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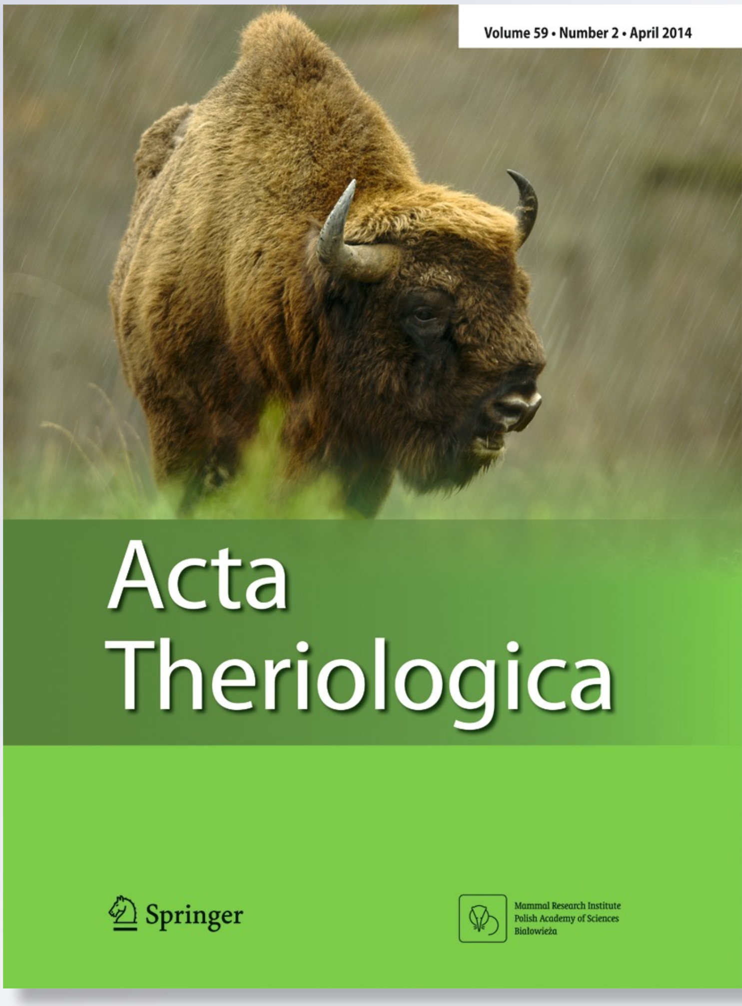


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ORIGINAL PAPER

# Using remote sensing data to model European wild rabbit (*Oryctolagus cuniculus*) occurrence in a highly fragmented landscape in northwestern Spain

**L. Tapia · J. Domínguez · A. Regos · M. Vidal**

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**Abstract** We model the occurrence of European wild rabbit in fragmented environments in a mountainous area of northwestern Spain (Gerês–Xurés Biosphere Reserve). We carried out a field survey by sampling the presence/absence of pellets in 237 plots (100×100 m) selected at random below an altitude of 800 m. For modelling purposes, we considered eight predictors related to vegetation, topography, human influence and heterogeneity. We obtained vegetation and ecological predictors from land use/land cover maps derived from Landsat Enhanced Thematic Mapper Plus images (acquired at the same time as the field data) and calculated vegetation indices by using a supervised classification method. We obtained topographical predictors from a Global Digital Elevation Model (GDEM) and used a generalized linear model to describe the occurrence of the European wild rabbit. The overall accuracy of the Landsat-derived map in Baixa Limia was 87.51 %, and the kappa coefficient was 0.85. The most parsimonious model included "grassland and crops", "mean slope", "distance to roads", "urban settlements" and "ecotone scrubland-forest". Five predictors were consequential, three of them with a positive sign for the presence of the species (scrub, urban settlements and ecotone scrubland-forest) and two with a negative sign (mean slope and distance to roads). The information on habitat requirements of European wild rabbit in the area provides a good framework for determining the habitat requirements of this keystone species in mountainous ecosystems in northwestern Iberian Peninsula.

**Keywords** European wild rabbit · Iberian Peninsula · Modelling · Occurrence · *Oryctolagus cuniculus* · Remote sensing

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## Introduction

Analysis of the relationships between species and their habitats is essential for establishing appropriate conservation management plans (Morrison et al. 1998; Jones 2001; Pearson 2007; Rodríguez and Tapia 2012). During the last two decades, numerous statistical procedures have been developed for modelling species distributions (e.g. Buckland and Elston 1993; Guisan and Zimmermann 2000; Scott et al. 2002; Phillips et al. 2006; Rodríguez et al. 2007; Elith and Leathwick 2009; Franklin and Miller 2009 and references therein). In spite of their biological and methodological limitations, these procedures provide a means of modelling habitat suitability using a limited number of observations and different environmental variables as predictors, even for large areas (Guisan and Zimmermann 2000; Seoane and Bustamante 2001; Rushton et al. 2004; Rodríguez et al. 2007; Tapia et al. 2007).

