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Habitat suitability model for red deer (*Cervus elaphus* Linnaeus, 1758): spatial multi-criteria analysis with GIS application

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Resumen

El seguimiento de las tendencias poblacionales es esencial para la gestión de la fauna silvestre. El principal objetivo de este estudio fue desarrollar un modelo que predijese áreas de expansión del ciervo (*Cervus elaphus* Linnaeus, 1758) en la Zona de Caza Nacional de la *Lombada* (ZCNL) - Bragança, una de las mayores poblaciones silvestres del país. Se aplicó un modelo multicriterio jerárquico (AHP) y técnicas de SIG de algebra matricial para su validación, que se realizó en tres fases: i) definición de los objetivos y análisis de factores ambientales, ii) desarrollo de una matriz de comparación de pares de factores y iii) asignación de pesos de acuerdo con los requerimientos de la especie en el área de estudio. Las variables para evaluar la adecuación del hábitat para el ciervo fueron: la red hidrográfica, las carreteras asfaltadas, la topografía (orientaciones del terreno) y el uso/cobertura del suelo. La validación se realizó mediante la localización exacta con GPS de 129 observaciones directas de ciervos (transectos lineales: octubre de 2010 - marzo de 2011). La aplicación del método AUC (*Area Under the Curve*) resultó en una tasa de éxito de 72% lo que sugiere que la metodología se podría aplicar a una mayor escala geográfica. Este es el primer estudio realizado en Portugal con esta metodología para analizar la adecuación del hábitat para el ciervo.
Palabras clave: *Cervus elaphus*, modelos de adecuación del hábitat, modelos multicriterio, SIG.

Abstract

Monitoring population trends is essential in wildlife management. In fact, to identify those environmental conditions linked to habitat use and selection is a key task in any conservation plan. Our aim in this work was predict red deer (*Cervus elaphus* Linnaeus, 1758) colonization in the *Lombada* National Hunting Area (LNHA), one of the largest wild populations in Portugal. The sharply increase in density and range of red deer over the last decades justify the careful monitoring of this population. A multi-criteria model using the Analytical Hierarchic Process (AHP) and GIS weighted spatial analysis with matrix algebra techniques were applied in this approach. This method was developed in three distinct phases: i) setting the objectives, ii) analysing pairs of factors through the application of a comparison matrix and iii) its synthesis with the weight assignment that followed a predetermined numeric range according to the ecological requirements of the study species. The variables used in the red deer habitat suitability model included the hydrographic network, asphalted roads, relief aspects and land use. From October 2010 to March 2011, a total of 129 observations along line transects were recorded and used to validate the final model. By using the AUC method it was obtained a success rate of 72%. Our results suggest that this method would be applied on a larger scale being suitable to predict red deer expansion. To our knowledge, this is the first study performed in Portugal using this methodological approach to assess the red deer-habitat relationships.
Keywords: *Cervus elaphus*, GIS, habitat suitability, multi-criteria models.

Introduction

Understanding how species are spatial and temporally distributed is a central topic in ecology. In fact, to identify those environmental conditions linked to habitat use and selection is a key task in any conservation plan (Guisan & Zimmermann 2000). Species distribution models (SDM) are currently recognised as extremely effective tools providing valuable and quantitative on the information by displaying the most important conditions and resources required by the individuals in a given spatial context (Guisan & Thuiller 2005). Therefore, habitat suitability models are important tools in conservation planning and game management (Pearce & Ferrier 2000). Even though predicting natural processes is difficult (*e.g.* Radeloff *et al.* 1999, Shi *et al.* 2006), many methodologies and mathematical approaches have been developed for such purposes. However, variability registered from different modelling techniques is one of the main issues for species distribution assessment. In this line, Araújo & New (2007) suggests an ensemble approach, where several models were tested in order to improve the results reliability. Nevertheless, the strategy to follow should reflect a trade-off between the specific objectives and the available data. There is a broad range of modelling techniques available to explore the correlation between species occurrence and predictor variables (*e.g.* food distribution, cover, human disturbances) (Guisan & Zimmermann 2000). These techniques include logistic multiple regression (Pearce & Ferrier 2000), regression trees (Stankovski *et al.* 1998), geographically weighted regression (Shi *et al.* 2006), spatial and space-time correlations (Epperson 2000) and some of the most widespread techniques as Maxent (Phillips *et al.* 2006) and BIOCLIM (Beaumont *et al.* 2005).

