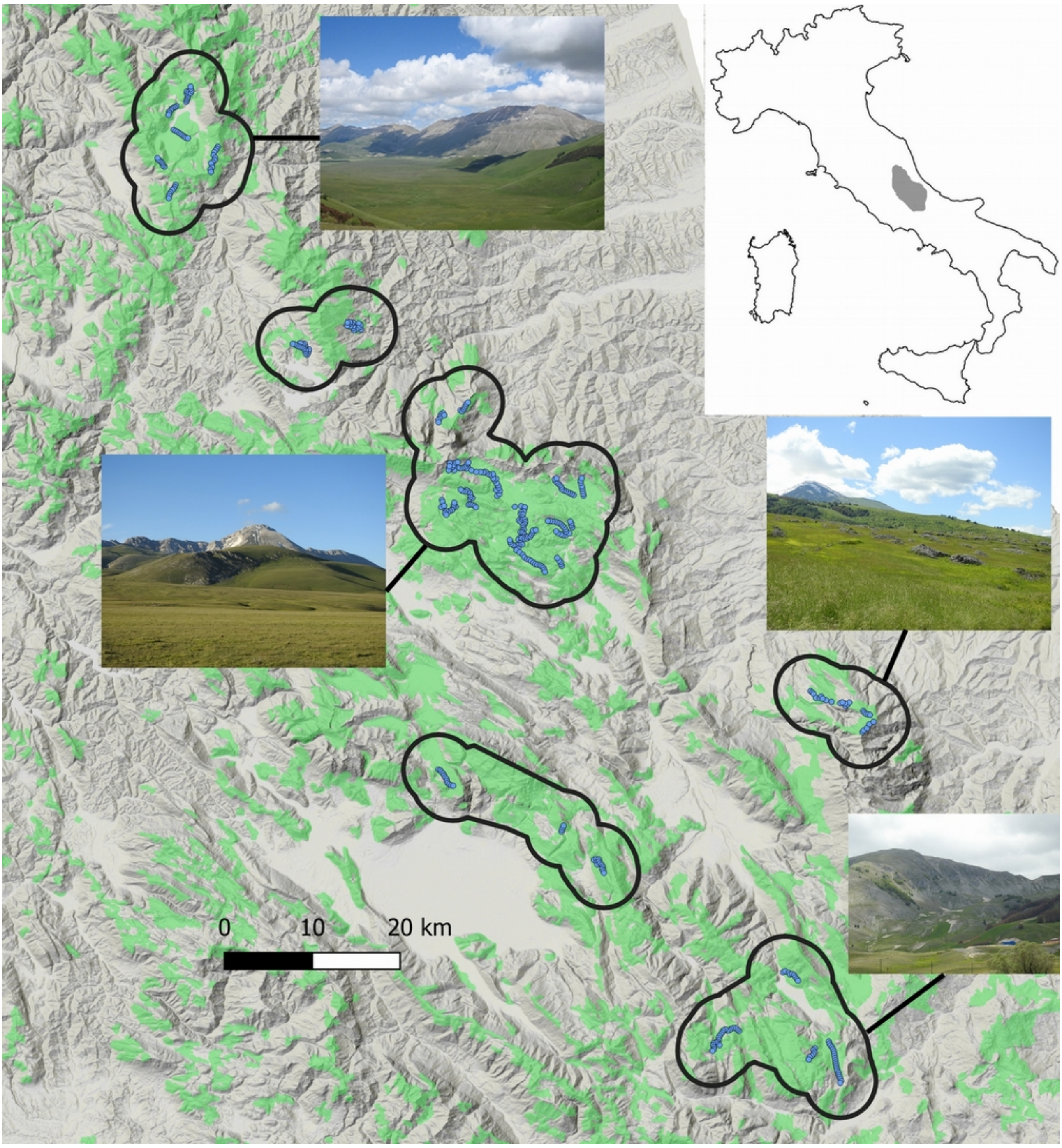

Figure 1. Study areas in the Central Apennines, encircled black, with some illustrative pictures taken from the fieldwork sites; from north to south: Sibillini, Laga, Gran Sasso, Majella (east), Velino-Sirente (west), Marsica. The location of point counts is shown by blue dots, whereas green areas depict semi-natural grassland of all kinds according to the CORINE (European Environment

Agency, 2016) landcover (categories 231 and 321). The grey area on the inset show the location of the study mountain system in Italy.

