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ORIGINAL PAPER

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Vegetation structure descriptors regulating the presence of wild rabbit in the National Park of Peneda-Gerês, Portugal

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Abstract The aim of this work is to assess whether there is a specific structural vegetation pattern for the wild rabbit *Oryctolagus cuniculus* (L., 1758) that might explain its spatial distribution. The species presence was approached through logistic regression modelling based on selected descriptors of vegetation landscape structure: number of homogeneous vegetation units, their areas and diversity values and heterogeneity indexes. All variables were derived for two hunting areas within the National Park of Peneda-Gerês in northern Portugal. The results show the wild rabbit preference for types of vegetation cover that offer, first of all, shelter, mainly in the form of shrub cover, and secondly, vegetation cover that always displays high fragmentation or high availability of resources. This animal avoids landscapes with homogeneous and continuous vegetation cover. The results obtained are suggestive of management actions to improve the habitat in order to encourage development of the species, whose presence will also favour the threatened and endangered predators that occur in the National Park of Peneda-Gerês.

Keywords *Oryctolagus cuniculus* · Logistic regression · Habitat preferences · Distribution · Vegetation structure · Portugal

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Introduction

The wild rabbit is the most popular small game species in Portugal and is addressed by most hunting exploitation plans. Unfortunately, its number has been drastically reduced because of two diseases, the myxomatosis and the rabbit viral haemorrhage (Villafuerte et al. 1994; Moreno et al. 1996a). Its recovery has been difficult due to the important agricultural changes that took place in the region during these last decades (Moreira et al. 2001): habitat destruction and hunting pressure. As a result, serious negative effects can arise in Mediterranean ecosystems, because this animal is the main food source for many predators (Delibes and Hiraldo 1981; Moreno 1991).

Analysis of different hunting areas elsewhere in Portugal (Santos 1998) and Spain (Fa et al. 1999) has shown a decrease in the density of rabbits, and a large difference has been noted between forecasts and capture results that is really below the environment potential.

Rational measures for exploitation and recovery are required, implying a good knowledge of the rabbit preferences in terms of territory occupation, in order to derive habitat management guidelines. In fact, of all the different management actions that can be implemented in a hunting area, those addressed at habitat amelioration are particularly relevant (Covisa 1998). Knowledge concerning the biophysical characteristics of an area and the biological necessities of the species are implied in the process.

Landscape patterns can play an important role for species with small vital areas, such as the wild rabbit (ONC 1985) and for species whose biological requirements must be fulfilled within a close vicinity (CERAFER 1975; Gibb 1993; Moreno et al. 1996b).

The aim of this study is to assess whether a specific pattern of vegetation structure is required by the species, by means of logistic regression. The results of this modelling approach indicate the presence/absence likelihood of a species, being frequently used to forecast the presence and habitat use for many species (Meriggi and Alieri 1989; Agustin et al. 1996; Brito et al. 1996; Martins and Borralho 1998). Future model validation will hopefully allow the definition of habitat management strategies in order to improve the species.

Materials and methods

Study area

The study was carried out in two hunting zones: Fafião with an area of 1,442 ha and Cabril with 1,629 ha. Both are located in the area of Cabril (Montalegre Council) in the National Park of Peneda-Gerês and are representative of mountain landscapes in northeastern Portugal.

The biophysical characteristics of both areas are similar because of their geographical vicinity (Fig. 1), but their landscape patterns of vegetation cover differ (Rodrigues 2000). This should allow comparisons of the wild rabbit presence at the spatial level of occupation, taking into account vegetation descriptors.

In broad terms, the climate can be considered Atlantic with a continental influence, meaning rainy and relatively cold winters and dry summers. The average annual rainfall is 1,472 mm and the mean annual temperature is 14 °C. It is included in the Eurosiberian biogeographic region, Galician-Portuguese sector. Granite-derived soils are dominant, and 90% of the study area is within an elevation range of 400 to 700 m, with a maximum elevation of 1,160 m.

