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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*

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Summary

Habitat selection has fundamental implications for species conservation, and in birds is often regarded as a multi-scale process. We investigated (under an information-theoretic approach) habitat selection by Woodchat Shrike *Lanius senator* in Italy (one of the most severely declining species in central and western Europe), considering five main types of potential determinants of shrike occurrence at the territory scale (1 ha): general structure (coarse landscape), woody vegetation, grassland habitats/bare ground, herbaceous crops, and management variables. The best supported models for species occurrence were those including general structure and woody vegetation traits. Variation partitioning suggested that overall, landscape general structure and woody vegetation explained the highest variation in shrike occurrence, and management the lowest. However, considering variation explained by only a single level, all levels performed nearly equally, but general structure did not explain an exclusive proportion of variation. A multi-level analysis suggested that shrike occurrence was eventually associated with specific habitat traits: isolated trees, shrubland and (secondarily) olive groves (all with positive effects), and dirt roads (negative effect). The most parsimonious multi-level models included only variables from woody vegetation and management traits, suggesting that the likely true determinants of species occurrence are highly specific and fine-scale habitat traits, consistent with variation partitioning. Woodchat Shrikes inhabit semi-open landscapes, within which they are attracted to shrubland and isolated trees (secondarily to olive groves) and avoid dirt roads. Suitable habitat conditions for the species depend on a trade-off between abandonment and intensive farming, and rural development programmes may be crucial for the conservation (or loss) of such conditions.

Introduction

Habitat selection is a key process with fundamental implications for species conservation (Cody 1985, Jones 2001). It is defined as the process an organism uses to choose its habitat, which results in habitat preferences consisting of differential use of specific resources relative to their availability (Hall *et al.* 1997). The choice of a habitat by a species has often been regarded as the outcome of a process involving multiple spatial scales (e.g. Johnson 1980, Orians and Wittenberger 1991, Jones 2001, Brambilla *et al.* 2010a). In several bird species, habitat selection seems to occur first at coarser scales, and then at finer scales, according to a hierarchical process (Johnson 1980, Jones 2001, Battin and Lawler 2006, Brambilla *et al.* 2006). Therefore, multiple scales representing 'coarse' and 'fine' habitat variables are often considered in habitat selection studies, especially for avian species.

Several bird species are threatened by unfavourable changes to their breeding habitat at different levels (Tucker and Evans 1997), and a particularly alarming case is represented by farmland birds (Fuller *et al.* 1995, Siriwardena *et al.* 1998, Krebs *et al.* 1999), which are dramatically and widely declining largely because of agricultural intensification (Tucker and Evans 1997, Chamberlain *et al.* 2000, Donald *et al.* 2001, 2006), especially through loss of ecological heterogeneity (Benton *et al.* 2003, Vickery and Arlettaz 2012), and land abandonment (e.g. Brambilla *et al.* 2010b). Both intensification and abandonment may affect the habitat of a species at different levels, from landscape structure (Suarez-Seoane *et al.* 2002, Benton *et al.* 2003, Brambilla *et al.* 2010b) to fine-scaled vegetation traits (e.g. Vickery and Arlettaz 2012).

Understanding the factors affecting habitat selection and the scale at which they act is thus necessary to promote species conservation and particularly urgent for threatened farmland birds. Among them, Woodchat Shrike *Lanius senator* is probably one of the most severely declining species in a large part of Europe, showing a continuous decrease over several decades in central and western Europe, whereas recent trends for south-eastern Europe are less negative (BirdLife International 2015). This species was formerly distributed in the whole Mediterranean region and in central Europe, but has undergone a large population decline and range contraction and now occurs mostly in southern Europe, where it is still declining in the western countries (BirdLife International 2015). The decline of the species in Italy is particularly alarming: the population underwent a 70–80% reduction in 2000–2012 (Nardelli *et al.* 2015) and is currently classified as 'Endangered' (Peronace *et al.* 2012), with a 'bad' conservation status (Brambilla *et al.* 2013a). Similar declines have been reported in the recent past for other countries, such as Spain, France, Switzerland, Germany, Poland, Croatia and Greece (BirdLife International 2015).

