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Habitat preferences of Sombre Tit (*Poecile lugubris*) in a karst environment

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Sombre Tit (*Poecile lugubris*) is one of the least studied passerine bird species in Europe, and the least known among Paridae species on the continent. The aim of the study is to identify its habitat preferences in a karst environment. The study took place in 2016–2017 within the "Rayanovtsi" Special Protection Area in Western Bulgaria – a limestone terrain with a mosaic of open areas, shrubs and scattered woodland, featured by sinkholes, rocks and caves. Territory and control plots were identified by means of point counts and territory mapping. To quantitatively describe the habitat structure and the fine-scale land-cover, 17 habitat variables were measured at both territory and control plots (the latter located at unoccupied sites), within a radius (180 m) approximating the territory size of the species. We used generalized additive models (GAMs) to identify the main predictors of species occurrence. Six habitat variables drove Sombre Tit occurrence according to the model: tree cover (quadratic effect), shrub cover (positive/quadratic effects), number of trees along the woodland edge and elevation (negative effects), solar radiation and woodland edge length (positive effects); tree and shrub cover were the most important predictors of species occurrence. Sombre Tits occurred at an average density of 0.36 pairs / 10 ha in the karst-dominated study area. Our results highlight the ecotonal habits of the species, provide a first quantitative description of its habitat preferences, and may be used to integrate the species' requirements into management plans of mosaic landscapes in Natura 2000 sites and other protected areas.

1. Introduction

Sombre Tit (*Poecile lugubris*) is one of the least studied passerine bird species in Europe, and the least known among Paridae species, because of its limited distribution on the continent and its unobtrusive behaviour. Its breeding range covers the Balkan Peninsula, Asia Minor, Levant, North Iraq, Caucasus and Iran (Cramp & Perrins 1993). By far the largest populations are thought to occur in Bulgaria and Turkey (Gosler *et al*. 2018).

Sombre Tits inhabit dry maquis areas with scattered trees and bushes, including olive (*Olea*) groves, wild plum (*Prunus*) orchards, vineyards, open oak (*Quercus*) forests including scrub oak, beech (*Fagus*), willows (*Salix*) and poplars (*Populus*); also conifers – spruce (*Picea*) and cedars (*Cedrus*), may be occupied, especially in areas of rocky limestone hills (Gosler *et al*. 2018). Early, anecdotal observations on Sombre Tits suggested that the species avoids dense forests (Löhrl 1966). According to general and qualitative descriptions of the species habitats in Bulgaria, Sombre Tit occurs regularly in deciduous woods but rarely in mixed or conifer woods. It inhabits mostly loose woodlands and their edges, orchards and parks. In addition, it is known for preferring dry eroded terrains covered by scattered trees and scrub vegetation, as well as gorges, canyons and other rocky areas mainly at mountain foothills. Sombre Tit is also a visitor in villages. Optimal habitats for the species are generally located between 300 and 1,000 m a.s.l., rarely up to 1,500 m a.s.l. (Nankinov 2009a).

While few species of the Paridae family occur in a broad range of habitats (such as the Great Tit *Parus major* in the Palearctic and the Black-capped Chickadee *Poecile atricapillus* in the Nearctic), most members of the family have more specialized ecological requirements. Nevertheless, even the least habitat-specialized species have an optimal habitat in which they achieve their highest breeding density and breeding success (Gosler *et al*. 2018).

Sombre Tit feeds mainly on small invertebrates, especially caterpillars and other larvae, occasionally seeds. It forages in lower branches of trees and shrubs and readily on the ground. It is monogamous and territorial, nesting in tree cavity or, less often, in rocks, and it also uses nestboxes (Cramp & Perrins 1993). It is a largely resident species, and moves in mixed-species flocks in winter, especially during its first year. Vertical migration is expected to occur in autumn (Cramp & Perrins 1993, Nankinov 2009a).