Over the last three decades, red deer (*Cervus elaphus*) populations have increased in numbers and distribution in Portugal (Vingada *et al.* 2010). A wide range of factors are related with the widespread distribution of this species, namely natural dispersion (Vingada *et al.* 2010), decrease of human pressure and rural exodus with consequent abandonment of agricultural fields. Since 1970's, red deer populations have recovered from a situation of virtual extinction being now common in many regions of Portugal, but especially close to the Spanish border (Vingada *et al.* 2010). Red deer play an important ecological role in maintaining floristic diversity and seed dispersal (Malo & Suárez 1995, Schütz *et al.* 2003). Moreover, it is also a wild prey of the endangered Iberian wolf (*Canis lupus signatus* Cabrera, 1907). In Portugal, one of the main red deer populations is located in the northeast of the country (Trás-os-Montes region). Santos (2009) showed that density varied between 2.27 and 4.70 red deer/km^2, however Carvalho (2011) reported a density decrease to 1.07 - 2.87 red deer/km^2 in the same population. By applying indirect methods (pellet group counts), Torres *et al.* (2012) identified the environmental variables that affect the distribution and occurrence of this population, showing that red deer was found in areas further away from roads, urban settlements, agricultural fields selecting patches with medium ground cover of shrubs and sparse tree cover.

In this study, it was applied an Analytical Hierarchy Process (AHP) (Saaty & Vargas 1991) coupled with Geographic Information Systems (GIS). This is the first study performed in Portugal using this methodological approach to analyse red deer – habitat relationships.

Due to current increase of red deer in Portugal, the identification of the environmental factors potentially linked to further expansions is needed. Hence, this study have two main mains: i) to construct a habitat suitability map for red deer in *Lombada* National Hunting Area, incorporating important ecological variables for the species and ii) highlight the use of a multi-criteria decision making based on the Analytical Hierarchy Process as an alternative way to define suitability classes.

Material and methods

Study area

The study was carried out in the Lombada National Hunting Area (20.830ha), Bragança (Figure 1). Most of the study area is located inside the Montesinho Natural Park that is part of the European Union's Natura 2000 Network. The altitude ranges from 530 to 1073 m.a.s.l. The climate, mainly Mediterranean, is influenced by three chains of mountains and molded by Castellano-Leones plateau. Mean annual temperature varies between 8 and 12.5ºC, registering a mean temperature of 3ºC and 21ºC in coldest and warmest month, respectively (Aguiar 2000). The vegetation, although dominated by scrubland, is varied and characterized by pyrenean oak (*Quercus pyrenaica*), sweet chestnut (*Castanea sativa*), scots pine (*Pinus*