The Woodchat Shrike is reportedly associated with different natural and anthropogenic landscape traits (Table 1). On the basis of previous knowledge, we identified some potential determinants of species occurrence: i) general habitat structure, i.e. coarse landscape characteristics, ii) woody vegetation (trees, shrubs), iii) grassland habitats and bare ground, iv) cultivated (herbaceous) crops, and v) human-related variables (grazing management, roads, fences). The general habitat structure included environmental variables allowing for a coarse description of land cover and topography in the cells: these kinds of variables are comparable to the ones which can be extracted by commonly available GIS layers. The other levels included more detailed descriptors of the species, which should be generally recorded in the field (as in our study case), or obtained by means of more sophisticated approaches.

With this work, we aim to identify the habitat factors affecting species occurrence at the territory level and to evaluate the relative importance of different categories of habitat factors, corresponding to the five groups outlined above, which have been already reported as potentially important for the species (Cramp and Perrins 1993, Shochat *et al.* 2002, Filippi-Codaccioni *et al.* 2010). Those individual levels represent different kinds of environmental factors which can potentially affect the occurrence of Woodchat Shrike at the territory level. Evaluating their relative importance has essential implications for conservation, as the maintenance or restoration of suitable conditions for the species should be pursued by means of different strategies (e.g. landscape planning vs. agri-environmental schemes), according to the types of factors driving shrike occurrence.

Methods

Study areas and fieldwork

Woodchat Shrikes were censused in two different study areas (Figure 1): Tolfa (Central Italy, Rome province, Lazio region) and hilly areas of Matera province (southern Italy, Basilicata region). The two areas were selected as representative of extensive farming landscapes of the Mediterranean region, i.e. the most important macro-habitat of the species in Europe. Within the two areas,

Table 1. Factors affecting Woodchat Shrike occurrence and habitat selection according to the available literature.

Factor	Type	Effect	Source
landscape openness	landscape	semi-open landscapes occupied	Cramp and Perrins 1993
slope	landscape	flat or gently sloping areas preferred	Cramp and Perrins 1993, Chiatante *et al.* 2014
trees	woody vegetation	tall and sparse trees needed, wood pastures occupied	Cramp and Perrins 1993, Salvo 2004, Radišić *et al.* 2008
shrubs	woody vegetation	shrubs or scrubland required	Cramp and Perrins 1993, Guerrieri Castaldi 2000, Radišić *et al.* 2008
garigue	grassland and bare ground	garigues occupied	Cramp and Perrins 1993
shrubs	woody vegetation	shrubs of average height 3.4 m preferred	Guerrieri and Castaldi 2000
woody crops	woody vegetation	associated with old orchards	Cramp and Perrins 1993, Salvo 2004, Radišić *et al.* 2008
grazing	human management	areas grazed by domestic animals preferred	Tucker and Evans 1997, Guerrieri and Castaldi 2000
grassland	grassland and bare ground	preys chased in sparse grass	Nisoria 1994
bare ground	grassland and bare ground	preys chased in bare patches	Nisoria 1994
cereal crops	cultivated crops	included in territories when contiguous to grazed grassland	Guerrieri and Castaldi 2000
cereal crops	cultivated crops	associated with intermediate cover	Chiatante *et al.* 2014
pseudosteppe	cultivated crops	associated with steppe-like habitats	Chiatante *et al.* 2014
cables	human features	favoured by length of cables	Chiatante *et al.* 2014
urbanized areas	human features	negatively affected by suburban areas	Chiatante *et al.* 2014

we defined seven and 12 sample plots, respectively, each one covering some tens of hectares. These plots include open and semi-open landscapes in areas with climate suitable for Woodchat Shrike. To each area, four visits were made by the same observers (A. S. in Tolfa, E. F. in Basilicata), in April–June 2011. The observers noted all shrike contacts on maps (1:2000), recording all territorial and breeding behaviours, such as carrying food for chicks, members of a pair seen together, singing males, aggressive behaviour, calling of juveniles, nest alarm, occupied nests. Pair territories were defined on the basis of all contacts with the species and were distinguished among each other mostly on the basis of simultaneous observations of different pairs or singing males, as usually done with passerine birds (e.g. Birrer *et al.* 2007, Ceresa *et al.* 2012, Brambilla *et al.* 2013b).

