Journal of Arid Environments 76 (2012) 43–48

Contents lists available at SciVerse ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Habitat selection by European badgers in Mediterranean semi-arid ecosystems

C. Lara-Romero[a,*], E. Virgós[a], G. Escribano-Ávila[a], J.G. Mangas[a], I. Barja[b], X. Pardavila[c]

[a] Área de Biodiversidad y Conservación, Escuela Superior de Ciencias Experimentales y Tecnología, Universidad Rey Juan Carlos, Departamental 1, Despacho 216, C/ Tulipán s/n, E-28933 Móstoles, Madrid, Spain

[b] Unidad de Zoología, Departamento de Biología, Facultad de Ciencias, Universidad Autónoma de Madrid, C/Darwin 2, E 28049 Madrid, Spain

[c] Área de Ecoloxía, Departamento de Bioloxía Fundamental e Ecoloxía, Universidad de Santiago de Compostela, Campus Sur s/n, 15782 Santiago de Compostela, Spain

ARTICLE INFO

Article history:
Received 2 July 2010
Received in revised form
6 June 2011
Accepted 19 August 2011
Available online 10 September 2011

Keywords:
AIC
Arid environments
Fruit orchards
Latrine
Low density
Meles meles

ABSTRACT

We studied the habitat selection patterns of badgers *Meles meles* (Linnaeus, 1758) in Mediterranean semi-arid ecosystems. Fifty-seven plots were sampled in two semi-arid regions of Spain. In each plot, badger latrines were located along 2.6 km transects. The number of badger latrines per km was used as a surrogate of badger abundance and as an index of habitat selection by badgers. For each plot, a series of environmental variables were measured at two spatial scales. These variables were related to land use and vegetation formation parameters that are considered potentially important for habitat requirements (i.e., food and shelter). The habitat selection model was carried out using generalised linear models (GLM) and an information-theoretic approach. Results indicated that badgers prefer fruit orchards, and shrub and rock-covered areas, which provide additional trophic and shelter resources, and avoid intensively cultivated fields and human settlements. We conclude that badger conservation in semi-arid environments of the Iberian Peninsula requires the existence of fruit orchards and the limitation of human development. Policies restraining agriculture intensification would encourage traditional or new non-intensive agricultural practices and increase shrub-patch availability, which would benefit this species.

1. Introduction

Habitat selection models are a useful tool in conservation biology and wildlife management (Caughley and Sinclair, 1994). They identify the processes involved in habitat choice by using statistical methods to relate species distribution to the spatial distribution of environmental factors (Guisan and Zimmermann, 2000). As habitat selection can occur at different scales, habitat selection models should include a multiscale approach varying from individuals to total species distribution (Johnson, 1980). Although many variables such as climatic conditions, ecological interactions or soil characteristics can influence habitat selection, vegetation (which represents shelter and trophic resources) is the most frequently discussed (Cody, 1985). Knowledge of how these variables affect habitat selection at different scales should be the first step in designing conservation strategies (Caughley and Sinclair, 1994).

The European badger, *Meles meles*, is widely distributed across the western Palaearctic region (Del Cerro et al., 2010) where it is mainly associated with deciduous woodlands and pastures (Kruuk, 1989; Feore and Montgomery, 1999). However, their versatile ecological requirements also allow them to occur in boreal forests, Mediterranean landscapes and steppes (Neal and Cheeseman, 1996). The southern limit of its distribution range runs along the border between semi-arid and hot-arid climate regions. Hence, aridity can be considered a limiting factor of badger distribution. This species reaches the southwestern limit of its distribution range in the Iberian Peninsula (Del Cerro et al., 2010). In this region, the highest badger densities and occurrences have been found in temperate areas in landscapes composed of a mosaic of deciduous forests and pastures (Virgós and Casanovas, 1999b). It is scarce in drier landscapes, which are dominant in most of the Iberian Peninsula (Revilla et al., 1999; Virgós and Casanovas, 1999a, b) probably due to reduced food availability (Rodriguez and Delibes, 1992; Virgós et al., 2004; Barea-Azcón et al., 2010) and fragmentation of key habitats, particularly in intensively cultivated areas (Virgós, 2001, 2002). In southeastern and central Spain, badgers occur in semi-arid regions where trophic resources, climate, and landscape pattern are extreme for the species. Nevertheless, little is known about badger distribution, abundance and habitat selection in semi-arid environments. Rodriguez and Delibes (1992) proposed that badgers can only reach high abundance in these regions by

* Corresponding author. Tel.: +34 91488 82 88; fax: +34 91664 7490.
E-mail address: carlos.lara@urjc.es (C. Lara-Romero).

