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THE INFLUENCE OF FOOD RESOURCES ON RED FOX LOCAL DISTRIBUTION IN A MOUNTAIN AREA OF THE WESTERN MEDITERRANEAN

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ABSTRACT. – Determination of species geographic distribution and factors constraining it is a fundamental step for wildlife management and conservation. Red fox (*Vulpes vulpes* Linnaeus, 1758) is a widely cited species in carnivore ecological literature, mainly due to its wide distribution, generalist behavior and commonness. Nevertheless, few data are available on distribution constraints in the south-western part of its range. Our study aims to describe what factors are constraining the local distribution of this carnivore in central-west Portugal – a mountainous Mediterranean area, with a strong Atlantic climatic influence. A presence/pseudo-absence (based on the detection of signs of presence) Logistic Regression Model (LR) and a presence-only Maximum Entropy Model (Maxent) were constructed, testing the effect of several biotic (e.g., prey distribution) and abiotic variables (e.g., land cover, distance to urban areas, distance to roads, elevation) as constraining factors in the local distribution of the fox. The resulting models, based on 30 positive fox signs (plus 30 random pseudo-absence in LR) showed that only variables directly associated with food resources (presence of agricultural patches, closeness to human settlements/structures and proximity to areas with wild rabbit occurrence) significantly influenced the presence of foxes. These results were consistent for both modelling approaches. The high model fit of the LR model (AUC = 0.808), together with that of the Maxent analysis (AUC = 0.728), gave a high degree of confidence on these results. Our results demonstrate that although subject to some criticism, the indirect census method is easy to implement and can provide reliable results on populations' distribution and limiting factors. This approach might, and should, be complemented with other methods (e.g., captures, non-invasive methods, etc.) in order to obtain more precise information on population dynamics and ecology.

INTRODUCTION

Wildlife population and species ecological adaptations are a function of regional environmental factors (e.g., cover, food) and relationships with other species, populations and abiotic events (e.g., disturbances or perturbations) (Morrison *et al*. 1998). To achieve effective management plans, wildlife managers should understand the responses of target species to the different constraining biotic and abiotic factors, by studying and managing species in an ecosystem context. One of the baselines to understand and manage wildlife is the assessment of species distributions. Species distributions are often defined by the ecosystem characteristics that influence their ecological parameters, such as spatial and temporal ecology (e.g., food, cover - Morrison *et al*. 1998), or predator or prey interactions.

The red fox (*Vulpes vulpes*) is one of the most common and widespread meso-carnivore in western Mediterranean Europe (Travaini *et al*. 1996, IUCN 2007). It has a low conservation status (Least Conce-rn) in Portugal and Spain (Blanco & González 1992, Cabral *et al*. 2005), being one of the two meso-carnivores that can be legally hunted and controlled in Portugal (along with the Egyptian mongoose, *Herpestes ichneumon* Linnaeus, 1758, Duarte & Vargas 2001, Cabral *et al*. 2005). Red fox populations also face a negative human attitude as the species is often considered harmful by sheep ranchers and small game hunters and managers (Virgós & Travaini 2005). Thus, it is important to have distributional data on this species in order to implement effective management measures focused on foxes, thereby maximizing potential prey conservation [e.g., wild rabbit, *Oryctolagus cuniculus* Linnaeus, 1758 which has IUCN Near Threatened status and decreasing populations], assure red foxes game sustainable exploitation and ecosystem sustainability (e.g., to prevent accelerated loss of genetic diversity and maintain communities with natural intra and interrelations; Franklin 1997).

Table I. – Habitat variables used to characterise fox presence sites. *1* indicates variables used in the logistic regression analysis.