Fieldwork and collection of environmental variables

We surveyed birds during the breeding season by means of 400 point counts (Bibby et al., 2000), in spring 2016 (June-July), within a 100 m-radius from the point. Points were located at an average elevation of 1530 m asl (range: 750 – 2130 m asl). Surveys were carried out by the authors between dawn and 11:00, and each survey lasted 10 minutes. A first survey covered all points between 9 and 29 June. After that, 172 points were surveyed once again between 30 June and 10 July. For each point, we computed topographic variables (slope and cumulative solar radiation, calculated for the 21st June as a reference day) and climatic factors (seven bioclimatic variables – BIO1 average annual temperature, BIO5 Max Temperature of Warmest Month, BIO6 Min Temperature of Coldest Month, BIO10 Mean Temperature of Warmest Quarter, BIO12 Annual Precipitation, BIO18 Precipitation of Warmest Quarter, BIO19 Precipitation of Coldest Quarter) in a GIS environment; the former were calculated in GRASS (Neteler et al., 2012) using a Digital Elevation Model (www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-eu-dem), whereas the latter were derived from the CHELSA database (http://chelsa-climate.org/; Karger et al., 2017). On the field, with the help of aerial ortophotographs (scale 1:2000) we recorded detailed land-cover considering natural, semi-natural and anthropogenic habitat types, by estimating to the closest 5% the cover of 19 variables describing forest habitats (broadleaved, coniferous or mixed), shrub patches, bare substrates, cultivated areas, built-up areas and roads, hedgerows and tree rows, wetlands, waterbodies and snowfields. We also counted the number of isolated shrubs and trees within the 100 m radius. We further collected data about management-related parameters (mowing, grazing, sward height). Finally, we recorded the occurrence of ski-pistes, discriminating between those which conserve the original grassland vegetation (or, at least, grassland characteristics comparable with the adjacent grassland not interested by ski-pistes), and those which show altered or degraded vegetation. Details about all the environmental predictors recorded at survey points are reported in Table S1; for further details on study area and fieldwork, see also Brambilla et al. (2019).

Data analyses

We built models using binomial Generalized Linear Models (GLM) to evaluate the importance of different groups of variables and of individual factors in affecting the occurrence of grassland passerine species. Before the analyses, we removed from the dataset 12 points, where we did not record any bird within the 100 m radius. We checked variable distribution and removed a few ones, which had value zero in most cases. All variables were standardized (centred around mean, scaled by standard deviation), to better evaluate multicollinearity and the relative effects (Cade, 2015; Schielzeth, 2010). We checked the database for possible outliers.

To take into account the effect of double counts performed in some sites, a species-specific weight was added to the models. All occurrence sites and all those surveyed twice were weighted one, whereas the absence sites surveyed once were weighted 0.5 (Brambilla et al., 2019).