The aim of the study is to identify Sombre Tit habitat preferences and the specific habitat features affecting its occurrence in a karst environment. Karst areas cover a significant part of Bulgarian territory (estimated at about 23% of the country area; Popov 2002) and, within the study region, they provide one of the species' typical habitat types – open oak forests including scrub oak and dry limestone areas, as mentioned above (see Nankinov 2009a, Gosler *et al*. 2018). Karst territories, with their habitat mosaics made up of different vegetation types, bare substrates, and complex topography, provide an ideal context to perform a detailed study on Sombre Tit ecology, and have never been considered for this kind of research anywhere in the species' breeding range.

Habitat preference studies are needed to explain distribution, to evaluate potential abundance in areas without exhaustive counts, to understand the relationship between a bird and its habitat, providing key information for conservation and for predicting possible consequences of future environmental changes (Bibby *et al*. 1998). The dramatic land-use changes currently affecting large areas in eastern and southern Europe, which have important implications for birds (Zakkak *et al.* 2014, Brambilla *et al.* 2017), coupled with the lack of quantitative, detailed, assessments of Sombre Tit habitat preferences, make such insights into the species ecology particularly urgent. In addition to this main aim, we also investigated the breeding density of the species, to complement the very few available information on the species.

2. Material and methods

2.1. Study area

The study took place in the "Rayanovtsi" Special Protection Area in Western Bulgaria (40 km NW of Sofia) (Fig. 1), within the Continental Biogeographical Region, characterized by moderate-continental climate (Stanev *et al*. 1991). It is a limestone area of 13,200 ha located in the southwest foothills of the Balkan Mountain Range, with elevation ranging from 560 to 1,206 m a.s.l. (Petrovski krust Peak on Chepan Mountain) and low level of urbanization.

The karst terrain is featured by sinkholes, bare rocks and caves and includes various habitats: different types of broadleaved woodland with beech (*Fagus*), oak (*Quercus*), and hornbeam (*Carpinus*), of which "Panonian woods with *Quercus pubescens*" is a priority habitat type according to Annex I of the EU "Habitats" Directive (92/43/EEC); dry grassland and scrubland; hay meadows, wetlands, cultivated lands and conifer plantations (*Pinus nigra*).

