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A model of habitat suitability for Krueper's Nuthatch *Sitta krueperi*

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Capsule The presence of Krueper's Nuthatches can be predicted by variables describing topography, vegetation structure and tree species, and knowledge of these can be used to determine sites for conservation action.

Aim To analyse the relationships between habitat suitability, as characterized by the presence or absence of Krueper's Nuthatches, and different predictor variables of forest and landscape diversity by building a logistic regression model.

Methods We investigated the influence of 11 environmental variables on the occurrence of Krueper's Nuthatches. Logistic regression, a particular case of GLM with binomial error distribution, was used to identify vegetation and topographical variables that provide an explanation for the presence/absence of Krueper's Nuthatches in the study region of South Anatolia, Turkey.

Results Tree height, and north and southeast directions of slope were positively correlated with the probability of occurrence of Krueper's Nuthatches. Altitude, the presence of Red Pine and Syrian Fir trees, the presence/absence of bushes, and southwest direction of slope were all negatively associated with the occurrence of Krueper's Nuthatches.

Conclusion The constructed habitat model could be used to predict locations suitable for the creation of reservoirs for the conservation of Krueper's Nuthatches in this region of southern Turkey.

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Krueper's Nuthatch *Sitta krueperi* is endemic mainly in Anatolia (Turkey), Lesvos Island (Greece), and the Caucasian region (Russia and Georgia) (BirdLife International 2004, Albayrak *et al.* 2006, Albayrak & Erdogan 2005a, 2005b). Krueper's Nuthatch populations, like those of many forest bird species, have been declining in Turkey and Lesvos Island (BirdLife International 2004). It is a species of conservation concern; categorized as a Species of European Conservation Concern, SPEC 2 (BirdLife International 2004) and Near Threatened (IUCN 2006). The species is strictly confined to coniferous habitats from sea level up to the tree line at 2400 m (Frankis 1991, Harrap & Quinn 1996, Matthysen 1998, Löhrl 1988, Albayrak & Erdogan 2005a, Cramp & Perrins 1993, Hagemeijer & Blair 1997). In Turkey, it occurs mostly between 1000 and 1600 m, mainly in forests of Black Pine *Pinus nigra*, Syrian Fir *Abies cilicica*, Lebanon Cedar *Cedrus libani*, Red Pine *Pinus brutia* and Juniper *Juniperus* spp. (Albayrak *et al.* 2006). They are mostly sedentary with some post-breeding dispersal and seasonal altitudinal movements (Cramp & Perrins 1993, Harrap & Quinn 1996, Handrinos & Akriotis, 1997).

Modelling habitat suitability has become an important technique in the planning of avian conservation strategies (Bradbury *et al.* 2005, Oja *et al.* 2005, Lopez-Lopez *et al.* 2006, Olivier & Wotherspoon 2006, Manton *et al.* 2005, Alderman *et al.* 2005, Osborne *et al.* 2001, Hashimoto *et al.* 2005, Guisan & Zimmermann 2000, Knight & Beale 2005). Habitat suitability models require the simultaneous consideration of information on key environmental variables in situations where the species is present or absent. Such information is now available for Krueper's Nuthatches following extensive field surveys.

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With the advent of more powerful statistical methods there has been an increasing use of predictive habitat models in conservation planning and wildlife management. Such modelling often employs logistic regression to model the presence/absence of a species at a set of survey sites in relation to environmental variables, thereby enabling the probability of occurrence of the species to be predicted at un-surveyed sites (Pearce & Ferrier 2000). These models are usually fitted using GLMs (McCullagh & Nelder 1989).

The aim of this study was to analyse the relationships between habitat suitability, as characterized by the presence or absence of Krueper's Nuthatches, and different predictor variables of forest and landscape diversity by building a logistic regression model. The aim was to obtain knowledge about the relationships between habitat and the distribution of Krueper's Nuthatches.