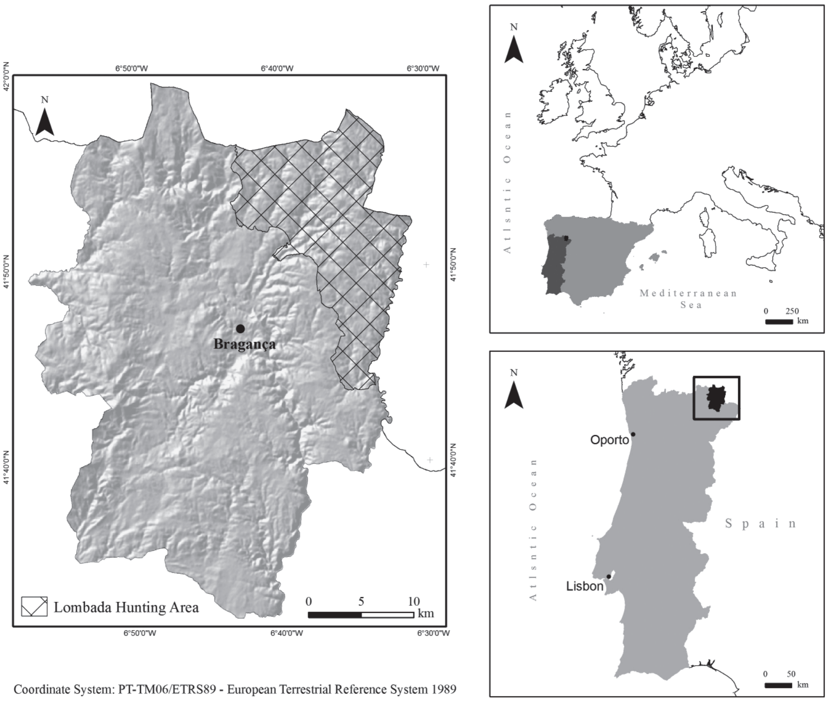

Figure 1. Location of study area.

sylvestris), european black pine (*Pinus nigra*), maritime pine (*Pinus pinaster*), and holm oak (*Quercus rotundifolia*). Main understory species are *Erica australis*, *Cystisus* sp., *Pterospartum tridentatum*, *Halimium lasianthum* subsp. *alyssoides* and *Cistus ladanifer.* Scattered pastures and agricultural crops can still be found along the study area. Three main rivers and some streams cross the study area. The riparian vegetation associated is mostly composed by common alder (*Alnus glutinosa*), ash (*Fraxinus angustifolia*), black poplar (*Populus nigra*) and white willow (*Salix salviifolia*).

Two others ungulates are present: roe deer *Capreolus capreolus* (Linnaeus, 1758) and wild boar *Sus scrofa* Linnaeus, 1758. Iberian wolf is one the red deer main predators and densities have been calculated in 1.6 - 3.1 wolves/100 km^2 (Moreira *et al.* 1997). Taking into account the European context, where wolf densities are generally <1 wolf/100 km^2 (Boitani 2000), these values can be considered high. Human population density is low (9.5 people/km^2). Road network can also be considered low since there are a few national roads connecting the small villages. Red deer hunting is allowed in the study area and hunting bags vary between 3-5 per year.

Survey design

Field work was conducted between October 2010 and March 2011 using line transects placed systematically to provide equal coverage of habitats that occur in the area (Figure 2). With this, the bias associated with the systematic prospection of areas with high or low deer densities was reduced (Marques *et al.* 2001). The sampling comprised