The inclusion of both remote sensing data and field survey data within modelling algorithms makes it possible to map species habitat and monitor temporal changes (Sarasola et al. 2008; Franklin and Miller 2009; Tuanmu et al. 2011; Rodríguez and Tapia 2012). Multispectral classification of remotely sensed data has been widely used to generate thematic land use and land cover (LULC) maps for different ecological applications. Remote sensing technology provides information at different spatial and temporal resolutions (Turner et al. 2003). Landsat data set has notable advantages, including a spectral coverage that is appropriate to the studies of vegetation properties and a spatial resolution for regional scale studies (Cohen and Goward 2004). The use of these techniques has been facilitated in recent years by the large amount of environmental information freely available via numerous web sites and by the implementation of such models with open-source software (Rodríguez et al. 2007).

Traditional classification techniques have typically mapped land cover by associating each pixel with a discrete category, under the assumption that each pixel represents a homogeneous area on the ground (Chuvieco 2008). These classifiers tend to be accurate in landscapes dominated by large homogeneous patches and less satisfactory in landscapes composed of many smaller heterogeneous patches, as in mountainous regions (Campbell 2008). Different approaches have been used to overcome these limitations, including regression techniques (Zhu and Evans 1992; Cohen et al. 2003), fuzzy clustering (Foody and Cox 1994), linear mixture modelling (De Fries et al. 2000) and artificial neuronal networks (Foody et al. 1997; Yuan et al. 2009). Several previous studies on the classification of multispectral images have confirmed that artificial neural networks (ANN) perform better than traditional classification methods, such as maximum likelihood classifiers, in terms of classification accuracy (Bischof et al. 1992; Foody 1995; Benediktsson and Sveinsson 1997; Foody and Arora 1997). For these reasons and taking into account the highly fragmented and heterogeneous landscape in the study area, ANN was considered suitable for constructing a land cover map with a satisfactory overall accuracy for the objectives of this study.

Many species of vertebrates require multiple habitats to obtain different resources on a variety of spatial and temporal scales (Law and Dickman 1998). This is true of the European wild rabbit (*Oryctolagus cuniculus*), which has recently been reclassified in the IUCN Red List of endangered species as near threatened in its natural range (IUCN 2013). A huge conservation effort is being undertaken in Spain for this keystone species in Iberian ecosystems (Delibes and Hiraldo 1981; Ward 2005; Delibes-Mateos et al. 2008; Ferreira 2012). The European wild rabbit is also an important game species in southern Europe, where it accounts for the largest proportion of the annual game bag (Ballesteros 1998; Ward 2005; Ferreira 2012). Although data on habitat selection in the Iberian Peninsula have been obtained (Caruso and Siracusa 2001; Virgós et al. 2003; Angulo 2003; Lombardi et al. 2007; among others), there is a lack of information about northwestern Iberia (Carvalho and Gomes 2003; Monzón et al. 2004; Tapia et al. 2010), where natural populations have become depleted in the last few decades (Fenner and Ross 1994; Villafuerte et al. 1995; Calvete et al. 2004; Tapia et al. 2010).

The aim of this study was to model the occurrence of European wild rabbit at microhabitat scale in fragmented environments in a mountainous area below 800 m.a.s.l. in northwestern Spain. For this purpose, we constructed logistic regression models with the presence/absence data (obtained from fieldwork) as the dependent variable and environmental data (obtained by remote sensing techniques) as predictors. Remote sensing data were acquired at the same time as the field data. We also compiled the existing information about the habitat preference of European wild rabbit in the Gerês–Xurés Biosphere Reserve in order to establish a framework of guidelines for the management of the species.