Variable name	Acronym		Type/class	Origin
Landscape unit where the sign was detected	Lands_unit	1	Categorical: Exotic stands; Rocky landscapes; Agricultural patches; Pine stands; Pasture; Deciduous forest; Scrubland	Field survey
Distance to houses/villages	Dist_hous	1	Distance (m)	GIS
Distance to paved roads	Dist_road	1	Distance (m)	GIS
Percentage of forest	Perc_for		% in a 200 m radius	GIS
Percentage of bare and rocky soil	Perc_bar	1	% in a 200 m radius	GIS
Percentage of agricultural patches	Perc_Agr_Patch	1	% in a 200 m radius	GIS
Percentage of scrubland	Perc_scrub	1	% in a 200 m radius	GIS
Percentage of houses/villages	Perc_hous	1	% in a 200 m radius	GIS
Altitude	Alt		Distance (m)	GIS
Percentage of slope	Perc_slope		Percentage (%)	GIS
Distance to areas with wild rabbit	Dist_rab	1	Distance (m)	Field survey (rabbit presence) and GIS

One of the problems that managers face when dealing with red fox in the Iberian Peninsula is the lack of distributional data and understanding of environmental constraints to the assessed range. Most available data focus on the species trophic ecology (e.g., Padial *et al.* 2002, Carvalho & Gomes 2004, Santos *et al.* 2007), or reveal some elements of spatial ecology as a by-product of other research (e.g., Gortázar *et al.* 2000, Barja *et al.* 2001). Although some data on red fox distribution and habitat use are already available in Spain (e.g., Fedriani *et al.* 1999, Duarte & Vargas 2001, Palomo & Gisbert 2002, Virgós *et al.* 2002), data are lacking in Portugal. Moreover, the available information for Iberia is concentrated in the typical Mediterranean biogeographic region, which dominates Iberia (EEA 1999), and is characterised by a climate with hot, dry summers and cool, wet winters, thus excluding some western mountain areas with a strong Atlantic influence.

Motivated by this lack of basic information, this study aimed to assess how environmental factors constrain red fox distribution in a mountain area with a more Atlantic climate, enclosed in a matrix of the Mediterranean biogeographic regions, in Central-West Portugal.

METHODS

Study area: The study was developed in the Serra de Montejunto Protected Landscape (Natura 2000 site PTCON 0048), a limestone mountain region (highest altitude: 666 m) located in Central-West Portugal (30º10'24''N/9º2'50''W). This region has a total area of 5000 ha, and the climate, although Mediterranean, has a strong Atlantic influence; mean annual temperatures that vary between 12.5 ºC and 16 ºC and total annual precipitation between 800 mm and 1000 mm (with 75-100 rainy days/year, and high humidity, 75 %-80 %; Rosalino *et al.* 2005).

The area is dominated by scrublands (e.g., *Quercus coccifera* Linnaeus, *Ulex* spp.), agricultural patches (such as olive groves, orchards and vineyards), stands of Eucalyptus (*Eucalyptus globulus* Labill) and Pine (*Pinus pinaster* Aiton), and pastures. Several villages are scattered throughout the area, with the exception of the central high mountainous region. Main activities are arable farming, some forestry (Pines and Eucalyptus), limestone mining, livestock farming (mainly sheep) and hunting, mainly wild-rabbit and partridge (*Alectoris rufa* Linnaeus 1758).

Methods: The study area was surveyed once between March and August 2005. Direct observations or signs of presence (e.g., scats, footprints, etc.) were recorded by highly experienced observers. Surveys were based on the 1x1 km Universal Transverse Mercator (UTM) grid and, in each of the 1 km^2 units one transect of 1.5 km was surveyed during daylight hours. Transects were divided into stretches in each land cover, and stretch length within each type of landscape patch was proportional to availability, i.e., 100 % of each 1 km^2 square corresponded to 100 % of the 1.5 km transect in the same square; the same proportion of each land cover unit within the 1 km^2 sampling square was walked in the 1.5 km transect. Starting from the unit's central point transects were walked towards its limits, using the available dirt roads. All 1 km^2 grid units of the study area (N = 50) were surveyed using the 1.5 km transects. In order to minimize the bias associated with sampling sites at different periods our sampling scheme was defined so that we could sample neighbouring squares in different months; thus we surveyed the study area using a stratified pattern in such a way that contiguous UTM squares (located N, S, E and W of the focal one) were not sampled in the same month.

