Ethology Ecology & Evolution, 2018
Vol. 30, No. 2, 178–186, https://doi.org/10.1080/03949370.2017.1323800

Short communication

Snake species richness predicts breeding distribution of short-toed snake eagle in central Italy

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Received 25 January 2017, accepted 27 March 2017

Birds of prey, as top predators, play a key role in ecosystem functioning by regulating prey populations and, by means of cascade effects, promoting biodiversity. This makes them adequate sentinels of ecosystem health. Here we analyse the relationship between the occurrence of breeding short-toed snake eagle (*Circaetus gallicus*) and both the richness of potential prey species and landscape characteristics by taking into account two different spatial scales (i.e. nest-site scale and landscape scale). The short-toed snake eagle offers an interesting case study for investigating the relationships between top predators, prey diversity, and habitats, because it is an extremely specialised raptor that feeds on mesopredators, mostly snakes. Additionally, short-toed snake eagles are mainly threatened by changes in agriculture and land use in Europe, which have reduced the extent of suitable hunting habitats, and by the decrease in snake populations. Our study was conducted in the Latium Region (central Italy) in 2007, where most of the Italian breeding population is concentrated. By means of habitat selection analyses using generalised linear models, our results showed that the species selected breeding areas characterised by low elevations, rugged slopes, and high snake species richness at the nest-site scale (1 km^2). At the landscape scale (25 km^2), the

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best model showed that birds selected areas characterised by lower elevations for nesting, with a tendency towards intermediate values of wood cover and high snake species richness. Our study highlights the strong relationship between snake species richness and the occurrence of breeding eagles at both spatial scales, with optimal breeding sites located closer to hunting areas than expected by chance. This study provides further support for the role of short-toed snake eagles as sentinel species for Mediterranean habitats, and highlights the link between the location of nesting sites and the occurrence of human-modified landscapes characterised by high prey richness.

KEY WORDS: bird of prey, elevation, habitat selection, mesopredator, raptors, wood cover.

INTRODUCTION

Birds of prey occupy a top position in the food web of most terrestrial habitats, which implies a high sensitivity of raptors to ecosystem dysfunction (Newton 1979). Their vulnerability to environmental changes combined with their occurrence range often being linked to high habitat quality and ecosystem productivity (Sergio & Newton 2003) lead conservationists to consider raptors sentinel and flagship species (Sergio et al. 2006, 2008). As top predators, raptors exert substantial top-down effects on lower trophic levels including regulating prey populations and, by means of cascade effects, promoting biodiversity (Sergio et al. 2014).

The short-toed snake eagle (*Circaetus gallicus*) offers an interesting case study for investigating the relationships between top predators, prey diversity, and habitats. In fact, it specialises in feeding on mesopredators, mostly snakes (Amores & Franco 1981; Bakaloudis et al. 1998), and requires heterogeneous landscapes with both open areas for catching prey and forests for nesting (Sánchez-Zapata & Calvo 1999). In Europe, the short-toed snake eagle is mainly threatened by changes in agriculture and land use, which have reduced the extent of suitable hunting habitat, and by the reduction of snake populations due to increased cultivation of monocultures, hedge destruction, the use of pesticides, and the abandonment of traditional farmland and subsequent afforestation (BirdLife International 2015).

In this study, we aim to analyse the link between the occurrence of breeding short-toed snake eagle and both the richness of potential prey species and landscape characteristics by taking into account two different spatial scales (1 and 25 km^2). The study focused on central Italy along the European–African flyway, where most of the Italian breeding population is concentrated (Agostini & Mellone 2008; Panuccio et al. 2012).

METHODS

Study area and breeding site survey

The study is based on a large survey of breeding short-toed snake eagle carried out in the Latium Region (Italy) in 2007, whose methods and results are reported in Speranza and Cecere (2008), and which is partially reported by Ceccarelli and Ricci (2007). The survey identified and localised 40 nesting sites, defined as very small areas inside which an active nest, or adult short-toed snake eagles showing specific behaviours (e.g. adults carrying nesting material;

copulation; displaying marked territoriality), has been observed, indicating a high probability of breeding. The Latium Region (17,203 km^2) is located in west-central Italy. Nearly one fourth of the territory (23%) is constituted by flat areas below 100 m above sea level (asl), while 52% is hilly (100–600 m asl), but both are mainly characterised by Mediterranean vegetation. The remaining area (23%) is mountainous (over 600 m asl) with more continental vegetation (Blasi 1994). Woods and forests cover 28.6% of the region, while agricultural land use represents 49.7% of the territory (Blasi 1994).