## Study area

The study area comprises the mountainous environment below 800 m.a.s.l. in the Baixa Limia site of community importance (34,627 ha), which includes Baixa Limia–Serra do Xurés Natural Park (20,920 ha) (Galicia, NW Spain; 42°00 N–8°00 W). The protected area borders the National Park of Peneda-Gerês in Portugal (around 70,000 ha) (Fig. 1), and together, these form part of the Gerês–Xurés Biosphere Reserve (259,496 ha). The zone is a mountain range that reaches altitudes above 1,500 m. The climate in the area is temperate oceanic sub-Mediterranean, with a mean annual temperature of 8–12 °C and a mean annual precipitation of 1,200–1,600 mm, which involves a significant water shortage in summer (Martínez-Cortizas and Pérez-Alberti 1999). The most common types of vegetation are scrub communities (*Ulex* spp., *Chamaespartium tridentatum*, *Erica* spp., *Genista* spp. and *Cytisus* spp.). Woods are highly fragmented and dominated by oaks (*Quercus robur*, *Q. pyrenaica*) and pines (*Pinus pinaster*, *P. sylvestris*). All plant communities in the study area are under strong pressure from frequent deliberate wildfires and extensive livestock grazing (Pulgar 2003) and by control of scrub cover and maintenance of pasture areas. Nevertheless, although this landscape has been intensely affected by human activity, the human population is currently quite low. The rural depopulation that took place in the early 1950s was accompanied by the abandonment of traditional agricultural and livestock activities. As a consequence, scrubland has encroached and forest has matured so that forests and scrublands have expanded considerably, while grassland and cropped areas have decreased in the study area during the last few years (Regos et al. 2012a).

## Material and methods

### Field work

We carried out a field-based faecal pellet survey in the study area, assuming a direct relationship between the presence of faecal pellets and the presence of European wild rabbits (Wood 1988; Palomares 2001). We carried out sampling, in