We adopted an information-theoretic approach, performing a model selection based on the Akaike's information criterion (Burnham and Anderson, 2002) corrected for small sample size (AICc). We implemented a previously developed two-step approach based on i) the identification of the relative support for the different groups of factors, and then ii) the selection of the most important predictors within each group (Assandri et al., 2017, 2016). Such an approach allowed us to both i) compare the importance of different types of environmental predictors (topography-climate, land-cover, management-structure) and ii) reduce the number of predictors included at each step. Ski-piste occurrence was included in the management-structure group. For each of the three groups of predictors, we thus performed an AICc-based model selection, by means of the package MuMIn (Bartoń, 2016). We then took the AICc values of the most supported model for the comparison among the relative explanatory power of different types of environmental predictors. At each modelling step, we firstly evaluated multicollinearity among predictors according to variance inflation factors (VIFs), and discarded the most problematic ones (VIF>3; Zuur et al., 2009). A few predictors were removed as they generated convergence issues. Variables tested were thus the following ones: for the climate-topography group, slope, solar radiation, BIO1, BIO12 and BIO19 (only BIO1 for skylark); for the land-cover group, broadleaved forest, shrubs, transitional shrubland, grassland, arable land, rock, buildings, hedgerows and tree rows, isolated shrubs; for the management-structure group, height of grassland sward, grazing, mowing, ski-pistes with altered vegetation. From each level, we i) selected the most supported models (ΔAICc<2), ii) excluded uninformative parameters, i.e. variables included only in models which comprised most parsimonious models as nested ones (Arnold, 2010; Jedlikowski et al., 2016), and carried out model averaging among the remaining models (or took the remaining single model). In the final step, we selected from each group all the variables with importance higher than 0.5 in the averaged model (or those included in the remaining model), and re-did the procedure. We thus obtained a synthetic, ‘final’ model by averaging (full average) the most supported ones (ΔAICc<2), or by taking the most supported if there were no alternative models (excluding those including uninformative parameters) with similar support.

Results

The model species were found in a varying number of sample sites, ranging from 185 for skylark, to 32 for water pipit and 53 for red-backed shrike. For all species, the synthetic model had a lower AICc value than the single-group models (Table 1). Land cover was definitely the single most important group for skylark, whereas the group “climate and topography” was by far the most relevant group for water pipit. Conversely, all three groups had similar importance for red-backed shrike (but the synthetic model was much more supported than the single-groups on).

Table 1. Relative support (AICc value) for the alternative models based on different groups of environmental predictors for the three study species.

species	land-cover	climate-topography	habitat structure-management	synthetic
skylark	295.5	366.8	368.2	283.0
water pipit	129.6	94.7	147.7	82.2
red-backed shrike	230.1	230.6	229.0	207.1

When identifying the most supported synthetic models, two models for skylark were included in the supported ones after the exclusion of uninformative parameters; they were thus averaged, and the resulting model suggested a positive effect of solar radiation and grassland cover, and a negative impact of ski pistes with altered vegetation, bare ground, buildings, hedgerows, rocks and shrubland (Table 2; the most supported model had adjusted R^2 equal to 0.36). For water pipit, in the synthetic analysis we identified only one most supported model, which included a positive effect of grazing, and a negative effect of average temperature and shrubland cover (Table 2; R^2 equal to 0.59). For red-backed shrike, the averaged model revealed a negative effect of broadleaved forest and grazing occurrence, a quadratic effect of (isolated) shrub cover (occurrence probability higher at intermediate values), and a positive effect of shrubland and grassland cover (Table 2; the most supported model had adjusted R^2 equal to 0.29).

Table 2. Averaged models for skylark *Alauda arvensis* and red-backed shrike *Lanius collurio* occurrence, and most supported model for water pipit *Anthus spinoletta* occurrence in the Central Apennines.

	β±ES	**Z**	**P**	**var. imp.**	**n° models**
skylark		averaged model			
intercept	-0.02±0.17				
ski-pistes (altered)	-1.24±0.72	1.72	0.086	1	2
bare ground	-0.53±0.31	1.72	0.086	1	2
buildings	-1.65±0.78	2.12	0.034	1	2
grassland	0.33±0.32	1.00	0.315	0.54	1
hedgerows	-0.74±0.37	2.01	0.044	1	2
rocks	-0.70±0.18	3.80	<0.001	1	2
shrubland	-0.43± 0.16	2.73	0.006	1	2
solar radiation	0.49±0.15	3.24	0.001	1	2
water pipit		most supported			
intercept	-4.86±0.72				
average annual temperature	-2.31±1.65	-5.07	<0.001		
shrubland	-2.23± 1.65	1.35	0.176		
grazing	1.44±0.56	2.56	0.010		
red-backed shrike		averaged model			
intercept	-1.53±0.37				
grazing	-0.93±0.43	2.13	0.033	1	2
shrubland	0.40±0.19	2.08	0.037	1	2
shrubs	2.06±0.34	6.06	<0.001	1	2
$shrubs^2$	-0.93±0.20	4.54	<0.001		
broadleaved forest	-0.42±0.51	0.83	0.409	0.56	1
grassland	0.23±0.32	0.73	0.464	0.44	1