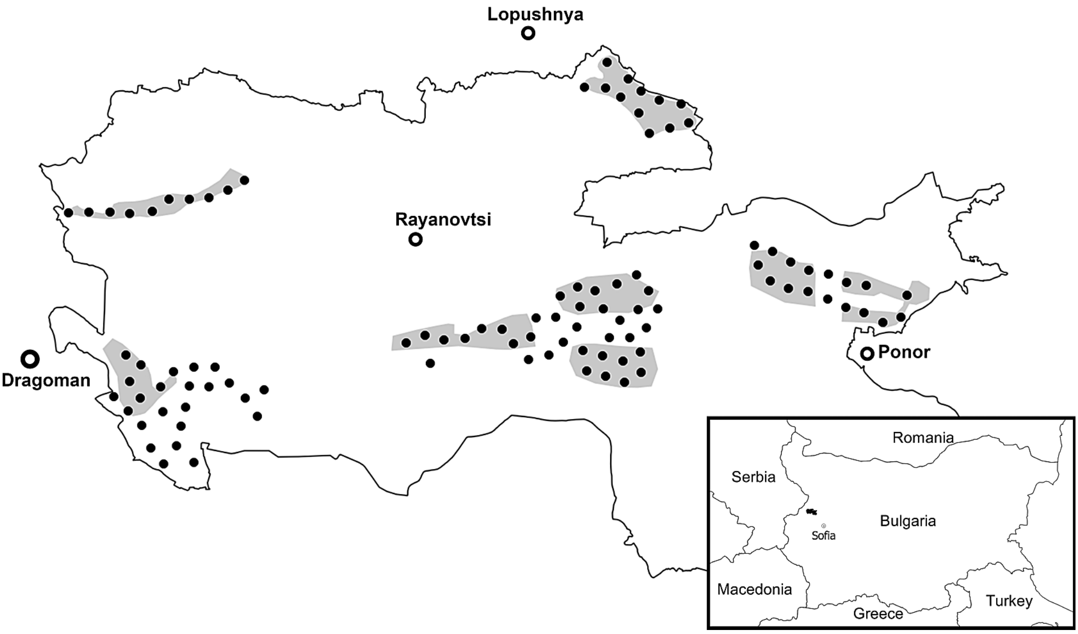

Fig. 1. Boundaries and location of the study area – "Rayanovtsi" Special Protection Area. Black dots denote point counts. Polygon areas where also territory mapping was performed are shaded in grey.

2.2. Fieldwork

Fieldwork was carried out in two subsequent years (2016 and 2017), during the breeding period of the species – between March and July (Nankinov 2009a). We combined two different survey methods to identify territory (and their centers) and absence sites: point counts and territory mapping. Within the Rayanovtsi SPA, we identified survey areas including potentially suitable habitats, and leaving out urbanized areas and other largely unsuitable habitats (e.g., large wetlands). Two (2016) and three (2017) replicated sessions of point counts (Bibby *et al.* 1998) were performed in 100 points (grouped in seven different plots; see Fig. 1) located in different habitat types. The minimum distance between points was set to 400 m, considering the large individual territories of the species (Cramp & Perrins 1993), to exclude possible overlap between neighbouring territories. Point counts were conducted in morning hours with counting sessions at each point lasting for 10 min, and detection based on visual and acoustic identification. Territory mapping was performed three (2016) and four times (2017) in eight plots (100–140 ha each) entirely located within the areas selected for point counts, and was performed in afternoon hours using playback stimulation (Bibby *et al.* 1998). Territory mapping in conjunction with point counts helped defining territory location as well as absence sites.

Territories were thus defined combining sightings obtained by the two methods, on the basis of all observations of territorial behaviour – singing male, alarm calls, carrying of nest material, foraging parents, presence of a family group – paying particular attention to simultaneous contacts between neighbouring birds. The center of each territory was defined by the midpoint of observations within the territory of each pair. Territories or territory centers are often used in bird ecology studies (e.g., Brambilla *et al.* 2016). Circular plots with 180 m-radius (hence with an area of 10.2 ha, approximately corresponding to the territory size of the species; Cramp & Perrins 1993, own data), were placed around all territory centers and around the same number of control (unoccupied) plots for both years, and were used to measure habitat variables.

In order to quantitatively describe the habitat structure and the fine-scale land-cover, 17 habitat variables (Table 1) were recorded directly in the

Table 1. Habitat variables measured within territory and control plots (radius 180 m).

Habitat variable	Description	Notes
Elevation	Elevation (m a.s.l.) of the plot center	
Distance to dirt road	Distance (m) of the plot center to the nearest dirt road	
Solar radiation	Mean values of total solar radiation (Wh / m^2 / day), taking into account the shadowing effect of reliefs	Calculated for 21st June
Slope	Mean values of slope (degrees)	
Hedges length	Length (m) of hedgerows	Hedge – non-herbaceous vegetation over 0.5 m height and 10 m length
Woodland edge length	Length (m) of the transitional zone between forest and open land	Woodland – group of trees over 1 ha
Number of solitary trees	Number of solitary standing trees with DBH > 10 cm	Trees – vegetation over 4 m height DBH – tree diameter measured at 1.30 m height
Number of trees along the woodland edge	Number of trees with DBH > 10 cm within the 5-metre belt along the woodland edge – includes the shrubs along the border	Trees – vegetation over 4 m height DBH – tree diameter measured at 1.30 m height
Distance to woodland	Distance (m) of the plot center to the nearest woodland patch	Woodland – group of trees over 1 ha
Tree cover	% cover of trees (including woodland)	Trees – vegetation over 4 m height Woodland – group of trees over 1 ha
Shrub cover	% cover of shrubs	Shrub – non-herbaceous vegetation over 0.5 m
Pasture cover suitable for grazing animals	% of pastures	Pasture – open grasslands with low vegetation
Meadow cover	% cover of meadows	Meadow – open grassland, mown for hay
Karst cover	% cover of bare rocks	
Cultivation land cover	% cover of cultivated land	
Grazing intensity	Categorical; 0–3 scale used to evaluate grazing activity	0 – no activity 1 – low intensity 2 – medium intensity 3 – high intensity
Mowing intensity	Categorical; 0–3 scale used to evaluate mowing activity	0 – no activity 1 – low intensity 2 – medium intensity 3 – high intensity