0140-1963/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jaridenv.2011.08.004

using productive patches devoted to orchards and other forms of cultivated land. Barea-Azcón et al. (2010) recently outlined a similar proposal. Therefore, badger distribution and abundance in semi-arid regions seem to be highly dependent on farming practices.

A large proportion of the farmland in semi-arid regions in Spain has a high environmental value as a semi-natural habitat subjected to extensive management practices (Blondel and Aronson, 1999; Reidsma et al., 2006). However, in the last few decades, the European Union's Common Agricultural Policy (CAP) has impacted the ecology of these agricultural systems, by promoting the specialisation and intensification of areas of high potential productivity and the abandonment of less productive and marginal lands (Oñate et al., 2007; Stoate et al., 2009). This process, far from disappearing, is likely to continue according to most land use predictions (Petit et al., 2001; Reidsma et al., 2006). As a consequence, low intensity agricultural practices and semi-natural vegetation have decreased, producing a loss of habitat heterogeneity (Berger et al., 2006; Stoate et al., 2009). Badgers inhabiting semi-arid environments in the Iberian Peninsula may be highly vulnerable to these changes, as they prefer heterogeneous habitats and those characterised by traditional agricultural practices (e.g., Kruuk, 1989; Feore and Montgomery, 1999; Virgós and Casanovas, 1999a; Rosalino et al., 2004), and are susceptible to habitat loss and fragmentation in intensive agricultural landscapes (Virgós, 2001, 2002).

The Mediterranean area is also one of the regions most threatened by global warming (Parmesan and Yohe, 2003). According to current predictions, most of its semi-arid landscapes could become more arid and extend northward, reducing overall habitat quality for badgers.

In this work, we studied the habitat selection patterns of European badgers in Mediterranean semi-arid habitats. We hypothesised that badger abundance would be positively correlated to the presence of natural vegetation, cultivated fruit orchards and rock blocks cover, which in combination provide trophic and shelter resources.

2. Methods

2.1. Study area

This study was carried out in two regions in the Iberian Peninsula (Spain) where agriculture is the main human activity and hunting and extractive activities are of minor relevance.

The northern study area was located in the southeastern Madrid region (40°09'N, 3°15'O), with an average annual temperature of 13.7 °C and an average annual precipitation of 410 mm. It is covered by xeric vegetation such as *Stipa tenacissima* L. (28%) with small patches of sclerophyllous holm oak forest dominated by *Quercus ilex* and *Quercus coccifera* (9%) and cultivated pine forest (*Pinus halepensis*) (6%). These patches are included in an agricultural matrix of intensive and monospecific olive tree (*Olea europaea*) plantations (18%) and non-irrigated crops, mainly cereal crops (25%). In this area, we did not find orchards of fruiting tree species that are known to be preferred by badgers in semi-arid landscapes (Rodriguez and Delibes, 1992).

The southern study area was located in the southeastern Andalusian region (37°00'N, 2°20'O), with an average annual temperature of 16.6 °C and an average annual precipitation of 310 mm. Its vegetation is comprised of xeric species such as *S. tenacissima* L. (56%) and a mosaic of small orchards with various fruit trees (mainly orange, lemon and almond trees) (9%), olive plantations (7%) and irrigated crops (12%). Forests are very scarce, and there is only one cultivated pine forest (*P. halepensis*) in the area (8%).

2.2. Survey procedure

This study was conducted in autumn 2007 and spring 2008, coinciding with the periods of high faecal marking rates in this species (Pigozzi, 1990; Virgós et al., Unpublished results), which maximises the probability of detection. We sampled 28 and 29 plots of 3 × 3 km in the northern and southern study areas, respectively. Plots were separated by a minimum distance of 2 km to mitigate spatial autocorrelation (Guisan and Zimmermann, 2000). The survey covered an area of approximately 1400 km^2 and 1700 km^2 in the northern and southern study areas, respectively.

Badger abundance was recorded using a modification of the methodology proposed by Tuyttens et al. (2001). In each plot, we sampled a 2.6 km × 5 m linear transect. The transects were walked following linear features such as hill slopes, gulches, natural narrow paths and ecotone edges among different habitat patches, as badgers tend to dig at such places (Kruuk, 1989). The number of badger latrines was recorded for each transect because this variable correlates better with badger density than the amount of faeces (Tuyttens et al., 2001; Mangas et al., Unpublished results). Thus, the number of latrines per kilometre of surveyed transect (hereafter latrine/km) was used as an index of badger abundance. Moreover, latrine distribution reflects the pattern of badger home range use, and marking such activity can be used as an index of habitat selection by badgers in low density populations (Balestrieri et al., 2009).