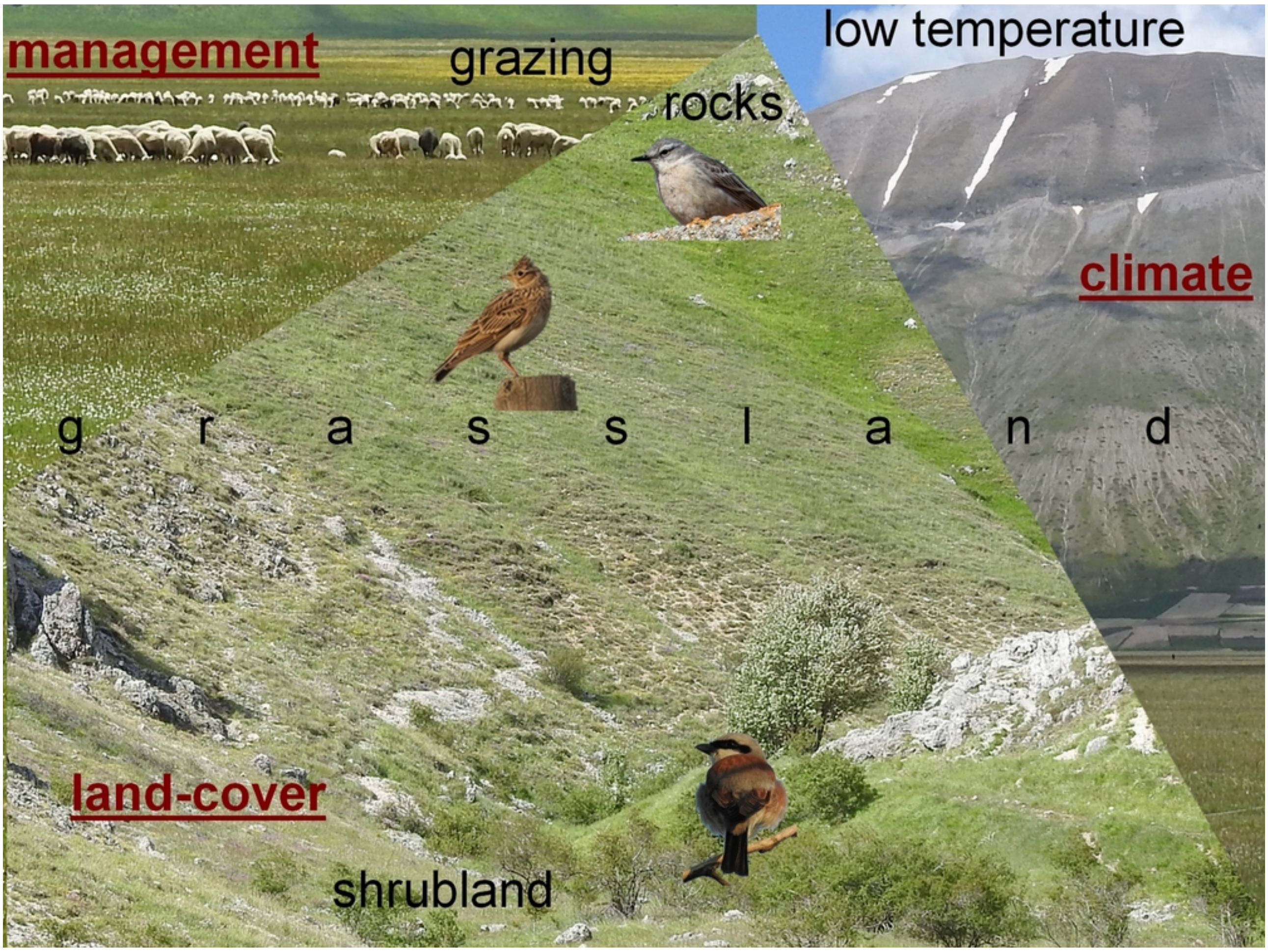

Figure 2. A graphical synthesis of some of the most important determinants of occurrence for the study species. Underlined words indicate the different types of determinants. Considering land-cover variables, all species inhabit grassland, but red-backed shrike (low picture) is tied to shrubland, which is avoided by both skylark (centre) and water pipit (up), whereas rocks favour water pipit but reduce occurrence probability for skylark. Grazing occurrence promotes water pipit presence but negatively affects red-backed shrike. Cold average temperatures favour water pipit occurrence.

Discussion

Disentangling the effect of key drivers of species occurrence

Climate and habitat changes due to land-use modifications are recognised among the most severe threats to biodiversity and ecosystems in recent decades, and are believed to be the most impacting pressures also for the decades to come. Specifically, these factors and the relative interactions are particularly concerning for birds (Jongsomjit et al., 2013; Mantyka-Pringle et al., 2015), and for mountain birds in particular (Chamberlain et al., 2016; Scridel et al., 2018). Our approach helps reveal the relative importance of key variables affecting grassland bird occurrence and hence the relative threat on those species posed by crucial factors such as climate change, land abandonment or intensification.

We focused on three declining species inhabiting mountain grassland, an environment currently experiencing a dramatic decline of its avifauna in Italy (Brambilla, 2019) and elsewhere (Batáry et al., 2007; Donald et al., 2001). The three target species were expected to show different levels of sensitivity to climate, land-use and management, respectively, according to their distribution and breeding ecology. Our approach, based on the evaluation of the effects of specific group of predictors and then of all the relevant predictors, allowed an identification of the most important type of (and individual) factors affecting species distribution over the study region. We predicted a strong importance of climate for water pipit; consistently, the model comprising variables belonging to the group “climate and topography” was the most supported among the single-group models, and annual average temperature was the most important predictor of species occurrence. We did not expect such an important effect of climate for skylark