Published by Associazione Teriologica Italiana
Hystrix, the Italian Journal of Mammalogy
Volume 28 (2): 247–252, 2017
Available online at:
http://www.italian-journal-of-mammalogy.it
doi:10.4404/hystrix-00005-2017

Research Article

# Habitat selection of European badger *Meles meles* in a highly fragmented forest landscape in northern Italy: the importance of hedgerows and agro-forestry systems

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*Keywords:*
poplar plantations
short rotation forestry
reforestations
habitat suitability
forest fragmentation
agro-ecosystems

*Article history:*
Received: 28 June 2016
Accepted: 4 July 2017

*Acknowledgements*
The authors thank Zeno Porro, Arianna Musacchio, Kati Sara Bovo, Arianna Bazzocchi, Chiara Gabba, Valerio Orioli, Valeria Cardinale, Giorgio Desperati, Pamela D'Occhio, Lorenza Colli, and Marco Lombardini for the help in the fieldwork.

**Abstract**

The European badger is a common and widespread species considered as a least-concern species by the IUCN. However, there are still many threats for its conservation, especially in areas where the original landscape has been highly modified by humans. The aim of this study was to define the habitat selection criteria of the European badger in a highly modified lowland area in northern Italy, with particular attention to the role that hedgerows and agro-forestry systems could have for this species. The study area is a typical lowland cultivated landscape, where small forest remnants are scattered within an agricultural matrix mainly characterized by intensive cereal crops and areas devoted to agro-forestry. Data collection followed a stratified random sampling design and consisted of detecting the presence of the species within 62 2-km cells. Presence signs were spotted along linear transect from April to September 2014. We investigated the association between species presence/abundance and the environmental variables measured within each cell by means of resource selection probability functions using GLMs. In our study area the European badger significantly depended on broadleaved forests, but the species also selected traditional poplar plantations, short rotation forestry, reforestations, and hedgerows. Conversely, the species avoided meadows with shrubs and trees and areas with scarce or absent vegetation. In conclusion, the European badger seemed to benefit from agricultural landscape elements, such as agro-forestry systems and hedgerows, which probably serve as forest surrogates for this species, both in providing food resources and suitable sett locations.

## Introduction

The European badger (*Meles meles* L.) is a common and widespread meso-carnivore, distributed in Europe and western Asia from Spain to Afghanistan. During the last century the size of European badger populations heavily fluctuated in large part of Europe (Griffiths and Thomas, 1993) and for this reason, in the 1970s and 1980s several European countries, including Italy, adopted protective measures for its conservation (Griffiths, 1991). Subsequently, the species was classified again as "Least Concern" by the IUCN, both in Italy (Rondinini et al., 2013) and in the rest of the countries (Kranz et al., 2008). However, there are still many active factors threatening the European badger throughout Europe. Among the main causes of mortality are road killing (Neal, 1986; Davies et al., 1987; Aaris-Sørensen, 1995; Rogers et al., 1997; van Langevelde et al., 2009), pathogens (e.g. rabies) (Smith, 2002), climate changes (Virgós et al., 2005; Nouvellet et al., 2013), which may interact with other anthropogenic processes to negatively influence population processes (MacDonald et al., 2010), and human-induced land-use changes. In particular, the European badger has been recognized as a species that strongly suffers from the loss of its original habitat due to conversion into intensive cultivated crops (van der Zee et al., 1992). Therefore, as highlighted by Piza Roca et al. (2014), it is crucial to investigate the habitat requirements of the European badger, particularly in highly modified landscapes, in order to evaluate how land-use changes affect the distribution of the species, and to identify new effective management measures for its conservation. Despite the European badger is a generalist species, several studies carried out in different European countries highlighted its strong dependence on forests (Skinner et al., 1991; Matyášťík and Bičík, 1999; Bičík et al., 2000; Virgós and Casanovas, 1999; Bartmańska and Nadolska M.l, 2003; Schley et al., 2004; Jepsen et al., 2005; Huck et al., 2008a; Holmala and Kauhala, 2009), and, particularly, on deciduous woodlands (da Silva et al., 1993). Other habitat sometimes used by the species are shrublands (Skinner et al., 1991; Schley et al., 2004; Huck et al., 2008a) and pastures (van Apeldoorn et al., 2006), that contain a higher biomass of earthworms (Kruuk, 1978; Hofer, 1988), which represent one of badgers' main food resource. In particular, some authors highlighted the preference of badgers for sett sites at or near the interface of woods or shrubs with pastures (Feore and Montgomery, 1999; van Apeldoorn et al., 2006). Far less used by the species are cultivated areas (Matyášťík and Bičík, 1999; Schley et al., 2004), where both the construction of setts and food researching are hindered. In agricultural contexts, the species prefer small landscape elements like hedgerows, orchards, particularly in semi-arid environments (Lara-Romero et al., 2012), and small patches of woodland, since they offer coverage and suitable badger sett location (Neal, 1972; Thornton, 1988; Skinner et al., 1991). In Italy, the species seems to select different habitats depending on the geographical and environmental context. In the Alps, a study reported that badgers used mainly open habitats, particularly meadows, avoiding villages and woodlands (Prigioni et al., 2008). Conversely, in the Prealps (Marassi and Biancardi, 2002) and Apennines (Biancardi et al., 2014), the species shows a strong selection for deciduous woods with a high tree coverage, while the presence of urban or industrial infrastructures resulted a factor of disturbance. This tendency is more evident in lowland areas of northern Italy, where Badger populations living in agricultural landscapes completely depend on habitats offering sufficient cover for their