2.3. Environmental variables

A series of environmental variables related to land use and vegetation formation were measured in each plot at two spatial scales (Table 1). These variables can potentially influence food and shelter availability for badgers, as they have been identified as the main components of badger habitat quality (Kruuk, 1989). At the microhabitat scale (e.g. transect scale), the environmental variables were measured in field surveys. Linear transects were divided into 200 m segments. The percent cover of eight environmental variables was visually estimated every 200 m along each transect, following protocols similar to those previously used for this species (Virgós and Casanovas, 1999a).

At the macrohabitat scale, we used ArcMap 9.2 GIS (ESRI© 2006) and a recent 1:50,000 vegetation/land use map (Spanish Ministry of the Environment and Rural and Marine Environments: www.marm.es) to obtain the land cover of 10 environmental variables within a 9 km^2 buffer zone around each transect. We considered 9 km^2 to reflect habitat selection at a level similar to the mean probable home range (Johnson, 1980) of this species in areas of low habitat suitability. This area is larger than the home ranges defined for Mediterranean ecosystems in previous studies (Revilla and Palomares, 2002; Rosalino et al., 2004), because resources are scarcer and more dispersed in semi-arid environments. Thus, according to the resource dispersion hypothesis (RDH: Kruuk, 1989), badgers will move longer distances, cover larger daily ranges and defend larger territories.

2.4. Statistical analyses

All variables were standardised to an average of zero and a standard deviation of one to increase the comparability of the effects of variables, and latrines per kilometre (latrine/km) were log-transformed to attain normality of data.

We used generalised linear models (GLMs) to determine habitat selection patterns of European badgers. Prior to building the models, a Pearson correlation analysis was carried out for the total set of environmental variables and loglatrine/km to avoid multicolinearity

Table 1
Description of the environmental variables used in this study. All variables were measured as the percent of cover.

Variable	Description
(a) *Field survey data*	
Trees (TRE1)	Holm oak (*Quercus ilex*), and pines (*Pinus pinaster*, *P. pinea*, *P. halepensis*)
Small shrubs (SRU1)	Shrubs less than 50 cm high
Tall shrubs (TRU1)	Shrubs more than 50 cm high and *Stipa tenacissima* L.
Rock blocks (ROC1)	Rocks more than 1 m high and slopes
Pastures (PAS1)	Herbaceous vegetation suitable for the grazing of livestock and wild animals
Olive plantations (OIL1)	Olive tree (*Olea europaea*)
Fruit tree orchards (FRU1)	Fruit trees except olive plantations
Cultivated fields (CUL1)	Irrigated and non-irrigated crops (mainly cereals)
(b) *Data from digital land use map*	
Pine forest (PIN2)	Pine forest (*P. pinaster*, *P. pinea*) and pine plantations (*P. halepensis*)
Holm oak woodland (OAK2)	Landscape with holm oak (*Q. ilex*), kermes oak (*Q. coccifera*), mastic tree (*Pistacia lentiscus*) and pastures
Riparian vegetation (RIP2)	Woody vegetation closely related with streams and rivers: willow (*Salix* spp.), white poplar (*Populus alba*) and black poplar (*P. nigra*)
Shrubs (RUB2)	*S. tenacissima* L and *Erica*, *Cistus* and *Retama* species.
Pastures (PAS2)	Grass or herbaceous vegetation
Fruit tree orchards (FRU2)	Orchards with various fruit trees, mainly orange (*Citrus sinensis*), lemon (*C. limonum*), almond (*Prunus dulcis*) and prickly pear (*Opuntia ficus indica*).
Cultivated fields (CUL2)	Irrigated and non-irrigated crops, mainly cereals
Shrubs and cultivated fields (MIX2)	Cultivated field with more than 30% of shrub
Olive plantations (OIL2)	Monospecific olive tree plantations
Human settlements (HUM2)	Cities, towns, villages, industries and greenhouse plantations

among predictors (Graham, 2003). We then built GLMs with all possible sets of variables that were uncorrelated to each other and significantly correlated to badger abundance (loglatrine/km). Therefore, the only constraint for model building was to use uncorrelated predictor variables in the same model.

The information-theoretic approach was used in model selection (Burnham and Anderson, 2002). This approach allows the "best" model to be selected and ranks the remaining models. The AIC value was calculated for each model using correction for small sample sizes (AICc), which is a measure of model fit adjusted for the number of parameters (Burnham and Anderson, 2002). Delta AICc (ΔAICc) was calculated as the difference in AICc between each model and the best model in the set. Models with AICc differences of less than two have substantial support (Burnham and Anderson, 2002). Therefore, models with ΔAICc greater than 2 were excluded from further calculations. Akaike weights (w_i) were calculated for the confidence set of models (ΔAICc<2) to determine the weight of evidence in favour of each model and to estimate the relative importance of each individual parameter in the set of candidate models (w_+). If no single model is clearly superior to the others in a set of models (model with greater w_i less than 0.9), a (weighted) model averaging approach should be used (Burnham and Anderson, 2002; Gibson et al., 2004). Hence, we used the entire set of plausible models (ΔAICc<2) to calculate model-averaged estimates for variables included in the confidence set of models and their unconditional standard errors (SE). This approach reduces model selection bias effects on regression coefficient estimates in all selected subsets (Burnham and Anderson, 2002).