field or, secondarily, via GIS (Geographical Information System). Measuring took place both years in early autumn, after the breeding season, at territory and control plots. Topographic variables (solar radiation and slope) were calculated in a GIS environment (GRASS 7.4.3, Neteler *et al*. 2012) based on a Digital Elevation Model (DEM) of the study area, which was derived from USGS website (https://lta.cr.usgs.gov/SRTM1Arc). For solar radiation, we considered the total radiation, which is the sum of direct, diffuse and reflected radiation due to sun irradiance, according to incidence solar angle, and the shadowing effect of topography; it is given in Wh / m^2 / day, and we computed it for a reference day (21st June) using the command r.sun in GRASS. Mean values per plot of solar radiation and slope were calculated in QGIS 2.18 Las Palmas.

Due to reduction of livestock grazing, several pastures have been invaded by shrubs and trees (*Prunus spinosa*, *Crataegus monogyna*, *Prunus cerasifera*, *Quercus* sp. etc.). Shrubs removal is

Table 2. Mean (median for categorical factors) values of habitat variables and standard error in territory and control plots.

Habitat variable	Territory plots		Control plots	
	Mean/Median	SE	Mean/Median	SE
Elevation (m a.s.l.)	820.17	10.54	837.47	11.15
Distance to dirt road (m)	178.37	24.60	209.74	29.00
Solar radiation (Wh / m^2 / day)	8969.51	13.09	8947.30	17.64
Slope (degrees)	7.22	0.37	8.02	0.50
Hedges length (m)	156.54	19.71	144.15	24.58
Woodland edge length (m)	557.98	57.99	346.06	59.43
Number of solitary trees	55.87	5.77	55.66	7.79
Number of trees along the woodland edge	50.25	6.83	45.45	12.93
Distance to woodland (m)	148.79	34.95	226.04	40.30
Tree cover (%)	20.85	2.09	20.55	3.47
Shrub cover (%)	15.65	1.40	10.09	1.28
Pasture cover (%)	58.62	2.66	60.38	3.76
Meadow cover (%)	2.52	1.00	5.45	1.90
Karst cover (%)	2.67	0.75	3.45	0.85
Cultivation land cover (%)	0.31	0.22	0.79	0.41
Grazing intensity (0–3 scale)	0	0.07	0	0.07
Mowing intensity (0–3 scale)	0	0.05	0	0.06

therefore currently practiced by some land owners to promote the maintenance of open landscapes, and part of it was performed during the breeding period of the Sombre Tit. As a result, some plots in the area underwent habitat changes at the time of the study. In order to ensure full correspondence between species presence and habitat variables, any habitat alteration within a certain year was taken into account. After cutting the above-ground part of the plants, stumps and roots remained and absence of herbaceous vegetation where shrubs had been growing was still visible at the time of the measurement. Within such plots, we estimated the shrub cover before removal, in order to include cover values close to those occurring at the time of territory onset.