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breeding sett location, i.e. woodland and shrubland patches, avoiding arable and urban areas (Remonti et al., 2006a; Balestrieri et al., 2009a). In highly modified landscapes, several researches have been published about the ecology of the European badger, but the majority of them was carried out in Britain (Kruuk and Parish, 1981; Butler and Roper, 1996; Blackwell and Macdonald , 2000; Hutchings et al., 2002; Carpenter et al., 2004; Davison et al., 2008) where the overall species ecology appears rather different compared to most European continental contexts. In Britain, indeed, the European badger shows a very high density (Remonti et al., 2006b; Byrne et al., 2014), ranging from 4.4–7.5 (Bristol, Harris and Cresswell, 1987; Cheeseman et al., 1988), to 16.9–35.3 adults $km^{-2}$ (Brighton, Huck et al., 2008b). Moreover, the typical British agro-ecosystems are composed of forest remnants and open areas (mainly pasturelands) which form mosaics that are not only not detrimental, but may even be favourable to the species (Kruuk, 1989; Seiler et al., 1995; Moore et al., 1999). Conversely, in fragmented landscapes of the rest of Europe, both in Mediterranean and continental countries, the agricultural matrix is mainly characterized by intensive crops and the species tends to live at lower densities (Byrne et al., 2014), ranging from 0.09–0.13 in Poland (Kowalczyk et al., 2003, 2006) to 1.5 adults $km^{-2}$ in Denmark (Elmeros et al., 2005). Several studies carried out in Spain clearly highlighted that forest loss and fragmentation have a strong negative effect on the species, and that its ecological requirements change according to the fragmentation degree (Virgós, 2001, 2002a,b). These studies were carried out in Mediterranean areas characterized by divided landscapes, where small and isolate woodland patches are embedded in arable fields, hedgerows and pastures were absent, and only continuous forests can provide suitable conditions for the meso-carnivore (Virgós, 2001, 2002a,b). To provide a more complete overview of the European badger ecological requirements in highly fragmented landscapes, it could be interesting to investigate the habitat selection of the species within continental Europe, where forest remnants are surrounded by an agricultural matrix devoted to intensive cereal crops, but hedgerows and other landscape elements providing tree-cover, such as agro-forestry systems, exist.

The main aim of this research was to explore the habitat requirements of the European badger in a highly fragmented lowland area in northern Italy, investigating both the presence and the abundance of the badger by resource selection functions. We paid particular attention to the species use of hedgerows and agro-forestry systems (i.e. traditional poplar plantations, short rotation forestry and reforestations), because these habitats are typical of the agro-ecosystems of northern Italy. Understanding if these systems can be used by the European badger as forest surrogates could have important implications for the conservation of the species in highly fragmented landscapes.