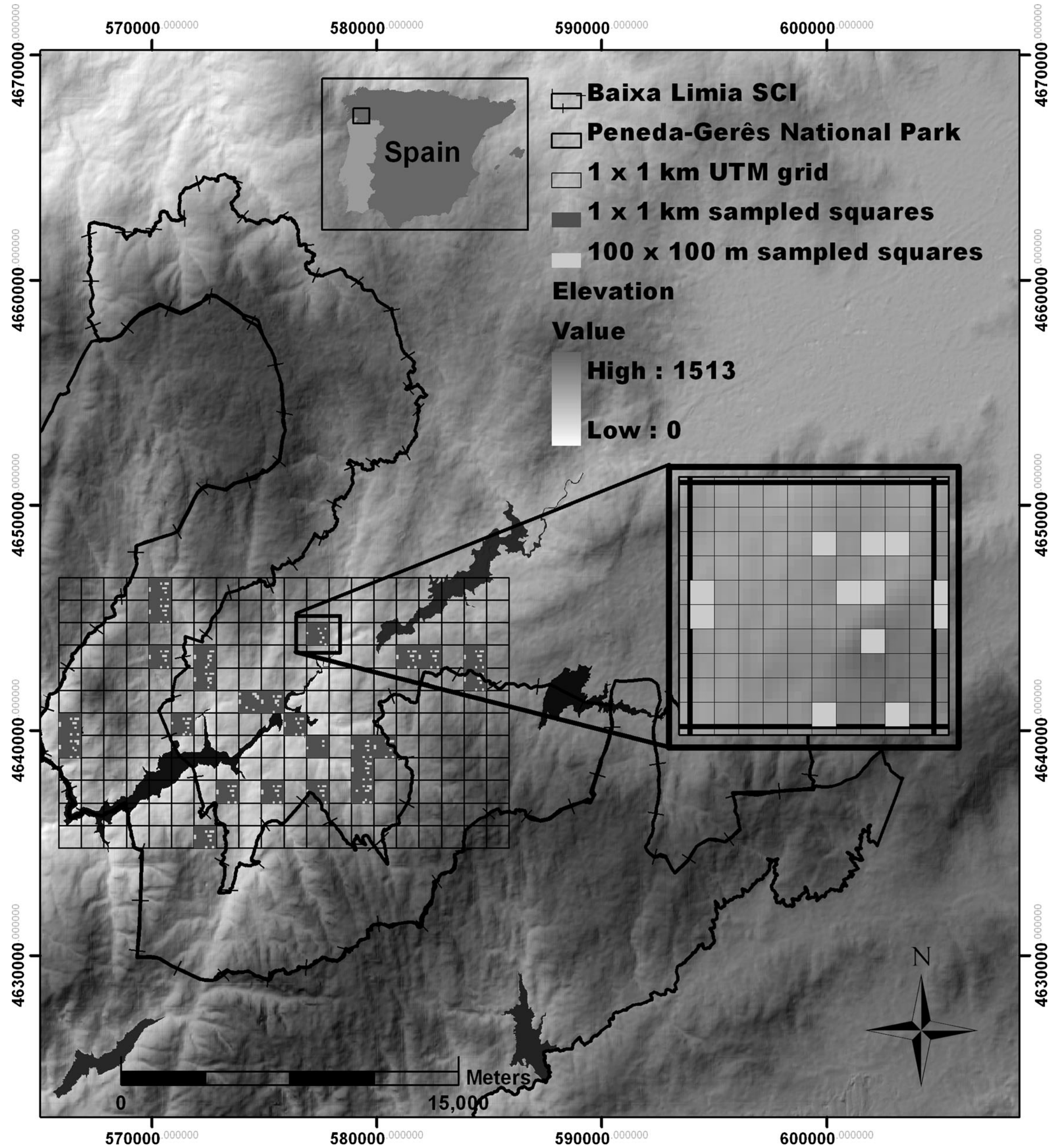


Fig. 1 Location of study area in the northwestern Iberian Peninsula and detail of the relief from hill shading map showing the 1×1 km UTM sampled cells and in more detail, the 100×100 m UTM sampled subgrids selected at random

June and July 2000, in 24 grids (1×1 km) identified in the universal transverse mercator (UTM) grid reference system and selected at random below an altitude of 800 m (Fig. 1). We divided each grid into squares of 100×100 m ($n$=100) and selected ten of these at random (Fig. 1). In the field, we identified the central point of each square with a GPS monitor. We then established a circular plot of radius 5 m (surface area=78.5 m$^2$) at each of these central points ($n$=237 plots) and recorded the presence/absence of rabbit faecal pellets. It was not possible to sample the total number of plots (240) due to accessibility limitations.

Remote sensing data

We obtained LULC predictors by using three Landsat Enhanced Thematic Mapper Plus (ETM+) images (March 20, 2000, June 8, 2000 and June 24, 2000) adquired on very close dates to the fieldwork. We implemented the supervised classification method (for vegetation) using the ANN algorithm (Richards and Jia 2006). All images were acquired with L1T processing level (geometric and terrain correction) and projected in the UTM grid reference system (WGS 84 datum, projection UTM 29 N) with a 30-m pixel resolution. An estimation of the RMS (root mean square) has been computed from the GCP provided by the US Geological Survey for each image. Since reflective multispectral bands of ETM+(1–5 and 7) have a nominal spatial resolution of 30 m×30 m, RMS was less than half the pixel size (average of 3.65 m) and an RGB composite from the same band (e.g. B4+B4+B4) but from different dates showed no visual misregistration; we considered that the geometric correction was good enough for the objectives of this study. Images were also radiometrically calibrated (using the Global Digital Elevation Model of a similar spatial resolution) according to Pons and Solé-Sugrañes (1994) model. Through this process, digital numbers were converted into reflectance values using the sensor calibration parameters and other factors such as atmospheric effects and solar incidence angle taking into account the relief, cast and self shadows (Pons and Solé-Sugrañes 1994). Classification of all Landsat images was based on the radiometric information from reflectance bands (1–5 and 7 bands) and two vegetation indices for each Landsat scene. Specifically, we calculated the normalized difference vegetation index (NDVI) (Rouse et al. 1974):

$$\mathrm{NDVI} = \frac{\rho\mathrm{NIR} - \rho\mathrm{Red}}{\rho\mathrm{NIR} + \rho\mathrm{Red}}$$

where ρNIR and ρRed are the reflectance for the near infrared and red wavelength bands, respectively. We also calculated the soil adjusted vegetation index (Huete 1988):

$$\mathrm{SAVI} = \frac{\rho\mathrm{IRC} - \rho\mathrm{Red}}{\rho\mathrm{IRC} + \rho\mathrm{Red} + L}(1 + L)$$

where $L$ is the soil brightness correction factor. We used these vegetation indices to enhance the contribution of vegetation in the spectral response and mitigate other factors such as soil, topography, lighting conditions and atmosphere.

We implemented the supervised classification by selecting ten classes based on main land use and vegetation cover types identified in the study area: (1) rocky areas (rocky soil with less 10 % of vegetation), (2) open scrub (with a range between 20–80 % of scrub, dominated mainly by *Erica* spp.), (3) scrubland (areas completely covered of scrub, dominated by *Cytisus* spp., *Ulex* spp. and *Erica* spp., including grazing lands), (4) deciduous woods (oaks and riparian woods, dominated by *Quercus robur*, *Q. pyrenaica* and other riparian species such as *Betula celtiberica*), (5) human settlements (rural and urban settlements including buildings and roads), (6) grassland and crops, (7) water reservoirs, (8) burned areas, (9) denuded soil (edges of reservoir, large sand roads and open pit mines) and (10) evergreen woods (coniferous mature woods dominated by *Pinus sylvestris* and *P. pinaster*).