To avoid possible pseudoreplication between years, we considered for model building only data collected in 2017, the year with more intensive fieldwork; however, to take into account the potential importance of consistent status between the two years, sites occupied or unoccupied both years (identical or overlapping for more than 50%) were weighted two in models (all others were weighted one). Then, we re-ran the model attributing identical weight to all samples. In total, 99 plots were analyzed: 52 territories (of which 12 occupied in both years) and 47 control plots (of which 12 unoccupied in both years).

2.3. Statistical analyses

We modelled tit occurrence according to the habitat variables measured within the 180 m-buffer from territory midpoints/control points.

Prior to analyses, we checked variable values and distribution and then excluded a few factors, which had most records equal to zero. We standardized (centered around mean and scaled by standard deviation) all the environmental predictors, as this simple transformation is recommended for a better evaluation of multicollinearity and its relative effect (Schielzeth 2010, Cade 2015). Finally, we checked whether outliers potentially affecting analyses occurred within the dataset. For the variables tested in the model, only the number of trees along the woodland edge included one outlier, and the modelled relationship did not vary substantially according to its inclusion or exclusion.

We thus related Sombre Tit occurrence to the environmental predictors, after discarding a few of them, which according to the relative value of the generalized variance inflation factors (gVIFs;

Zuur et al. 2009), inflated multicollinearity of the models, considering a cut-off value of 4.0. We also excluded slope, which inclusion led to convergence problems and which was not supported in a single-variable model ($P = 0.211$), and hedges length; the latter was tested again in the final model but its inclusion was not supported. Hence, the variables entered in the model were elevation, solar radiation, distance to woodland, woodland edge length, number of trees along the woodland edge, number of solitary trees, tree cover, shrub cover, meadow cover and karst cover (see Tables 1, 2 for a detailed description of each variable). We used generalized additive models (GAM), with a binomial error distribution. As dependent variable we used Sombre Tit occurrence/absence. We built models using the 2017 data; plots known to be consistently occupied or unoccupied in both years (see above) were weighted two, all other plots one. Habitat variables were tested as smooth terms; in addition, we entered in the model a tensor term for longitude and latitude, to overcome the potential effect of spatial autocorrelation. We obtained progressively simpler models according to a step-down procedure, removing variables until all variables had a P-value < 0.1 (Zuur *et al.* 2009, Calvi *et al.* 2018). Then, we re-ran the so obtained model weighting one all samples. This analysis was performed with the package mgcv (Wood 2019) in R (R Development Core Team 2016); species-habitat relationships were plotted using the package visreg (Breheny & Burchett 2018).

3. Results

3.1. Breeding density

A total of 51 territories were identified in 2016 and 52 in 2017 by means of the combined approach including both point counts and territory mapping. Breeding density (in number of breeding pairs per 10 ha) was estimated on the basis of 37 pairs in 2016 and 33 pairs in 2017 within the plots with territory mapping totaling 970 ha. A mean value of 0.36 pairs / 10 ha was thus found in the karst-dominated environment (0.38 pairs / 10 ha in 2016 and 0.34 pairs / 10 ha in 2017) with sparse tree cover (solitary trees and patchy woodlots), moderate shrubs cover and high total solar radiation.

3.2. Habitat preferences

According to the GAM model, six variables were likely important for habitat preferences of Sombre Tits: tree cover (quadratic effect; $\chi^2 = 13.37$, $P = 0.001$), solar radiation (positive effect; $\chi^2 = 1.96$, $P = 0.081$), shrub cover (positive/quadratic effect; $\chi^2 = 3.18$, $P = 0.054$), number of trees along the woodland edge (negative effect; $\chi^2 = 2.32$, $P = 0.070$), elevation (negative effect; $\chi^2 = 2.52$, $P = 0.076$), and woodland edge length (positive effect; $\chi^2 = 1.58$, $P = 0.096$). The role of the spatial tensor was irrelevant. The species-habitat relationships are visually displayed in Fig. 2. This model explained 28.4% of the total deviance, and had a rather good discriminatory ability over the dataset (AUC of the ROC plot equal to 0.82).