Each site where individuals or signs of presence were detected was geographically located using a GPS receiver (Garmin eTrex; accuracy: 3 m) and characterised according to several environmental parameters, which included landscape units, distances to human settlements and paved roads, altitude, slope, and distance to the nearest area with presence of wildrabbits (Table I). Fox signs located within a short distance of one another (< 200 m – this was the radius of the circular areas used for characterize presence and pseudo-absence sites. See below a description) were excluded from analysis since they could bias results due to the possible characterization of the same area more than once (overlapping of the more than one 200 m buffer areas).

Rabbit areas were concurrently assessed with the walked transects. Wildrabbit's observations or signs of presence were recorded at each location and geo-located. This last variable was included in the analysis since rabbits are often referred to as foxes' main prey in Mediterranean habitats (Fedriani *et al.* 1999).

Data quality assessment: Spatial autocorrelation was assessed by Moran's I index (I), and its significance derived from the standard z-variate based on an assumption of normality (Moran 1950, Sawada 1999). To prevent problems associated with correlation between independent variables (Tabachnick & Fidell 1996), the Spearman's rank correlation coefficient (r_s), for continuous variables, and the phi coefficient (r_Φ), for binomial variables (Siegel & Castellan 1988), were used to test variables' associations. Cook distance was used to assess the existence of outliers (Maroco 2007). Since we had a medium/low sample size we used a resubstitution method (data used for training and testing are the same; Fielding & Bell 1997).

Data analysis: Two modelling approaches (presence/absence and presence only) were considered to test the effect of the biotic and abiotic factors as constrainers of red fox distribution. We used as presence/absence model a logistic regression (LR) algorithm to assess the contribution of each predictor variable to the likelihood of presence of the red fox. We characterized the habitat composition in the vicinity of each fox presence site, by creating a 200 m radius around each location, representing an area of 12.5 ha. The use of this value derives from the smallest fox core areas assessed for a population living in Mediterranean rural areas (± 12 ha; Pandolfi *et al.* 1997). Additionally, an equal number of sites where the species was not detected (pseudo-absences) were randomly selected and characterised similarly to the presence sites. Site selection was made using the Random Point Generator (© Stephen Lead) extension for ArcView version 3.1 (ESRI, California, USA), and applying the following criteria: each site was located 200 m apart from each other (to avoid overlap between site characterization) and 100 m from study area limits (to avoid characterising areas outside the study area); all sites where located on dirt roads and 200 m away from fox signs. Each site was checked in the field to assure that no fox signs were detected. We used a Forward: Likelihood Ratio method, as described by Maroco (2007) and following recommendations by Hosmer & Lemeshow (1989) for the logistic regression. This statistical technique is adequate for analysing presence/absence of a particular species at a site (Zuur *et al.* 2007) and is sensitive to different proportions of samples where animals were present compared to pseudo-absences (Hosmer & Lemeshow 1989).

The first step to select variables to be included in the LR model is to test which factors are statistically associated with the dependent variable (likelihood ratio test - G). Thus, we used the criteria suggested by Hosmer and Lemeshow (1989) and any variable whose univariate test had a p-value < 0.25 was a candidate for the multivariate model.

Due to the high number of variables when compared with the sample size (Burnham & Anderson 2002), in the model selection procedure we used the Akaike's Information Criterion (AIC) to choose, from all possible regression models, that which had the lowest AIC value ("best model"). The significance of regression parameters was tested using the Bayesian Information Criterion (BIC, for which a value > 2 implies a relationship, Zuur *et al.* 2007) and the likelihood ratio test (considered more reliable for small samples; Agresti 1996). Models goodness-of-fit were assessed by: i) the percentage of correct classifications (a measure, derived from the confusion matrix, of how the produced model classifies known cases as presence or absence; it is divided in Sensitivity – conditional probability that a positive case is correctly classified – and Specificity – conditional probability that a negative case is correctly classified; Fielding & Bell 1997); ii) Huberty's standard normal statistics to assess if the predicted success of the classifiers exceed the expected by chance (Fielding & Bell 1997) and iii) Pearson residuals chi-square test. We also calculated the area under the curve (AUC), derived from receiver-operating characteristics plots (ROC), which is obtained by plotting sensitivity *vs* (1-specificity). Although AUC has been the target of some criticism (e.g., due to the uncertainty of absences in presence-absence models; Lobo *et al.* 2007), it can be used to assess how a species is restricted to part of the variation range of the modelled predictors (Lobo *et al.* 2007).