To support the classification procedure, training and test areas were selected for each of the ten classes considered. They consisted of a set of pixels identified over different RGB composites, obtained by combining satellite bands, airborne photography and by information gathered from field surveys. Specifically, we used digital orthophotos in natural colour at 1:18,000 scale from Plan Nacional de Ortofotografía Aérea of 2003. NDVI and 457 RGB composites were especially useful to discriminate "burned areas" (Chuvieco 2008).

We assessed the accuracy of the LULC map (derived from satellite data) by confusion matrices using the percentage of pixels classified per class, the overall accuracy and the kappa coefficient (Foody 2002). The overall accuracy corresponds to the percentage of pixels correctly allocated to each class and is computed across the main diagonal of the confusion matrix. The kappa coefficient takes into account both the pixels in the main diagonal and the marginal values in the confusion matrix (Foody 2002; Richards and Jia 2006). This accuracy assessment was performed over the training and test areas.

## Predictive variables

For each 100×100 m square sampled, we considered four sets of candidate predictors related to vegetation, topography, human

**Table 1** Predictors selected to model the European wild rabbit occurrence in the Baixa Limia lowlands

| Predictors | Description |
|---|---|
| Vegetation | |
| Scrub (SC) | Proportion in % of 30 m pixels belonging to "scrub" category in sampling squares |
| Grassland and crops (GC) | Proportion in % of 30 m pixels belonging to "grassland and crops" category in sampling squares |
| Topography | |
| Slope (S) | Mean slope in sampling squares |
| Aspect (A) | Majority value (the mode) of aspect in each sampling squares |
| Human influence | |
| Human rural settlements (US) | Proportion in % of 30 m pixels belonging to "urban settlements" category in sampling squares |
| Distance to roads (DR) | Mean distance (expressed in m) to the roads and footpath within the sampling squares |
| Ecological heterogeneity | |
| Ecotone scrubland-forest (SF) | Length of boundaries (expressed in m) between scrubland (including "scrubland" and "rock and scrub" categories) and forest (including "deciduous woods" and "evergreen woods" categories) |
| Ecotone scrubland–grassland and crops (SGC) | Length of boundaries (expressed in m) between scrubland (including scrubland and rock and scrub categories) and grassland and crops category |

**Table 2** Confusion matrix and statistic accuracy assessment for the classification

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total | CoE | UA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Rocky | *415* | 0 | 0 | 0 | 77 | 0 | 0 | 10 | 0 | 23 | 525 | 20.95 | 79.05 |
| 2. Dam reservoirs | 0 | *1,463* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,463 | 0 | 100 |
| 3. Evergreen woods | 0 | 0 | *631* | 0 | 3 | 8 | 0 | 0 | 4 | 1 | 647 | 2.47 | 97.53 |
| 4. Grassland and crops | 0 | 0 | 0 | *161* | 72 | 14 | 0 | 0 | 12 | 1 | 260 | 38.08 | 61.92 |
| 5. Urban settlements | 34 | 0 | 0 | 8 | *917* | 0 | 0 | 27 | 0 | 48 | 1,034 | 11.32 | 88.68 |
| 6. Scrubland | 0 | 0 | 10 | 10 | 13 | *581* | 0 | 1 | 18 | 51 | 684 | 15.06 | 84.94 |
| 7. Burned areas | 0 | 0 | 0 | 0 | 1 | 0 | *388* | 0 | 2 | 0 | 391 | 0.77 | 99.23 |
| 8. Denuded soil | 3 | 0 | 0 | 3 | 41 | 0 | 0 | *58* | 0 | 0 | 105 | 44.76 | 55.24 |
| 9. Deciduous woods | 0 | 0 | 2 | 7 | 0 | 94 | 0 | 0 | *469* | 0 | 572 | 18.01 | 81.99 |
| 10. Open scrub | 82 | 0 | 1 | 1 | 93 | 5 | 4 | 11 | 2 | *503* | 702 | 28.35 | 71.65 |
| Total | 534 | 1,463 | 644 | 190 | 1217 | 702 | 392 | 107 | 507 | 627 | 6,383 | Overall accuracy, 87.51 % | |
| OE | 22.28 | 0 | 2.02 | 15.26 | 24.65 | 17.24 | 1.02 | 45.79 | 7.5 | 19.78 | | | |
| PrA | 77.72 | 100 | 97.98 | 84.74 | 75.35 | 82.76 | 98.98 | 54.21 | 92.5 | 80.22 | | Kappa coefficient, 0.85 | |