Re-running the same model without weights confirmed the importance of the two most influential variables, i.e., tree cover (quadratic effect; $\chi^2 = 13.61$, $P < 0.001$) and shrub cover (positive/quadratic effect; $\chi^2 = 4.81$, $P = 0.025$), which maintained the same effect but became even more significant. The importance of the other variables decreased, as all their P-values increased (being between 0.1 and 0.2 for most variables).

4. Discussion

This study is the first detailed, quantitative, investigation on the habitat preferences of the unobtrusive Sombre Tit, the least known of European Paridae. Coherently with the available published information, Sombre Tit occurrence is associated with mosaic landscapes with moderate shrub and tree cover and relatively high solar radiation. Even if further investigation is required to assess the degree of generality of our findings and hence the potential extrapolation to other areas, the results we provided offer a first insight into the species' preferred environment. Its population in Bulgaria represents a considerable part of the European one (BirdLife International 2015), with a highly representative distribution all over the country (Grozdanov *et al.* 2007).

The effects of both shrub and tree cover, the most important variables indicating species occurrence, denote the dependence of the species on trees, which provide holes used as breeding sites, and on shrubs, which are mainly used for hiding or

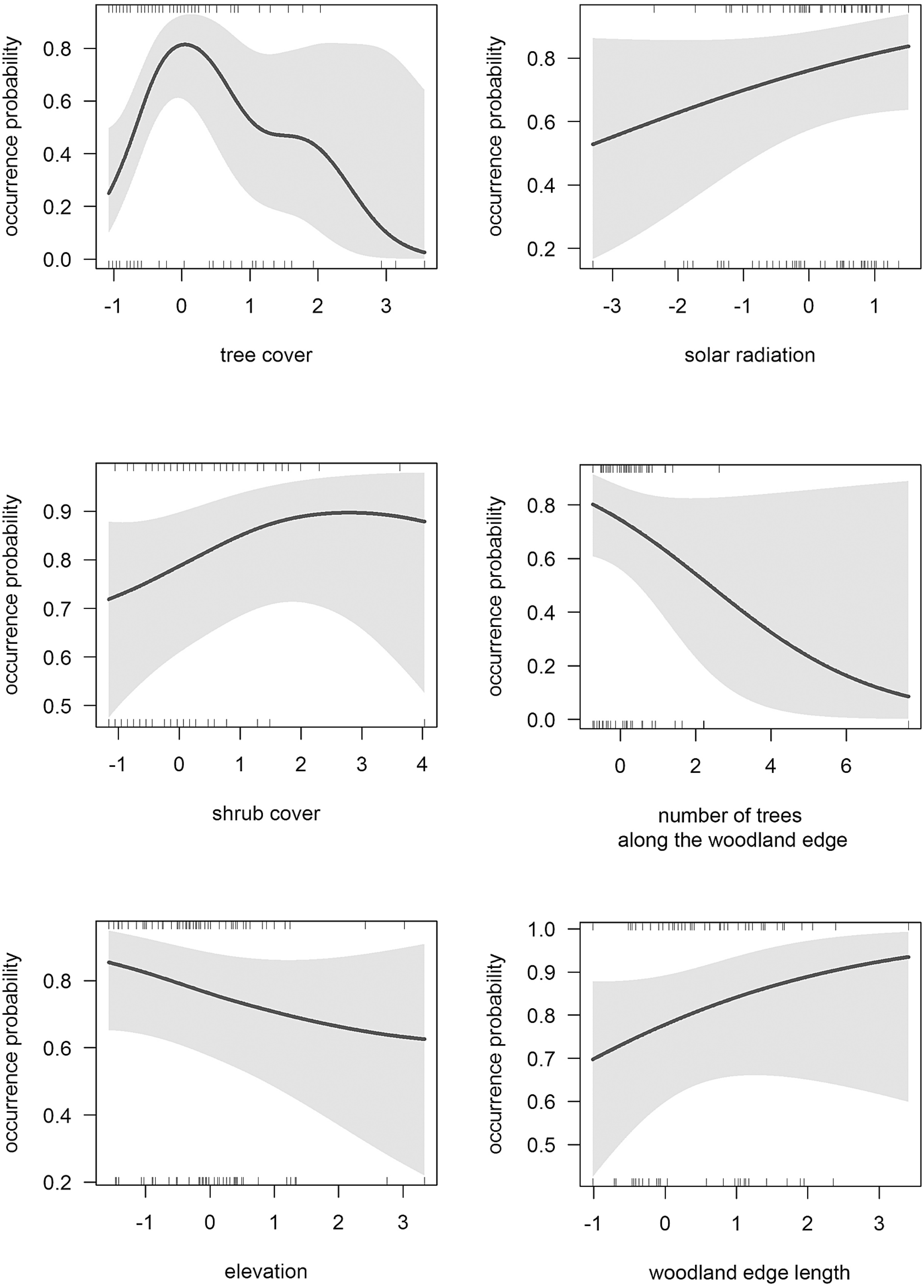

Fig. 2. Occurrence probability of Sombre Tit according to tree cover, solar radiation, shrub cover, number of trees along the woodland edge, elevation, and woodland edge length.

perching. Both trees and shrubs are undoubtedly also related to foraging habitats; however, shrub and tree cover exceeding certain values had been reported to be unsuitable for Sombre Tit, which favours sparsely wooded areas rather than dense forests (Gosler *et al.* 2018). Such a preference for an intermediate cover of woody vegetation is confirmed by the quadratic relationship that we found between the species occurrence and the overall tree cover. The quadratic/positive effect of shrub cover further highlight the link between the species and semi-open habitats. Shrub cover in the studied plots did not exceed 52%, and we found highest occurrence probability (≥ 0.8) for shrub cover above 21%.