## Materials and methods

### Study area

The present study was carried out in an area of about 2900 $km^2$ located in the western floodplain of Lombardy, (45°11′ N, 9°5′ E, northern Italy) (Fig. 1a). The Ticino River flows through the study area from North to South and enters the Po River, which flows from West to East, while the Sesia River and the Lambro River flow along the western and the eastern boundaries of the study area, respectively. The climate is continental and temperate, with rainfalls (700 mm/year on average) concentrated in spring and autumn. During the winter, persistent fog is fairly common. The landscape characterizing the study area has been deeply modified during the last centuries due to the development of urbanization and road infrastructures, and the spread of intensive agriculture practices. Currently, the territory is dominated by cultivated areas, especially paddies (39.4%) and other annual crops (mainly wheat, maize, and alfalfa) (29.1%). The remaining surfaces are covered by urban areas (10.3%), rivers and water bodies (2.0%), agro-forestry systems (6.8%), and broadleaved forests, which represents only 4.9% of the total area; other categories (i.e. orchards, vineyards, meadows, and shrublands) represented the 7.5% of the surface (Fig. 1b). Continuous forests are mostly located along the main rivers and in the southern part of the study area, where the Apennine mountain chain begins, while residual broadleaved forest fragments (95% of which are smaller than 10 hectares) are scattered in the intensively cultivated matrix. In our study area, forests are mainly composed of pedunculate oak (*Quercus robur*), common hornbeam (*Carpinus betulus*), field maple (*Acer campestre*), field elm (*Ulmus minor*), and common ash (*Fraxinus excelsior*), while close to the rivers and streams they mainly include trees like the common alder (*Alnus glutinosa*), poplars (*Populus alba*, *P. nigra* and *P. canadensis* cultivar), and willows (*Salix* sp.).

### Survey Design

In order to obtain an overall representative sample of the European badger's presence within the study area and to account for its overall heterogeneity, the sampling units were selected according to a stratified cluster sampling design (Krebs, 1999; Barabesi and Fattorini, 20013). In particular, using ArcGIS v10.2.1. (ESRI, Redlands, CA) we superimposed a 2 km squared grid on the study area, and measured the following environmental variables within each cell of the grid: percentage of broadleaved forest cover, distance from two source areas (continuous forests along the Ticino River and of the Apennines), density of hedgerows, density of main roads, and degree of forest fragmentation calculated by a *Modified Proximity Index* (McGarigal and Marks, 1994; Bani et al., 2006). We chose a 2 km grid in order to obtain a cell size comparable to the European badger home range in northern Italy (3.83 $km^2$; Remonti et al., 2006b). We calculated the environmental variables starting from the most recent regional land use map DUSAF 4.0 (ERSAF, 2014). Subsequently, we performed a k-means cluster analysis, defining the number of *k* on the basis of a dendrogram obtained with a preliminary hierarchical cluster analyses on the same data (Lance and Williams, 1967; Punj and Stewart, 1983), and a one-way ANOVA, in order to identify homogeneous landscape units (LUs) with respect to the five environmental variables (Legendre and Legendre, 1998). We randomly selected 62 cells of the 2-km grid (10% of the study area), proportionally allocated in relation to each LU extension (Krebs, 1999) (Fig. 1c). In order to assess the European badger presence within the se-