Environmental variables

In addition to the 40 points of presence, we generated 40 random points (absence) within the borders of the Latium Region, while avoiding urban areas and bodies of water, using ESRI-ArcGIS 9.2. Around each point, we generated two square cells with different sizes: 1 km^2 for the nest-site scale and 25 km^2 for the landscape-level scale (López-López et al. 2006). All 160 cells (80 for each scale) were characterised by seven variables: (1) average "slope" and (2) average "elevation", obtained by a digital elevation model (DEM) 20 m raster re-classified by a grid with 60 × 60 m pixel; random plots were coerced within the optimal elevation range known for the species (0–1600 m asl; values over this range are considered uncommon for the species, Cramp & Simmons 1980); (3) amount of "urban" and (4) "wood" habitats, obtained by re-classifying the CORINE Land Cover map for 2006 (class 1 and 3.1, respectively) by a grid with 60 × 60 m pixel; (5) squared-transformed wood cover, "wood^2", was entered to account for possible non-linear relationships, e.g. selection (or avoidance) of intermediate values; (6) "wood-edge", calculated as the sum of perimeters of wood patches was used as a proxy for ecotonal habitats; (7) predicted number of "snake" species obtained from the Regional Ecological Network raster (RER – Rete Ecologica Regionale, Scalisi et al. 2011) downloaded from http://dati.lazio.it/geoserver/reteecologicalazio/wms?service=WMS&version=1.1.0&request=GetCapabilities. RER is a multilevel raster including species distribution models (SDM) for all the vertebrate species occurring in the Latium Region. Models for all nine snake species occurring in the region were validated by means of independent data sets of species occurrence. Since it is based on SDMs, the variable "snake" does not provide the actual number of snake species for a given spatial scale, but rather the predicted number of species. Even considering this limit, we have to acknowledge that RER is currently the best source of information on snake species occurrence at a regional scale.

The amount of open area was indirectly included in the analyses, since it was highly negatively correlated with wood cover at both 1 km^2 ($r = -0.92$) and 25 km^2 scales ($r = -0.73$).

Data analysis

Habitat selection was assessed using logistic generalised linear models (GLM) with the presence/absence of each cell treated as a dependent variable and the seven environmental variables treated as independent variables (see. e.g. López-López et al. 2006 for similar methods). Akaike's information criterion (AIC) was used to select the best models ($\Delta AIC \leq 2$), which were then used to perform model averaging with their corresponding Akaike weights (Burnham & Anderson 2002). To avoid problems with parameter estimations, we first checked for pair-wise correlations between variables (Zuur et al. 2007). All analyses were performed in R ver. 3.3.2 (R Core Team 2016) separately for 1 and 25 km^2 scales, using the "MuMIn" package (Barton 2013) for model averaging. Final models were validated by means of the Area Under the Receiver Operating Characteristic Curve (AUC) using the "pROC" package for R (Robin et al. 2011).

Table 1.

Best logistic regression models (ΔAIC ≤ 2) at two spatial scales comparing occupied and a random sample of available locations.

Scale	Model	AIC	ΔAIC	w_I
1 km^2	Elevation + Slope + Snake	80.92	0.00	0.69
	Elevation + Slope + Wood + Wood^2 + Wood-edge + Urban + Snake	82.56	1.64	0.31
25 km^2	Elevation + Wood + Wood^2 + Urban + Snake	87.40	0.00	0.43
	Elevation + Wood + Wood^2 + Wood-edge + Urban + Snake	88.09	0.69	0.31
	Elevation + Wood + Wood^2 + Urban	88.45	1.05	0.26

RESULTS

None of the environmental variables were highly correlated to each other at 1 km^2, allowing us to include all of them in the GLMs. At the 25 km^2 scale, slope and elevation were highly correlated (r = – 0.72); we chose to enter elevation in the models since it has been found to predict the presence of the short-toed snake eagle at a larger scale (Panuccio et al. 2015). The best models (ΔAIC < 2) for both spatial scales are shown in Table 1. The final model at a nest-site scale (1 km^2) showed that the species selected breeding areas characterised by lower elevations, higher slopes, and higher snake species richness (Table 2; Fig. 1). At a landscape scale (25 km^2), the final

Table 2.

Coefficient estimates of the final model, obtained by averaging the best-performing models (shown in Table 1) with the corresponding Akaike weights separately at the two different spatial scales. Significant P-values (P < 0.05) are highlighted in bold.