These figures are fully coherent with a previous study on the impact of forest encroachment, which revealed that Sombre Tit can tolerate 25–50% of forest encroachment (Zakkak *et al*. 2014). Higher tree cover and higher shrub cover imply less open areas, the latter being likely important in providing part of the feeding resources needed during the breeding period. Sombre Tit indeed is known to forage in trees, as well as in shrubs and on the ground (Cramp & Perrins 1993, Nankinov 2009b). Similarly to other Paridae species with larger mass, such as the Great Tit, Sombre Tits tend to hop-forage more on or near the ground (Gosler *et al*. 2018).

Contrary to typical interior woodland species, which generally avoid forest edges if they are able to meet their resource needs within their territories (McCollin 1998), Sombre Tits were always detected in grasslands or scrubland (on the ground or perching on a shrub/tree), or near the forest edge, whereas they were never found in interior forest habitats far from the edge. In Prespa National Park (Greece) the species entirely avoided close and dense forests (Catsadorakis & Källander 1999). As a secondary cavity-nester, Sombre Tit is dependent on available tree holes, which are not necessarily provided by trees belonging to forests. Individual trees, woodland edges and small woodland patches in combination with open areas indeed appear to be important components of the breeding habitat.

These results indicate two types of preferred habitats: the ecotone between broad-leaved forest and open land, and the sparsely wooded areas. The importance of the former is suggested by the positive effect of woodland edge length, which positively affect the occurrence of other bird species (e.g., Oja 2005, Brambilla & Rubolini 2009).

Other factors, even if less important than tree cover and shrub cover, are likely to affect habitat suitability for Sombre Tits. We found a negative effect of the variable “number of trees along the woodland edge”, which could be due to different possible causes. First, natural or residual woodlots with smaller number of older trees, with higher DBH, could provide better nesting habitat than denser but younger trees (or pinewood plantations with abundant trees along the edge). In addition, woodland edge dominated by lower vegetation (e.g., shrubs) – or with scattered trees might be favoured because they offer most profitable foraging habitat.