METHODS

Study site

The study area was located in the southern part of the Mediterranean region of Turkey in the West and Middle Taurus Mountains (Fig. 1). The climate of the province was typical of the Mediterranean area: hot and dry summers and temperate and rainy winters. The annual mean temperature varied between 17 °C along the coastal area and 8 °C in the inner highlands. The annual mean precipitation varied from 400 to 900 mm, with maximum values during the autumn and minimum values in the summer. The topography was generally mountainous, ranging from sea level to 3750 m asl. The vegetation was mainly Mediterranean bush forests. Twenty-six percent of the area (172.431 km^2) was wooded, and 32% of this woodland consisted of several large conifer forests (Albayrak, T. unpublished data). The

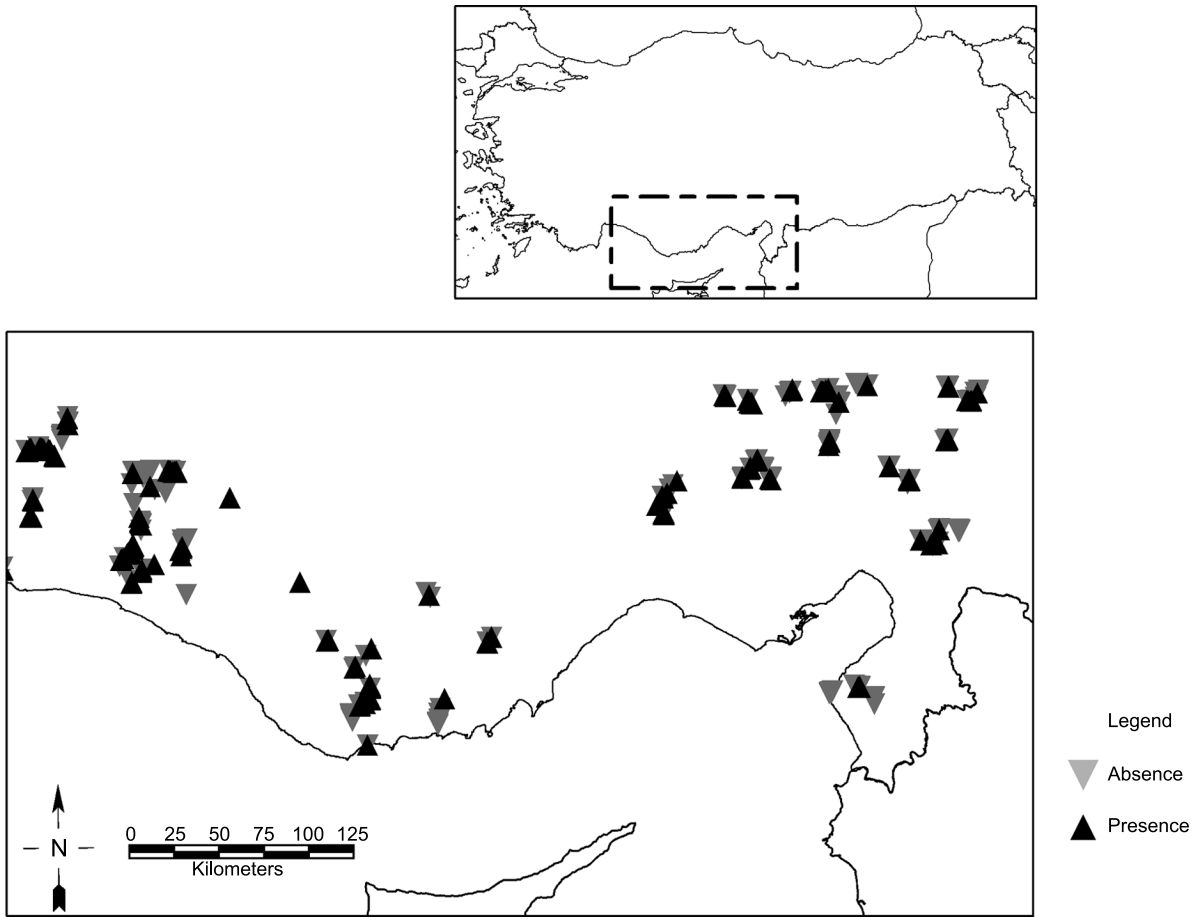


Figure 1. Location of the study area and the point survey sites in South Anatolia, Turkey.

dominant tree species were Red Pine, Black Pine, Syrian Fir, and Lebanon Cedar.