In addition to the previous analysis, we tested for differences in badger abundance between the northern and southern areas using a *t*-test. We also compared if the key variables explaining badger abundance differed between areas, as an additional evidence of the importance of these habitat elements on badger distribution in semi-arid landscapes. We used MANOVA and associated protected ANOVAs to test for differences between areas.

All analyses were performed using the STATISTICA 7.0 software package.

3. Results

3.1. Variable correlation

We found that three variables were positively correlated to badger abundance (loglatrine/km): fruit orchards (FRU2) ($r = 0.29$, $p < 0.05$), rock blocks (ROC1) ($r = 0.30$ $p < 0.05$) and shrubs (RUB2) ($r = 0.27$, $p < 0.05$). Three other habitat quality variables were negatively correlated to badger abundance (loglatrine/km): cultivated fields (CUL1) ($r = -0.33$, $p < 0.01$), shrubs and cultivated fields (MIX2) ($r = -0.28$, $p < 0.05$) and human settlements (HUM2) ($r = -0.27$, $p < 0.05$). In relation to predictor multicolinearity, only fruit orchards (FRU2) and cultivated fields (CUL1) were completely independent, while the rest of predictors were correlated to at least one other predictor (Table 2).

3.2. Generalised linear model analyses

We combined the environmental variables selected by Pearson correlation analysis to designate 27 *a priori* multiple regression subset models. According to the rule that $\Delta i < 2$ suggests substantial evidence for the model (Burnham and Anderson, 2002), the first thirteen models were most likely to explain badger distribution in the study area and were therefore included in our set of confidence models (Table 3). Model 1 was the most parsimonious model; however, an Akaike weight (w_i) of 0.12 suggested substantial model selection uncertainty. The difference in w_i between the first and thirteenth ranked models was only 0.07, also indicating strong support for the thirteen models (Table 3).

The relative importance of each variable in the set of confidence models (w_+) was estimated as the sum of the Akaike weights of candidate models ($\Delta i < 2$) including that variable. cultivated fields (CUL1) was a very important variable in explaining badger distribution, followed by fruit orchards (FRU2), human settlements (HUM2), shrubs and cultivated fields (MIX2), shrubs (RUB2) and rock blocks (ROC1) (Table 4). Based on model averaging, badger abundance increased with the presence of fruit orchards (FRU2), shrubs (RUB2), rock blocks (ROC1) and decreased with the presence of cultivated fields (CUL1), shrubs and cultivated fields (MIX2) and human settlements (HUM2) (Table 4). However, only cultivated fields (CUL1), fruit orchards (FRU2) and human settlements (HUM2) had statistical support, as their 90% confidence intervals excluded the zero value (Table 4).

Table 2
Variables that showed correlation (Pearson's coefficient) with badger abundance (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$). For abbreviations see Table 1.

	ROC1	CUL1	loglatrine/km	FRU2	MIX2	RUB2
CUL1	−0.22					
loglatrine/km	0.30*	−0.33**				
FRU2	0.26	−0.12	0.29*			
MIX2	−0.36**	0.20	−0.28*	−0.22		
RUB2	0.44***	−0.19	0.27*	0.15	−0.58***	
HUM2	−0.28*	0.12	−0.27*	−0.12	0.17	−0.19

Table 3
Highest ranked generalised linear models using AICc-based model selection for *Meles meles*. The table also shows model number (Ni), maximised log-likelihood function (log(*L*)), number of estimated parameters (K); AICc differences (ΔAICc) and Akaike weights (w_i). For abbreviations see Table 1.