Shrubland dominates the landscape, but some forest stands of maritime pine (*Pinus pinaster*) are also found, as well as small patches of the *Quercus robur* and *Q. pyrenaica* oaks. Cattle breeding is the main economical activity, being concentrated on agricultural areas near small villages.

Methods

The study area is covered by three orthophotomaps at the 1:18,000 scale that were divided into a grid of 25-ha cells, defined as squares of 500×500 m. In this way, 159 cells were obtained—54 in the Fafião area and 105 in the Cabril area.

The factors previously mentioned, plus the climatic characteristics of the region (Blanco and Villafuerte 1993) may explain the low density of rabbits noted by hunting managers in the study area (Rodrigues 2000). In order to identify the rabbit distribution patterns, its presence within each cell was assessed by the presence of signs, mainly pellets, during a survey made in July 1999.

Vegetation cover was categorised into seven different types that were identified and delimited in the orthophotomaps and within each cell: pine trees (P), high shrubland (MG, taller than 0.5 m and composed mainly of *Cytisus* sp. and *Erica* sp.), low shrubland (M, lower than 0.5 m and composed mainly of *Chamaespartium tridentatum* and *Ulex* spp.), oak woodland (C), birch woodland (V, *Betula celtiberica*), evergreen mountain grassland (L) and agricultural land (A). Small roads and rock outcrops were also accounted for. Each one of these nine cover types, further verified in the field, represents a landscape unit (UP).

The number of vegetation patches comprising a landscape unit or vegetation type within a cell was determined by the CANVAS 5.0 software (for Macintosh), and their respective areas and perimeters were estimated in order to calculate the heterogeneity (*IC*) and diversity (*D*) indexes proposed by Burel and Baudry (1999).

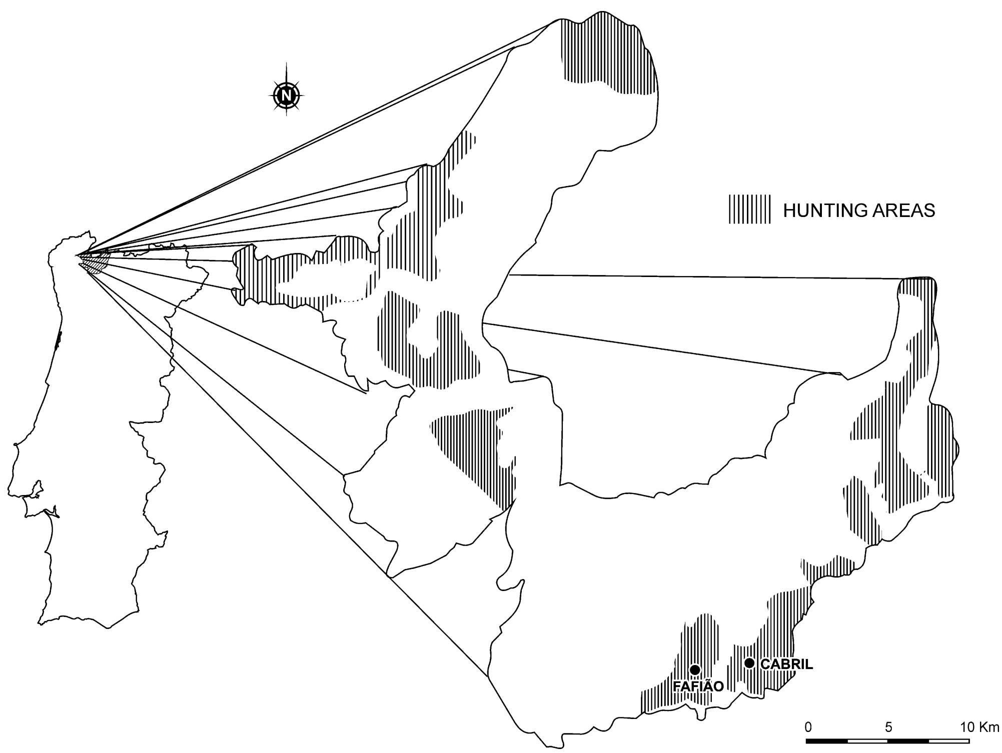
IC expresses the level of landscape fragmentation in the form of continuity/discontinuity of vegetation cover at the spatial analysis level (the cell), according to the existing number of vegetation patches.