Bird census and environmental data

The bird survey was conducted at 433 count points during the breeding season, March–June 2005–2006. The breeding season of Krueper's Nuthatches was from mid-March to the end of June (Albayrak & Erdogan 2005a). Each count point was visited once in the morning between 07:00 and 11:00 or in the afternoon between 15:00 and 19:00. A modified unlimited-distance point count (Bibby *et al.* 1998, Bibby *et al.* 1992), using three-minute playback, was used for the presence/absence data of Krueper's Nuthatches. Always males, occasionally females and juveniles gave a response to playback from a maximum distance of 150 m. during all the stages of the breeding season (Albayrak, T. unpublished data). There was a minimum of 300 m distance between each count point to avoid double counting (Fig. 1). All count points were within coniferous forests. Species presence/absence records were assumed to be reliable owing to the Nuthatches' territorial behaviours in the breeding season. We also recorded 11 different habitat parameters at each point. These data were collected at each point within a radius of 30 m. Global positioning satellite (Magellan SporTrack Color) was used to determine altitude and topographic maps were used to determine slope. Mean top of canopy tree height, bottom of canopy tree height, proportion of tree cover etc. of all trees were determined at each point (see Table 1). We used the shadow method or pencil method to determine tree height in the field. Descriptions and abbreviations of these variables forming the initial pool of predictors and the summary statistics of the continuous type of independent variables are given in Tables 1 and 2, respectively. Pearson correlation coefficients between the continuous variables are shown in Table 3.

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Table 1. Descriptions and abbreviations of the independent variables used to model the occurrence of Krueper's Nuthatches.

Abbreviation	Meaning	Type	Levels	Description
TH	Tree height	Continuous variable	N/A	Mean top of canopy of tree height (cm) within 30-m radius of the selected point
BCnTree	Bottom of canopy of tree	Continuous variable	N/A	Mean bottom of canopy of tree height (cm) within 30-m radius of the selected point
PTree	Proportion of tree cover	Continuous variable	N/A	Mean proportion of trees' cover (%) within 30-m radius of the selected point
DBH	Diameter at breast height	Continuous variable	N/A	Mean diameter of trees at breast height (cm) within 30-m radius of the selected point
Alt	Altitude	Continuous variable	N/A	Mean altitude within 30-m radius of the selected point
GSlp	Gradient of slope	Continuous variable	N/A	Mean gradient of slope (degree) within 30-m radius of the selected point
PABus	Presence/absence of bushes	Factor	2	1 = presence; 0 = absence
PAGrs	Presence/absence of grass	Factor	2	1 = presence; 0 = absence
	Species of trees	Factor	2	Red Pine (0/1)*; Black Pine (0/1); Cedar (0/1); Fir tree (0/1)
	Directions of slope	Factor	2	North (0/1); northeast (0/1); east (0/1); southeast (0/1); South (0/1); southwest (0/1); west (0/1)
	Types of soil	Factor	2	Rocky (diameter of particle > 200 mm) (0/1); stony (20–200 mm) (0/1); gravelly (2–20 mm) (0/1); rough sandy (0–2 mm) (0/1)

*0, absence; 1, presence.

Table 2. Summary statistics of the continuous variables.

Variable Name	Minimum	Maximum	Mean	se
Alt	46	1809	875.59	21.71
TH	300	3500	1682.48	23.45
BCnTree	0	800	373.46	10.45
DBH	15	80	41.68	0.54
PTree	25	90	54.97	0.83
GSlp	4	40	23.83	0.55

See Table 1 for explanation of the variable names.

Table 3. Pearson product–moment correlation coefficients between the continuous variables.

	Alt	TH	BCnTree	DBH	PTree
TH	–0.138**				
BCnTree	–0.206**	0.293**			
DBH	0.005	0.589**	0.212**		
PTree	–0.029	–0.161**	0.034	–0.205**	
GSlp	–0.231**	–0.004	–0.118	–0.048	0.038

See Table 1 for explanation of the variable names; $*P < 0.05$; $**P < 0.01$.