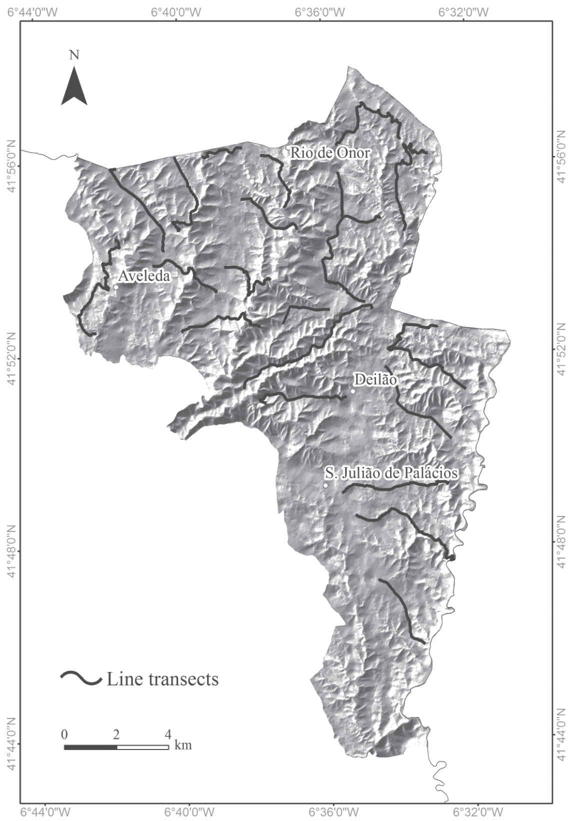

Figure 2. Line transects in the study area.

two distinct periods: mating season (September - October) and late winter.

Twenty one lines transects were established, with an average length of 4.3 (1.78 - 6.82) km and totalling 90.3 km. Short transects gave us the possibility to achieve a better representation of whole study area. When a red deer or a group was detected, the distance from the observation point to the animal group was recorded. Through GPS location and trigonometric operations we could estimate the exact position of the animals observed that was then used to validate the final model.

Environmental variables

The variables were selected considering their applicability to the scale of our study area, relevant predictive power (Post & Forchhammer 2002) and their relationship with the ecological requirements of the species (Guisan & Zimmermann 2000). Based on previous studies (San-José *et al.* 1997, Torres *et al.* 2012) and in our own field experience, we selected the variables that could potentially influence the species occurrence. These variables were classified into four classes: habitat composition (Thomas *et al.* 1979, San-José *et al.* 1997, Debeljak *et al.* 2001), human disturbance (Hewinson *et al.* 2001, Dziba *et al.* 2003), topographic factors (Acevedo *et al.* 2011) and distance to water courses (Thapaliya 2008). For the habitat composition class we have used three general land use predictor variables divided in forest, agricultural and urban areas. This information was obtained from CORINE Land Use/Land Cover database (CLC06) with spatial resolution (pixel width) of 250 meters. Forest areas include the broad-leaved and coniferous woodland, the wetlands and the scrubland (dense and sparse). Agricultural land included herbaceous and woody crops, the arable horticulture and the heterogeneous crops and urban areas included houses, buildings and industrial areas. Since red deer hunting is allowed in the study area, it is expected that human disturbance factors will influence red deer distribution as they can be considered as analogues to predation risk (Lima & Dill 1990). Therefore, we consider the distance to the closest urban area and to the closest asphalted road (Acevedo & Cassinello 2009). Additionally, we selected a topographic factor that can potentially affect the red deer occurrence, *i.e.* the relief aspect (Acevedo *et al.* 2011). This variable was classified in five discrete classes (North, West, South, East and Flat).

Multi-criteria analysis: an overview of the AHP method

The criteria weights were obtained using the Analytical Hierarchy Process (AHP) (Saaty & Vargas 1991) and employed in the GIS based MCDM. A MCDM combines the environmental factors under analysis in a single parameter of evaluation (Chen *et al.* 2010). This method allows integrating heterogeneous data derived from different sources and correlating their respective weights. The main goal of this approach is to achieve the best solution that takes into account all the conflicting input criteria. The AHP process is based in three fundamental steps: i) develop the AHP Hierarchy, ii) pairwise comparisons between all factors using a given scale, and iii) final weights definition. The final solution will be a choice between alternatives or criteria, which should be measured and evaluated.

A weighted linear combination was used since it is the most prevalent procedure for multi-criteria evaluation. Factors (*e.g.* variables) are combined together by applying a weight to each one followed by the sum of the weights applied to each factor. The output is a habitat suitability map.

$$S = \sum (w_i x_i)$$

(where S is suitability, w_i is the weight of factor i, x_i is the criterion score of factor i,).

In this particular case the final result is a Habitat Suitability Index (HSI) that represents quantitatively the capacity of an area to fulfill the requirements of a study species.