Both classification results (in row) and ground truth (in column) in pixels

*OE* omission errors in %, *PrA* producer's accuracy in %, *CoE* commission errors in %, *UA* user's accuracy in %

influence and heterogeneity (Table 1; for methodological details, see Regos et al. 2012b). We selected these independent variables from among the possible classes (see above) by taking into account the main habitat requirements of the species in the Iberian Peninsula (e.g. Ballesteros 1998). The first set was related to the vegetation cover. We extracted these variables from the Landsat-derived map and estimated them from the percentage of area occupied by each class for each sampling square. We estimated the surface area of the scrub from the sum of the surface areas of open scrub and scrubland (see above). The use of topographic data may provide information about microclimatic conditions reflecting the changes of vegetation cover at finer grain than a land cover map, as the predictive ability of models including vegetation and topoclimatic variables is slightly superior (Seoane et al. 2004). We considered the topographic variables average slope and aspect (modal value), which we obtained from the GDEM with a resolution approximately of 30 m pixels (http://www.gdem.aster.ersdac.or.jp).

We obtained the factors in the categories human influence and ecological heterogeneity for each sampling square from topographic maps at a scale of 1:25,000 and the Landsat-derived map previously vectorized. We used MiraMon software (Pons 2000) for radiometric correction of Landsat images and ENVI 4.0 software (Research System 1996) for classification. We used MiraMon and ArcGIS 9.3 (Environmental Systems Research Institute, Inc.) to obtain the information related to the different environmental variables. We compared the resulting accuracy with a previously established threshold of acceptance (Serra et al. 2003) to evaluate whether the results of the classification were satisfactory.

**Table 3** Summary of model selection results for European wild rabbit occurrence in the 100×100 m UTM grid in the Baixa Limia lowlands ($n$=237)

| Model | AICc | $\Delta_i$ AICc | $W_i$ |
|---|---|---|---|
| *GC+S+DR+US+SF* | *142.329* | *0* | *0.031* |
| SC+S+DR+US+SF | 142.609 | 0.28 | 0.027 |
| SC+S+DR | 143.016 | 0.687 | 0.022 |
| SC+S+DR+SF | 143.082 | 0.753 | 0.022 |
| SC+S+US+SF | 143.13 | 0.801 | 0.021 |
| SC+S+DR+US | 143.32 | 0.991 | 0.019 |
| GC+S+US+SF | 143.357 | 1.028 | 0.019 |
| S+DR+US+SF | 143.46 | 1.131 | 0.018 |
| SC+GC+S+DR+US+SF | 143.595 | 1.266 | 0.017 |
| GC+DR+US+SF | 143.616 | 1.287 | 0.017 |
| GC+S+DR+SF | 143.682 | 1.353 | 0.016 |
| SC+S+US | 143.794 | 1.465 | 0.015 |
| SC+S+DR+US+SF+SGC | 143.865 | 1.536 | 0.015 |
| SC+S | 143.873 | 1.544 | 0.015 |
| SC+S+US+SF+SGC | 144.063 | 1.734 | 0.013 |
| SC+S+SF | 144.122 | 1.793 | 0.013 |
| SC+GC+S+US+SF | 144.138 | 1.809 | 0.013 |
| SC+GC+S+DR+SF | 144.248 | 1.919 | 0.012 |
| GC+S+DR+US+SF+SGC | 144.322 | 1.993 | 0.012 |

Models with $\Delta i$<2 are shown and ranked by descending Akaike weights ($Wi$) (for predictor codes, see Table 1)

## Statistical analysis

We used generalized linear models to model the occurrence of European wild rabbit in the Baixa Limia lowlands, we specifically used a binary logistic model with binomial distribution and logit link. We considered all models of main effects combining the eight selected predictors, and we used the corrected Akaike information criterion (AICc) to select the best model. We used this expression of AIC because $n/K<40$ (Anderson et al. 2000). We obtained the AICc and $\Delta_i$ values for each model $i$, where $\Delta_i$=AICi−AIC$_{\text{minimum model}}$. Generally, models with $\Delta_i$ values $\Delta_i\leq2$ have strong support, whereas those with values >10 have little support. The weight of each model was calculated as $W_i$ (Anderson et al. 2000):

$$W_i=\frac{\exp\left(-\frac{1}{2}\Delta_i\right)}{\sum_{r=1}^{R}\exp\left(-\frac{1}{2}\Delta r\right)}$$

The sum of all weights equals the unit, and the value of each $W_i$ indicates that the model $i$ is the best overall Kulback–Leibler model (Anderson et al. 2000; Johnson and Omland 2004). The importance of each predictor was obtained by adding the Akaike weights to the models in which that variable is present (Burnham and Anderson 1998). The addition of the weights of each variable was considered consequential when $\sum W_i>0.5$ (Taylor and Knight 2003). We used the IBM SPSS Statistics statistical package for all statistical analyses.