IC is calculated as:

$$IC = \log_{10}(U^2) \quad (1)$$

where U is the number of vegetation patches within each cell. *IC* increases with an increasing U, and is independent from vegetation nature. $IC = 0$ when there is only one patch.

Fig. 1 Location of the Fafião and Cabril hunting zones from the National Park of Peneda-Gerês (Portugal)



D was calculated for each type of vegetation found in the cell, based on the number of patches it is subdivided into and their spatial dimensions:

$$D = \sum \left(P_i \times N_i^2\right)/S \times \sum S_i \times [(S \times 100) - 50S] \quad (2)$$

where P_i is the perimeter of each patch for the vegetation type i, N_i total number of patches for a given vegetation type, S area of the cell (25 ha), and S_i area of each patch. D expresses the fragmentation of each vegetation type, and therefore, increases when the number of patches is high and their size is small.

Data analyses

Logistic regression (Walker and Duncan 1967) is one of the most popular methods available to model the relationship between a dependent dichotomous variable and a set of independent variables. The logistic function estimates a continuous, non-linear estimate of the probability of an event, in this case, the presence or absence of the wild rabbit. The JMP 4.02 software (SAS Institute 2000) was used to estimate the coefficients of the logistic model:

$$P_c = \frac{1}{(1 + \exp(b_0 + b_1x_1 + \ldots + b_ix_i))} \quad (3)$$

where P_c is the probability of rabbit presence, varying in the (0,1) interval, b_0 to b_i are the regression coefficients estimated by maximum likelihood and x_1 to x_i are the independent variables previously defined IC, UP, D for each vegetation type and the areas of each vegetation type (A_M, A_{MG}, A_P, A_V, A_C, A_A, A_L).

During the exploratory data analysis phase, and for each hunting area, the capability of the independent variables to discriminate between the two possible outcomes regarding rabbit status was examined by univariate logistic regression. Relatively uncorrelated variables ($P > 0.05$) that differed between rabbit status ($P < 0.05$) and were significantly related to its presence/absence ($P < 0.05$) were selected for the initial multivariate models. The remaining variables were added in turn to these models and checked for significance. Standard tests and statistics for logistic regression were used in the analysis (Trexler and Travis 1993): the likelihood ratio test to assess the overall model significance; Wald's test to determine the significance of an individual variable in the presence of the other variables included in the model; and the odds ratio, useful as a quantifier of the probability of occurrence when an analysed independent variable changes by a given amount.

Analysis of concordance between the observed rabbit presence and the outcome of the model was employed to evaluate the model's performance using a 2×2 classification table. It allows the calculation of five indexes that describe the predictive capacity of the model (Saveland and Neuenschwander 1990; Pearce and Ferrier 2000): sensitivity or hit, the correctly predicted proportion of events; specificity or correct rejection, the correctly predicted proportion of non-events; false positive fraction or false alarm rate, the proportion of non-events predicted as events; false negative fraction or miss rate, the proportion of events predicted as non-events; and accuracy, the total fraction of the sample that is correctly classified. Additionally, signal detection theory (Saveland and Neuenschwander 1990; Pearce and Ferrier 2000) was used to compute the area under the ROC (receiver operating characteristics) curve, which describes the compromise between sensitivity and the false positive fraction as the decision threshold changes and assesses the overall model performance.

Results

Vegetal cover in the Fafião area is mainly composed of pines (*P. pinaster*), whose occupation represents 43.84% of the area, and shrubs (M = 17.89%; MG = 25.85%). The two shrubland types are found in an important percentage of the cells, where the pine-high shrubland association is common (66.66%), rather than the pine-low shrubland association (42.86%). Rabbits were present in 30 of the 54 analysed cells (56%).