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Statistical analyses and software

In order to build habitat models based on presence/absence data, GLMs were used. In this study, logistic regression, a particular case of GLM with binomial error distribution, was used to analyse data such as the presence/absence of species. In general, a GLM has three components: the linear predictor, a link function, and an error structure (Fırat & Onay 1999). The logistic regression model used in this study is presented in Equation 1:

$$Logit(p) = a_0 + a_1x_1 + a_2x_2 + ... + a_kx_k \qquad (1)$$

where p represents presence or absence of Krueper's Nuthatch, a_0 is a constant, and a_1 to a_k are the coefficients of the k predictor variables (x_1, x_2, …, x_k) listed in Table 1. Since the response variable (presence/absence of Krueper's Nuthatch) follows a binomial distribution, the *logit* was used as the link function. The error structure was assumed to be binomial (McCullagh & Nelder 1989).

The estimates of probability of occurrence of Krueper's Nuthatch can be obtained using Equation 2:

$$\hat{p} = \frac{\exp(\hat{a}_0 + \hat{a}_1x_1 + \hat{a}_2x_2 + ... + \hat{a}_kx_k)}{1 + \exp(\hat{a}_0 + \hat{a}_1x_1 + \hat{a}_2x_2 + ... + \hat{a}_kx_k)}. \qquad (2)$$

The estimated value of the linear systematic component of the model for the ith observation can be found using Equation 3:

$$\hat{\eta}_i = \hat{a}_0 + \hat{a}_1x_{1i} + \hat{a}_2x_{2i} + ... + \hat{a}_kx_{ki}. \qquad (3)$$

From this, the fitted probabilities can be found from Equation 4.

$$\hat{p}_i = \exp(\hat{\eta}_i) / \{1 + \exp(\hat{\eta}_i)\}. \qquad (4)$$

In order to select the most parsimonious model amongst a set of logistic models for each subset of variables, an automatic stepwise model-selection procedure was used, starting from a null model containing the intercept only. PROC LOGISTIC procedure with STEPWISE option of the MODEL statement in SAS program was used to build models and obtain the estimated probabilities (SAS Institute 1987). There has been recent criticism of the stepwise procedures (Wittingham *et al.* 2006) and the use of the AIC as a selection criterion in multi-model inference has been suggested as a useful alternative method. However, Stephens *et al.* (2007) suggested that stepwise approaches will continue to have an important role in fitting habitat models because of their computational simplicity.

It is important to emphasize that a GLM was used with a predictive rather than inductive goal. Under such circumstances, accuracy of model predictions is more important than significance of particular ecological terms (Legendre & Legendre 1998). A receiver operating characteristics (ROC) curve was used to assess the accuracy of the logistic model (Swets 1988, Murtaugh 1996, Fielding & Bell 1997). ROC curves are constructed by plotting the sensitivity of a model (or true positive rate) on the y-axis against the corresponding 1–specifity (or false positive rate) on the x-axis. The area under the ROC curve (AUC) is often used as a convenient measure of overall model fit and ranges between 0.5 and 1.0 (for a perfect fit) (Manel *et al.* 2001, Osborne *et al.* 2001, Thuiller 2003, Thuiller *et al.* 2005, Brotons *et al.* 2004, McPherson *et al.* 2004, Allouche *et al.* 2006). AUC can be interpreted as the probability of a model to render a higher predicted value of presence for a species at a site where the species exists than for a species at a site where the species does not exist (Zweig & Campbell 1993, Cumming 2000, Seoane *et al.* 2004). In this study, the ROC plot and AUC value are obtained using SAS software (SAS Institute 1987).

RESULTS

The habitat model was built for the presence of Krueper's Nuthatches and the results are illustrated in Table 4. The best logistic regression model identified the variables, Red Pine and Syrian Fir trees, altitude, tree height, presence/absence of bushes and north, southeast, and southwest directions of slope, as the most parsimonious predictors (χ^2 = 60.49; df = 8; P < 0.0001). As can be seen from Table 4, the greatest contribution came from altitude (P < 0.0001) and

Table 4. Summary results of the logistic regression analysis. The significance of the coefficients was assessed using the Wald χ^2 statistic.

Variable	Estimate	se	Wald χ^2	*P*-value
Intercept	3.896	1.018	14.66	0.000
Red Pine tree	–1.559	0.717	4.73	0.029
Syrian Fir tree	–0.676	0.491	1.90	0.168
TH	0.001	0.000	3.86	0.049
Alt	–0.004	0.001	27.26	0.000
PABus	–0.519	0.445	1.36	0.244
Slope direction north	1.608	0.488	10.86	0.001
Slope direction southeast	0.691	0.549	1.58	0.208
Slope direction southwest	–2.258	0.743	9.24	0.002

See Table 1 for explanation of the variable names.

north direction of slope ($P < 0.001$). The inclusion of the fir tree and presence/absence of bushes did not have a significant effect on the predicted power of the model.