A grid of 100 m × 100 m cells (1 ha-cells) was then superimposed on each study plot. The specific cell size was established on the basis of the territory size of the species reported in the literature (Harris and Franklin 2000, Lefranc and Worfolk 1997), often being fairly small (no more than 1 ha) (Cramp and Perrins 1993). A cell was defined as occupied when it included one territory of the species (in one case, two territories occurred within the same cell). When needed, the exact location of the cells including territories was manually adjusted to better match the territory extent. Grid cells were then used as sample units for territories and control plots, and all habitat variables recorded referred to the 1-ha cells. Within each one of the 19 sample plots (see above), unoccupied 'control' cells were randomly selected in the same number of occupied ones. This led to an average number of 1.7 occupied and 1.7 control cells within each sample plot; this balanced design prevented clustering of territories within the two areas and the associated potential spatial biases.

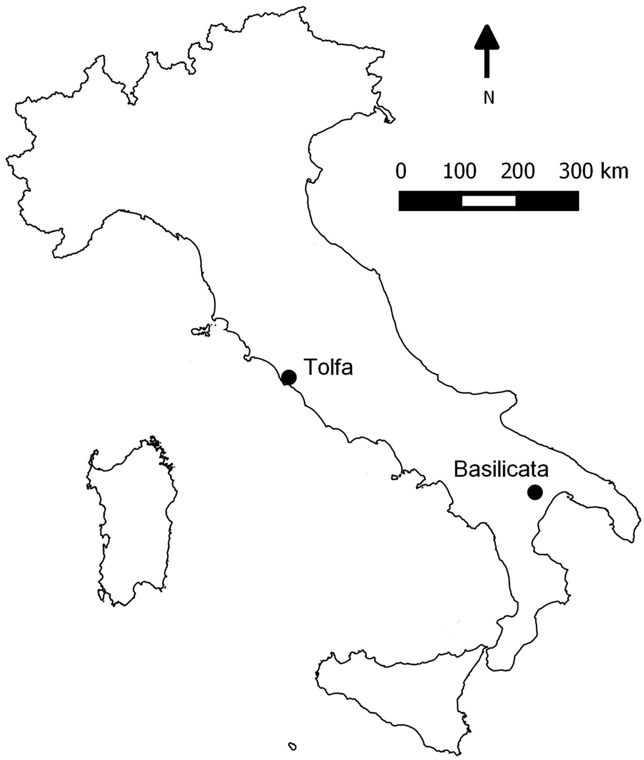

Figure 1. Location of study areas in Italy. Each study area included 7–12 plots within which fieldwork was carried out.

Habitat variables

We recorded directly in the field some habitat variables describing the following habitat characteristics: i) the general structure of the habitat, ii) the specific features of the woody vegetation, i.e. trees, shrubs and permanent (woody) crops, iii) the type of herbaceous layer and the occurrence of rocky or bare surfaces, iv) the features of cultivated (herbaceous) crops, and v) variables describing human management and impact, such as road and fence length and occurrence of domestic grazing animals (Table 2). Habitat variables were recorded in all the selected cells (occupied and unoccupied; see above).

Statistical analyses

Land-cover variables were arcsine square-root transformed before analyses. In each subset, VIF (Variance Inflation Factor) values were lower than 2.2 in all cases; in the multi-scale final model (see below), VIF values were lower than 1.6.