The Cabril area is dominated by M, which represents 73.89% of the total area. Almost half (47.6%) of the cells have this vegetation type only. The presence of rabbit was confirmed in 52 of the 105 analysed cells (50%).

The average IC value calculated for the Fafião area was 1.2 against 0.9 for the Cabril area. Nevertheless, if in Cabril we disregard the cells exclusively covered by shrubs, the average IC value approaches Fafião's value (1.14). It is then obvious that a large area is covered by continuous shrubland in the Cabril hunting zone.

Table 1 compares the average value of each independent variable in relation to the rabbit presence or absence in both hunting areas. Tables 2 and 3 display the correlation coefficients between the independent variables that significantly ($P < 0.05$) explain the presence of rabbits in each hunting area.

According to Table 1, the presence of wild rabbit in Fafião is positively related to shrubland diversity or area occupied by shrubland in the cell, which makes sense, since shrubs provide the required shelter (ONC 1985). Shrub cover is of major importance for the rabbit's distribution, even in landscapes where pine stands are dominant. In the Cabril area, rabbits' presence can be explained by a larger number of variables (Table 3) associated with vegetation types other than shrubs; this implies that shrub cover does not by itself explain the

Table 1 Averages of the independent variables associated to the presence or absence of rabbit in the studied hunting areas

Variable[a]	Fafião		Cabril	
	Absence	Presence	Absence	Presence
D_M	**0.089**[b]	**0.830**	1.059	1.480
D_P	0.389	1.067	0.392	1.457
D_{MG}	0.509	0.529	0.046	1.584
D_C	6.637	0.005	0.000	0.024
D_V	0.000	0.000	0.000	0.003
D_A	0.180	0.046	0.417	0.520
D_L	0.272	0.202	0.793	0.399
IC	0.946	1.486	0.806	1.014
UP	3.291	3.900	**2.250**	**3.435**
A_M	**0.471**	**4.291**	**7.737**	**5.022**
A_{MG}	3.284	4.117	**0.020**	**1.147**
A_P	6.426	6.295	0.239	0.941
A_V	0.000	0.000	0.000	0.052
A_C	0.131	0.376	0.000	0.532
A_A	0.318	2.312	0.001	0.087
A_L	0.084	0.125	**0.001**	**0.306**

[a] D_M–D_L Diversity index (D) for each type of vegetation: *M* low shrubland, *P* pine, *MG* high shrubland, *C* oak woodland, *V* birch woodland, *A* agricultural land, *L* grassland; *IC* heterogeneity index; *UP* landscape unit; A_M–A_L area (ha) of each type of vegetation
[b] Averages in *bold* for the same hunting area within a line are significantly different ($P < 0.05$), according to the Tukey-Kramer HSD test

Table 2 Correlation matrix between the independent variables with a significant effect in the presence of rabbit in Fafião

	D_P	IC	A_M
D_M	−0.13	0.12	0.36**
D_P	–	0.51***	−0.22
IC	–	–	0.01

Significant correlation levels: *5, **1, ***0.1%

Table 3 Correlation matrix between the independent variables with a significant effect in the presence of rabbit in Cabril

	D_C	UP	A_M	A_{MG}	A_C	A_A	A_L
D_{MG}	−0.03	0.37***	−0.23*	−0.05	−0.03	−0.04	−0.06
D_C		0.14	−0.13	0.51***	0.37***	0.25**	0.10
UP			−0.23*	0.07	0.14	0.42***	0.27**
A_M				−0.18	−0.19	−0.01	−0.03
A_{MG}					0.32**	0.25*	0.15
A_C						0.21*	0.17
A_A							0.66***

Significant correlation levels: *5, **1, ***0.1%

presence of rabbits, which have to fulfil their different biological necessities in small areas.