Pairwise comparisons

Criteria weights were assigned according to Saaty's pairwise comparisons (Saaty & Vargas 1991). By using this comparison matrix subjectivity is minimized. In the first step, a qualitative numerical scale was used to score each pairwise comparison between the chosen criteria. Applying a scale using 9-point rating scale ranging from 1 (equal importance) to 9 (strongly more important) and reciprocal values, the relative preference between two variables under analysis was achieved (Table 1). Before any map algebra operations, all continuous variables were standardized (linear scaling and scale inversions) to avoid the effect of different measurements scales and to facilitate direct comparison.

$$x_i = \frac{(R_i - R_{min})}{(R_{max} - R_{min})}$$

(where R_i is the raw score of factor i)

The comparison matrix was then filled in both directions (Table 2). By using the given values, the specific weights for each criterion were calculated in order to be used in the weighted linear combination (Table 3).

Table 1. Saaty's pairwise comparisons. The values varies between 1 and 9 (factor on vertical axes is more important than the factor on horizontal axes) or 1/3 and 1/9 (factor on vertical axes is less important than the factor on horizontal axes).

Degree of importance	Definition
1	Equal importance
3	Weak importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9	Reciprocal values

Data analysis

Based on the Area Under the Curve (AUC) method, the spatial model obtained was validated using the presence points of the red deer observed groups and pseudo-absences obtained through random points dispersed across all the study area. In the first time, a Receiver Operating Characteristics (ROC) plot was obtained by plotting true positive fraction on the *y* axis against false positive fraction on the *x* axis (Fielding & Bell 1997). According to the same authors, this method provides a way to compare classifiers testing the model accuracy and allowing their validation independent of distortions and potential bias. The output values vary between 0.5 and 1. The first indicates that the scores of the two groups do not differ, while the second expresses a non-overlapping of the group scores. Furthermore, by using a logistic regression we compared the predictive performance of the heuristic and statistical procedures. We evaluated the effectiveness of a multicriteria decision in order to test it as an alternative way to obtain habitat suitability maps in the lack of presence/absence data. The AUC value was used to measure the predictive performance of the models.

The final model representing the habitat suitability for the study area was divided into three classes of suitability through the application of Natural

Table 2. Comparison matrix with the relative weight assigned to the factors under analysis.

Variables	Forest areas	Agricultural areas	Distance to asphalted road network	Distance to hydrographic network	Distance to urban areas	Relief aspects
Forest areas	1	-	-	-	-	
Agricultural areas	1/7	1	-	-	-	-
Distance to asphalted road network	1/5	1/3	1	-	-	-
Distance to hydrographic network	1/3	3	5	1	-	-
Distance to urban areas	1/9	1/5	5	1/7	1	-
Relief aspects	1/5	1/3	3	1/5	1/5	1

Table 3. Final factor weights to be applied.

Forest areas	Agricultural areas	Distance to asphalted road network	Distance to hydrographic network	Distance to urban areas	Relief aspects
0.38	0.12	0.04	0.22	0.14	0.10

Breaks method, which is one of the most common procedures to classify the quantitative data (Conolly & Lake 2006). As Hirzel *et al.* (2006) argued the low number of classes provides most honest and robust information. The method mentioned above is the most suitable for continuous data creating a set of logical and coherent classes through the definition of natural clusters (Jenks & Caspall 1971). The class ranges are defined comparing them with the distribution of the entire dataset allowing the identification of break points. Finally, the data available are divided in order to maximize the differences among the number of classes desired.

Habitat evaluation and the selection of habitat patches with high suitability were performed through the comparison between high habitat suitability patches areas and the species annual home range. Since there was no information regarding red deer home ranges in the study area, we used home range values from other areas from the Iberian Peninsula that shared environmental characteristics with the study area.