To qualitatively describe the habitats occupied by the species, we performed a comparison of habitat features between occupied (n = 33) and unoccupied cells (n = 33), evaluating differences by means of a t-test or a χ^2-test (the latter adopted for grazing occurrence; Table 3).

We then built GLM models with territory occurrence as the dependent variables, by relating it to the different habitat variables. We adopted an information-theoretic approach (Burnham and Anderson 2002), performing a two-step analysis. As a first step, to evaluate the relative importance of each group of variables and of individual factors within each group, all possible models for each

Table 2. Habitat variables considered in this study to evaluate habitat selection according to five different levels of habitat traits.

Variable	description
general structure	
slope	slope in degrees within the cell
herb_layer	percentage cover of all grassland and grassland-like habitats (excluding arable land)
shrub_tot	percentage cover of all shrub habitats
bare_tot	percentage cover of all types of bare ground
urban	percentage cover of urbanized areas
arable	percentage cover of arable land
fine-level habitat: woody vegetation	
shrub_1	percentage cover of shrubland lower than 1 m
shrub_1_3	percentage cover of shrubland of height comprised between 1 and 3 m
shrub_3	percentage cover of shrubland taller than 3 m
woodland	percentage cover of woodland
isolated_shrubs	percentage cover of isolated shrubs
isolated_trees	percentage cover of isolated trees
shrubland	percentage cover of compact shrubland
olive_groove	percentage cover of olive grooves
fine-level habitat: grassland and bare areas	
grazed_grass	percentage cover of grazed grassland
unmown_grass	percentage cover of unmanaged grassland
rock	percentage cover of rocky areas
bare_ground	percentage cover of grazed bare soil
gariga	percentage cover of gariga (herbs and sparse shrubs of arid areas, height<50 cm)
fine-level: herbaceous crops	
pseudosteppe	percentage cover of pseudosteppe
wheat_barley	percentage cover of wheat or barley
other_cereals	percentage cover of cereals different from wheat or barley
mixed_fodder	percentage cover of mixed fodder crops
management and anthropic traits	
fences	length (m within the cell) of fences
paved_road	length (m within the cell) of paved roads
dirt_road	length (m within the cell) of unpaved roads
goats_sheep	occurrence of grazing goats or sheep (0/1)
cows	occurrence of grazing cows (0/1)
horses	occurrence of grazing horses (0/1)

group were ranked using the Akaike Information Criterion corrected for small sample sizes (AIC_c). We checked the potential occurrence of quadratic relationships by entering the squared term of each variable, and then retained in the set of variables that were entered in the model the quadratic terms that showed a negative effect coupled with a positive effect of the linear term. As a second step, from each of the five different types of habitat traits, we selected the variables included in the most parsimonious models (models with $\Delta AIC_c < 2$) for each group, with the exception of the 'uninformative parameters' (cf. Arnold 2010). The latter are variables included only in models that comprised more supported and simpler models as nested ones (Ficetola *et al.* 2011); AIC_c used as the unique criterion for model selection may indeed over-select complex models (Richards 2005). With the resulting set of variables, we worked out a single, multi-scale model. Then, all possible models were ranked according to AIC_c, and an average model was obtained by averaging the most supported models (models with $\Delta AIC_c < 2$). Model ranking according to AIC_c and model averaging was done using the package 'MuMIn' (Bartoń 2014) in R (R Development Core Team 2013).

Table 3. Average features of shrike territories and control plots; * indicates significant ($P < 0.05$) differences (assessed by means of a t-test on arc-sin square-root transformed variables for land cover and road length, and by χ^2-test for grazing occurrence).