Coefficients of the final logistic regression models to predict the probability of rabbit presence in both hunting areas (Figs. 2, 3) are given in Table 4, whilst Table 5 presents statistics describing the model's performance. The best possible model for Fafião accounts for a reduction in deviance of 43% when compared with the null model, and uses A_M (deviance reduction = 27%) and IC (deviance reduction = 16%) as independent variables. Table 4 provides also an alternative model for Fafião (deviance reduction = 30%) based on D_M and IC. In the case of Cabril, none of the remaining variables could significantly add to the explanation provided by the variable UP (deviance reduction = 24%).

The predictive models emphasise the species preference for a landscape structured in a mosaic. In the Cabril zone, where shrubs prevail, the probability of the rabbit presence rises with the increase in UP and the species avoids areas uniformly covered by a single vegetation type. In the Fafião zone, IC is important to define the species presence mainly when shrub occupation percentage is low (less than 20%). In this situation, the wild rabbit avoids areas uniformly covered by pine forest and prefers cells whose IC values are above the calculated mean value (1.2) for Fafião—that is, where the different types of vegetation cover are highly fragmented and consequently, the edge effect is large.

Performance of the models is considered adequate because the area under the ROC curve (Table 5) is higher than 0.8, and the analysis of concordance (through the sensitivity and specificity indexes) shows good agreement between the observed and predicted values, but the type I error is slightly higher.

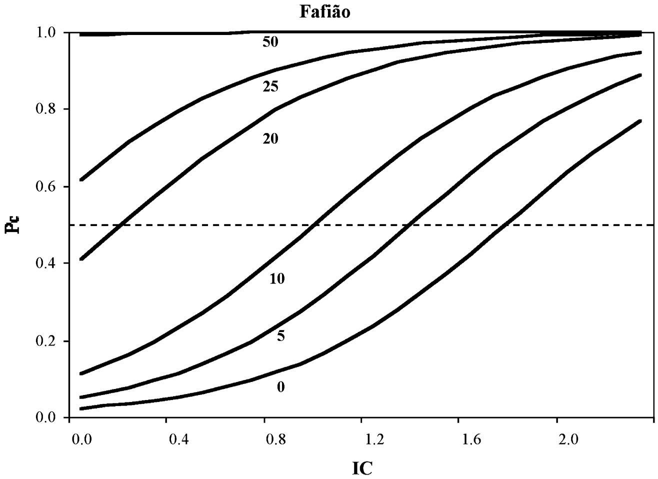


Fig. 2 Probability of rabbit presence in Fafião as a function of the heterogeneity index (IC) for different shrubland cover values, expressed as percentages of the total cell area

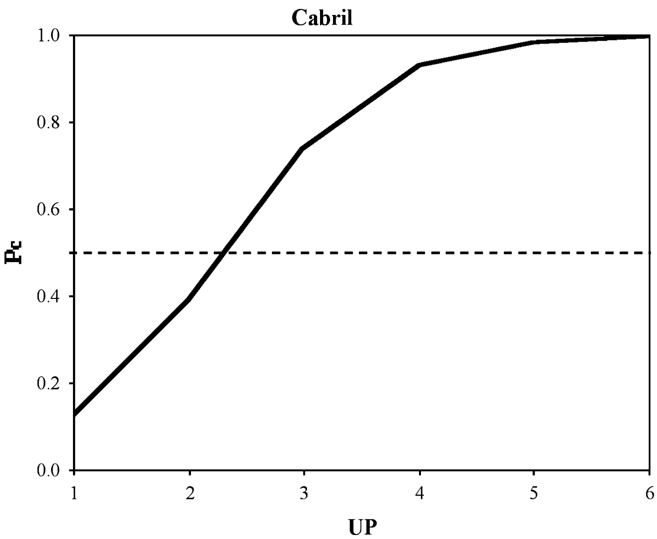


Fig. 3 Probability of rabbit presence in Cabril as a function of the landscape units (UP)

Discussion and conclusions

The wild rabbit is a species adapted to quite diverse environments, but the study done by Blanco and Villafuerte (1993) in Spain reveals that some environmental variables limit its density: its presence is rare in elevations higher than 1,200 m and where rainfall is high (such as in the study area, which belongs to the Eurosiberian region) or in cold mountain regions. In the above-mentioned study, and in agreement with our results, it was concluded that the rabbit is more frequently found in shrubland, although there were not any significant density differences related to the dispersion of vegetation cover between shelter and feeding areas.