and red-backed shrike, and no climatic variable was included in the ‘final’ models for those species. For the latter, this occurred despite the climate-topography model basically had the same support of the others. It is likely that climatic and topographic factors can predict the species’ occurrence thanks to indirect effects, which disappear when the ‘true’ determinants of occurrence are included (i.e. particular combinations of climatic and topographic variables may appear suitable because they are more frequently associated with the habitats required by the species). On the other side, we expected management factors to be particularly relevant for skylark and land-cover for red-backed shrike. These expectations were not completely met, as for skylark land-cover was the most important group, and most variables included in the 'final' average model belong to it. For red-backed shrike, all three groups received similar support; the 'final' average model included land-cover variables and grazing, a management factor.

Environmental determinants of grassland bird occurrence

We thus found evidence for effects of all different types of environmental determinants, largely consistent with the expected species-habitat relationships. Results indicate that land-cover is an important predictors for all species (especially for skylark and red-backed shrike), with management factors also invariably contributing to explain occurrence patterns. Climate does not significantly affect occurrence of skylark and red-backed shrike in the study region. Conversely, water pipit is the species most sensitive to climate change, and in particular to warming, as expected on the basis of previous findings from both the same area and data analyzed at different scales and with different approaches (Brambilla et al., 2019), and from the Alps (Brambilla et al., 2017a, 2016; Chamberlain et al., 2013). It is also negatively affected by shrubland (but apparently not by isolated shrubs), i.e. by the woody vegetation able to colonize the high elevation habitats favoured by the species. Trees would also discourage the species occurrence, but are extremely rare in the cold belt inhabited by water pipit. Grazing increased occurrence probability for water pipit, which probably benefits from the low and sparser vegetation ensured by grazing (even if sward height was not included in the most supported model), which also limits shrub encroachment.