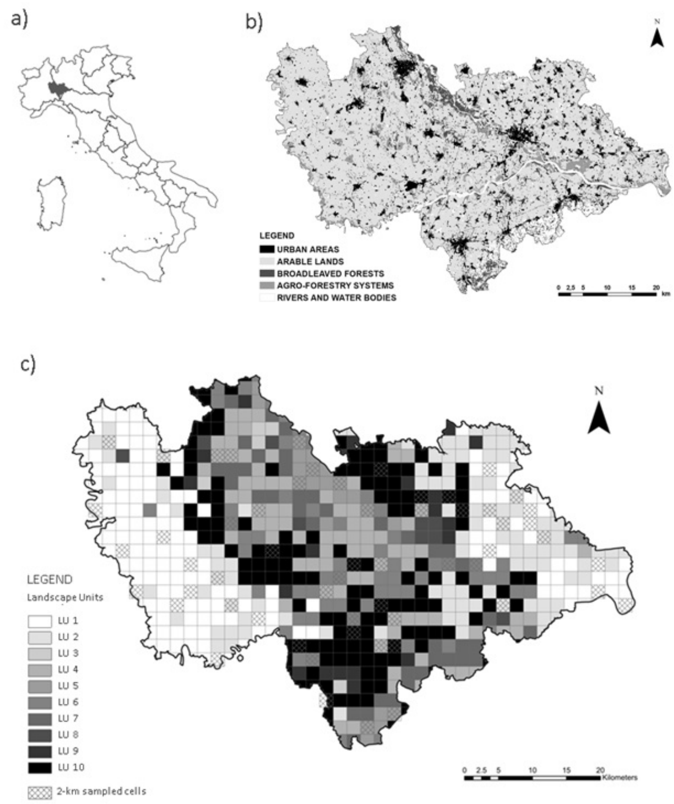


**Figure 1** – a) Study area location in northern Italy, b) broadleaved forest and agro-forestry cover within the study area, c) the ten landscape units (LUs) characterizing the study area and the 62 2-km sampled cells..

**Table 1** – Mean and range (min-max) of the 16 environmental variables measured in the 62 2-km sampled cells used for the study of habitat selection of the European badger in northern Italy.

| Environmental variables | Mean | Range (min–max) |
|---|---|---|
| Urban areas (% cover) | 7.14 | 0.07–35.00 |
| Croplands (% cover) | 60.62 | 10.97–94.02 |
| Orchards (% cover) | 0.09 | 0.00–2.82 |
| Traditional poplar plantations (% cover) | 10.82 | 0.00–62.25 |
| Short rotation forestry (SRFs) / reforestations (% cover) | 1.41 | 0–19.17 |
| Broadleaved forests (% cover) | 8.84 | 0–57.92 |
| Meadows (% cover) | 3.02 | 0.00–15.04 |
| Meadows with shrubs and trees (% cover) | 0.16 | 0.00–2.51 |
| Scrublands (% cover) | 0.84 | 0–8.37 |
| Transitional woodland/shrub areas (% cover) | 1.78 | 0–14.70 |
| Areas with scarce or absent vegetation (% cover) | 0.69 | 0.00–10.00 |
| Marshes and ponds (% cover) | 0.29 | 0–6.20 |
| River and streams (% cover) | 2.64 | 0–17.31 |
| Main roads density (%) | 1.40 | 0.26–2.59 |
| Hedgerows density (m/km$^2$) | 1188.00 | 123.00–2788.00 |
| Shannon-Wiener Index | 0.27 | 0.00–0.75 |

lected cells we used a multi-level sampling design (Sutherland, 2006), superimposing a 250 m grid and randomly selecting 6 cells (10% of the 2 km cell). Finally, within each 250 m cell, we identified two linear transects approximately 250 m long, which were placed opportunistically along footpaths considering land use covers and the presence of natural vegetation (e.g. forests, hedgerows, ditches). Overall, between April and September 2014, we collected European badger data along 675 linear transects (Krebs, 1999) by spotting signs of presence (i.e. latrines, setts, and footprints) (Sadlier et al., 2004).

## Data analysis

### Presence model

We evaluated the habitat requirements of the European badger with a resource selection probability function following a presence vs absence approach (Boyce et al., 2002; Manly et al., 2002)by means of a Generalized Linear Model (GLM) with a binomial error distribution (Keating and Cherry, 2004; Rushton et al., 2004). Thus, the independent variable was binary, with 1 assigned to the 2 km presence cells and 0 assigned to the 2 km absence cells. Further, within each 2 km cell we measured 16 environmental variables (Tab. 1), the values of which were standardized by means of an autoscaling procedure before modelling. The variables kept in the model were chosen following an Information-Theoretic Approach (Anderson et al., 2000, 2001; Burnham and Anderson, 2002) using the Akaike Information Criterion (AIC) (Akaike, 1973; Anderson and Burnham, 2002). We considered only the best model, i.e. the model with the lowest AIC. We evaluated the goodness of fit of the model by the Nagelkerke $R^2$. Subsequently, we tested the model ability to distinguish between occupied and unoccupied sites by means of the area under the curve (AUC) of the Receiver Operating Characteristic plot (ROC curve) (Pearce and Ferrier, 2000; Fawcett, 2006). We classified the accuracy of the diagnostic test by the traditional academic point system (Swets, 1988): 0.90–1.00=excellent; 0.80–0.90=good; 0.70–0.80=sufficient; 0.60–0.70=poor; 0.50–0.60=fail.