Variable	territory	control
	mean ± SE	mean ± SE
general structure		
slope	13.94 ± 1.89	12.70 ± 1.85
herb_layer	51.55 ± 5.51	54.36 ± 6.43
shrub_tot*	25.06 ± 3.20	15.39 ± 2.68
bare_tot	1.76 ± 0.51	6.00 ± 2.22
arable	16.03 ± 5.47	23.33 ± 6.54
fine-level habitat: woody vegetation		
shrub_1	11.79 ± 3.15	7.12 ± 1.97
shrub_1_3	7.39 ± 1.45	4.48 ± 1.06
shrub_3	5.88 ± 1.58	3.79 ± 1.63
woodland	2.12 ± 1.19	1.82 ± 1.54
isolated_shrubs	5.24 ± 1.17	4.33 ± 1.15
isolated_trees*	4.06 ± 0.86	1.36 ± 0.36
shrubland*	12.73 ± 3.34	5.00 ± 2.01
olive_grove	0.91 ± 1.96	4.55 ± 8.08
fine-level habitat: grassland and bare areas		
grazed_grass	21.76 ± 5.32	27.88 ± 6.79
unmown_grass	4.09 ± 3.01	0.30 ± 0.30
rock	1.09 ± 0.42	0.76 ± 0.37
bare_ground	0.61 ± 0.36	4.09 ± 2.25
gariga	6.21 ± 3.84	8.18 ± 3.81
fine-level: herbaceous crops		
pseudosteppe	19.48 ± 5.73	18.00 ± 5.80
wheat_barley	4.76 ± 3.33	3.94 ± 2.75
other_cereals	8.79 ± 4.17	18.18 ± 6.36
mixed_fodder	2.48 ± 2.48	1.21 ± 0.95
management and anthropic traits		
fences	3.94 ± 2.38	11.82 ± 7.12
paved_road	1.52 ± 1.52	3.03 ± 3.03
dirt_road	0.61 ± 0.61	9.39 ± 4.81
goats_sheep (frequency)	0.27	0.15
cows (frequency)	0.67	0.55
horses (frequency)	0.27	0.24

Finally we performed a variation partitioning analysis to compare the contribution of variables measured at different scales in affecting habitat selection by Woodchat Shrike. This analysis partitions the variation in habitat selection into components associated with different levels. To reduce the number of levels (maximum number allowed for the analysis is four), we summarised our levels as follows: i) general structure, ii) woody vegetation, iii) grassland, bare areas and cereals, iv) management and anthropogenic traits. The fractions of variation were calculated from the adjusted R^2, which allows an unbiased estimation of the portions of the variation explained by single levels and by their combination (Peres-Neto *et al.* 2006). This analysis was carried out by means of the "vegan" package (Oksanen *et al.* 2013) in R.

Results

Woodchat Shrikes (34 territories occurring within 33 cells) occupied cells characterised by a prevailing cover of grassland, which on average occurred over around half of the cell, and with a significantly higher availability of isolated trees and shrubland than unoccupied cells (Table 3).

Among the sets of candidate models reflecting different potential determinants of habitat selection in shrikes, the ones including the most supported models were general structure and woody vegetation (Table 4).

At the general landscape level, Woodchat Shrikes were associated with intermediate grassland cover and (small) patches of bare ground. Regarding woody vegetation, shrikes preferred areas with higher availability of isolated trees, olive groves and shrubs (especially those < 1 m). The analyses based on descriptors of grassland and bare soil habitats revealed a quadratic effect of grazed grassland, and a minor negative effect of bare ground. Considering herbaceous crops, a quadratic relationship with cereal crops different from wheat and barley was found. Among human and management traits, the most important factor was the length of dirt roads within the cell, which exerted a negative effect on species occurrence.

In the multi-level analysis, the most supported models (Δ $AIC_c < 2$) were averaged and led to the model described in Table 5. The R^2 of the two most supported models was equal to c.0.27. According to the averaged model, obtained from a set of possible models including the most important factors from the different levels considered, shrike occurrence was favoured by isolated trees, shrubland and (secondarily) olive groves, and negatively affected by dirt roads (Table 5).