Ni	Model	log (*L*)	k	AICc	ΔAICc	w_i
1	CUL1 + FRU2 + HUM2	−74.37	3	157.18	0.00	0.12
2	CUL1 + FRU2	−75.79	2	157.81	0.63	0.09
3	CUL1 + FRU2 + MIX2 + HUM2	−73.51	4	157.87	0.69	0.09
4	ROC1 + CUL1 + FRU2	−74.71	3	157.88	0.70	0.09
5	CUL1 + FRU2 + RUB2	−74.71	3	157.88	0.70	0.09
6	CUL1 + FRU2 + MIX2	−74.74	3	157.93	0.75	0.08
7	CUL1 + FRU2 + RUB2+ HUM2	−73.60	4	157.96	0.78	0.08
8	CUL1 +MIX2 + HUM2	−74.93	3	158.32	1.14	0.07
9	ROC1 + CUL1	−76.11	2	158.43	1.25	0.07
10	CUL1 + HUM2	−76.16	2	158.55	1.37	0.06
11	CUL1 + RUB2 + HUM2	−75.16	3	158.77	1.59	0.06
12	CUL1 + MIX2	−76.28	2	158.78	1.60	0.06
13	CUL1 + RUB2	−76.45	2	159.12	1.94	0.05

3.3. Differences in abundance and key habitat variables between the northern and southern study areas

Badgers are more abundant in the southern area than in the northern area (mean and range): 0.44 (0–1.82) and 0.10 (0–0.90) latrines/km respectively (*t*-test: $t = 3.24$, $p = 0.002$). Furthermore, the key habitat variables detected in the previous section differed between these areas ($F_{6,50} = 15{,}78$, $p < 0.001$). Variables which were positively correlated to badger abundance were more abundant in the southern area: rock blocks (ROC1) ($F_{1,55} = 24.81$, $p < 0.001$), fruit orchards (FRU2) ($F_{1,55} = 9.26$, $p = 0.003$) and shrubs (RUB2) ($F_{1,55} = 49.20$, $p < 0.001$). In contrast, shrubs and cultivated fields (MIX2) and human settlements (HUM2), which were negatively correlated to loglatrine/km, were more abundant in the northern area ($F_{1,55} = 21.229$, $p < 0.001$ and $F_{1,55} = 10.18$, $p = 0.002$, respectively). We did not detect significant statistical differences for cultivated fields (CUL1) ($F_{1,55} = 1.43$, $p = 0.24$).

4. Discussion

The three factors which had the greatest influence on badger occurrence in the studied semi-arid environments were cultivated fields (negative), fruit orchards (positive) and human settlements (negative).

In the Netherlands, cultivated fields have been positively associated with badger distribution (Van Apeldoorn et al., 1998), but in our study they had a clear negative influence on badger abundance, which is consistent with findings in other Mediterranean ecosystems (Remonti et al., 2006; Santos and Beier, 2008). Cultivated fields in the semi-arid environments of the Iberian Peninsula are intensive and dominate the landscape. This human use has reduced available vegetation patches and has fragmented the landscape, reducing suitable habitat for badgers and increasing population isolation, as outlined by Virgós (2001, 2002) in a series of studies in central Spain. Moreover, intensive crop cultivation has been reported to affect animal prey availability for badgers, forcing badgers to a highly imbalanced diet (Remonti et al., 2011). Hence, the lack of shelter and food, may reduce the quality of these areas and deter their use by badgers. Finally, badgers have been perceived as agricultural pests, and they may have experienced human persecution, especially in agricultural areas (Virgós., Unpublished results). Therefore, the negative influence of agricultural fields may be explained, at least partly, by intentional disturbance.

As predicted, the percentage of landscape covered by fruit orchards (FRU2) partially explained badger distribution and abundance in the studied semi-arid ecosystems. These results are supported by the absence of this habitat in the northern area, where badger occurrence is much lower. To our knowledge, this is the first time that cultivated fruit trees have been reported as a key factor for badger habitat selection, perhaps because fruit plantations were absent in many of the previously studied areas. Our results are consistent with Mediterranean diet studies that reported a high frequency of fruits in badger diets (reviewed in Rosalino and Santos-Reis, 2009). Climatic conditions in semi-arid regions of the Iberian Peninsula limit earthworms, the prevailing food source of badgers (Kruuk, 1989; Neal and Cheeseman, 1996; Virgós et al., 2004) and fresh fruit availability (Herrera, 1989). Therefore, the only abundant natural food for badgers in most of these areas seems to be arthropods (Rodriguez and Delibes, 1992). In our study area, fruits orchards were found to be a crucial food-providing habitat for badgers, as they increase the natural trophic resource supply and produce an increase in habitat quality. Furthermore, traditional agricultural practices (e.g., lower use of pesticides and agricultural machinery) could provide additional benefits for badgers, such as higher arthropod diversity and abundance (Bengtsson et al., 2005), or the appearance of small banks and slopes covered by vegetation, which are suitable sites to dig burrows. The cultivation of fruit trees in the semi-arid environments of the Iberian Peninsula depends on artificial irrigation, which has expanded rapidly in the last few decades. Although this has had negative consequences for some species inhabiting these areas (Oñate and Peco, 2005; Abellan et al., 2006), other studies have shown that, irrigated areas can provide habitats for some species under certain management conditions (Bielsa et al., 2005; Abellan et al., 2006). This is the case in our study area, where badgers benefit from low intensity cultivated fruit tree orchards. These findings support the idea that some human activities can positively contribute to biodiversity, especially in the Mediterranean area (Perevolotsky and Seligman, 1998; Fonderflick et al., 2010). The importance of some types of agricultural practices for badger occurrence has also been outlined in other studies (Kruuk, 1989; Virgós and Casanovas, 1999a; Rosalino et al., 2004).