We excluded the presence of spatial autocorrelation of the dependent variable using Moran's I test with 999 permutations (Cliff and Ord , 1981) by means of the `spdep` package in R (Bivand et al., 20015). Moreover, we calculated the Variance Inflation Factor (VIF) with a threshold of 3 to test the collinearity of variables (Fox and Monette, 1992; Guisan et al., 2002; Zuuret al., 2010). Finally, we performed the Kolmogorov-Smirnov test to check for residual normality (Legendre and Legendre, 1998) and the Durbin-Watson to test for their autocorrelation (Savin and White, 1997; Crawley, 1993).

**Table 2** – Best presence model for habitat selection by the European badger in northern Italy.

| Environmental variables | Estimate | SE[a] | z value[b] | $p(>\|z\|)$[c] |
|---|---|---|---|---|
| (Intercept) | 0.996 | 0.387 | 2.573 | 0.01 |
| Broadleaved forests | 1.112 | 0.546 | 2.035 | 0.042 |
| Traditional poplar plantations | 1.742 | 0.668 | 2.607 | 0.009 |
| Meadows with shrubs and trees | −0.732 | 0.372 | −1.969 | 0.049 |
| Areas with scarce or absent vegetation | −1.149 | 0.51 | −2.253 | 0.024 |
| Hedgerow density | 0.603 | 0.367 | 1.642 | 0.101 |

[a] SE: standard error of estimates;
[b] z value: Wald statistic for testing the hypothesis that the corresponding estimate is equal to zero (null hypothesis);
[c] $p(>|z|)$: probability that the null hypothesis is true.

### Abundance model

We investigated how the 16 environmental variables affect the European badger's abundance in our study area by formulating a GLM with a Poisson error distribution. We used as an index of the relative abundance of the European badger its occupancy (Hanski and Gilpin, 1997; He and Gaston, 2000a,b; Holt et al., 2002; Royle and Nichols, 2003; MacKenzie and Nichols, 2004), that is the number of 250 m cells occupied by the species within each 2 km cell. Similarly to the presence model, all variables were standardized and subsequently selected following an Information-Theoretic Approach by means of the AIC. We evaluated the goodness of fit of the model from the explained deviance.

For the abundance model we performed all the diagnostic tests described for the presence model and we also checked for over-dispersion (Cameron and Trivedi, 1990) using the `AER` package in R (Kleiber and Zeileis, 2015).

All the analysis were performed using the statistical software R v.3.0.3 (www.cran.r-project.org).

## Results

### Landscape Units classification

The k-means cluster analysis identified 10 homogeneous LUs within the study area. The one-way ANOVA showed that the values of the environmental variables taken into account to perform the clusters were significantly different between the 10 LUs. The LUs were defined as follows: *LU1*, arable lands far from source areas (198 cells, 28.1%); *LU2*, arable lands with a high hedgerows density (111 cells, 15.7%); *LU3*, urban areas (5 cells, 0.7%); *LU4*, zones near source areas with moderate forest fragmentation (81 cells, 11.5%); *LU5*, source areas (22 cells, 8.5%); *LU6*, zones far from source areas with moderate forest fragmentation (60 cells, 8.5%); *LU7*, zones with high forest fragmentation (40 cells, 5.7%); *LU8*, zone mainly occupied by infrastructural networks (9 cells, 1.3%); *LU9*, suburban areas (22 cells, 3.1%); *LU10*, arable lands near source areas (157 cells, 22.3%).

### Presence model

Throughout the study area, 38 2 km cells were found to be occupied by the European badger. The best presence model selected with the Information-Theoretic Approach had a Nagelkerke $R^2$ of 0.368. The model highlighted the positive effect of the broadleaved forest and traditional poplar plantation covers and of the hedgerows density on the European badger's occurrence probability. Conversely, the meadows with shrubs and trees and the areas with scarce or absent vegetation negatively affected the presence of the species (Tab. 2). The ROC plot showed a good discriminatory ability of the model (AUC=0.804,