Additionally we used the Maximum Entropy Modelling approach (from Maxent) to define the maximum entropy presence-only model. This model has been broadly used to create species distribution models based on potential biotic and abiotic factors. For this modelling approach we used the geographic coordinates of the red fox detections, and as potential predictor variables, raster datasets of landcover, distance to roads, distance to urban areas and modelled rabbit distribution (from Maxent). We allowed the model to run until convergence was achieved and model performance was assessed using AUC.

The landscape analysis and the evaluation of habitat variables were derived from a GIS built using ArcView version 3.1 (ESRI, California, USA), and based on photointerpretation of aerial photography. GridTools (Jenness 2006), Patch Analyst (grid) 2.3 (© Dr. Rob Rempel) and Patch Analyst (Elkie *et al.* 1999) extensions were used to perform some habitat analysis. Moran's I index (I) values were determined by ROOKCASE Microsoft Excel Add-in (Sawada 1999). Maximum entropy model was created in MaxEnt software package (http://www.cs.princeton.edu/~schapire/maxent/). The remaining statistical analyses were performed using the SPSS for *Windows*, release 16 (SPSS Inc., Chicago, USA) package.

Table II. – Selected variables incorporated in the best logistic regression model obtained for the red fox data (B, Model coefficient for each variable; SE, Standard error; BIC, Bayesian Information Criterion; Exp(B), odds ratio corresponding to a one unit change in the variable).

	B	SE	Likelihood ratio test			BIC	Exp(B)
			χ^2	df	p-value		
Perc_Agr_Patch	0.020	0.010	4.716	1	0.030	2.472	0.980
Perc_hous	7.736	12329.132	6.756	1	0.009	- 1.778	2290.112
Dist_rab	-0.005	0.001	14.090	1	< 0.001	8.152	0.995
Constant	1.628	0.555					5.095