Grazing had been also reported as an important driver of red-backed shrike occurrence or abundance, with the species preferring grazed areas over unmanaged ones in several parts of its breeding range (Brambilla et al., 2007; Casale and Brambilla, 2009; Laiolo et al., 2004; Pedersen et al., 2018; Vanhinsbergh and Evans, 2002). Surprisingly, we found a strong negative effect of grazing occurrence on the species' presence; out of 127 sites with grazing, only 8 were occupied by the species, *contra* 45 occupied sites out of 261 without recent grazing. While several sites for which a positive effect of grazing had been reported in the literature were characterized by cattle grazing, in the study area sheep and, secondarily, goats and horses are more widespread, whereas cattle are less frequent. Current knowledge does not allow to distinguish between a possible impact of different grazers and a possible effect of management. The negative effect we found refers to grazing occurring during the fieldwork and, hence, during the breeding season; it is thus possible that livestock, shepherds and/or shepherd dogs may determine disturbance to breeding birds. This definitely warrants further investigation, because grazing is a key management also for conservation of grassland habitats and birds; impacts on species of conservation concern should be reduced by e.g. grazing plans including rotation targeted at preserving key shrub patches from direct disturbance during the breeding season (June and early July for red-backed shrike).

In addition to land-cover factors, which highlighted the species' link with grassland and the negative effects of other land-cover types, skylark occurrence probability was negatively impacted by buildings and by ski-pistes with altered grassland, whereas it increased with solar radiation. The latter was the only effect of topographic variables that emerged from the analyses. The negative effect of buildings and ski-pistes confirmed the sensitivity of the species to anthropic alteration of semi-natural grassland; even if it relies on anthropogenic habitats like mown or grazed secondary grassland, skylark is affected by urbanization and human disturbance, as already found in very different areas (Loretto et al., 2019), and is favoured by the cover of semi-natural grassland (Zellweger-Fischer et al., 2018). The negative effect of ski-pistes is coherent with general findings on Alpine valleys (Caprio et al., 2011; Rolando et al., 2007) and is particularly concerning, given that in recent years several new ski sites (or the enlargement of existing ones) have been proposed in different areas in Italian mountains, and future expansion of ski resorts are expected to be particularly impacting for alpine bird species (Brambilla et al., 2016).

We showed how climate, habitat and management traits differently contribute to determine patterns of occurrence in three declining passerine species inhabiting mountain grassland, an increasingly threatened ecosystem because of opposite pressures such as abandonment (Brambilla et al., 2017b) and intensification (Assandri et al., 2019a). Conservation strategies for these species and their habitats need to embrace i) landscape planning to preserve grassland and habitat mosaics, ii) a spatially explicit identification of climate *refugia* for water pipit, and iii) dedicated habitat management. The latter should include measures to prevent new ski-pistes over areas suitable for grassland birds, and subsidies to carefully plan grazing, promoting its maintenance at adequate density (to avoid overgrazing) in sites suitable for water pipit, and excluding access to shrub patches and hedgerows in breeding areas of red-backed shrike in June-early July. Considering the great (and increasing) appeal of traditional agricultural and pastoral products in the region (Di Renzo, 2013), coupled with the potential that small-scale economic activities have for the maintenance of landscapes suitable not only for production but also for recreation and biodiversity (Assandri et al., 2019a, 2018; Lindemann-Matthies et al., 2010), it should be possible to combine local, sustainable economies with biodiversity conservation by means of the integration of the above points into informed landscape planning (Geneletti et al., 2020; Ronchi, 2018). This should be feasible within the framework of the management plans of the several National Parks and other protected areas (Natura 2000 sites) that occur in the study region.

Acknowledgements

This work had been funded by MAVA Foundation within the project ‘Mediterranean Mosaics Phase II’. A. Galimberti and M. Bonora respectively provided the pictures of water pipit and skylark used in Fig. 2.

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