## Results

### Accuracy of the classification technique used

The overall accuracy of the Landsat-derived map in Baixa Limia was 87.51 % (percentage of pixels correctly assigned to the corresponding thematic class), and the kappa coefficient was 0.85 (Table 2). Commission and omission errors for "reservoirs", "burned areas" and "evergreen wood" were below 3 % (Table 2). The lowest thematic accuracy was registered in "denuded soil", although this category does not have any biological significance for the species. The other accuracy values ranged between 60 % and 99 % (Table 2).

### Occurrence and habitat use of European wild rabbit

Below an altitude of 800 m, the presence of European wild rabbit (faecal pellets) was detected in 54.1 % of the 1×1 km UTM grids and in 10.1 % of the 100×100 m squares.

The most parsimonious model included grassland and crops, mean slope, distance to roads, urban settlements and ecotone scrubland-forest, and another eighteen models were also competent ($\Delta_i\leq2$) (Table 3). All variables except "aspect" were included in at least one of the nineteen models.

Five predictors were consequential, three with a positive sign for the presence of the species (rock and scrub, urban settlements and ecotone scrubland-forest) and two with a negative sign (mean slope and distance to roads) (Table 4).

## Discussion

Previous studies have shown that the digital data obtained by remote sensing and GIS can improve the accuracy of models (Newton-Cross et al. 2007; Morán-Ordóñez et al. 2012), as they provide environmental information not otherwise available. However, studies that use these techniques as the only source of environmental data on species distribution models are still scarce. In many cases, in situ collection of environmental data is often limited by purely logistical issues, such as limited accessibility to remote areas or the huge cost associated with complete coverage of the study area. The results of the present study confirm that digital data-based models can solve many of the problems associated with field data in wildlife modelling, especially when working in fragmented landscapes and with species, such as wild rabbit with small home ranges. In this respect, the overall accuracy for the Landsat-derived map was higher than the proposed threshold of 85 % for individual classifications (Campbell 2008). This confirms that the remotely sensed data were suitable for the extraction of environmental variables and subsequent modelling of the wild rabbit at microhabitat scale.

The results of the study demonstrated that the European wild rabbit is scarce and localized, and they also highlighted the poor conditions of the populations throughout the Gerês–Xurés Biosphere Reserve (Carvalho and Gomes 2003; Monzón et al. 2004; Tapia 2004; Tapia et al. 2010).

All of the predictors included in the most parsimonious model and the consequential predictors obtained are biologically significant and are relevant to the habitat preferences of the European wild rabbit (Gálvez-Bravo 2011). However, adaptation of the species to different environments, together with low densities obtained, generates difficulties in modelling the wild rabbit

**Table 4** Relative importance of effect magnitudes as calculated by summing Akaike weights across all possible models and direction of the effects of the predictors used to model the European wild rabbit occurrence

| Dependent variable | Predictor | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SC | GC | S | A | US | DR | SF | SGC |
| Presence of European wild rabbit | *+0.66* | +0.42 | *−0.69* | +0.26 | *+0.58* | *−0.67* | *+0.61* | +0.36 |

Italicized values over 0.5 are considered as consequential (for predictor codes, see Table 1) occurrence at microhabitat scale, as highlighted in previous studies in the area (Carvalho and Gomes 2003; Monzón et al. 2004).

Below 800 m.a.s.l., altitude is not a limiting factor for the presence of the European wild rabbit (Fa et al. 1999; Gálvez-Bravo 2011), in contrast with mountainous areas of Gerês–Xurés, in which this variable limits both the distribution and the abundance of the species (Tapia et al. 2010). Occurrence was associated with areas dominated by scrub with low slopes and also by edge areas of scrubland-forest. This indicates a greater tolerance to wooded areas at low altitude within which the rabbit is more abundant than in high zones (Tapia et al. 2010).

The steepest areas include a higher abundance of rocky zones and hard shallow soils, which explains the negative predictive value, given the preference of rabbits for softer soils for burrowing (Purroy and Varela 2003; Calvete et al. 2004; Gálvez-Bravo 2011).

The positive association between rabbit occurrence and rural settlements and grassland and cropped areas indicates that rabbits prefer heterogeneous rural areas in Gerês–Xurés. Such areas probably provide a combination of good feeding opportunities and scrubs with lower density of woody vegetation at the ground level but with a dense overhead cover (*Cytisus* spp., *Genista* spp.) for protection against predators (Villafuerte and Moreno 1997; Carvalho and Gomes 2003; Lombardi et al. 2003; Beja et al. 2007).