**Table 3** – Best abundance model for habitat selection by the European badger in northern Italy.

| Environmental variables | Estimate | SE[a] | z value[b] | $p(>\|z\|)$[c] |
|---|---|---|---|---|
| (Intercept) | 0.010 | 0.141 | 0.072 | 0.943 |
| Short rotation forestry /reforestations | 0.244 | 0.121 | 2.024 | 0.043 |
| Transitional woodland/shrub areas | 0.254 | 0.101 | 2.516 | 0.012 |
| Traditional poplar plantations | 0.501 | 0.145 | 3.453 | 0.001 |
| Meadows with shrubs and trees | −0.316 | 0.18 | −1.752 | 0.08 |
| Areas with scarce or absent vegetation | −0.383 | 0.191 | −2.008 | 0.045 |
| Hedgerow density | 0.363 | 0.147 | 2.471 | 0.013 |

[a] SE: standard error of estimates;
[b] z value: Wald statistic for testing the hypothesis that the corresponding estimate is equal to zero (null hypothesis);
[c] Pr(>|z|): probability that the null hypothesis is true.

$p<0.001$). There was no collinearity between variables (VIF<3) and the residuals were normally distributed (Kolmogorov-Smirnov test, D=0.172, $p=0.057$) and independent (Durbin-Watson test, DW=2.08, $p=0.228$).

## Abundance model

The abundance of the European badger within the 2 km cells ranged from 0 to 4 250 m cells out of the 6 randomly selected, with a mean of $1.20 \pm 0.15$ occupied 250 m cells. The best abundance model selected with the Information-Theoretic Approach explained 31% of the variance. The model highlighted a positive effect of SRFs/reforestations, transitional woodland/shrub areas, traditional poplar plantations, and hedgerows density on the abundance of the species. Conversely, the meadows with shrubs and trees and the areas with scarce or absent vegetation negatively affected abundance (Tab. 3). There was no collinearity between variables (VIF<3) and the residuals were normally distributed (Kolmogorov-Smirnov test, D=0.084, $p=0.780$) and independent (Durbin-Watson test, DW=1.79, $p=0.220$). The model results were not over-dispersed (dispersion indices=0.799, $p=0.931$).

## Discussion

The main aim of this research was to define the ecological requirements of the European badger in a highly human-modified area and to study the importance of hedgerows and agro-forestry systems as an alternative habitat to broadleaved forests for the species occurrences or abundance. As the European badger often inhabits agricultural landscapes, this information is crucial for the conservation of the species. Indeed, landscape composition and configuration in agricultural contexts constantly changes due to the change of economic interests. Knowing the ecological requirements of the European badger in these dynamic landscapes is key in order to predict how this species will respond to future landscape changes and to prevent its decline or even local extinction phenomena.

Our analysis showed a strong positive effect of broadleaved forests on the presence of the European badger in our study area. Indeed, the importance of forests, as well as of forest remnants, for the species is a general rule in Europe (Feore and Montgomery, 1999; Matyáštík and Bičík, 1999; Virgós, 2002b; Balestrieri et al., 2006; Kowalczyk et al., 2006; Do Linh San et al., 2007; Rosalino et al., 2008; Balestrieri et al., 2009a; Holmala and Kauhala, 2009). Woodlands represent the favorite habitat for this species, particularly for sett location (Piza Roca et al., 2014), since they provide shelter and a structural support for the construction of setts within the root system (Palphramand et al., 2007). Moreover, forests in our study area also include riparian woodlands, which are another important habitat for the species (Virgós and Casanovas, 1999; Molina-Vacas et al., 2009; Santos et al., 2011), most likely because of their association with sandy soils which are very suitable for den excavation (Balestrieri and Remonti, 2000; Bičík et al., 2000; Rosalino et al., 2005; Reid et al., 2011; Obidzińskiet al., 2013).

Our analysis also showed the positive effect of hedgerows density both on the presence and the abundance of the European badger. Indeed, hedgerows may offer coverage and suitable sett locations for the species, especially in agricultural areas (Piza Roca et al., 2014; Dondina et al., 2016). O'Brien et al. (2016) highlighted the importance of hedgerows in providing safe shelter in areas with a very low forest cover. The authors also suggested that the European badgers probably select hedgerows because they provide abundant and diversified food resources, such as invertebrates (Thomas and Marshall, 1989; Facey et al., 2014), berries, small mammals, and birds (Gelling et al., 2007). In addition, in our study area hedgerows are often located along sloping ditches, and, as suggested by Piza Roca et al. (2014), a suitable sett location for the species should be characterized by some degree of slope, other than by sandy soil and vegetation cover.