However, badger abundance was negatively affected by human presence (HUM2). We found that badgers avoided areas around villages, industries or habitats with human settlements. These findings are consistent with evidence from other countries where urban and infrastructure expansion contributed to the decline of badger populations (Lankester et al., 1991; Skinner et al., 1991). Although no studies have been carried out on the impact of urban expansion on badger populations in our study area, the increase in urban sprawl and associated infrastructures in the last few decades in Spain (OSE, 2006) is believed to have increased habitat loss, population fragmentation and traffic causalities, primarily affecting low density badger populations (Virgós and Casanovas, 1999a; Revilla et al., 2000). Further research is needed to determine the impact of human activities on the ecology and abundance of badgers in semi-arid Mediterranean areas.

Table 4
Relative importance (w_+) and model-averaged estimates for variables of linear generalised models. Statistics include the model-averaged parameter estimates (Estimate), the unconditional standard errors (SE), and confidence intervals (CI) of the candidate set models. For abbreviations see Table 1.

Variable	w_+	Estimate	SE	Upper 90%	Lower 90%
intercept		−1.587	0.119	−1.391	−1.783
CUL1	1.00	−0.282	0.121	−0.084	−0.481
FRU2	0.64	0.237	0.118	0.431	0.043
HUM2	0.48	−0.201	0.120	−0.004	−0.398
MIX2	0.30	−0.187	0.127	0.021	−0.395
RUB2	0.27	0.178	0.122	0.379	−0.023
ROC1	0.15	−0.201	0.120	0.087	−0.023

In agreement with our predictions, shrubs cover (RUB2) and rock blocks cover (ROC1) had a positive effect on badger abundance, although neither of these effects was strong, as their 90% confidence intervals included the zero value. These factors have previously been identified as key factors for badger abundance because of their role in proving shelter and good thermic isolation, two important factors in badger site selection (Virgós and Casanovas, 1999a for rock blocks; Revilla et al., 2000; Remonti et al., 2006; Mangas et al., 2008 for shrubs).

Agricultural field-shrub mosaic (MIX2) had a negative effect on badger abundance, though its effect was not strong, as its 90% confidence intervals included the zero value. The negative association of these mosaics with badgers is somewhat surprising because badgers mainly inhabit mosaic habitats (e.g., Kruuk, 1989; Feore and Montgomery, 1999; Virgós and Casanovas, 1999a; Rosalino et al., 2004). Our results could be due to the very small size and dispersed distribution of shrub-patches in the landscape, which may not provide the minimum critical size and connectivity to be used by badgers (Virgós, 2002). Further research is needed to clarify the effects of agricultural field-shrub mosaics on badgers.

Our results suggest that badger conservation in semi-arid environments of the Iberian Peninsula requires the existence of low intensity cultivated fruit orchards and the limitation of human development. Policies that restrain agricultural intensification encourage traditional or new non-intensive agricultural practices and increase shrub-patch availability, which would apparently benefit this species. Therefore, the reform of the CAP that decoupled payments from production in 2005 may be negative for badger conservation because of facility specialisation and land use intensification (Oñate et al., 2007; Stoate et al., 2009). Furthermore, badgers inhabiting semi-arid regions of the Iberian Peninsula could be negatively affected by the consequences of global warming. Water shortages and climatic variability is likely to result in lower productivity and reduced water availability for irrigation (Maracchi et al., 2005). This could reduce the creation of low intensity fruit orchards, which require some water input to be productive. In this scenario, habitat quality for badgers and thus badger abundance would be significantly reduced, affecting their conservation status in this region.

Acknowledgements

We would like to thank E. F. Boluda, Y. Arnaud, M. Barea-Azcón, E. Ballesteros and R. Barrientos for providing field assistance; Manuel Lara Romero and Lori J De hond for their help with English editing of the manuscript. Three anonymous referees provided valuable comments on the manuscript. This work was part of Project CGL-2005-07681 (Spanish Ministry of Science and Innovation). C. Lara-Romero was supported by a FPI grant (Spanish Ministry of Science and Innovation) and G. Escribano-Ávila was supported by a FPU grant (Spanish Ministry of Education).

References

Abellan, P., Sanchez-Fernandez, D., Millan, A., Botella, F., Sanchez-Zapata, J.A., Gimenez, A., 2006. Irrigation pools as macroinvertebrate habitat in a semi-arid agricultural landscape (SE Spain). Journal of Arid Environments 67, 255–269.