Results

The habitat suitability model derived from weight assignment and matrix algebra operations corresponds with the observed densities of red deer in *Lombada* National Hunting Area (Figure 3). Our results show that the northern and central parts of study area are more suitable for red deer occurrence than the southern part. By dividing the suitability model into three quantitative parameters approximately 58% of the study area is classified as high suitable for red deer. The remaining 42% are divided into moderate (27%) and low suitability (15%). The comparisons of variables with the final model achieved makes possible to observe that red deer occurs in areas further away from roads, villages and agricultural fields. Moreover, they also show that red deer occurrence is mainly related with forested areas.

The presented model was validated with a total of 129 group observations. By applying the Area Under the Curve (AUC) method, it was obtained a success rate of 72% for the Analytical Hierarchic Process (Figure 4). On the other hand, the value of the success rate obtained for the logistic regression model was 69% (Figure 5). The values shown in Table 4 indicate the regression coefficients and the Wald statistic which tests the contribution of each predictor.

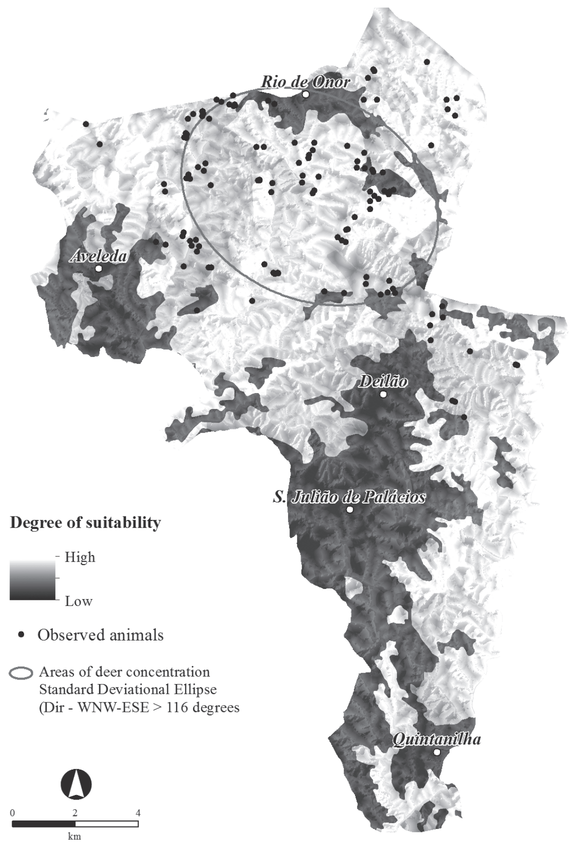

Figure 3. Habitat suitability model output. Graduated colours from black (unsuitable areas) to white (suitable areas).

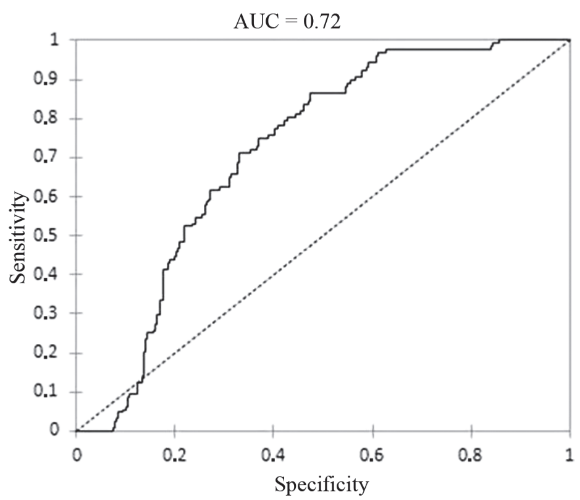

Figure 4. Area under the ROC curve used to assess the accuracy of the Analytical Hierarchic Process.

By using the standard deviational ellipse in *ArcGIS 9 3.1*, it was determined an area of preferential red deer concentration (WNW - ESE) which corresponded to the northern part of the study area.