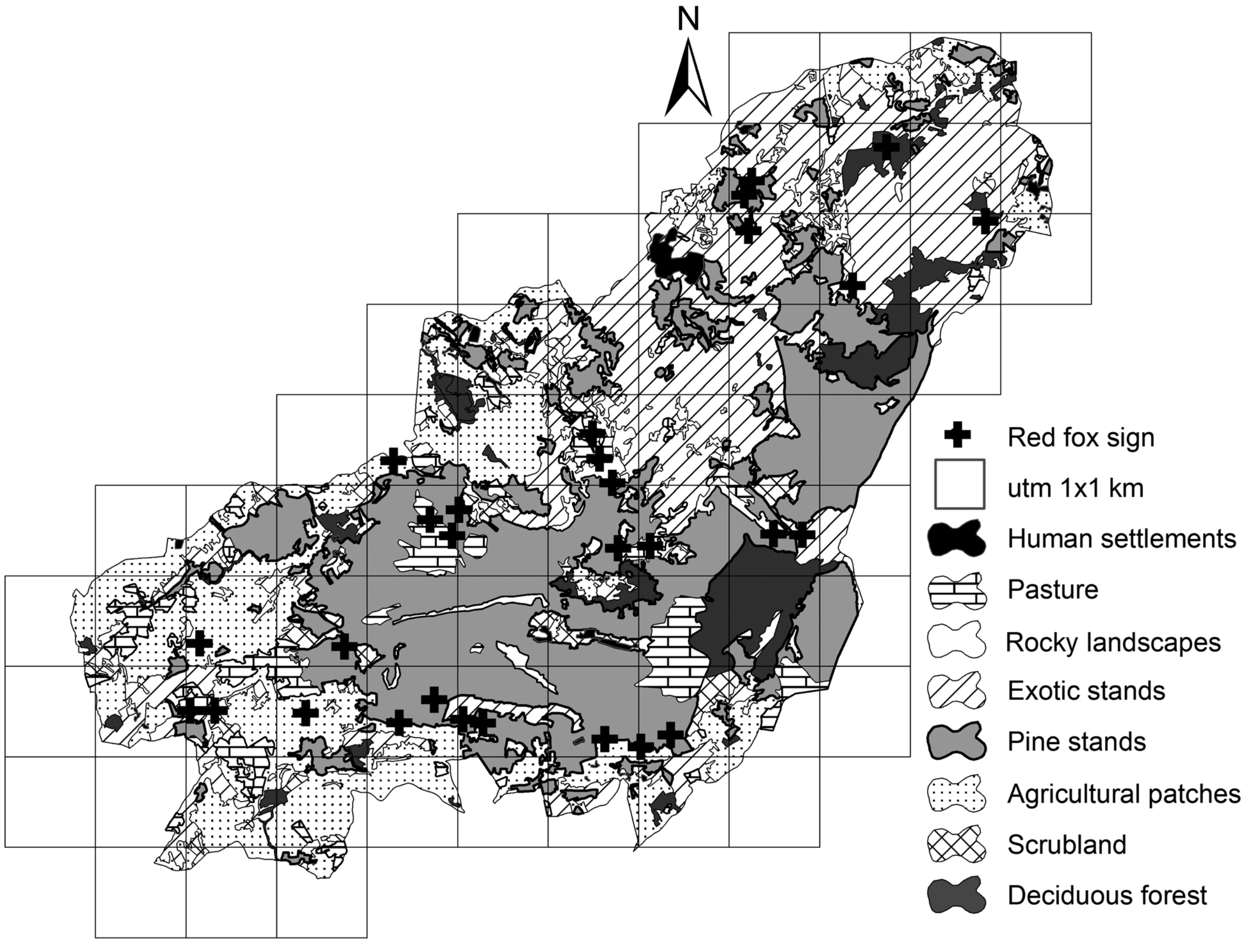

Fig. 1. – Land cover units present in the study area, UTM (WGS84) 1 km grid and red fox confirmed presence sites.

RESULTS

We detected 42 red fox signs of presence (90 % of which were scats), from which only 30 were used in the analysis, since 12 were located within a short distance of each another (< 200 m) and could bias our analysis due to possible autocorrelation and pseudoreplication.

The spatial distribution of presence and pseudo-absence sites did not reveal any significant autocorrelation ($I_{fox\_presence} = 0.715$, z-Normal $I_{fox\_presence} = 1.543$, $p = 0.062$; $I_{fox\_pseudoabsence} = -0.411$, z-Normal $I_{fox\_pseudoabsence} = -1.363$, $p = 0.087$). Three pairs of variables revealed high collinearity, and therefore for each pair, those that had the higher *p-value* in the G test were excluded from further analysis. Consequently, only eight variables were tested in the Logistic Regression Model (Table I). All these eight independent variables were associated at $p < 0.25$ with the dependent variable and thus qualify as candidates for the multivariate model. No observation was identified as an outlier by the Cook Distance statistics.

The best produced model ($AIC = 73.919$; $AIC_{null\ model} = 85.178$) incorporated only three variables (Table II) and was well adjusted to the data (-2log likelihood = 58.117, $p = 0.640$) and statistically significant