Balestrieri, A., Remonti, L., Prigioni, C., 2009. Habitat selection in a low-density badger *Meles meles* population: a comparison of radio-tracking and latrine surveys. Wildlife Biology 15, 442–448.

Barea-Azcón, J.M., Ballesteros-Duperon, E., Gil-Sanchez, J.M., Virgós, E., 2010. Badger Meles meles feeding ecology in dry Mediterranean environments of the southwest edge of its distribution range. Acta Theriologica 55, 45–52.

Bengtsson, J.N., Ahnstrom, J., Weibull, A.C., 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. Journal of Applied Ecology 42, 261–269.

Berger, G., Kaechele, H., Pfeffer, H., 2006. The greening of the European common agricultural policy by linking the European-wide obligation of set-aside with voluntary agri-environmental measures on a regional scale. Environmental Science & Policy 9, 509–524.

Bielsa, I., Pons, X., Bunce, B., 2005. Agricultural abandonment in the North Eastern Iberian Peninsula: the use of basic landscape metrics to support planning. Journal of Environmental Planning and Management 48, 85–102.

Blondel, J., Aronson, J., 1999. Biology and Wildlife of the Mediterranean Region. Oxford University Press, Oxford.

Burnham, K.P., Anderson, D.R., 2002. Model selection and multimodel inference. A practical information-theoretic approach. Springer-Verlag, New York.

Caughley, G., Sinclair, A.R.E., 1994. Wildlife Ecology and Management. Blackwell Scientific Publications, Boston.

Cody, M.L., 1985. Habitat selection in birds. Academic Press, Orlando.

Del Cerro, I., Marmi, J., Ferrando, A., Chashchin, P., Taberlet, P., 2010. Nuclear and mitochondrial phylogenies provide evidence for four species of Eurasian badgers (Carnivora). Zoologica Scripta 39, 415–425.

Feore, S., Montgomery, W.I., 1999. Habitat effects on the spatial ecology of the European badger (*Meles meles*). Journal of Zoology 247, 537–549.

Fonderflick, J., Lepart, J., Caplat, P., Debussche, M., Marty, P., 2010. Managing agricultural change for biodiversity conservation in a Mediterranean upland. Biological Conservation 143, 737–746.

Gibson, L.A., Wilson, B.A., Cahill, D.M., Hill, J., 2004. Spatial prediction of rufous bristlebird habitat in a coastal heathland: a GIS-based approach. Journal of Applied Ecology 41, 213–223.

Graham, M.H., 2003. Confronting multicollinearity in ecological multiple regression. Ecology 84, 2809–2815.

Guisan, A., Zimmermann, N.E., 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135, 147–186.

Herrera, C.M., 1989. Frugivory and seed dispersal by carnivorous mammals, and associated fruit characteristics, in undisturbed mediterranean habitats. Oikos 55, 250–262.

Johnson, D.H., 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61, 65–71.

Kruuk, H., 1989. The Social Badger: Ecology and Behaviour of a Group-Living Carnivore (*Meles meles*). Oxford University Press, Oxford.

Lankester, K., Van Apeldoorn, R., Meelis, E., Verboom, J., 1991. Management perspectives for populations of the Eurasian badger (*Meles meles*) in a fragmented landscape. Journal of Applied Ecology 28, 561–573.

Mangas, J.G., Lozano, J., Cabezas-Diaz, S., Virgós, E., 2008. The priority value of scrubland habitats for carnivore conservation in Mediterranean ecosystems. Biodiversity and Conservation 17, 43–51.

Maracchi, G., Sirotenko, O., Bindi, M., 2005. Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. Climatic Change 70, 117–135.

Neal, E., Cheeseman, C., 1996. Badgers. T & AD Poyser, London.

Oñate, J.J., Atance, I., Bardaji, I., Llusia, D., 2007. Modelling the effects of alternative CAP policies for the Spanish high-nature value cereal-steppe farming systems. Agricultural Systems 94, 247–260.

Oñate, J.J., Peco, B., 2005. Policy impact on desertification: stakeholders' perceptions in southeast Spain. Land Use Policy 22, 103–114.

OSE (Observatorio de la Sostenibilidad en España), 2006. Cambios de ocupación del suelo en españa: implicaciones para la sostenibilidad Mundi Prensa Libros Madrid.

Parmesan, C., Yohe, G., 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421, 37–42.

Perevolotsky, A., Seligman, N.G., 1998. Role of grazing in Mediterranean rangeland ecosystems - Inversion of a paradigm. Bioscience 48, 1007–1017.