		Coefficient estimate	z value	P
1 km^2 scale	(Intercept)	– 5.41 ± 1.95	2.59	**0.009**
	Elevation	– 0.004 ± 0.001	2.56	**0.01**
	Slope	0.24 ± 0.07	3.38	**< 0.001**
	Wood	– 0.08 ± 0.06	1.30	0.19
	Wood^2	$0.75 \times 10^{-3} \pm 0.61 \times 10^{-3}$	1.22	0.22
	Wood-edge	0.03 ± 0.05	0.66	0.50
	Urban	– 4.18 ± 0.04	0.01	0.99
	Snake	0.63 ± 0.19	3.24	**0.001**
25 km^2 scale	(Intercept)	– 4.43 ± 2.93	1.49	0.14
	Elevation	– 0.003 ± 0.001	1.99	**0.046**
	Wood	0.22 ± 0.11	1.96	0.05
	Wood^2	– 0.002 ± 0.001	1.80	0.07
	Wood-edge	– 0.07 ± 0.07	1.11	0.27
	Urban	– 0.17 ± 0.12	1.37	0.17
	Snake	0.32 ± 0.18	1.72	0.09

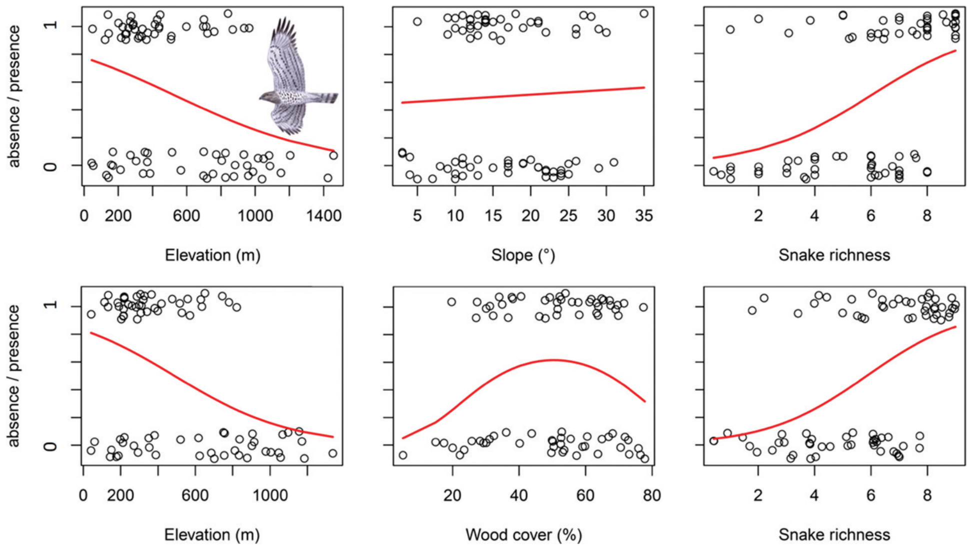

Fig. 1. — Relationship between the presence/absence of short-toed snake eagles and environmental variables at a nest-site (1 km^2, upper panels) and a landscape scale (25 km^2, lower panels) in the Latium Region, central Italy. Only significant and nearly significant relationships are shown (see Table 2). Points of presence/absence are jittered on the Y-axis with random noise to enhance visualisation.

model showed that birds selected areas characterised by lower elevations for nesting with a tendency towards intermediate values of wood cover (with a peak around 50%; see Fig. 1) and snake species richness and had a smaller effect size compared to the same effect at a nest-site scale (1 km^2) (Table 2; Fig. 1). The model validation performed by the AUC showed that final models predicted 89.2 and 85.6% of data, respectively, for nest-sites and landscape scales.

DISCUSSION

The highlight of this study is the strong relationship between snake species richness and the occurrence of breeding short-toed snake eagles at both spatial scales (1 and 25 km^2). The same link was found in other Mediterranean environments, such as southeastern Spain and across Italy, but at a much larger scale (100 km^2; Moreno-Rueda & Pizarro 2007; Panuccio et al. 2015). The result that prey species richness can explain nest-site selection at a very fine scale (1 km^2) suggests that optimal breeding sites are placed as close as possible to hunting areas, as has previously been shown for another raptor species, the red kite (*Milvus milvus*, Pfeiffer & Meyburg 2015). High numbers of prey species could favour the short-toed snake eagle, since different snake species can be active at different times (Ernst et al. 2012; Rocha et al. 2014) and/or select different microhabitats (Gomes & Almeida-Santos 2012), which increases the probability of the predator contacting potential prey. The stronger relationship at a small scale (1 km^2) with respect to larger scales [both the 25 km^2 of the present study and 100 km^2 reported in Moreno-Rueda and Pizarro (2007)] implies that nest-site selection by the short-toed snake eagle is in accordance with prey occurrence. This may suggest an ability for this raptor to assess habitat quality when establishing breeding territories after returning from African wintering grounds; this is a useful skill that has been observed in other bird species (Orians & Wittenberger 1991).