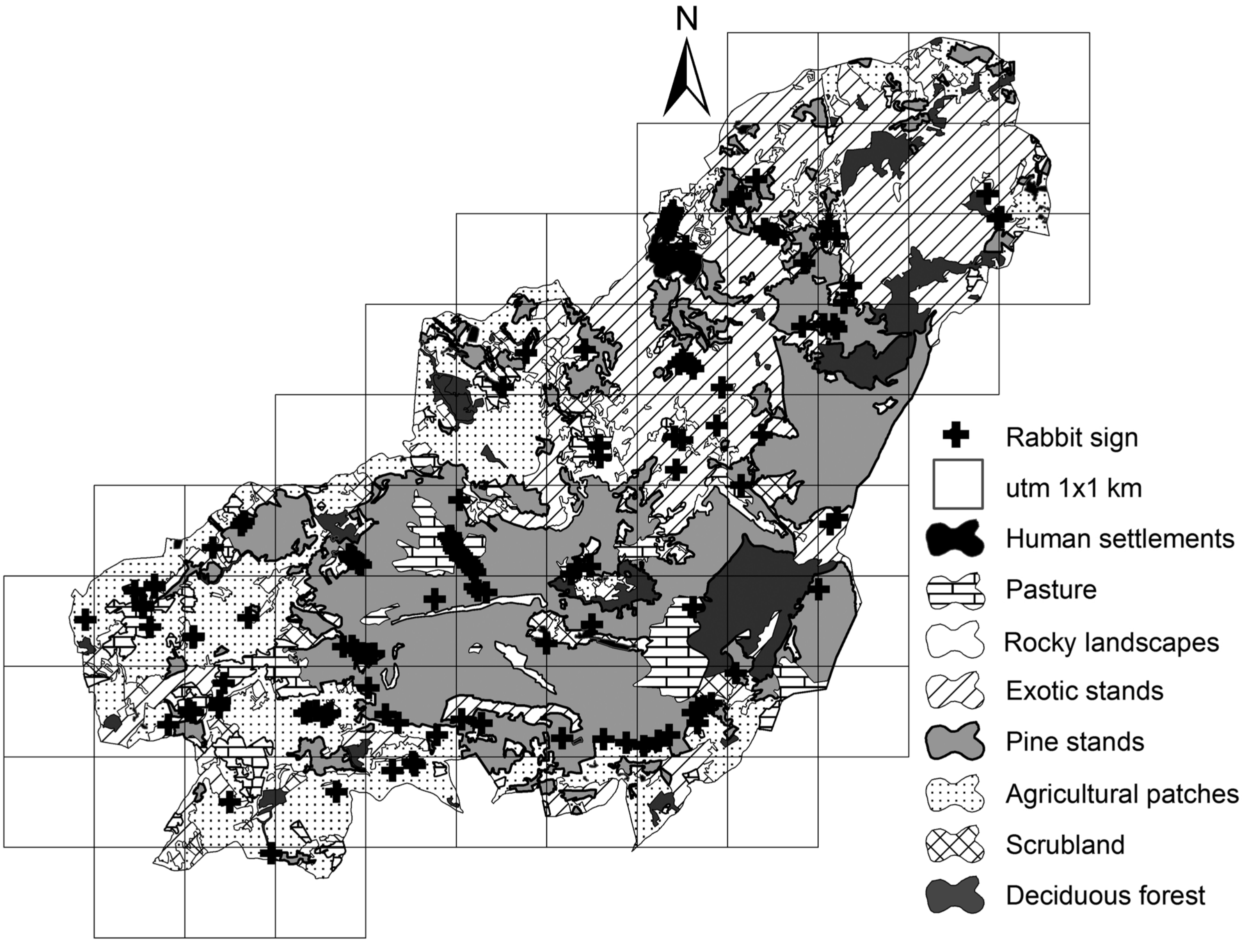

Fig. 2. – Land cover units present in the study area, UTM (WGS84) 1 km grid and rabbit confirmed presence sites.

($G^2 = 17.259$, df = 3, p = 0.001; $\chi^2_{\text{Hosmer-Lemeshow}} = 6.952$, df = 8, p = 0. 542).

The accurate performance of the model was confirmed by the medium/high percentage of correct classifications (71.7 %), which was considerably higher than the proportional percentage of random correct classifications (50 %; z = 16.444, p < 0.001). The medium/high sensitivity (76.7 %) and specificity (66.7 %) also confirmed the good performance of the model. Moreover, the goodness of fit of the selected regression model was also confirmed by the Pearson residuals test ($\chi^2 = 68.579$, df = 59, p = 0.198). Finally, the value of the area under each curve, derived from the ROC curve (AUC = 0.808, p < 0.001) demonstrates that presences show a high degree of relation with agricultural patches, high percentage of human structures and low distance to areas with wild rabbits (see Lobo *et al*. 2007 for AUC interpretation).

Maxent results were consistent with those of the Logistic regression, with land cover being the most important factor (42.2 %) especially orchards, followed by the distribution of rabbit (25.4 %; Fig. 2) and distance to roads (24.9 %). The model AUC was 0.728, and that of the wild rabbit was 0.696.

DISCUSSION

In an Atlantic influenced mountain of the central-west Mediterranean, red fox presence seems to be determined by the occurrence of agricultural patches (such as orchards, vineyards and olive groves), a high percentage of human structures in the vicinity and the low distance to areas with wild rabbits. All these variables have a common denominator: food.