Moreover, comparing the results obtained by the presence and the abundance models, it is clear that traditional poplar plantations have a positive effect for the European badger both on its occurrence and abundance, whereas meadows with shrubs and trees and areas with scarce or absent vegetation have a negative effect. On the one hand, the selection of poplar plantations could be due to the scarcity of understory and to the their ground layer management (i.e. ploughing, mechanical weeding, etc.), which increase the probability of food recruitment related to the easiness of digging in short grass surfaces (Piza Roca et al., 2014). Indeed, the European badger feeds on earthworms living in the soil, which constitute an important food item in northern Italy (Balestrieri et al., 2004, 2006, 2009b) and in other localities (Kruuk, 1978; Brøseth et al., 1997; Goszczyńsk et al., 2000; Palphramand et al., 2007; Cleary et al., 2009). Thus, a large extension of poplar plantations corresponds to a higher availability of food resources, and it is probably the reason why poplar coverage determines a higher badger abundance, other than a higher presence probability of the species. On the other hand, the species seems to avoid meadows with shrubs and trees probably because these habitats are unmanaged by humans, and are thus characterized by high herbaceous layers which prove unsuitable for the digging activities of European badgers in search for food (Kruuk et al., 1979). Open areas with scarce or absent vegetation also seemed to be avoided, probably because these quite sterile habitats are rather poor in food resources.

Our analysis showed the positive effects of SRFs and reforestations, such as that of transitional woodland and scrubland, on the abundance of the species only. In our study area, these three land cover types have a similar vegetation structure, characterized by a very developed understory, because SRFs and reforestations are not managed with ploughing or mechanical weeding. This structure offers good shelter to the European badger and is an important factor for badger sett location, as highlighted by other studies (Prigioni and Deflorian, 2005; Molina-Vacas et al., 2009; Lara-Romero et al., 2012; Requena-Mullor et al., 2014). However, the fact that SRFs and reforestations positively affected only the abundance of the European badger and not its presence, may suggest that these habitats are not able to guarantee the occurrence of the species. Indeed, in our study area SRFs and reforestations have a maximum permanence of 20 years (during which SRFs are periodically cut every 3–5 years), a time that is likely not long enough to ensure the maintenance of a stable European badger population. On the other hand, when SRFs or reforestations are associated with forests, they provide an additional amount of suitable habitat allowing badger populations to reach a greater population size, as pointed out by the positive effect of these landscape elements in the abundance model.

In conclusion, the species needs areas characterized by the compresence of a high vegetation cover for sett building and grasslands for food searching (Fedriani et al., 1999; Zabala et al., 2002; Do Linh San et al., 2007; Rosalino et al., 2005; Piza Roca et al., 2014). Based on our analysis, it seems that in a continental lowland area with a highly fragmented forest cover and a well-developed agro-forestry economy, the European badger uses broadleaved forests and hedgerows to build setts and traditional poplar plantations as nocturnal feeding areas. Moreover, the analysis showed that SRFs and reforestations can play the role of forest surrogates for the species, when they are associated with original forest patches occupied by the species, increasing the habitats surface that can be colonized by the species and allowing populations to reach higher densities.

These results highlighted the importance of maintaining a high degree of heterogeneity in agricultural landscapes in order to ensure the survival of European badger populations. It is crucial that the spread of intensive crops does not exclude the presence of traditional poplar plantations, although generally less productive, or hedgerows, which are of poor economic interest for landowners. Moreover, it is fundamental to maintain surfaces devoted to SRFs and reforestation, which depends on the availability of public funds. If no public funding is provided in the future, there will be a great loss of suitable habitat for the European badger within the agricultural lowland area of the region. Moreover, agro-forestry systems with relatively short life cycles do not allow sustaining stable badger populations over time. Therefore, we suggest to locate them closed to forest habitats in order to guarantee the survival of badger populations when arboreal cultures are cut. Alternatively, rotational plantation plans could be established, as they would ensure the continuous presence of SRFs or reforestations in the landscape.

To our knowledge, this is the first research underlining the importance of agro-forestry systems for the European badger. Therefore, the information obtained through this study could be fundamental for the conservation of the species in continental European agro-ecosystems.

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*Associate Editor:* D.G. Preatoni