Figure 2 illustrates the relationship between the mean probability of occurrences of Krueper's Nuthatches with the continuous type prediction variables, tree height and altitude, selected by the automatic stepwise regression method. Among the continuous type of prediction variables which were included in the final model, only tree height was positively associated with the probability of occurrence, whereas altitude was negatively associated (Table 4). The logistic regression model used in this study predicted the highest probability of occurrence (of approximately 0.69) for Red Pine and the lowest for Syrian Fir (0.43). The predicted probability for the presence of bushes was rather high at 0.68. The probability of occurrence was predicted to increase at first, with an increase in tree height and then decreases with the taller trees. It is clear from Fig. 2 that as the altitude increases the probability of occurrence of Kreuper's Nuthatches decreases from 0.95 to 0.17. Three of the directions, north, southeast, and southwest, were significant variables for the occurrence of Krueper's Nuthatches, and the mean probability was predicted to be the highest for northerly facing slopes (0.72) followed by southeasterly direction (0.55) and the lowest for slopes facing a southwesterly direction (0.27).

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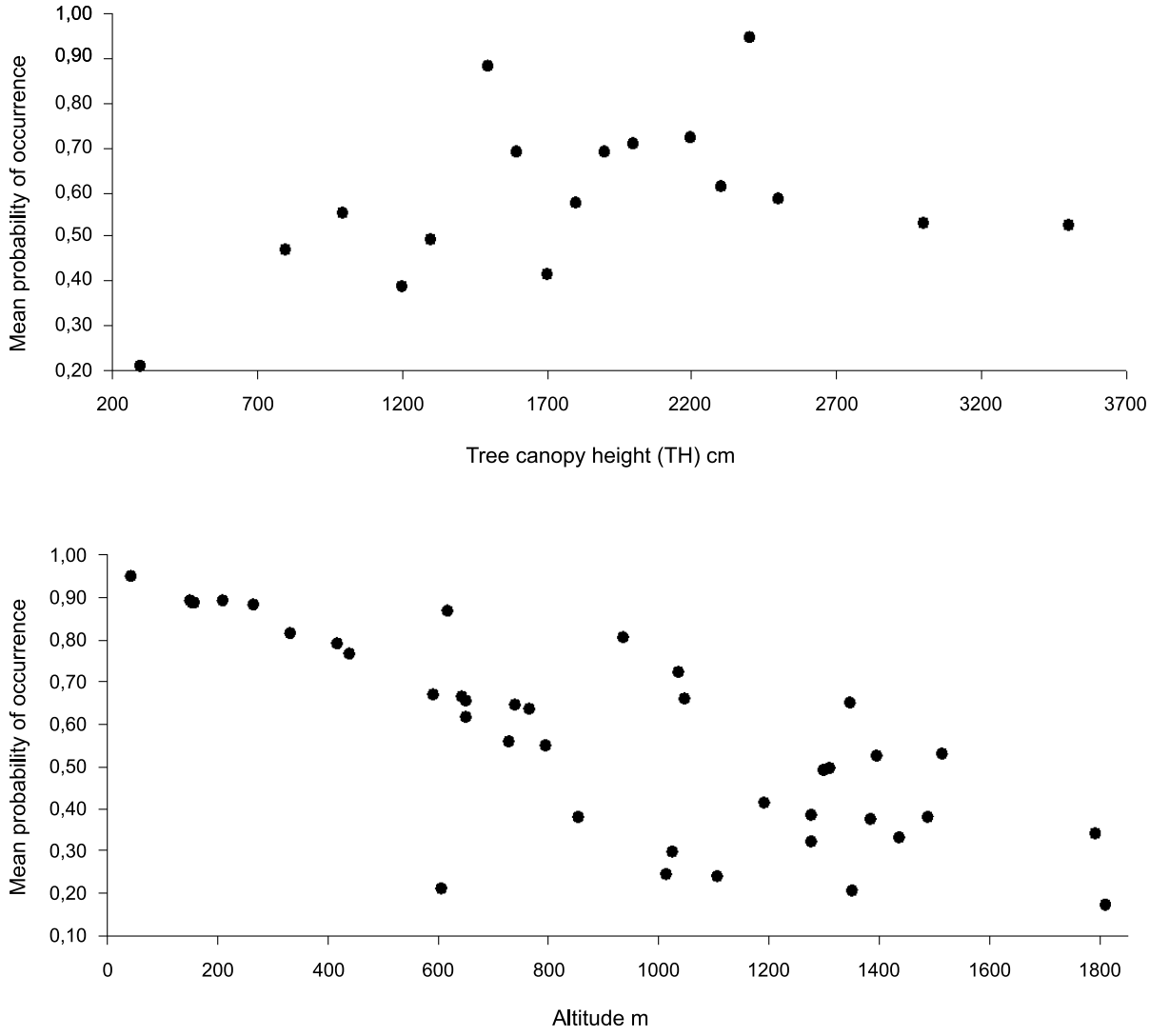