At the same time, considering that this bird mainly catches the most abundant snake species with a preference for the largest individuals (Gil-Sánchez & Pleguezuelos 2001), the short-toed snake eagle could favour snake richness through a top-down regulation process. Thereby, eagles would regulate the population size of the commonest species and reduce inter-specific competition among snakes as a cascading effect (Moreno-Rueda & Pizarro 2007).

In addition to snake species richness, the presence of breeding pairs at a small landscape scale was positively related to high slopes. Reliefs with deep sides are also selected by the species breeding in the Alicante province in Spain (López-Iborra et al. 2011). The study area (Latium Region) is characterised by a high density of human population, in particular in the areas surrounding Rome and in the flat areas. Therefore, we can expect that short-toed snake eagles prefer rugged areas for breeding, where human pressure is lower than elsewhere. Alternatively, eagles could select these rugged sites in order to take advantage of rising thermal updrafts, which are used for soaring and searching for food, as has also been hypothesised for juvenile Bonelli's eagles (*Hieraaetus fasciatus*) selecting steeper slopes for their temporary settlements (Balbontín 2005). Low elevations were preferred by short-toed snake eagles for breeding (average elevation of occurrence: 424 m, SD: 237 m asl) at both small and large spatial scales. The short-toed snake eagle arrives from wintering grounds in March, when temperatures are still cold at higher elevations for finding reptiles. Moreover, considering that elevation is strongly correlated with the average temperature during the breeding season ($r = -0.96$; $n = 40$ actual nesting sites; average temperature in May–August from WorldClim; Hijmans et al. 2005), we can conjecture that low elevations were selected due to higher temperatures, which in turn can also favour snake activity. At a large scale, breeders preferred areas characterised by intermediate values of wood cover and avoided both heavily open and wooded landscapes. The species needs open areas for hunting (Bakaloudis et al. 1998), but also woods for nesting (López-Iborra et al. 2011). Interestingly, the amount of wood-edge, which is an indirect measure of habitat heterogeneity, was not a key factor explaining the presence of the species. However, other studies have reported that ecotonal habitats are the preferred hunting areas for the short-toed snake eagles (Sánchez-Zapata & Calvo 1999). The finer spatial scale of our analysis in comparison with previous studies could probably account for this difference, since landscape heterogeneity arises at larger spatial scales.

In conclusion, this study provides further support for the role of short-toed snake eagles as sentinel species for Mediterranean habitats, and highlights the link between the location of nesting sites and the occurrence of human-modified landscapes characterised by high prey richness.

ACKNOWLEDGEMENTS

We thank Stefano Ricci, Valter Ceccarelli, Massimo Brunelli, Francesca Zintu, Fabio Borlenghi, Alberto Sorace, Ferdinando Corbi, Luigi Corsetti, Silvano Roma, and Emiliano De Santis for their great work during the short-toed snake eagle survey carried out in Latium in 2007 under the framework of the *BirdMonitoring 2007* project, funded by Direzione Regionale

Ambiente e Cooperazione tra i Popoli, Regione Lazio and managed by LIPU and the Regional Agency of Parks (ARP Lazio). We thank Javier Balbontín and Miguel Ferrer for constructive comments on a previous draft of the manuscript.

Pascual López-López is supported by a 'Juan de la Cierva-incorporación' postdoctoral grant of the Spanish Ministry of Economy and Competitiveness (Reference IJCI-2014-19190). Simona Imperio is supported by the Project of Interest "NextData" (PNR 2011-2013). This study also benefited from collaboration with the European Union's Horizon 2020 project ECOPOTENTIAL (No. 641762).

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

FUNDING

This work was supported by the Direzione Regionale Ambiente e Cooperazione tra i Popoli, Regione Lazio; LIPU; Regional Agency of Parks (ARP Lazio); a Juan de la Cierva-incorporación' postdoctoral grant of the Spanish Ministry of Economy and Competitiveness [IJCI-2014-19190]; Project of Interest "NextData" [PNR 2011–2013]; and the European Union's Horizon 2020 project ECOPOTENTIAL [641762].

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