The models derived in this study also agree with the wild rabbit preferential habitat defined by Gibb (1993)

Table 4 Logistic regression models to predict the presence of rabbit in the studied hunting areas. *P* Overall model significance, *b* (SE) estimated regression coefficient (standard error), *P* (Wald) significance of each independent variable based on the Wald statistic, *Exp (b)* odds ratio, and the percent change in the odds of rabbit occurrence for each additional unit of an independent variable is given by 1−Exp (*b*)

Model	*P*	*b* (SE)	*P* (Wald)	Exp (*b*)
Fafião 1[a]	< 0.0001	–	–	–
Constant	–	3.779 (1.282)	–	–
IC	–	−2.167 (0.769)	0.0048	0.11
A_M	–	−0.681 (0.244)	< 0.0001	0.51
Fafião 2[a]	< 0.0001	–	–	–
Constant	–	2.529 (0.915)	–	–
IC	–	−1.617 (0.590)	0.0062	0.20
D_M	–	−3.265 (1.577)	0.0384	0.04
Cabril	< 0.0001	–	–	–
Constant	–	3.444 (0.916)	–	–
UP	–	−1.495 (0.347)	< 0.0001	0.22

[a]Alternative models for the same hunting area

Table 5 Performance indicators of the logistic models. *C* Area under the ROC curve

Model	Sensitivity	Specificity	False-positive fraction	False-negative fraction	Accuracy	C
Fafião 1	0.80	0.79	0.21	0.20	0.80	0.89
Fafião 2	0.83	0.67	0.33	0.17	0.76	0.85
Cabril	0.83	0.75	0.25	0.17	0.80	0.82

as an interrupted, dominant shrub layer, satisfying the biological demands of the species, with a small home range where it is essential to have proximity between food and shelter areas (ONC 1985; Martins and Borralho 1998).

Concerning the dimension of the spatial unit of analysis used in this study (a square cell of 25 ha), theoretically, it should be adjusted to match the studied species home range (Laymon and Reid 1984; Martins 1998) in order to capture the species perception of space. According to data obtained by Fullagar (1981), the wild rabbit home range in Australia is not higher than 11 ha. Nevertheless, the independent variables used to evaluate vegetation structure influence on rabbit presence, namely *IC*, *UP* and *D*, allowed to successfully define landscape elements that are positively chosen by this species and which, indirectly, relate to the edge effect and the mosaic division of the landscape.

The models obtained for the hunting areas explain adequately the spatial occupation by the species, which selects areas that display low and relatively open shrub cover (20–30%), or, alternatively, dense and highly fragmented shrubland or included in a mosaic landscape. The species rejects uniform and continuous tracts of pine woodland or shrubland. This is consistent with the higher abundance of the species where habitat interfaces occur, as detected by Trout et al. (2000) in Great Britain.

In terms of species abundance improvement, even if the climate characteristics of both hunting zones impose limitations upon population size, given their geographical location, some habitat management measures can be taken according to the results of this study. In continuous forest stands, it is important to maintain a shrubby understorey and to favour small overstorey openings in order to increase the spatial heterogeneity. Actions aimed at the creation of a mosaic structure should be implemented in areas with dense and continuous shrubland, such as the introduction of crops adequate to the species and small groves with native tree species, and small, prescribed fires to diversify the shrubland age structure.

New land-use policies and practices—which favour the increase in forested areas rather than the traditional land-use mosaic (alternation between agriculture, range and forest) typical of northern Portugal—may lead to rarefaction in the species, unless new approaches to habitat management are adopted within a landscape ecology framework.

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