Discussion

To our knowledge, this is the first study performed in Portugal using AHP and GIS weighted spatial analysis with matrix algebra techniques to assess the red deer - habitat relationships. Our model are in agreement and reflect in a spatially and qualitative way the results of previous studies conducted by Torres *et al.* (2012) for the same study area. Based on these authors' results, we have defined the weights to be applied and we hypothesized that the red deer occurrence might be mainly related with macro-habitat structure and human disturbance factors. Our results show that red deer used areas with coniferous and deciduous forests, where they can find refuge from adverse climatic conditions, human activities and wolf predation, interspersed by scrubland and meadows. These mixed areas with higher densities of heather and *Leguminosae* interspersed with ground cover and sparse tree cover provides food availability, which is essential to this species as it is considered a capital breeder (Clutton-Brock *et al.* 1983). Such ecotones provide a greater variety of plant species locally abundant. These transition habitats are important for red deer to cope with seasonal changes in resource availability by feeding grasses and/or shrubs (Putman & Flueck 2011) but they also provide hiding cover, important in our study area against wolf predation.

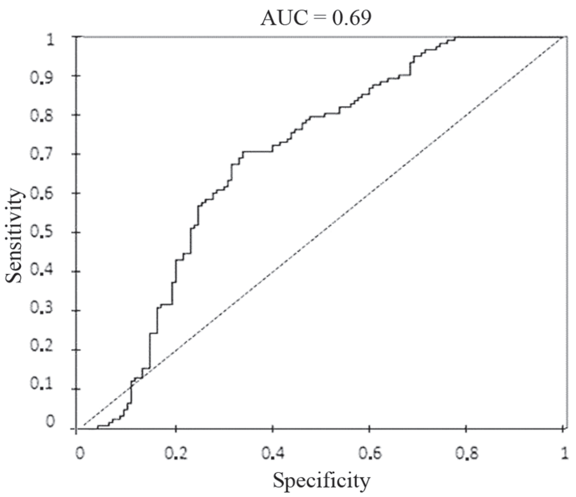

Figure 5. Area under the ROC curve used to assess the accuracy of the Logistic Regression model.

Our results showed that only 15% of the study area, the southwest part, comprises less suitable habitat for red deer. This might be due to the fact that this area is characterized by a fragmented landscape divided into small patches of agricultural crops with high pressure of human disturbance and livestock. Another important factor is the presence of feral dogs in the close vicinity of human settlements and the high pressure from illegal hunting, which is believed to be commonplace in the study area. According to Jiang *et al.* (2009), human activity is an important factor that influences red deer space use.

Mysterud *et al.* 2002 showed that agricultural crops provided an important food resource for red deer in winter. However, our results showed that red deer used areas further away from agricultural fields, which is in agreement with Torres *et al.* (2012). Interestingly, this fact deserves future investigations as this can be an adaptation to contrasting seasonality. In our study area, this fact can be related with the adoption of hiding behaviours to reduce the predation risk. Some studies demonstrated a preference for red deer to shrub species like *Pterospartum tridentatum*, *Cistus ladanifer*, *Halimium lasianthum* subsp. a*lyssoides*, *Rubus ulmifolius* and *Erica* sp. (Alvarez & Ramos 1991, Ferreira 1998). In the northern part of our study area, these species predominate thereby suggesting that red deer fulfills it foods requirements in the shrub layer rather in the agricultural fields. Our results also shown that some groups occurred

Table 4. Variables considered in the logistic regression model and their coefficients (β), standard deviation (S.D.), Wald test values and significance (ρ).

Variables	β	S.D.	Wald	ρ
Land use	0.003	0.004	0.754	0.385
Distance to asphalted road network	0.001	0.001	3.534	0.600
Distance to hydrographic network	0.001	0.001	4.310	0.042
Distance to urban areas	0.002	0.001	12.858	0.001
Relief aspects	-0.054	0.116	0.215	0.643
Constant	-2.244	1.241	3.269	0.071

in areas considered unsuitable scattered throughout the northern part of the study area. These areas correspond to small patches close to disturbance factors and close to agricultural crops and apparently do not have shelter habitats. The presence of contiguous suitable habitat in their surrounding might explain the occurrence of red deer groups in these unsuitable areas.