Table 4. Candidate models reflecting different potential determinants of habitat selection in Woodchat Shrikes. The most supported models ($\Delta AICc \leq 2$) are shown per each subset of variables. For categorical variables, the symbol + indicates inclusion in the model; for continuous variables, the β value is reported to illustrate the effect on species occurrence.

Models							AICc	Δ	ω
General structure									
intercept	bare_tot	bare_tot^2	herb_layer	herb_layer^2	slope				
-0.46	15.80	-66.89	7.44	-6.22			86.0	0.00	0.080
-0.81	15.85	-69.70	7.79	-6.64	0.04		86.7	0.71	0.056
fine-level habitat: woody vegetation									
intercept	isolated_trees	olive_groves	shrubs_1	shrubs_1_3					
-1.50	7.11	3.34	2.43				86.7	0.00	0.150
-1.24	5.99		2.47				87.8	1.11	0.086
-1.85	5.63	3.86	2.84	2.11			87.9	1.20	0.083
-0.79	6.03	3.12					88.3	1.63	0.066
fine-level habitat: grassland and bare areas									
intercept	bare_ground	grazed_grass	grazed_grass^2	rocky_areas	unman_grass				
0.11	-2.86	5.76	-5.65				91.1	0.00	0.106
-0.04		5.62	-5.44				91.4	0.25	0.094
-0.12		5.66	-5.41		1.92		92.4	1.24	0.057
0.04	-2.72	5.79	-5.61		1.74		92.5	1.32	0.055
-0.15		5.83	-5.62	2.19			93.1	1.93	0.040
fine-level: herbaceous crops									
intercept	other_cereals	other_cereals^2							
	4.32	-3.95					93.2	0.00	0.091
	-0.66						94.3	1.04	0.054
management and anthropic traits									
intercept	dirty road	cows	goats_sheep	horses	fences	paved_roads			
0.12	-0.04						91.5	0.00	0.103
-0.21	-0.04	+					92.6	1.02	0.062
-0.01	-0.04		+				92.8	1.27	0.055
0.04	-0.04			+			93.4	1.84	0.041
0.15	-0.04					-0.01	93.4	1.90	0.040
0.15	-0.04				-0.01		93.5	1.95	0.039

Table 5. Average model obtained by averaging the most supported models (Δ AIC_c < 2; uninformative parameters excluded) among the ones built combining the most important habitat variables from each single level (see text for details). For each variable, the coefficient in the model (± SE for the averaged model) and the relative variable importance are shown. The latter is calculated considering the sum of weights of the models in which each variable appears (Burnham and Anderson 2002).

model	intercept	dirt_road	isolated_trees	olive_grove	shrubland	logLik	AICc	delta	weight
1	-1.49	-0.07	9.76	3.53	3.11	-33.5	78.0	0.00	0.19
2	-1.21	-0.07	8.52		3.13	-35.09	78.8	0.84	0.12
averaged	-1.38 ± 0.51	-0.07 ± 0.05	9.27 ± 2.95	3.53 ± 2.44	3.11 ± 1.21				
variable importance		1.0	1.0	0.6	1.0				

Variation partitioning suggested that woody vegetation explained a slightly higher variation in shrike occurrence than the other levels; however, when considering the variation exclusively explained by each single level, all levels are nearly equal, except for general structure, which did not explain any exclusive portion of variation (Figure 2).

Discussion

In birds as well as other animals, the choice of breeding habitat is a key process and can be affected by environmental factors acting at different spatial scales (e.g. Ficetola *et al.* 2011), or very different in nature, e.g. from land-cover type to topographical and management attributes (e.g. Chiatante *et al.* 2014) and highly specific resources (e.g. Jedlikowski *et al.* 2014). Conservationists should therefore identify the scale(s) and the factors likely to be most important for habitat selection and focus on these key resources.