An animal's presence in a particular area generally results from a complex set of factors, namely food availability, cover type, intra and interspecific relationships (e.g., mate, predator-prey interaction, symbiosis), refuge availability and human pressure (direct or indirect). However, for a carnivore species such as the red fox, which is highly adaptable and resilient to humans (Nowak 2005), has few predators (Macdonald & Reynolds 2004) and is very adjustable to available habitats (Macdonald & Reynolds 2004), food availability might be the factor to which it is more susceptible. Consequently, this carnivore should be more common (or even reach higher densities) in areas where food is more abundant and energetically more profitable.

In fact, that seems to be the case in Serra de Montejunto Protected Landscape, where red foxes use or inhabit areas where food is more readily available and accessible, such as orchards (including vineyards and olive groves), areas near human activities (isolated houses and villages) and where wild rabbits are present. Red foxes are characterised as generalist carnivores which might include a wide variety of different items in their diet (see Larivière & Pasitschniak-Arts 1996). In some areas or at least in certain seasons, they consume a large percentage of fruits and seeds (e.g., Padial *et al.* 2002, Carvalho & Gomes 2004, Santos *et al.* 2007); in others, wild-rabbits or rodents form the bulk of their diet (Jaksic & Soriguer 1981, Forman 2005).

Most of the seed and fruits can be easily found on agricultural patches such as orchards, vineyards and olive groves. This food is less abundant in patches such as Pine and Eucalyptus plantations, which dominate the landscape. The positive influence of these fruit patches on red fox's distribution is clearly related to the fact that on those areas animals can find one of the food resources they need to survive (since fruits are rich in sugars; Herrera 1987).

Moreover, rural areas with high human influences (villages, isolated houses and their surroundings) support a high abundance of commensal rodents (e.g., *Rattus* spp., *Mus* spp.), due mainly to a surplus of food resources usable by these mammals (Castillo *et al.* 2003). In a cascade effect, the availability of rodents in those patches will promote the presence of predators using them as prey (Santos *et al.* 2007), such as the red fox, thus contributing to the observed distribution pattern in Serra de Montejunto.

Finally, the fact that the probability of red fox presence is inversely related to the distance to areas with wild rabbits, a species often mentioned as an important prey for foxes (Fedriani *et al.* 1999), corroborates, once more, our hypotheses that food availability seems to be the main constraint to red fox distribution in this south-western mountain area of the species range in continental Europe.

Since patches that have high food availability are fundamental to guarantee red fox survival and successful reproduction, they must be defended and reclaimed from other individuals (from the same or sympatric species) (Macdonald 1995). This behaviour is usually implemented using scent communication, an effective mean of information exchange between individuals (Gorman & Trowbridge 1989), which often use scats as a vehicle for odour release (Macdonald 1995). Thus, as scats are used for scent marking important resource patches (e.g., food), the selection of variables related to this factor is enhanced in our analysis, since more scats should be found in key areas to effectively achieve their role.

Although this was a time limited study, its results can, and should, be viewed as a first approach and indicative of what could be influencing the presence of foxes in this south-western European region. Some criticism can be suggested due to the sampling method (field surveys based on signs of presence), especially associated with the different detectability of footprints according to soil characteristics, with the fact that animals do not defecate throughout their entire used home-range and because faeces detectability varies with land cover. However, several studies have demonstrated that this indirect census technique can be considered accurate enough to monitor red foxes in all (or almost all) habitats (Sadlier *et al.* 2004, Barea-Azcón *et al.* 2007). Furthermore, this methodology is not labour intensive or expensive when compared with direct methods (e.g., captures). Therefore, we believe this methodological approach is sensitive enough for understanding the potential local distribution of the fox population in the Serra de Montejunto Protected Landscape (Portugal) and to assess possible variables that influence this distribution. Nevertheless, we believe that other methods, such as capture-recapture or non-invasive methods (e.g., microsatellite analysis), should also be applied to complement with other essential data that go beyond species distributions, such as population dynamics, abundance, etc. Allying the results presented herein with those obtained from other methods can further our understanding of red fox ecological constraints and requirements that would inform the planning of an effective management of a species.

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