Allen *et al.* (1987) stated that a habitat suitability model must consider the concept of "evaluation unit". According to the same authors, this is defined as the minimum area of contiguous habitat that a population requires to persist in each stage of its life cycle. Therefore, the habitat evaluation was made on the basis of animal annual home range. Since in our study area we do not have red deer home range information, we used values recorded in other regions of the Iberian Peninsula: *Monfrague* National Park (Carranza *et al.* 1991) and *Sierra Morena* (Soriguer *et al.* 1994). The values of home ranges registered in these populations show that the northern part and the transboundary region of the study area gathered the habitat requirements for the species occurrence. The regions near the border with Spain have areas of contiguous habitat and low human pressure and could be considered a potential biological corridor for red deer dispersion enhancing the movement among isolated habitat patches. The effective conservation of these areas can mitigate the pernicious effects of habitat fragmentation on population dispersion. This fact reinforces the importance and the need for an Iberian cross-border management of red deer populations emphasizing sustainable practices that enable the conservation and exploitation of this species. The correct population management coupled with a detailed knowledge about species dynamics is crucial to improve the accuracy of predictive models and allows the adoption of correct management approaches that reflects the balance between economic value and impact. Moreover, habitat suitability models are important tools, which can provide valuable information to achieve important management goals (*e.g.* trees protection for commercial forestry, conservation of the habitats and management for hunting exploitation (Pérez-Espona *et al.* 2009)).
The success rate obtained in the model validation shows that the correct selection of the environmental variables is reflected in the quality and predictive power of the final output. Due to subjectivity associated with MCDM approach, the adoption of a Saaty's pairwise matrix (Saaty & Vargas 1991) and the final validation of the results are crucial to reduce the bias related to the predictions. Testing the same variables in a logistic regression approach we obtained an AUC value lower than for analytic hierarchic process (0.69 against 0.72, respectively) therefore we believe that the heuristic model applied in this study can be an alternative useful method. While AHP depends on the expert opinions (knowledge-driven), logistic regression is relied only on the data (data-driven). Logistic regressions, being a data-driven method where the the relative importance of the data is determined by the data itself should be the selected method when species data (presence, presence-absence) is available. The AHP method associated with GIS environment enhances the predictive performance of MCDM. We are aware that the model can be implemented in a larger scale in order to understand the species distribution and to identify possible biological corridors. Despite this, additional research is needed for testing other variables. Future investigation should be able to include predator activity as well as interspecific competition. Some variables that were used (*i.e.* land use) need to be updated to reduce uncertainties of the results. The variables selection and respective weight assignment were based in specialized bibliography and in our own field experience, however subjective judgment is a reality. The model validation was made using the data obtained by a direct count method. In such methods, the detection probability varies between open and closed areas. This fact, can introduce a possible bias that potentially reduces the effectiveness of the model evaluation. In order to reduce the uncertainties of direct observations, future models should be validated through the application of indirect records of the species presence.

This study is a preliminary effort to understand and model the red deer habitat relationship in the southwestern edge of its European distribution. The methodology approach offers a simple and flexible way to meet the objectives set for this study. The habitat suitability maps produced in this study can be easily interpreted by non-experts (*e.g.* wildlife rangers, hunters) and landowners. In addition, as mentioned by Chen *et al.* (2010), the multi-criteria decision making using the analytical hierarchy process allows understanding how changes in the variable weights are reflected in the quantitative and spatial results.

Being aware of the uncertainties related with habitat suitability maps, we believe that expert knowledge coupled with GIS environment and field data (use to validate the final model) provides a quick and effective analysis of species-habitat relationships.

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