Several farmland bird species have been declining over decades in Europe and elsewhere, largely because of habitat changes induced by intensification and other modifications to the farming

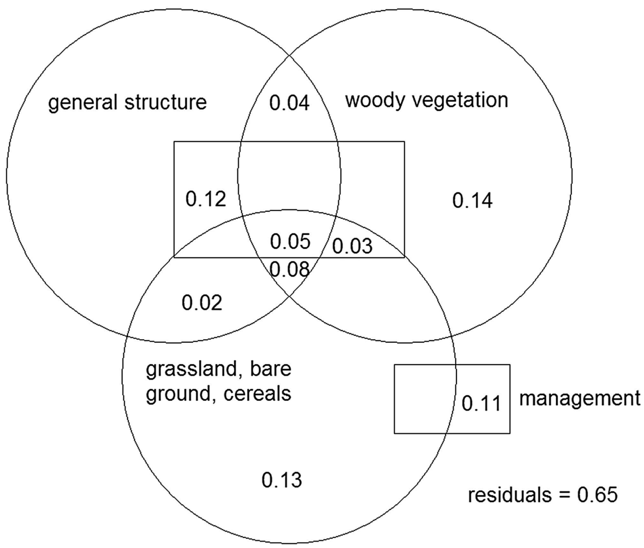

Figure 2. Results of variation partitioning for the occurrence of Woodchat Shrike in terms of fractions of variation explained by the different levels. Variation in occurrence is explained by four groups of explanatory variables (the two fine-level habitat types "grassland and bare areas" and "herbaceous crops" were considered together in this analysis; see text for details).

regime (Donald *et al.* 2001, Benton *et al.* 2002), but also because of land abandonment, which has negative impacts especially on Mediterranean birds (Preiss *et al.* 1997, Suárez-Seoane *et al.* 2002); both pressures may alter habitat at different levels. Woodchat Shrike has been declining for several decades in most of its European range, which constitutes the major portion of its global distribution (BirdLife International 2015), creating concerns over its future prospects. Although conditions experienced in wintering areas and during migration are also potentially important for the species (Cramp and Perrins 1993), breeding habitat availability and quality are likely to be crucial for its conservation, as they are for other shrike species (e.g. Red-backed Shrike, *Lanius collurio*; Brambilla *et al.* 2009a, 2010b), so it is essential to identify the factors driving species occurrence.

Here, we analysed potential determinants of shrike occurrence, considering different categories of habitat descriptors and evaluating their relative importance. Finally, from the output of this analysis, we selected the factors most likely to be involved in the habitat preferences of the species, and evaluated the most important habitat variables eventually associated with habitat selection by Woodchat Shrikes. Such habitat factors are also likely to be the most relevant for conservation through habitat preservation or restoration in breeding areas, including Italy, where the species underwent a dramatic population decline coupled with a 15% range contraction in the last decade (Nardelli *et al.* 2015), and in the rest of the Mediterranean region, where the species usually inhabits similar semi-open landscapes.

Among the different subsets of candidate models, the one describing the general landscape structure and that characterising woody vegetation were the most parsimonious. The final models better describing habitat selection by Woodchat Shrikes included only variables from woody vegetation and from human-related traits. This could suggest that although 'coarse' landscape variables are able to capture most of the variation when different sets of variables are considered in isolation, the true determinants of species occurrence are likely to be represented by highly specific and fine-scale habitat traits. This is further confirmed by the variation partitioning analysis, which highlighted how the variables associated with landscape structure did not explain exclusive parts of variation, despite explaining a large amount of it in conjunction with other variables. In short, this means that landscape variables may be successfully used to predict species occurrence, but are likely less important when planning habitat management for conservation. This seems to be a rather common pattern for shrike species, which are associated with well-defined landscapes but show a strong selection for (or avoidance of) very specific habitat traits within such landscapes (Brambilla *et al.* 2009a, Chiatante *et al.* 2014).