Topographical variables – solar radiation and elevation – strongly affect microclimate, vegetation types and the local pool of plant and animal species, being thus potentially important for the fine-scale distribution of many bird species (Austin & van Niel 2010). Elevation was negatively related to Sombre Tit occurrence. However, such a negative effect is likely to be mediated by climate and habitat features, which vary along montane gradients and often have a complex relationship with elevation (McCain & Grytnes 2010); therefore, such an elevation effect is probably not generalizable over other portions of the species range. Solar radiation influenced positively Sombre Tit occurrence throughout the study area, where the species was more frequently found on sunny, well exposed sites. Previous studies in Bulgaria revealed a preference of the species for southern slopes of mountains (Nankinov 2009b), coherently with the positive effect of solar radiation found in this study.

In conclusion, our work provides a first quantitative assessment of Sombre Tit habitat preferences, highlighting its ecotonal habits and disclosing the most important drivers of habitat selection in this understudied and poorly known species. Concomitantly, the results of this study could be used for habitat management targeted at Sombre Tit conservation. In particular, the maintenance of sparse trees and intermediate cover of shrubland at forest edges, especially on sunny slopes, seems to be the most important management recommendation for the species.

Current government measures targeted at limiting the number of shrubs and trees within subsidized pastures are likely to impact very differently on sets of species displaying different habitat associations. Tree and shrub removal should be implemented only out of the breeding season of Sombre Tit and other species nesting in ecotones. According to the requirements of the study species, ideally 21–52% (values resulting in occurrence probability ≥ 0.8) of shrub cover should be maintained. Shrub removal, in case of higher cover, could have positive effect on Sombre Tit too, if performed out of the breeding period. In any case, complete removal of shrubs or small trees along the woodland border or in their vicinity, should be avoided in areas important for Sombre Tit conservation. Such management recommendations could be used to improve management plans of mosaic landscapes in Natura 2000 sites and within other protected areas in eastern Europe.

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Balkanintiaisen elinympäristövaatimukset karstialueilla

Balkanintiainen on yksi Euroopan vähiten tunnetuista lintulajeista, ja vähiten tutkittu tiaislaji koko mantereella. Tutkimuksen tavoitteena oli tunnistaa balkanintiaisen elinympäristövaatimuksia karstialueilla. Tutkimus suoritettiin vuosina 2016–17 Länsi-Bulgarian ”Rayanovtsi”-suojelualueella: suojelualue kattaa kalkkikiviperäisen alueen, joka on mosaiikki avoimia alueita, pensaikoita, metsäsaarekkeita, luolia ja onkaloita. Balkanintiaisen reviirit ja kontrollialueet (ei-asutettu alue) kartoitettiin pistelaskennan ja reviirikartoituksen keinoin.

Jotta voitiin selvittää kvantitatiivisesti kasvillisuutta ja elinympäristön ominaisuuksia, mitattiin 17 eri elinympäristömuuttujaa 180 m halkaisijaltaan olevilta reviiri- ja kontrollialueilta. Tärkeimmät selittävät ympäristömuuttujat selvitettiin GAM-mallien avulla: balkanintiaisen esiintymistä selitti puuston ja pensaikon kattavuus, puiden lukumäärä avoimen alueen reunoilla, maastonkorkeus, aurinkoisuus ja puurajan pituus. Näistä tärkeimmät olivat oli puuston ja pensaikon peittävyys. Balkanintiaisten tiheys oli keskimäärin 0.36 paria / 10 hehtaaria tällä karstialuella. Nämä ensimmäiset tulokset balkanintiaisen reviirinvalinnasta mahdollistavat lajin ympäristövaatimusten sisällyttämisen Natura 2000 -alueiden ja muiden suojelualueiden sekä luonnonhoitotoimenpiteiden suunnittelussa.

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