Petit, S., Firbank, R., Wyatt, B., Howard, D., 2001. MIRABEL: models for integrated review and assessment of biodiversity in European landscapes. Ambio 30, 81–88.

Pigozzi, G., 1990. Latrine use and the function of territoriality in the European badger, *Meles meles*, in a Mediterranean coastal habitat. Animal Behaviour 39, 1000–1002.

Reidsma, P., Tekelenburg, T., Van den Berg, M., Alkemade, R., 2006. Impacts of land-use change on biodiversity: an assessment of agricultural biodiversity in the European Union. Agriculture Ecosystems & Environment 114, 86–102.

Remonti, L., Balestrieri, A., Prigioni, C., 2006. Factors determining badger *Meles meles* sett location in agricultural ecosystems of NW Italy. Folia Zoologica 55, 19–27.

Remonti, L., Balestrieri, A., Prigioni, C., 2011. Percentage of protein, lipids, and carbohydrates in the diet fo badger (*Meles meles*) populations across Europe. Ecological Research 26, 487–495.

Revilla, E., Delibes, M., Travaini, A., Palomares, F., 1999. Physical and population parameters of Eurasian badgers (*Meles meles*) from Mediterranean Spain. Zeitschrift Fur Saugetierkunde- Mammalian Biology 64, 269–276.

Revilla, E., Palomares, F., 2002. Spatial organization, group living and ecological correlates in low-density populations of Eurasian badgers, *Meles meles*. Journal of Animal Ecology 71, 497–512.

Revilla, E., Palomares, F., Delibes, M., 2000. Defining key habitats for low density populations of Eurasian badgers in Mediterranean environments. Biological Conservation 95, 269–277.

Rodriguez, A., Delibes, M., 1992. Food habits of badgers (*Meles meles*) in an arid habitat. Journal of Zoology 227, 347–350.

Rosalino, L.M., Macdonald, D.W., Santos-Reis, M., 2004. Spatial structure and land-cover use in a low-density Mediterranean population of Eurasian badgers. Canadian Journal of Zoology-Revue Canadienne De Zoologie 82, 1493–1502.

Rosalino, L.M., Santos-Reis, M., 2009. Fruit consumption by carnivores in Mediterranean Europe. Mammal Review 39, 67–78.

Santos, M.J., Beier, P., 2008. Habitat selection by European badgers at multiple spatial scales in Portuguese Mediterranean ecosystems. Wildlife Research 35, 835–843.

Skinner, C., Skinner, P., Harris, S., 1991. The past history and recent decline of badgers Meles meles in essex, an analysis of some of the contributory factors. Mammal Review 21, 67–80.

Stoate, C., Baldi, A., Beja, P., Boatman, N.D., Herzon, I., Van Doorn, A., de Snoo, G.R., Rakosy, L., Ramwell, C., 2009. Ecological impacts of early 21st century agricultural change in Europe - A review. Journal of Environmental Management 91, 22–46.

Tuyttens, F.A.M., Long, B., Fawcett, T., Skinner, A., Brown, J.A., Cheeseman, C.L., Roddam, A.W., MacDonald, D.W., 2001. Estimating group size and population density of Eurasian badgers *Meles meles* by quantifying latrine use. Journal of Applied Ecology 38, 1114–1121.

Van Apeldoorn, R.C., Knaapen, J.P., Schippers, P., Verboom, J., Van Engen, H., Meeuwsen, H., 1998. Applying ecological knowledge in landscape planning: a simulation model as a tool to evaluate scenarios for the badger in the Netherlands. Landscape and Urban Planning 41, 57–69.

Virgós, E., 2001. Role of isolation and habitat quality in shaping species abundance: a test with badgers (*Meles meles* L.) in a gradient of forest fragmentation. Journal of Biogeography 28, 381–389.

Virgós, E., 2002. Are habitat generalists affected by forest fragmentation? A test with Eurasian badgers (*Meles meles*) in coarse-grained fragmented landscapes of central Spain. Journal of Zoology 258, 313–318.

Virgós, E., Casanovas, J.G., 1999a. Badger Meles meles sett site selection in low density Mediterranean areas of central Spain. Acta Theriologica 44, 173–182.

Virgós, E., Casanovas, J.G., 1999b. Environmental constraints at the edge of a species distribution, the Eurasian badger (*Meles meles*): a biogeographic approach. Journal of Biogeography 26, 559–564.

Virgós, E., Mangas, J.G., Blanco-Aguiar, J.A., Garrote, G., Almagro, N., Viso, R.P., 2004. Food habits of European badgers (*Meles meles*) along an altitudinal gradient of Mediterranean environments: a field test of the earthworm specialization hypothesis. Canadian Journal of Zoology-Revue Canadienne de Zoologie 82, 41–51.