Figure 2. Relationships between the mean probability of occurrence of Krueper's Nuthatches with the continuous variables Tree Height (cm) and Altitude (m).

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To obtain a summary measure of discrimination capacity, the AUC was calculated. Overall the ROC plot for the selected model had an AUC of 0.767, indicating that the model can correctly discriminate between presence and absence of the species 76.7% of the time and the model could be considered as having good discrimination ability with this value.

DISCUSSION

Habitat management decisions are frequently taken at a small scale, affecting particular populations of particular species (Knight & Beale 2005). There have been few studies of Krueper's Nuthatches' habitat preferences (Albayrak & Erdogan 2005a, Albayrak *et al.* 2006) and no quantitative studies. This is the first study to investigate the associations of Krueper's Nuthatches with broad habitat variables. Although we used 11 habitat variables, our results show that a relatively simple set of predictor variables modelled using GLM can accurately predict the occurrence of Krueper's Nuthatches in the Mediterranean region of Turkey. Among the predictors selected to reflect breeding habitat preferences by the automatic stepwise model-selection procedure were Red Pine and Syrian Fir trees, tree height, altitude, presence/absence of bushes, and north, southeast, and southwest directions of slope.

It is a general rule that the more predictors are selected the more difficult it is to explain the model. Complex models with several predictors become very complicated and generally difficult to interpret in biological terms. Interaction terms might be added to the logistic regression model used in this study. However, such terms are sometimes difficult to interpret ecologically, and given the predictive power of the model reported here, we decided not to include them. In the modelling of bird–habitat relationships, it is important to note that the selection among sources of potential explanatory variables should be done on the grounds of data availability.

Our analysis shows that altitude and north and southwest directions of slope are the most important predictor of the probability of occurrence of Krueper's Nuthatches in South Anatolia. In addition, Red Pine trees and tree height are also important predictors of the best logistic regression model. Nest entrances of Krueper's Nuthatches were mainly found in southern (39%), and eastern (33%) directions and the nest height of natural cavities above the ground and the dbh of the nest tree were positively correlated (r = 0.57; $P < 0.05$; n = 17) (Albayrak & Erdogan 2005a). This finding supports the results of our logistic regression analysis. We suggest that Krueper's Nuthatches prefer high tree trunk dbh and high trees, because these improve breeding success and protect the birds from predators.

The results of this study and others (Shukuroglou & McCarthy 2006, Knight & Beale 2005, Manton *et al.* 2005, Alderman *et al.* 2005) have indicated that other environmental or biological factors may be more important in determining the distribution of birds.

This study has not fully answered why Krueper's Nuthatches occur so frequently in southern Turkey. However, it has elucidated the association between the presence of Krueper's Nuthatches and specific aspects of habitat. Results obtained in this study would be interesting for applied conservation and future research especially global distribution modelling of this rare bird species. An ongoing study will involve such a predicted distribution model including an accuracy test with an independent data set from other study areas by geographic information system (Albayrak, T. unpublished data). Finally, the habitat model obtained could be used to predict where efforts aimed at creating population reservoirs for the conservation of Krueper's Nuthatches are likely to be most successful.

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A model of habitat suitability for Krueper's Nuthatch *Sitta krueperi*

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