The association with intermediate grassland cover detected at the landscape level clearly reflects the general link with semi-open habitats, characterised by a mosaic of grassland or grassland-like cover and shrubs and trees (Cramp and Perrins 1993, Nisoria 1994, Guerrieri and Castaldi 2000), whereas the positive selection for small extent of bare ground is likely due to the need for areas where obtaining invertebrate prey is enhanced by their high detectability and accessibility (Nisoria 1994, Schaub 1996, Cramp and Perrins 1993). The positive effect of isolated trees, shrubs and olive groves mirrors the need for nesting and perching sites well known for that species (Cramp and Perrins 1993 and references therein). Considering the other types of habitat traits, a quadratic relationship with cereal crops had been already reported from another area in southern Italy (Chiatante *et al.* 2014), and is consistent also with anecdotal evidence reported from central Italy (Guerrieri and Castaldi 2000). The analyses based on descriptors of grassland and bare soil habitats revealed a quadratic effect of grazed grassland, and a negative effect of bare ground in grazed grassland. The former is fully consistent with the association with semi-open landscapes (see above), whereas the latter contrasts with the selection for small patches of bare ground found at landscape level, but it should be noted that such a negative effect of this specific type of bare ground is likely minor (the retention of the variable in the model resulted in a negligible improvement of model fit; see Table 4). The negative effect of dirty roads found in the human-related model had never been reported before, and suggests a negative effect of anthropogenic disturbance on the species.

Conservation implications

Woodchat Shrikes inhabit semi-open landscapes (on average, territories are made up of c.52% of grassland, and c.16% of arable land), within which they are attracted to shrubland and isolated trees (and secondarily to patches of olive groves), whereas they tend to avoid dirt roads. As already reported for the Red-backed Shrike (Brambilla *et al.* 2007, 2009a, 2010b, Ceresa *et al.* 2012) and for other farmland bird species in Italy (Brambilla *et al.* 2008, 2009b, 2013a, Rippa *et al.* 2011), the maintenance of suitable conditions for the species depends on a trade-off between abandonment and intensive farming, which are both highly detrimental to species preferring semi-open landscapes. The general model built upon the results of the single-level models confirmed the importance of isolated trees, shrubland, olive groves and dirt roads, suggesting that the availability of nesting and perching sites and the lack of direct human disturbance could be key features for the species in semi-open Mediterranean landscapes.

Those results may be used for the definition of conservation measures and in particular for an updating or revision of agri-environmental measures, such as those included in the Rural Development Programme (RDP). The main implications of our findings are: i) the importance of conserving low-intensity farmland systems, which harbour a compact mosaic of open habitats, different crops and shrub/tree patches, positively selected by several species of conservation concern, including Woodlarks *Lullula arborea* (Brambilla and Rubolini 2009, Brambilla *et al.* 2012), pipits *Anthus* spp. (Morales *et al.* 2012), shrikes (Brambilla *et al.* 2010b, Chiatante *et al.* 2014), buntings *Emberiza* spp. (Brambilla *et al.* 2012, Brambilla 2015); ii) the need to preserve some woody vegetation, and in particular shrubs and isolated trees, which have been reported to be favoured also by another threatened shrike species, the Lesser Grey Shrike *Lanius minor* (Chiatante *et al.* 2014). Some national or regional RDPs include among the measures adopted for grassland conservation the removal of trees and shrubs; controlling shrub encroachment is often needed to conserve open habitats, especially when they are facing abandonment, but should be done with care (Vassilev *et al.* 2011) to avoid the removal of breeding and perching sites for shrikes and other bird species (Nikolov 2010).

Furthermore, RDPs frequently include measures promoting new roads in cultivated areas to improve access to crops and fields. Considering the negative effect of dirt roads on the species occurrence, it would be important to prevent the construction of new roads in farms hosting Woodchat Shrikes or other sensitive species, and caution should be used about road promotion in RDPs.

In conclusion, our suggestions confirm and integrate previous recommendations for Woodchat Shrikes in Mediterranean landscapes, which focused on management primarily targeted at increasing perching and nesting sites, such as isolated trees and shrubs, in open landscapes with low levels of urbanisation (Chiatante *et al.* 2014).

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