The preference of rabbits for areas close to roads and footpaths showed has been documented previously in other sites in the Iberian Peninsula (Calvete et al. 2004; Gea-Izquierdo et al. 2005). Rabbits may build their warrens within road embankments, which provide support for the structures, as a behavioural adaptation, and road verges may be safer breeding zones (Bautista et al. 2004). These effects may be reinforced by the absence of shooting by hunters near roads.

The relationship between the presence and abundance of rabbits and habitat types often may be distorted (Soriguer and Palacios 1996; Vargas 2002; Angulo 2003; Carvalho and Gomes 2003). Other variables not considered, such as abundance of predators and human activities (hunting pressure, restocking), are probably also involved in the patterns of occurrence and habitat use. These factors appear to determine the distribution and abundance of this species in microscale analysis (Angulo 2003; Carvalho and Gomes 2003; Monclús and De Miguel 2003; Virgós et al. 2003; Lombardi et al. 2007). Despite these limitations, the microhabitat scale models obtained in this study are consistent with the patterns obtained for the neighbouring Portuguese areas of the biosphere reserve at microhabitat resolution scales (Carvalho and Gomes 2003;

**Table 5** Summary of the main results obtained in the research articles performed at Gerês–Xurés Biosphere Reserve area about habitat preferences of European wild rabbit

| Article | Altitude range (m) | Dependent variable | Digital information sources for ecological predictors | Scale of analysis | Habitat preferences results |
|---|---|---|---|---|---|
| Carvalho and Gomes 2003 | 800–1,400 | Presence/absence of pellets | Orthophoto map and ground corrected 16 m of resolution | Circular plots of 100 m radius | Intermixture of foraging (pasture/fields and scrubland) and shelter (tall scrubland, rocks and forest edge) habitat patches |
| Monzón et al. 2004 | 400–700 | Presence/absence of pellets | Orthophoto map 1:18,000 | Grid of 25 ha cells | Scrubland diversity and cover; the species reject uniform and continuous tracts of pine woodland or scrubland |
| Tapia et al. 2010 | 800–1,500 | Abundance of pellets (using spatial extrapolation techniques) | 150,000 digital maps with resolution of 250×250 m; sources, Corine land cover project and third Spanish Forest Inventory for land use variables; digital elevation model at 250 m resolution for topographic variables | Grid of 2×2 km cells | Areas with scarce forest surface at lower altitude; higher availability of open land dominated by scrublands with the presence of appropriate feeding areas (pasture areas) and better soil conditions for establishment of warrens |
| Present study | 300–800 | Presence/absence of pellets | Land use/land cover maps derived from Landsat ETM+ images with a 30-m pixel resolution (acquired at the same time as the field data) and calculated vegetation indices by using a supervised classification method; topographical predictors were obtained from a Global Digital Elevation Model (GDEM) | Squares of 100×100 m | Areas dominated by scrubland with gentle slopes and edge areas of scrubland-forest; it selects heterogeneous habitats in rural areas (grassland and crops) with presence of mature scrubs |

Monzón et al. 2004) and mosaic ecosystems in the centre and south of the Iberian Peninsula (Herranz et al. 2000; Angulo 2003; Lombardi et al. 2003; Virgós et al. 2003; Lombardi et al. 2007).

## Management implications

Habitat management is considered an effective tool for the recovery of wild rabbit populations in the Iberian Peninsula (Catalán et al. 2008). The information accumulated in the last 10 years about its habitat requirements in the area (Carvalho and Gomes 2003; Monzón et al. 2004; Tapia et al. 2010; present study) provides a good overall picture in different environments of Gerês–Xurés Biosphere Reserve (Table 5).

The management guidelines to improve wild rabbit populations in Gerês–Xurés Biosphere Reserve include: (1) the preservation of the traditional land uses, especially in the settlements areas, and rural mosaic habitats to favour the connection among patches, (2) the promotion of ecotone interface between tall scrubs, open fields and plots of native tree species to increase the intermixture between shelter and feeding habitats in areas with dense and continuous scrubland, (3) the incorporation of land management actions such as the introduction of crops adequate to the species and small groves with native tree species and small prescribed fires to diversify the scrubland age structure, (4) in areas at higher elevation (above 800 m.a.s.l.), the conservation of open habitats with suitable vegetation structure (scrubland, grassland), avoiding intensive silviculture and reforestation and (5) a revision of the current hunting plans in the biosphere reserve area is also required.

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